Palynological and palynofacies analyses of Upper Cretaceous deposits in the Haţeg Basin, southern Carpathians, Romania

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ABSTRACT

We present biostratigraphical and palaeoenvironmental analyses based on palynology and palynofacies of marine and terrestrial deposits that crop out in the central and northwestern part of the Haţeg Basin. Samples were collected from the Răchitova and Sînpetru formations. The former yielded well-preserved palynological assemblages of both terrestrial and marine origin, represented mainly by diverse spore and pollen associations, but with dinoflagellate assemblages of low diversity and low to moderate abundance. The terrestrial palynoflora is dominated by fern spores and subordinate gymnosperm and angiosperm pollen. This assemblage is indicative of a vegetation of subtropical to warm-temperate climate and suggests fluvial to coastal habitats, as well as well-drained and higher altitude areas. The Răchitova Formation is here dated as Santonian−early late Campanian, based on the dinocyst species *Isabelidinium microarmum* and some fern spores and early angiosperm pollen. The Sînpetru Formation, previously dated as Maastrichtian, yielded only terrestrial palynoflora, but with a low content in palynomorphs. Nevertheless, its palynological assemblage, composed of Maastrichtian pollen and spores, indicates lowland or coastal habitats and warm and humid climatic conditions, alternating with periods of arid climate. The palynofacies constituents used to reconstruct the depositional environments suggest that during the Santonian−early late Campanian, strata were laid down in an inner-outer neritic environment (with some fluctuations of water depth). This succession is followed by a deltaic to pond or lake depositions during the Maastrichtian, as indicated by the presence of large translucent phytoclasts in these deposits. A new dinocyst subspecies, *Isabelidinium microarmum* subsp. *bicavatum*, which is a distinguishable bicavate cyst, is described herein; this represents a possible key taxon for the lower to lower upper Campanian.

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1. Introduction

The Maastrichtian terrestrial strata exposed in the Haţeg Basin (western part of the southern Carpathians, Romania), are well known for their palaeontological content, comprising mainly various species of dinosaur (including egg nests), mammals and other vertebrates (Csiki and Grigorescu, 2000; Grigorescu, 2010; Csiki et al., 2010; Botfalvai et al., 2017; Csiki-Sava et al., 2018). Mega- and mesofloral remains from the Maastrichtian deposits of the Haţeg Basin have previously been described by Mărgărit and Mărgărit (1967), May Lindfors et al. (2010) and Popa et al. (2014,

2016). The megaflora is rare, being represented by ferns (*Asplenium foersteri*), monocotyledons (*Sabalites longirhachis*) and dicotyledons (*Araliaephyllum* sp., *Myrica primigenia* and *Proteophyllum decorum*). The mesoflora recorded from the northwestern part of the basin includes fruits and seeds (aff. *Klikovispermum* and aff. *Eurya*) that belonged to plants of the *Normapolles* complex (May Lindfors et al., 2010).

The first palynological study on Maastrichtian successions of the Haţeg area were carried out by Stancu et al. (1980) and Antonescu et al. (1983), who recorded terrestrial palynomorphs such as fern spores (*Polypodiaceoisporites*, *Leiotriletes*), *Normapolles* pollen (*Trudopollis*, *Oculopollis*) and a few gymnosperms. Other palynological studies of the same deposits have highlighted an assemblage with numerous fern spore taxa (inclusive of freshwater ferns) and various species of angiosperm pollen (*Normapolles* group),
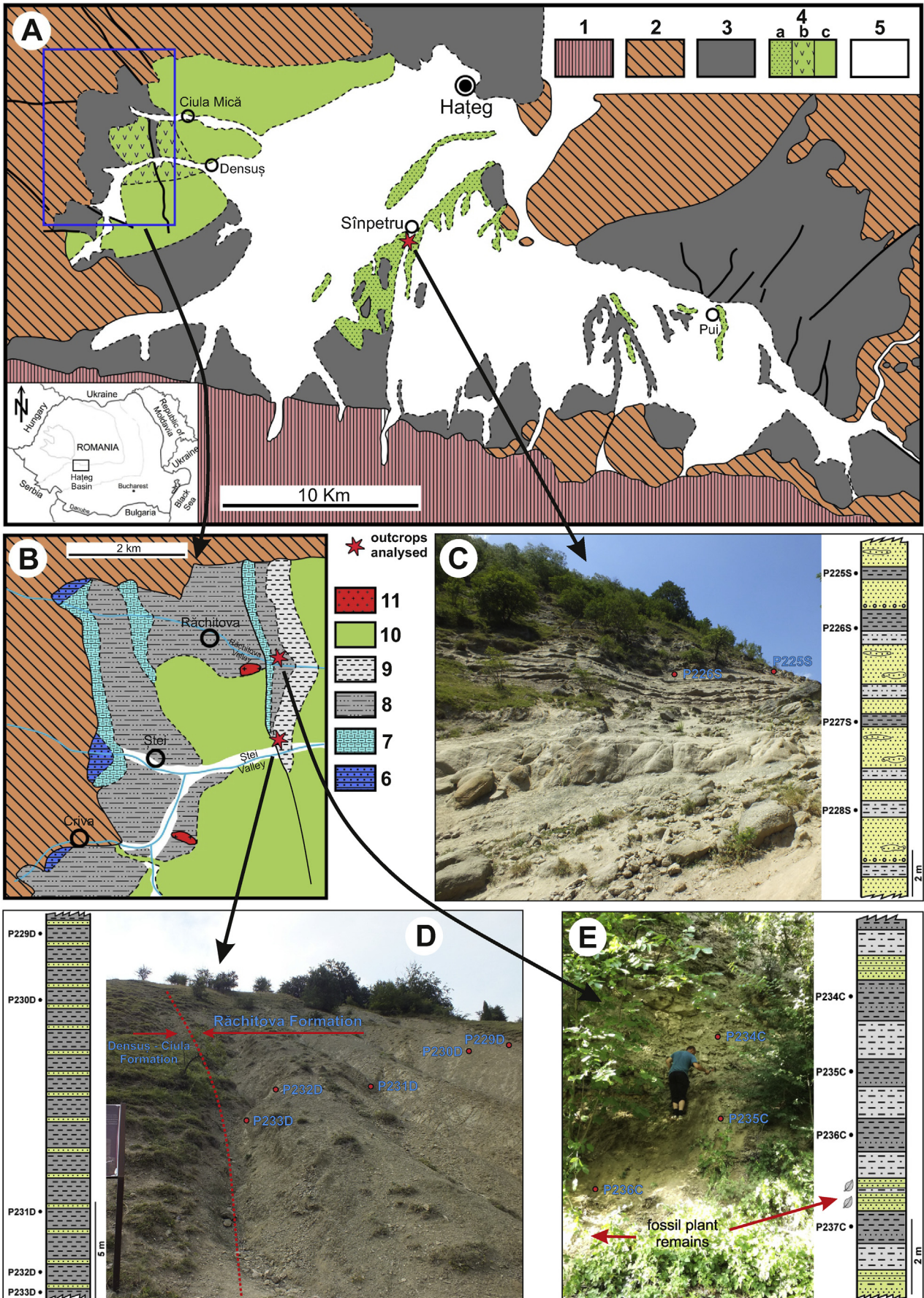
indicating a subtropical climate (Van Itterbeeck et al., 2005; Csiki et al., 2008).

In the deeper parts of the Haţeg Basin, outcropping Maastrichtian terrestrial successions rest on Cenomanian–Campanian strata that are mainly marine (Grigorescu and Melinte, 2001; Melinte-Dobrinescu, 2010). Based on the lithological and sedimentological characteristics of these marine strata in the northwestern Haţeg area, Melinte-Dobrinescu (2010) suggested a mainly deep-water palaeoenvironment for this interval.

The present study aims to contribute to the palynological data for Upper Cretaceous terrestrial and marine deposits that crop out in the central and northwestern part of the Haţeg Basin. The dinoflagellate cyst assemblage, identified in marine deposits of the region, is here described for the first time. The present work also aims to establish palaeoenvironmental conditions during deposition of this interval, as based on palynofacies characteristics and the palynomorph taxa.

2. Geological setting

The Haţeg Basin, located in the western part of the Southern Carpathians in Romania (Fig. 1A), includes a basement of crystalline rocks of the Getic Nappe, a tectonic unit that belongs to the Median Dacidic Nappe System (Săndulescu, 1984), and a cover of sedimentary rocks of about 4 km in thickness. This basin is created in response to the Late Cretaceous collision of at least three plates (Getic and Danubian units and an allochthonous continental block of the Moesian Platform; Fig. 1), upon closure of a narrow oceanic basin (Willingshofer et al., 2001). The oldest deposits that cover the Getic basement are Lower Jurassic terrestrial clastics. Starting in the Middle Jurassic, marine sedimentation comprised limestones and marls (Stilla, 1985; Pop, 1990). This type of deposition continued up to the Aptian, when reef and fore-reef limestone were laid down. The Middle Jurassic–Aptian marine sedimentation is followed by exhumation and erosion of the area, as indicated at the Aptian–Albian boundary by bauxites accumulated within a palaeokarst (Năstăseanu, 1975).

At the start of the Late Cretaceous (early Cenomanian), the Haţeg region evolved towards a longitudinal basin (east–west direction), which allowed the accumulation of deep-marine hemipelagic deposits (Stei and Răchitova formations) in the northwest, and shallow-water ones in the southeast (Grigorescu and Melinte, 2001; Melinte-Dobrinescu, 2010). The marine sedimentation ended towards the top of the Campanian throughout the Haţeg region, with deep-to shallow-water deposits being unconformably covered by Maastrichtian terrestrial strata that are assigned to the Sînpetru and Densuş-Ciula formations.

Tectonic and palaeogeographic studies support the presence of an archipelago of islands in the northeast Tethys during the Late Cretaceous (Dercourt et al., 2000; Csontos and Vörös, 2004). The "Haţeg Island", with a total surface of around 80,000 km^2 (Dercourt et al., 2000), was then included into the Tisza-Dacia block (Csontos and Vörös, 2004).

3. Stratigraphical framework

Our palynological and palynofacies study has been carried out on marine deposits (Răchitova Formation) in the northwestern part

of the Haţeg Basin and terrestrial strata (Sînpetru Formation) in the central part (Fig. 1).

3.1. Răchitova Formation

This unit was first described by Grigorescu and Melinte (2001), the stratotype being located in the Răchitova Valley (Fig. 1B). The Răchitova Formation (~900 m thick) is divided into two members, the Lower Member and Upper Member. The former comprises 500–700 m of sandy turbidites (Melinte-Dobrinescu, 2010), represented by calcareous sandstones, grey siltstones and claystone interlayers. In the studied outcrop along the Răchitova Valley (Fig. 1E), this member is characterized by the presence of a level with poorly preserved fossil plant remains, considered as a lithological marker for its lower part by Melinte-Dobrinescu (2010). The Lower Member was dated as early Santonian–early/late Campanian on the basis of calcareous nannofossil taxa indicative of zones CC16 up to CC20 (Melinte-Dobrinescu, 2010).

The Upper Member is ~300 m thick at the Răchitova Valley site and consists of turbidites, represented by grey claystones with centimetre-thick calcarenite interlayers. A nannofossil event, i.e., first occurrence datums of Uniplanarius sissinghii and U. trifidus, indicates a late Campanian age for this member (Grigorescu and Melinte, 2001; Melinte-Dobrinescu, 2010). Strata assigned to this member are strongly folded (Fig. 1D) and crop out along the Ştei Valley (Fig. 1B).

3.2. Sînpetru Formation

This formation is distributed across the central-eastern parts of the Haţeg Basin (Fig. 1A), mainly along the Sibişel and Bărbat valleys. Although the entire stratigraphic interval of the formation is not exposed, Nopcsa (1905) estimated the Sînpetru Formation to have been approximately 2,500 m thick, as based on the distribution of exposures within the basin. The commonest rocks comprise poorly sorted fluvial sandstones (or conglomerate) and floodplain mudstones (Bojar et al., 2005; Therrien, 2006), yielding large numbers of fossil vertebrate remains (Grigorescu, 2010). Along the Sibişel Valley, the Sînpetru Formation includes two members. The lower member displays an admixture of grey-green mudstones with red mudstones and sandstones (Fig. 1C), while the upper member is characterised by the presence of coarser channel deposits (Grigorescu, 1992; Bojar et al., 2005; Therrien, 2006). Different types of palaeosols are also mentioned for this formation (Therrien et al., 2009). The Sînpetru Formation was first assigned to the upper Maastrichtian on the basis of the presence of the pollen Pseudopapilopollis praesubhercynicus (see Antonescu et al., 1983). This assignment was later questioned by Van Itterbeeck et al. (2005), who suggested a lower/upper Maastrichtian boundary interval. Palaeomagnetic studies indicate that the Sînpetru Formation was laid down between the beginning of Chron 32n.1 and the end of Chron 31n (68.7–71.5 Ma) (Panaiotu and Panaiotu, 2010).

4. Material and methods

Altogether, thirteen samples of claystone were collected from three outcrops of the Haţeg Basin, namely: four samples from the

Fig. 1. **A**. Simplified geological map of the Haţeg Basin (modified after Grigorescu et al., 2010). Legend: 1 – Danubian Nappe System (crystalline basement); 2 - Getic Nappe System (crystalline basement); 3 – pre-Maastrichtian sedimentary cover (mainly marine); 4 – Maastrichtian terrestrial deposits: a – Sînpetru Formation, b - volcano-sedimentary beds (lower member of the Densuş-Ciula Formation), c - epiclastic beds (middle–upper members of the Densuş-Ciula Formation); 5 - Cenozoic sedimentary rocks and Quaternary terraces. **B**. Detailed geological map of the northwestern Haţeg Basin (according to Melinte-Dobrinescu, 2010). Legend: 6 – Federi Formation (Albian–lower Cenomanian); 7 – Ştei Formation (Cenomanian–lower Santonian); 8 – Răchitova Formation, Lower Member (upper Santonian–lower Campanian); 9 – Răchitova Formation, Upper Member (upper Campanian); 10 - Densuş-Ciula Formation (Maastrichtian); 11 – magmatic rocks. **C**. Maastrichtian terrestrial deposits of the Sînpetru Formation (Sînpetru section). **D**. Contact between the marine deposits of the Răchitova Formation (Upper Member) and reddish continental deposits of the Densuş-Ciula Formation. **E**. Santonian turbidites of the Răchitova Formation (Lower Member).

Sînpetru Formation (Sînpetru locality; thickness of strata ~15 m; co-ordinates N 45°32′37.74″, E 22°54′33.77″), five samples from the Upper Member of the Răchitova Formation (the western part of Densuş; thickness of deposits ~20 m; co-ordinates N 45°34′58.27″, E 22°46′00.50″) and four samples from the Lower Member of the Răchitova Formation (the western part of Ciula Mică; thickness of deposits ~10 m; co-ordinates N 45°35′54.72″, E 22°45′55.64″) (Fig. 1; Appendix A).

Sample preparation follows the method described by Batten (1999). Approximately 50 g of sediment was sampled for organic matter analyses. These samples were treated with HCl (37%) to remove carbonates and HF (48%) to remove the silicate minerals. Denser particles were separated from the organic residue using ZnCl$_2$ with a density of 2.0 g/cm^3. The residual matter was mounted on the slides using glycerine jelly. A representative selection of palynomorphs and palynofacies constituents (Figs. 2–6) was photographed using a digital Leica DFC 420 camera mounted on a Leica DM 1000 microscope. All the microscopic slides are deposited in the collections of the Geology Department, "Al. I. Cuza" University of Iaşi.

Palynofacies characterisation was done by counting 300–400 of unoxidised palynodebris in each sample. Three main groups of kerogen constituents proposed by Tyson (1995), Mendonça Filho et al. (2002), Carvalho et al. (2006) and Țabără et al. (2015, 2017) have been recognised in the studied samples, namely: (I) palynomorphs (spores, pollen, dinoflagellate cysts and algae); (II) phytoclasts (opaque and translucent organic particles derived from terrestrial plants), and (III) amorphous organic matter (AOM) which includes structureless organic components derived from phytoplankton or degraded higher plant debris.

Several interpretative parameters, based on palynofacies observations (i and ii ratios are expressed in decimal logarithms; Tyson, 1995), were used for palaeoenvironmental analyses, namely:

(i) the ratio of opaque to translucent phytoclasts (O:Trans). The opaque phytoclasts are derived from the oxidation of translucent particles that have suffered a transport over a prolonged period of time (Tyson, 1995; Carvalho et al., 2013). A high abundance of opaque phytoclasts mainly suggests a distal depositional environment (Țabără et al., 2017). In contrast, the high relative abundance of translucent particles (e.g. woody tissues) indicates strong terrestrial influx, with deposition in nearshore proximal settings (e.g. fluvio-deltaic systems; Tyson, 1995). The ratio tends to increase distally and can be used to interpret proximal-distal trends (Steffen and Gorin, 1993).

(ii) the continental/marine palynomorphs ratio (C/M). This ratio is calculated by the number of all terrestrial palynomorphs (pollen + spores) divided by the number of marine palynomorphs (dinoflagellate cysts). Consequently, the C/M ratio generally decreases offshore and can be used as an indicator of proximal-distal trends (Pellaton and Gorin, 2005). Also, onshore-offshore depositional environments and transgressive-regressive trends can be inferred based on a spore-pollen-microplankton (SPM) ternary diagram as proposed by Federova (1977) and Duringer and Doubinger (1985).

(iii) Peridinioid/gonyaulacoid dinocysts ratio (P/G). This ratio is used in the manner described by Versteegh (1994) and Carvalho et al. (2016), using formula P/G = P/(P + G), where P is the number of peridinioid cysts and G is the number of gonyaulacoid cysts. A peridinioid-dominated assemblage (high values of P/G) indicates nutrient-rich and low salinity conditions, related to nearshore environments (brackish water and lagoons). In contrast, a gonyaulacoid-dominated assemblage (low values of P/G) reflects generally open-marine environments (Carvalho et al., 2016).

5. Results

5.1. Palynological content

The recovered assemblages show a low to moderate diversity and include a total of 83 taxa (Appendix A), mainly consisting of cryptogam spores (36 taxa), angiosperm pollen grains (19 taxa) and dinoflagellate cysts (16 taxa). Dinoflagellate cysts were discovered for the first time in the Haţeg Basin during the present study. Additionally, some gymnosperms (10 taxa) as well as rare occurrence of freshwater algae, bryophytes and foraminiferal linings were identified in our samples.

5.1.1. Răchitova Formation

In the Lower Member of this unit, the recovered palynoflora consists mainly of terrestrial palynomorphs. Among these, the fern spores are the most abundant (74–84% of the total palynomorphs). This principal terrestrial group is generally dominated by Deltoidospora minor, D. australis, Cicatricosisporites spp., Echinatisporis longechinus, Gleicheniidites senonicus, Polypodiaceoisporites sp. and Verrucingulatisporites sp. Other frequently identified spore taxa include Appendicisporites tricornitatus, Foveosporites canalis, Laevigatosporites ovatus, Lycopodiumsporites austroclavatidites and Vadaszisporites minutireticulatus. Gymnosperm pollen generally represent a minor component of the assemblage; taxa identified include Araucariacites australis, Pinuspollenites sp., Alisporites sp., Classopollis sp. and Ephedripites. Angiosperm pollen occur in low diversity and number of specimens. Some taxa of Normapolles group (e.g. Trudopollis nonperfectus, T. primigenius, Suemegipollis triangularis and Oculopollis sp.) are the most frequently observed.

The dinocyst assemblage recovered from the Lower Member of the Răchitova Formation shows a very low diversity, reflecting a reduced marine influence. Odontochitina operculata, Isabelidinium acuminatum and cf. Turnhosphaera hypoflata are the only dinoflagellate cyst taxa recorded from this unit. Other marine microfossils (e.g. foraminiferal test linings) and some specimens of freshwater algae (Chomotriletes fragilis) represent a minor component in the assemblage.

In the Upper Member of the Răchitova Formation, the five samples collected in the Densuş outcrop yielded a diverse palynological content (Appendix A). The assemblage includes both terrestrial and marine palynomorphs. The cryptogam spore assemblage (15–60% of the total palynomorphs) is roughly similar to that identified from the Lower Member of the Răchitova Formation (see above) and is represented by several genera, including Cicatricosisporites, Deltoidospora, Echinatisporis, Gleicheniidites and Polypodiaceoisporites. The two taxa, Zlivisporites blanensis and Schizaeoisporites sp., occur only in this member. Gymnosperms are represented mainly by Pinuspollenites sp., Araucariacites australis, Inaperturopollenites sp. and Classopollis sp. Angiosperm pollen occur in a low diversity. They include triaperturate taxa (Tricolpites spp.), Normapolles group (Trudopollis hemiperfectus, T. primigenius, Longanulipollis sp.) and a minor fraction of palm trees pollen (Monocolpopollenites sp.).

The dinoflagellate cysts show low diversity, but are common to abundant in two samples (P230D–48.3% and P232D–56.1%), reflecting two short episodes of more pronounced marine influence. The commonest dinocyst species is Isabelidinium microarmum, which is associated with other species such as Isabelidinium cooksoniae, I. cretaceum, Spinidinium eggeri, Elytrocysta cf. druggii and Chatangiella cf. granulifera. Freshwater algae are absent.
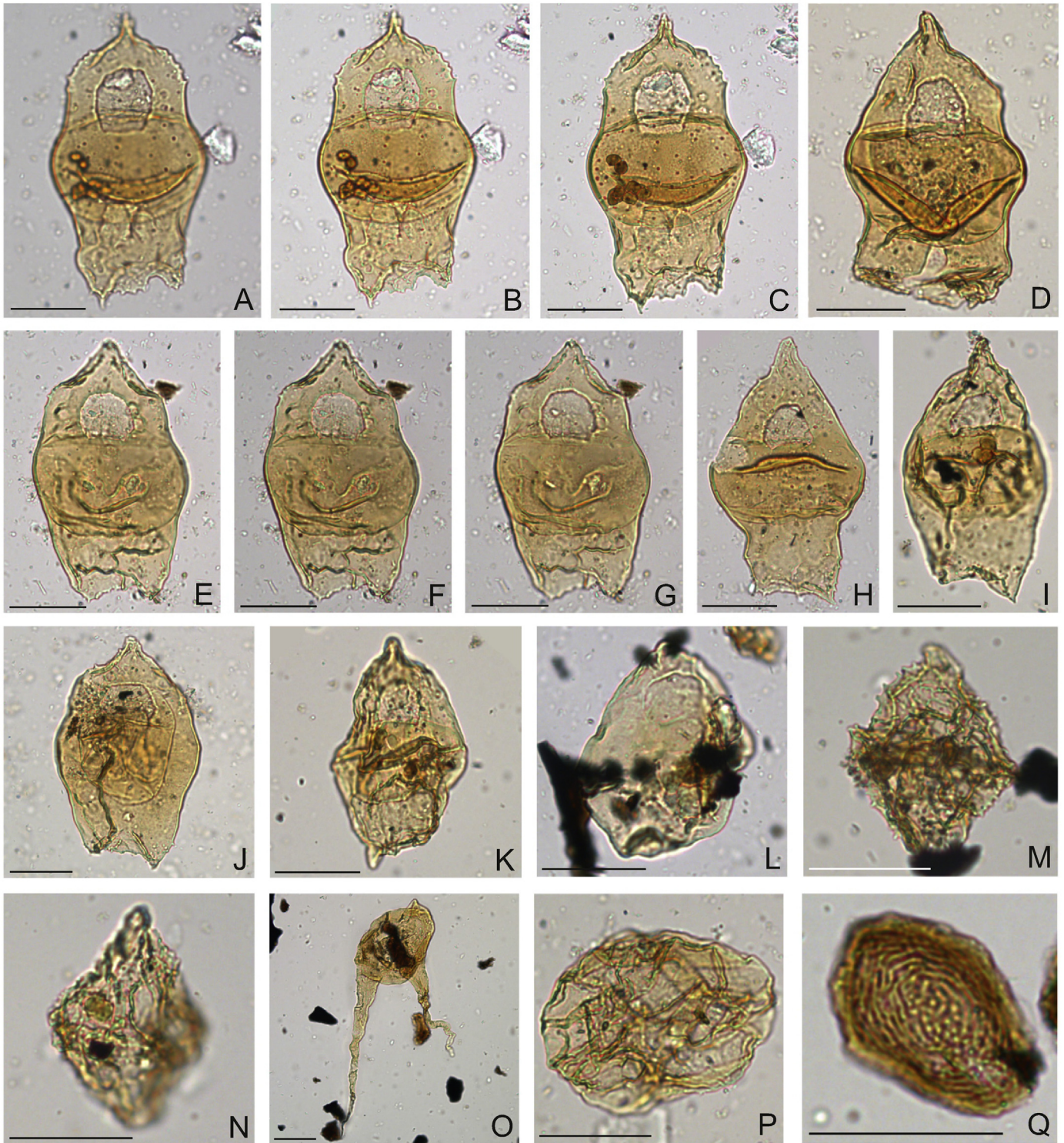
Fig. 2. Selected dinoflagellate cysts and freshwater algae from the Răchitova Formation (scale bar: 30 μm; the three numbers between brackets are related to samples, palynological slides and England Finder co-ordinates, respectively). A–C. *Isabelidinium microarmum* subsp. *bicavatum* subsp. nov. (holotype) (P232D, BH232-2, C41). D. *Isabelidinium microarmum* subsp. *bicavatum* subsp. nov. (P232D, BH232-1, K31-2). E–G. *Isabelidinium microarmum* subsp. *bicavatum* subsp. nov. (paratype) (P232D, BH232-4, L18). H. *Isabelidinium microarmum* subsp. *bicavatum* subsp. nov. (P232D, BH232-4, E40-2). I. *Isabelidinium microarmum* subsp. *microarmum* (P230D, BH230-1, H18). J. *Isabelidinium microarmum* subsp. *microarmum* (P232D, BH232-2, B22-4). K. *Isabelidinium acuminatum* (P230D, BH230-2, L16-2). L. *Isabelidinium cretaceum* (P229D, BH229-1, B32). M. *Spinidinium eggeri* (P230D, BH230-3, L20-2). N. *Spinidinium balmei* (P230D, BH230-2, B28-1). O. *Odontochitina operculata* (P236C, BH236-2, N27). P. cf. *Turnhosphaera hypoflata* (P234C, BH234-1, R31-3). Q. *Chomotriletes fragilis* (P237C, BH237-3, Q34-2).
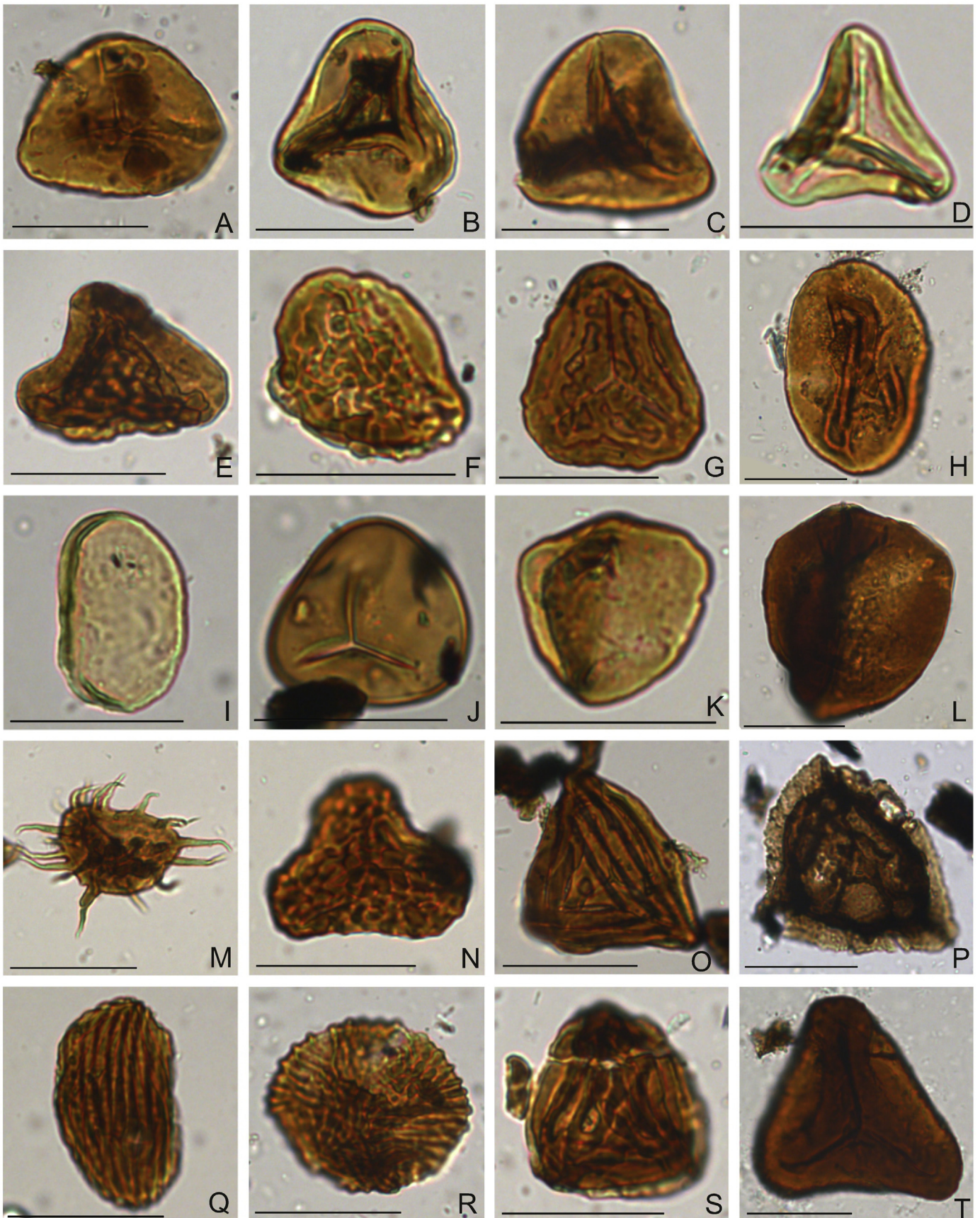
Fig. 3. Light photomicrographs of selected cryptogam spores recorded in the Răchitova and Sînpetru formations (scale bar: 30 μm; the three numbers between brackets are related to samples, palynological slides and England Finder co-ordinates, respectively). A. *Deltoidospora australis* (P234C, BH234-4, B44-1). B. *Deltoidospora toralis* (P236C, BH236-2, C11-3).

5.1.2. Sînpetru Formation

Our samples yielded a poorly preserved and poorly diverse palynoflora incorporating 14 terrestrial taxa (9 spores, 2 gymnosperm pollen and 3 angiosperm pollen). Two samples (i.e., P226S and P228S) are almost barren in palynomorphs. Among the pteridophytes, *Polypodiaceoisporites*, *Laevigatosporites* and *Deltoidospora* are the commonest taxa. Gymnosperm pollen are rare (only *Classopollis* and *Araucariacites* have been encountered), as are angiosperm pollen (few specimens of *Trudopollis*, *Semioculopollis* and *Caryapollenites*). Freshwater algae are also rare, while dinoflagellate cysts are absent.

The low content of the palynomorphs in the Sînpetru Formation can be related to palaeoenvironmental conditions (shallow water, continental deposition, strong oxidation of organic matter due to bacterial degradation).

5.2. Palynofacies compositions

In most studied samples, particulate organic matter (POM) of terrestrial origin clearly predominates. Four main constituents of POM were recognized, namely: translucent phytoclasts, opaque phytoclasts, palynomorphs and AOM (granular form, marine origin). Generally, the Răchitova Formation contains a moderate to high amount of kerogen, while the Sînpetru Formation is poor in POM content.

5.2.1. Răchitova Formation

The Lower Member of this formation is characterised by a predominance of organic matter of terrestrial origin. Opaque phytoclasts are frequently encountered (55−69%; Fig. 6), being commonly small in size (10−50 μm) and rounded (Fig. 7J) and rarely lath-shaped. The translucent phytoclasts are subdominant components (28−44%) consisting of woody tissues (Fig. 7F), cuticles (sometimes large in size; Fig. 7C) and numerous small yellow-brown fragments. Continental palynomorphs are rare (1−3% of total POM), mostly fern spores. Occasionally, some dinoflagellate cysts show framboidal pyrite on their surface (Fig. 7D), indicating anoxic environment within sediments. The palynofacies in the Lower Member of the Răchitova Formation also includes small amounts of phytoplankton, rare specimens of foraminiferal test linings and reworked Palaeozoic scolecodonts (Fig. 7E). The granular AOM (marine origin) is absent.

In the Upper Member of the Răchitova Formation, a change in the palynofacies composition was noted. In the lower part of the studied section, sample P233D is characterised by a predominance of granular AOM mixed with small equidimensional opaque phytoclasts, belonging to the inertinite group (Fig. 7I). Other samples (i.e., P232D, P230D, P229D; Fig. 6) exhibit an abundance of opaque phytoclasts (60−90% of total POM), often having small dimensions and rounded shapes (Fig. 7H), as a result of prolonged transport. Samples showing this type of palynofacies, mainly rich in opaque phytoclasts, also include well-preserved specimens of dinoflagellate cysts (mainly *Isabelidinium* spp.) and fern spores. Some rare occurrences of foraminiferal test linings (Fig. 5I, J) in sample P229D were observed.

5.2.2. Sînpetru Formation

The palynofacies composition of this formation is characterised by a predominance of the terrestrial POM. In terms of quantity, a smaller amount of organic matter was identified in the Sînpetru Formation, compared to the one recovered from the Răchitova Formation.

In sample P227S, the palynofacies is dominated by large fragments of spongy tissues (called aerenchyma; Fig. 7A, B), which form spaces or air channel in leaves of aquatic plants in order to help them float. The fragments of aerenchyma identified in this sample are very similar to those of the extant genus *Nymphaea* (for a review, see Catian and Scremin-Dias, 2015 or http://cupac.bh.cornell.edu/). Other translucent phytoclasts, such as woody tissues, cuticles and rare opaque phytoclasts with angular shape or lath-shaped (Fig. 7G), occur in this unit. The palynological assemblage is poorly preserved and consists mainly of fern spores associated with some gymnosperm and angiosperm pollen and rare occurrences of freshwater algae. Marine phytoplankton is absent from this formation.

6. Discussion

6.1. Biostratigraphy

The dinocyst assemblages and *Normapolles* group (early angiosperms) from the studied sections contain few taxa, which are commonly known to represent biostratigraphical markers in the Upper Cretaceous. Some taxa of fern spores were also used for biostratigraphical dating.

6.1.1. Răchitova Formation

In the Lower Member of the Răchitova Formation, the dinoflagellate cyst assemblage recorded in the samples collected from the Ciula Mică outcrop shows a low diversity and a lack of biostratigraphical markers. Nevertheless, a biostratigraphic information is provided by *Isabelidinium acuminatum*, which ranges from the Cenomanian to the Paleocene (Stover and Evitt, 1978; Ioannides, 1986). According to Williams and Bujak (1985) and Aleksandrova et al. (2012), this taxon has its first occurrence in the lower Santonian. Another dinocyst taxon identified in sample P234C is cf. *Turnhosphaera hypoflata*, known from the Coniacian to upper Maastrichtian (Kirsch, 1991; Slimani, 2000, 2001; Slimani et al., 2011; Slimani and Louwye, 2012). This species also occurs in the Upper Member of the Răchitova Formation.

Two fern spores, namely *Appendicisporites tricornitatus* and *Vadaszisporites sacali*, occur only in the interval P234C−P237C (Appendix A). Both species are common in Lower Cretaceous deposits from Hungary (Juhász, 1975), Romania (Apuseni Mountains; Antonescu, 1973), Spain (Barrón et al., 2015) and Sweden (Vajda and Wigforss-Lange, 2006). Furthermore, *A. tricornitatus* may have persisted up to the Santonian (Vajda et al., 2016) and *V. sacali* up to the early Campanian in Hungary (Góczán and Siegl-Farkas, 1990).

Early angiosperms (*Normapolles* group) are biostratigraphically significant for dating Upper Cretaceous deposits, due to their rapid radial evolution. The various *Normapolles* pollen types observed in the Lower and Upper Member of the Răchitova Formation provide o good opportunity for the biostratigraphical control in the Upper Cretaceous. *Trudopollis nonperfectus* and *T. fossulotrudens*, which range from the Santonian to Campanian (Newman, 1965; Halamski et al., 2016; Polette and Batten, 2017), occur in the sampling interval

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C. *Deltoidospora minor* (P230D, BH230-1, G28-2). D. *Gleicheniidites senonicus* (P225S, BH225-4, C19-3). E. *Polypodiaceoisporites* sp. (P230D, BH230-2, K35-2). F. *Polypodiaceoisporites* sp. (P234C, BH234-3, M43-1). G. *Polypodiaceoisporites retirugatus* (P234C, BH234-2, D10-2). H. *Laevigatosporites nutidus nutidus* (P234C, BH234-2, L25-1). I. *Laevigatosporites ovatus* (P225S, BH225-2, E44-4). J. *Leiotriletes wolffi brevis* (P237C, BH237-3, A28-4). K. *Triplanosporites microsinuosus* (P236C, BH236-3, B9-1). L. *Triplanosporites sinomaxoides* (P234C, BH234-1, R30-3). M. *Echinatisporis longechinus* (P237C, BH237-2, F21-4). N. *Trilites* sp. (P237C, BH237-1, Q17-2). O. *Appendicisporites tricornitatus* (P237C, BH237-1, C14-2). P. *Zlivisporites blanensis* (P229D, BH229-2, F36-1). Q. *Cicatricosisporites dorogensis* (P237C, BH237-3, P38-4). R. *Cicatricosisporites venustus* (P234C, BH234-2, B28-1). S. *Cicatricosisporites spiralis* (P234C, BH234-3, O18-2). T. *Biretisporites spectabilis* (P235C, BH235-4, D39-4).
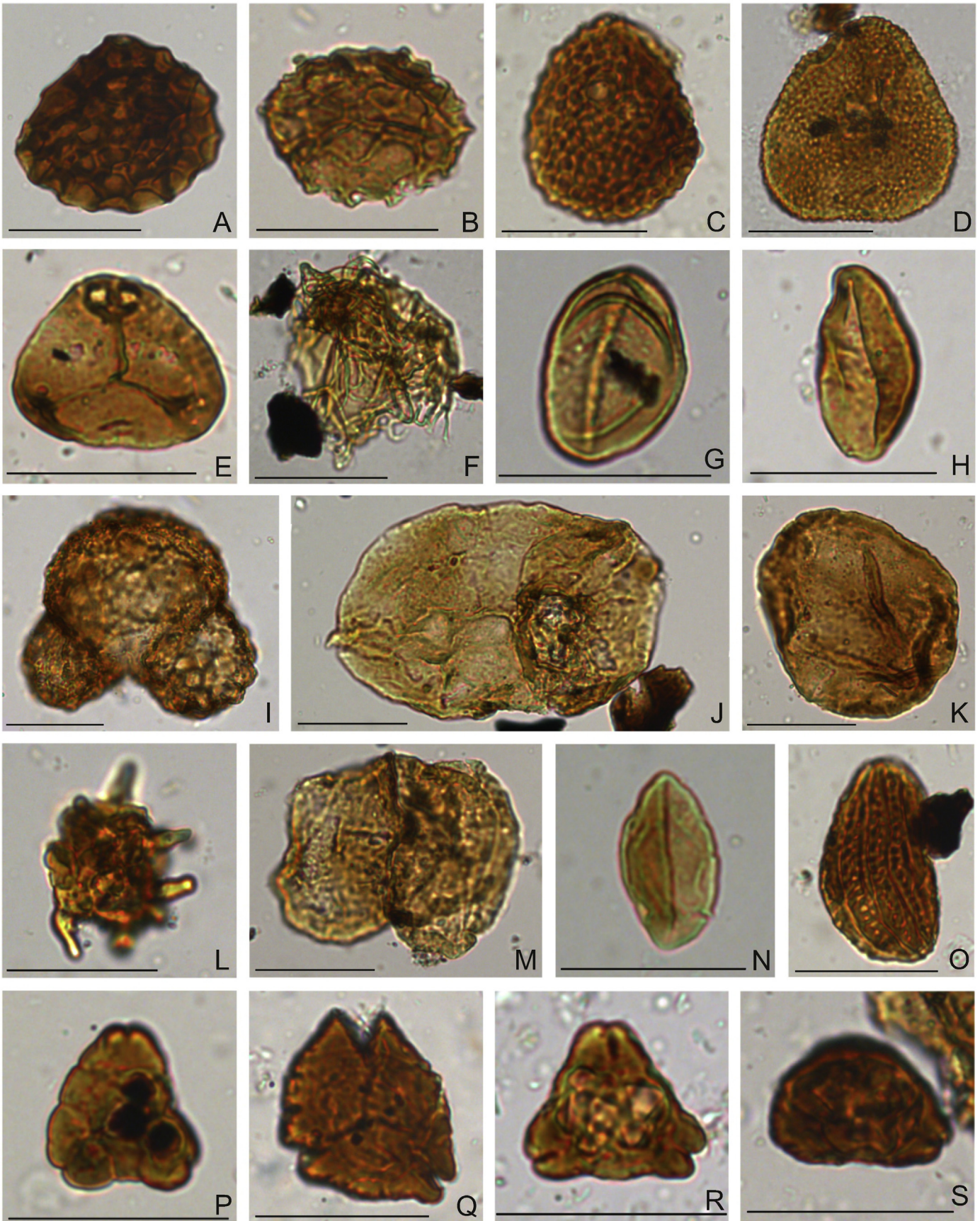
Fig. 4. Selected terrestrial palynomorphs (cryptogam spores, gymnosperm and angiosperm pollen grains) from the Răchitova and Sînpetru formations (scale bar: 30 μm; the three numbers between brackets are related to samples, palynological slides and England Finder co-ordinates, respectively). A. *Lycopodiumsporites austroclavatidites* (P236C, BH236-3,
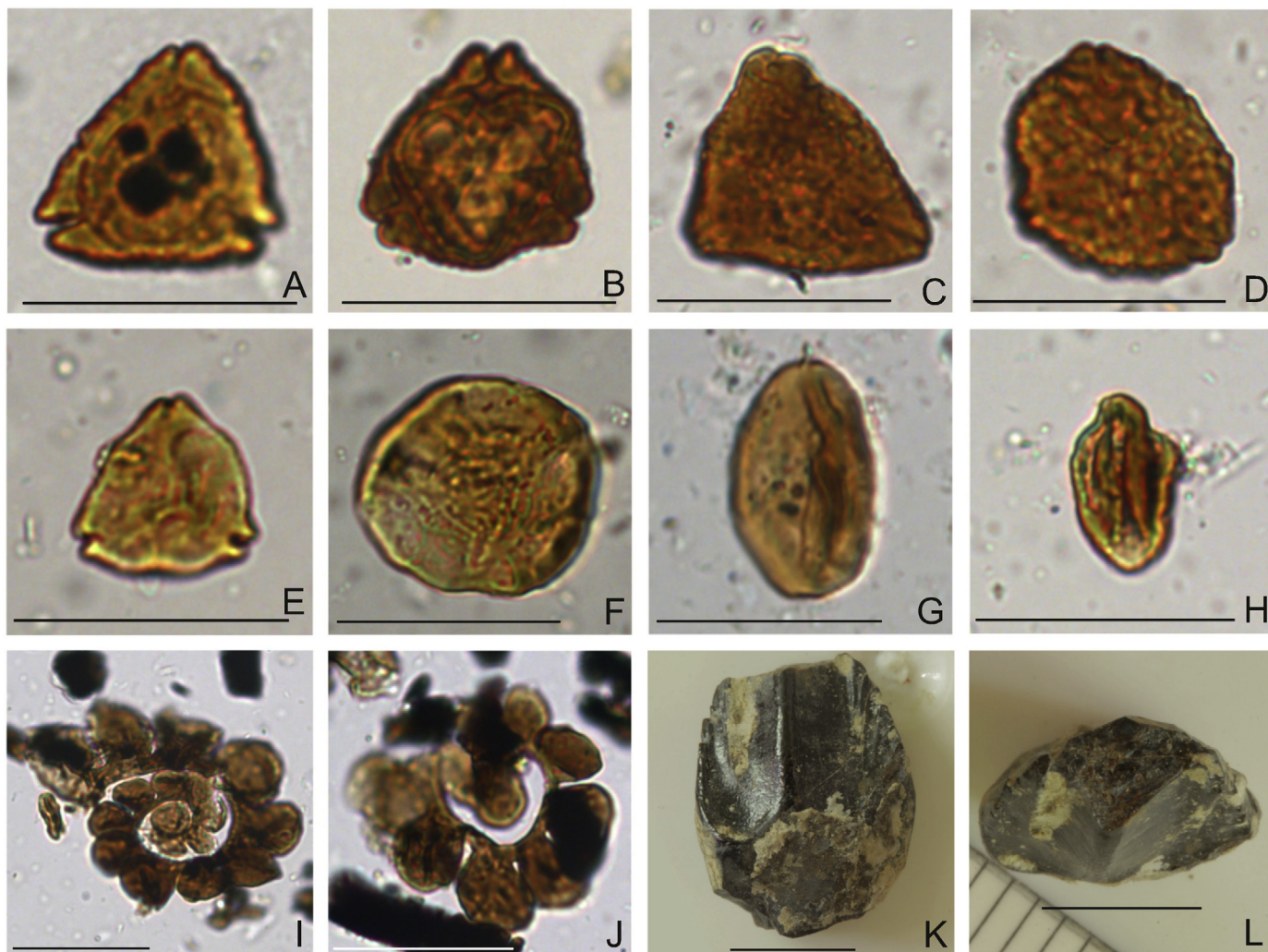
Fig. 5. Selected angiosperm pollen grains (A–H) recorded in the Răchitova Formation (scale bar: 30 μm; the three numbers between brackets are related to samples, palynological slides and England Finder co-ordinates, respectively). Other types of fossils (I–L). A. *Trudopollis nonperfectus* (P235C, BH235-3, H10-1). B. *Trudopollis hemiperfectus* (P230D, BH230-3, J39-2). C. *Trudopollis baculotrudens* (P234C, BH234-4, D33-1). D. *Trudopollis fossulotrudens* (P234C, BH234-3, L9). E. *Myricipites bituitus* (P234C, BH234-5, J22-4). F. *Caryapollenites* sp. (P234C, BH234-4, R39-2). G. *Tricolpites* cf. *parvulus* (P232D, BH232-3, G23-4). H. *Tricolpites* sp. (P234C, BH234-2, Q21-2). I, J. Foraminifers test lining (P229D, BH234-1, K12-3). K, L. tooth of *Zalmoxes* sp. (scale bar: 5 mm), Sînpetru Formation.

P235C–P230D. Other taxa identified from the Răchitova Formation (i.e., *Suemegipollis triangularis*, *Trudopollis baculotrudens* and *T. primigenius*) are typical of the Late Cretaceous, mainly Santonian–Maastrichtian (Antonescu, 1973; Kedves and Herngreen, 1981; Lebedeva and Kuz'mina, 2018).

In the Upper Member of the Răchitova Formation, the palynological assemblage recorded from the Densuș section contains few Late Cretaceous dinocyst taxa. The most important of these is *Isabelidinium microarmum*, which is highly abundant in the sampling interval P232D–P229D. This species has its first occurrence worldwide in the lower Campanian (Ioannides and McIntyre, 1980; Ioannides, 1986; Slimani, 2001; Aleksandrova et al., 2012; Radmacher et al., 2015) and may have persisted up to the lower upper Campanian (Powell, 1992; Slimani, 2001; Fensome et al., 2016) or Maastrichtian (Rauscher and Doubinger, 1982). Considering that some dinocyst taxa (e.g., *Areoligera* spp., *Cerodinium diebelii*), whose first occurrences are known from the middle upper Campanian in the Northern Hemisphere (Costa and Davey, 1992; Slimani, 2001; Williams et al., 2004; Slimani et al., 2016), are absent from our assemblages, we can at least assign the sampling interval P232D–P229D, in which *Isabelidinium microarmum* is encountered, to the lower to lower upper Campanian interval. The other dinocyst taxa observed in the Upper Member of the Răchitova Formation, such as *Chatangiella* cf. *granulifera* and *Spinidinium eggeri*, range from the Coniacian to lower upper Campanian (Slimani, 2001; Lebedeva, 2006; Aleksandrova et al., 2012) and from the Santonian to Maastrichtian (Kirsch, 1991; Schiøler et al., 1997), respectively.

H12). B. *Lycopodiumsporites clavatoides* (P237C, BH237-4, D25-2). C. *Vadaszisporites gregussi* (P234C, BH234-4, S32). D. *Vadaszisporites sacali* (P235C, BH235-1, A23-1). E. *Undulatisporites* sp. (P234C, BH234-2, D28-4). F. *Azolla* sp. (P235C, BH235-2, H19-2). G. *Classopollis* sp. (P225S, BH225-3, L42-3). H. *Cycadopites follicularis* (P237C, BH237-3, N33). I. *Pinuspollenites* sp. (P230D, BH230-4, Q31-2). J. *Alisporites* sp. (P237C, BH237-4, P27-1). K. *Araucariacites australis* (P234C, BH234-1, J32-2). L. *Elaterocolpites castelainii* (P233D, BH233-3, K28-1). M. *Podocarpidites* sp. (P230D, BH230-4, C9-2). N. *Monocolpopollenites* sp. (P237C, BH237-3, F43-3). O. *Trisectoris* cf. *reticulatus* (P234C, BH234-4, D11). P. *Suemegipollis triangularis* (P237C, BH237-2, J23-4). Q. *Longanulipollis* sp. (P232D, BH232-5, K22-1). R. *Trudopollis primigenius* (P232D, BH232-3, O23-1). S. *Trudopollis* cf. *capsula* (P232D, BH232-4, H39).
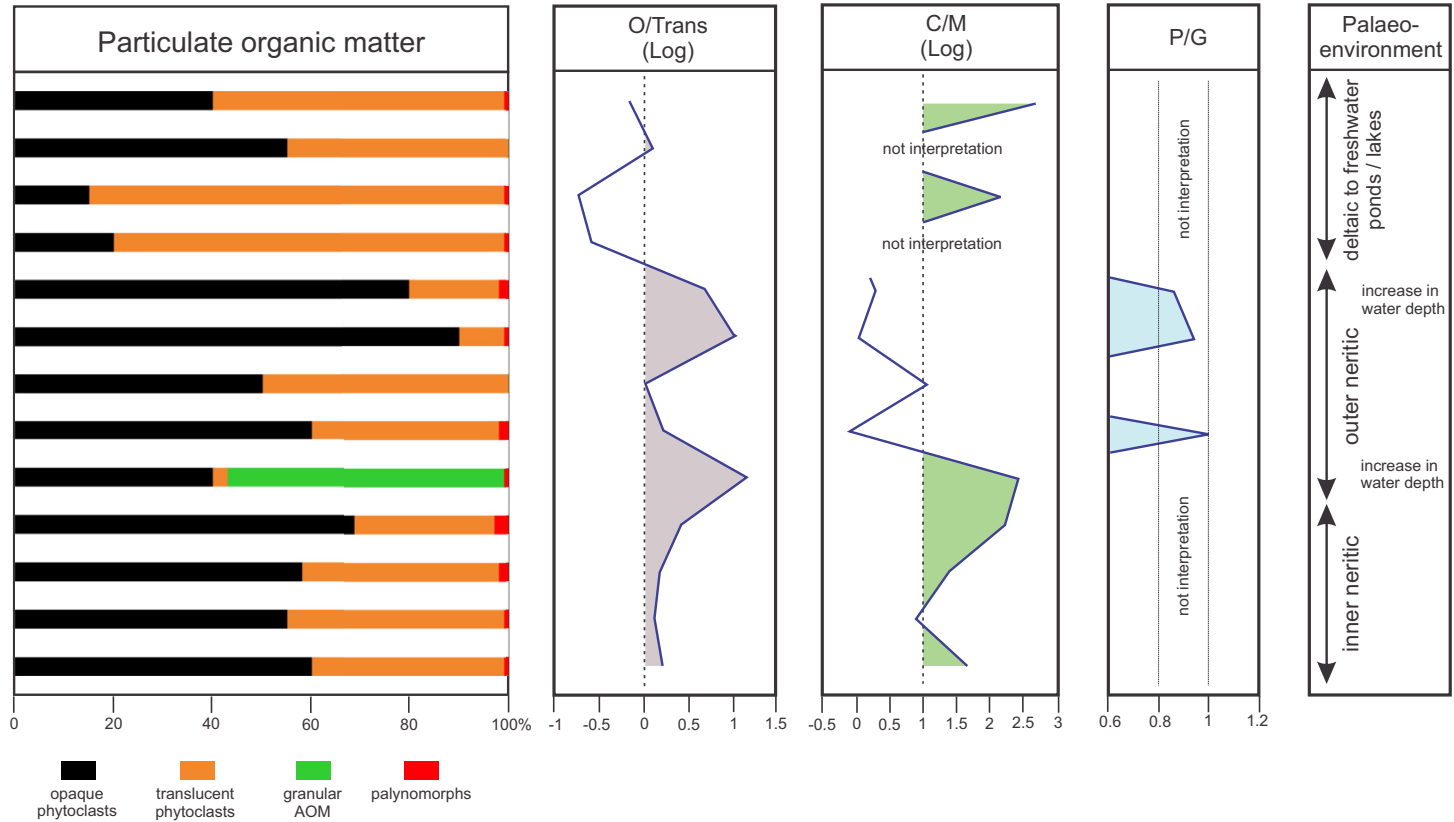
Fig. 6. Relative abundances of particulate organic matter in the Răchitova and Sînpetru formations. Palynofacies parameters (O/Trans, C/M and P/G) and palaeoenvironment interpretations are also shown. O/Trans − opaque to translucent phytoclasts ratio; C/M− continental/marine palynomorphs ratio; P/G - peridinioid/gonyaulacoid dinocysts ratio.
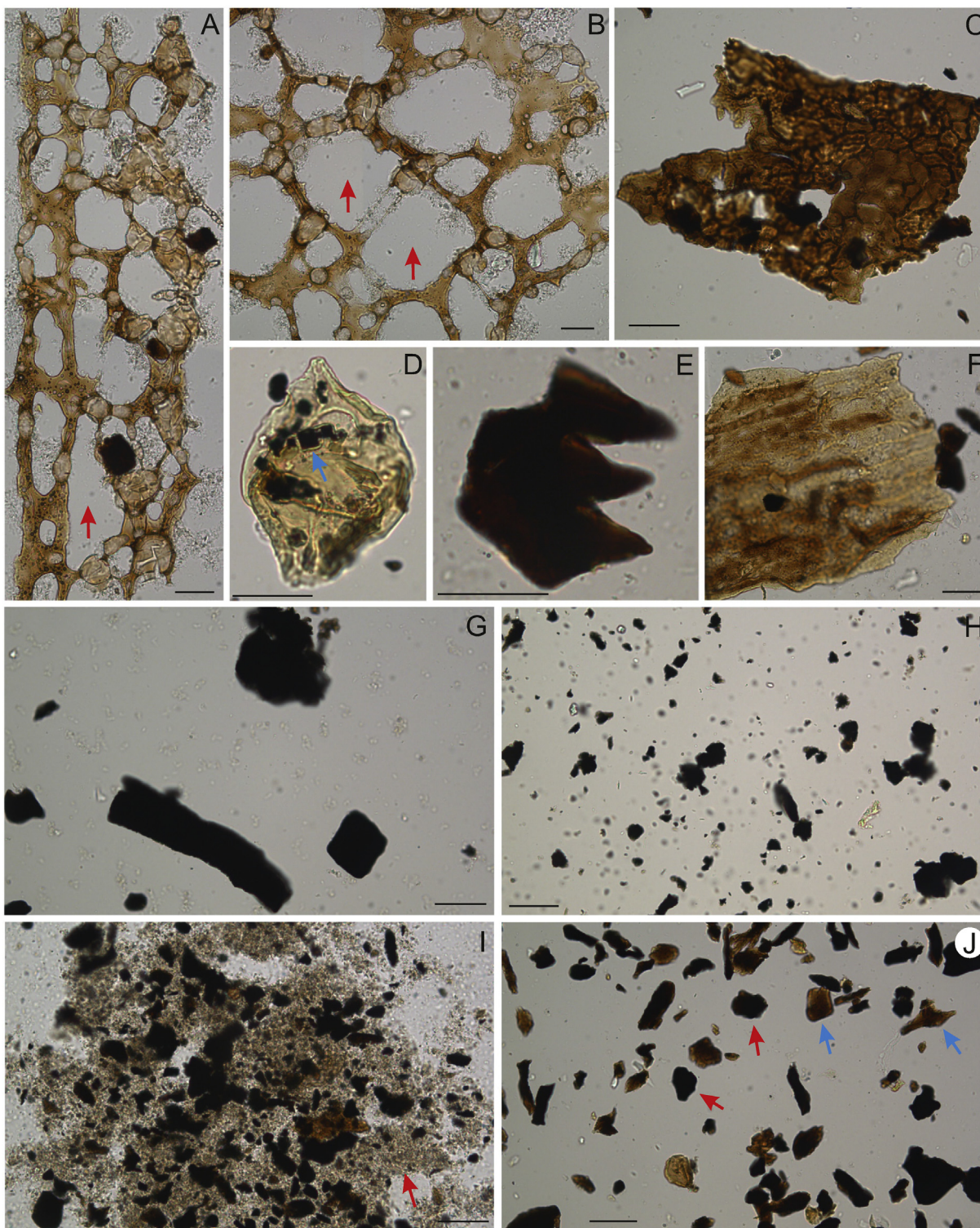
Fig. 7. Typical constituents of POM recognized in the Răchitova and Sînpetru formations (all unoxidized residues; scale bar: 30 μm; the three numbers between brackets are related to samples, palynological slides and England Finder co-ordinates, respectively). A, B. large fragments of spongy tissues (aerenchyma), probably belonging to the genus *Nymphaea* (red arrows - intercellular air spaces) (P227S, BH227-5, D41). C. Cuticles, large in size (P237C, BH237-3, N41-2). D. Cyst of *Isabelidinium*, with crystals of framboidal pyrite (blue arrow) (P236C, BH236-4, L33-1). E. Reworked scolecodont (P234C, BH234-3, G31-2). F. Woody tissues (P234C, BH234-4, R10-4). G. Angular opaque phytoclasts, lath-shaped (P226S, BH226-2, J18-1). H. Opaque phytoclasts with small dimensions and rounded shapes (P230D, BH230-4, L33-1). I. Granular AOM (red arrow) mixed with opaque phytoclasts small in size (P233D, BH233 -4, C3). J. Opaque phytoclasts (red arrows) mixed with translucent phytoclasts (blue arrows) of terrestrial origin (P237C, BH237-1, B24-1). (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

Two taxa of the *Normapolles* group, namely *Trudopollis exemplum* and *T.* cf. *capsula*, which also range from the Santonian to Maastrichtian (Polette and Batten, 2017), occur in the Upper Member. According to Portnyagina (1981), *Longanulipollis* and *Oculopollis* prevail in Campanian assemblages, but are absent from lower Maastrichtian deposits in the Skale zone of the Carpathians. The occurrence of *Longanulipollis* sp. in samples P232D and P230D suggests a Campanian age for this interval.

Taxa (with the exception of *Suemegipollis triangularis*) used to date the Răchitova Formation represent the first evidence of their presence in the Upper Cretaceous deposits of the Hațeg Basin. In summary, all the bioevents listed above, dated by dinocyst marker taxa, some fern spores and pollen belonging to the *Normapolles* group, suggest a Santonian age for the studied interval P237C–P234C in the Lower Member of the Răchitova Formation (Ciula Mică outcrop) and an early to early late Campanian date for the Upper Member of the same formation (sampling interval P233D–P229D, Densuş outcrop).

6.1.2. Sînpetru Formation

The age of this formation is more difficult to establish due to its low content in palynomorphs and long-ranging taxa such as *Deltoidospora minor*, *Gleicheniidites senonicus* and *Laevigatosporites ovatus*. All taxa identified by us from the Sînpetru Formation were also previously recorded from the same deposits by Van Itterbeeck et al. (2005) and Csiki et al. (2008). Therefore, we agree the early/late Maastrichtian age of this formation, as suggested by Van Itterbeeck et al. (2005) on the basis of a more conclusive palynological content.

6.2. Palaeoenvironmental considerations and palaeoclimatic implications

Dispersed organic matter components, as well as types of palynomorphs and their diversity, can be reflective of the depositional environments. Factors, such as proximity of the terrestrial vegetation to water, climate, sea level changes, accumulation rate of deposits and biological activity affect the distribution of organic matter (Batten, 1996). A large proportion of terrestrial POM (phytoclasts, pollen grains and spores, freshwater algae), as well as a small amount of marine material (dinoflagellate cysts, granular AOM, foraminiferal test linings), were recorded in the deposits discussed here (Fig. 6).

6.2.1. Răchitova Formation

In the Lower Member of this formation, the palynofacies composition exhibits a clear proximal signature, as demonstrated by the predominance of phytoclasts (97–99%; Fig. 6) and a taxonomic diversification of terrestrial palynomorphs. The O/Trans ratio shows values of 0.09–0.39, suggesting a more inner neritic environment. This suggestion is also supported by the low content of the marine fraction (few dinocysts and rare foraminiferal test linings), as well as by the C/M ratio, the latter having a higher value (2.23) in P234C sample (Fig. 6). The occurrence of a level with fossil plant remains in the lower part of the Ciula Mică section (Fig. 1E) and the high frequency of fern spores in the sampling interval P234C–P237C (Fig. 8) support the proximity to terrestrial sources or redeposition of continental organic matter from fluvio-deltaic sources (Tyson, 1995). This paleoenvironment interpretation is slightly different from previous ones: the Santonian deposits from the northwestern part of the Hațeg basin (Răchitova–Ştei area) were earlier interpreted as proximal turbidites deposited in a deep-marine environment (Melinte-Dobrinescu, 2010) and palaeocurrent data indicated a transport from east to west of these turbidites, accumulated into a longitudinal basin (Pop et al., 1972).

In the present study, terrestrial palynomorphs identified from Santonian deposits reveal a diverse vegetation with elements of subtropical to warm-temperate forests. The occurrence of hygrophytic fern spores, such as *Deltoidospora*, *Gleicheniidites*, *Laevigatosporites* and *Polypodiaceoisporites*, is consistent with plant communities growing in fluvial and tidally influenced coastal plain environments (Abbink et al., 2004; Raine et al., 2011). Additionally, the presence of the *Chomotriletes fragilis* (freshwater algae) indicates that this ecosystem incorporated ponds or lakes. Coastal environments may also have included mangrove-type vegetation, including *Alisporites* pollen, probably produced by seed ferns (Barrón et al., 2015). Besides vegetation typical of low elevation areas, other terrestrial palynomorphs (e.g., *Araucariacites*) suggest a well-drained and higher altitude habitat (Bowman et al., 2014; Michels et al., 2018). Pollen grains comparable with *Araucariacites australis* are produced today by *Araucaria araucana* (see Bowman et al., 2014), which grows in cool temperate conditions of the southern hemisphere (7–8 °C: coldest month; 17–19 °C: warmest month). A relative abundance of araucarian pollen was recorded in sample P234C (Appendix A). It seems that the higher altitude area was also preferred by some early angiosperms (parent plants of pollen *Trudopollis* spp.), this palaeoflora generally required cooler and wetter conditions (Daly and Jolley, 2015).

In the Upper Member of the Răchitova Formation, the POM assemblage shows a different composition compared to that described from the Lower Member of the same formation. In the lower part of the Densuş section (P233D sample; Fig. 6), the relative abundance of marine AOM reflects low-energy conditions, and possibly a higher relative sea level during the early Campanian. A similar environment was previously indicated by Pop (1990) and Melinte-Dobrinescu (2010), who suggested, based on lithological and sedimentological data, that a regional transgression took place in the Hațeg area, starting from the Santonian/Campanian boundary and ending in the late Campanian.

According to Valdés et al. (2004) and Ercegovac and Kostić (2006), the colour of marine AOM derived from the phytoplankton degradation generally varies from yellow-green under oxic sedimentary conditions in coastal area, to brown under dysoxic/anoxic conditions in pelagic zones. In our study, the marine AOM identified in the lower part of the Densuş section shows a light colour (Fig. 7I), suggesting a more neritic environment for this interval. The SPM ternary diagram of Federova (1977) also supports a mainly shallow-marine setting and less offshore conditions for the deposits assigned to the Upper Member of the Răchitova Formation (Fig. 8).

The sampling interval P232D–P230D is rich in dinoflagellate cysts compared to the Lower Member and contains a peridinioid-enriched assemblage (Appendix A). Among common peridinioid representatives, different species of *Isabelidinium* were recorded. The occurrence of these peridinioids in our assemblages is indicative of typical neritic environments (Wall et al., 1977; Prauss, 2006; Tahoun et al., 2018). A peridinioid-dominated assemblage also indicates nutrient-rich and low salinity conditions related to freshwater influx into a marine environment (Van Helmond et al., 2015).

In summary, the high abundance of marine AOM and opaque phytoclasts of small dimensions and with rounded shapes, as well as the increase of the O/Trans ratio in the top of the Densuş section (Fig. 6), suggest an outer neritic environment for the Upper Member of the Răchitova Formation. However, the abundance of the inner neritic peridinoid dinoflagellate cysts (mainly *Isabelidinium*) in three samples (P232D, P230D and P229D) of the Upper Member may be interpreted as related to transport by paleocurrents to a distal area of the sedimentary basin. The transport of other types of palynomorphs (spores, pollen) to a distal area of the basin during deposition of the Upper Member cannot be excluded.
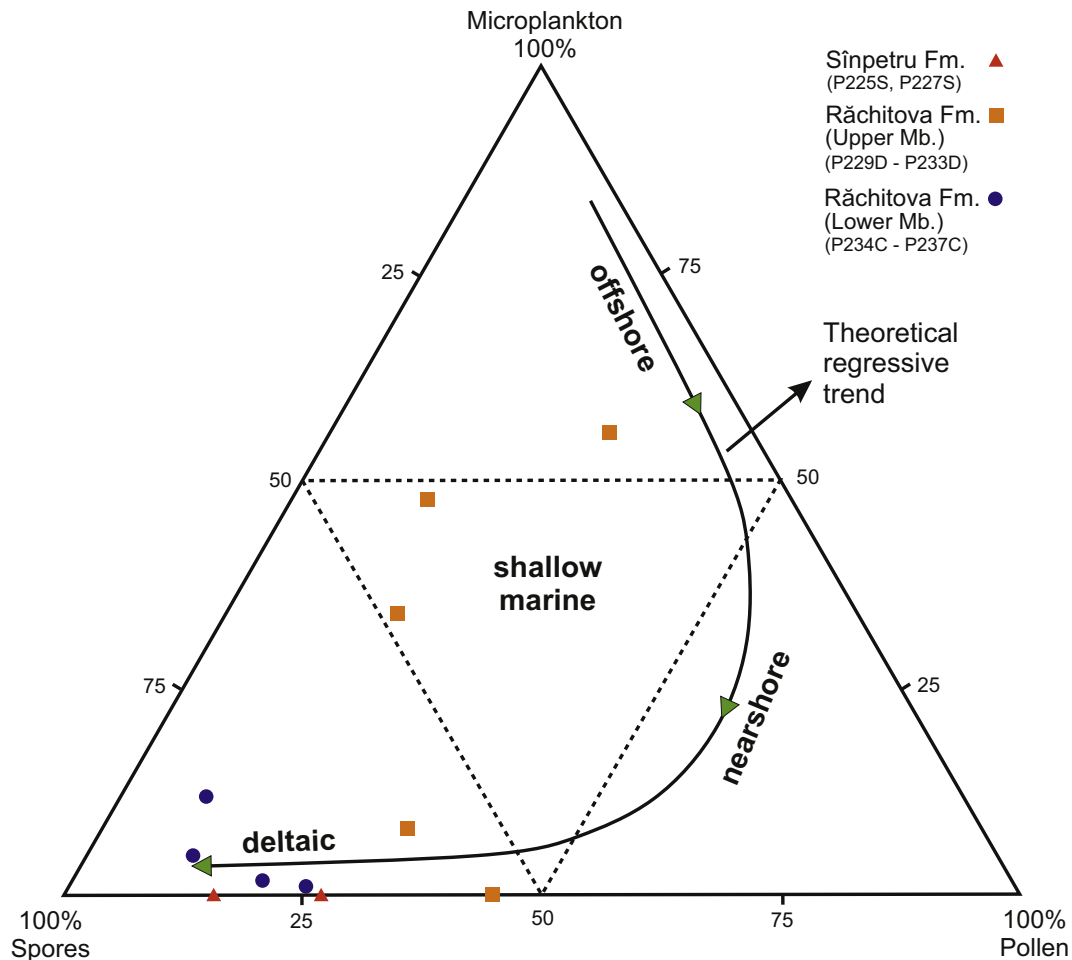
Fig. 8. Spore–pollen–microplankton ternary plot (after Federova, 1977; Duringer and Doubinger, 1985), with inferred depositional environments for the Santonian–Maastrichtian interval in the Haţeg area.

The early Campanian plant palynomorphs identified in the Upper Member of the Răchitova Formation reveal a similar vegetation to that described from the Lower Member of the same formation. The ferns, which most likely grew on riverine flood plains, are well represented by various species of thermophilous spores. The *Classopollis* pollen, produced from drought-resistant and thermophilous cheirolepidiacean conifers, shows a constant occurrence in the sampling interval P233D–P229D. The Cheirolepidiaceae often grew on drained slopes and coastal habitats (Wang et al., 2005) and are adapted to arid climate conditions and hypersaline soils (Michels et al., 2018). Other gymnosperms such as *Araucariacites*, *Pinuspollenites* and some early angiosperms (e.g., *Trudopollis* spp.) are indicative of higher altitude areas.

6.2.2. Sînpetru Formation

The palynofacies assemblages recovered from the Sînpetru Formation show a low content in organic matter, as well as a low diversity of palynomorphs due to the strong oxidation conditions during the sedimentation of these terrestrial strata. The particulate organic matter is dominated by translucent phytoclasts (woody tissues, spongy tissues, cuticles), while opaque phytoclasts are rare. Some large fragments of spongy tissues (Fig. 7A, B; P227S sample), which belong to aquatic plants leaves (probably *Nymphaea*), indicate a short transport of these phytoclasts and supports their deposition in deltaic environments or freshwater ponds or lakes. These environments are also indicated by the O/Trans ratio (with

values ranging from −0.74 to 0.08; Fig. 6), C/M ratio (2.17–2.69), as well as the occurrence of freshwater algae. In the grey-green mudstone intercalation, located near the P227S sample, a tooth of the herbivorous dinosaur *Zalmoxes* (Fig. 5K, L), as well as other bone fragments of dinosaurs, were identified.

The lack of dinoflagellate cysts in the samples from the Sînpetru Formation analysed may support a typical continental setting for the Sînpetru depositional site.

The Maastrichtian palynological assemblage is predominated by hygrophytic fern spores such as *Laevigatosporites*, *Polypodiaceoisporites*, *Deltoidospora* and *Gleicheniidites*, and can therefore be attributed to lowland, fluvial or coastal habitats and a warm climatic conditions. In the upper part of the Sînpetru section (P225S sample; Fig. 1C), a relative abundance of *Classopollis* pollen was observed. *Classopollis*-producing-plants (namely Cheirolepidiaceae) were adapted to an arid climate and hypersaline soils of the coastal habitats (Michels et al., 2018). According to Therrien et al. (2009), the investigation of Maastrichtian palaeosols assigned to the Sînpetru Formation reveals that the Sînpetru landscape was a mosaic of wetlands, seasonal wetlands and better-drained habitats. However, some periods of aridity have been suggested by the same authors based on palaeosol structures, roots of deeply-penetrating plants which were forced to seek water at great depth having been observed.

The plant pollen which grow in higher altitude areas have rare occurrences in our Maastrichtian palynological assemblages.

However, previous palynological studies (i.e., Van Itterbeeck et al., 2005) performed on the same deposits show an assemblage including gymnosperms such as *Pinuspollenites*, *Abiespollenites* and *Araucariacites*. These taxa may belong to a forest vegetation that grew on higher areas of the Haţeg island.

The source of food for the Maastrichtian herbivorous dinosaurs of the Haţeg island includes mainly araucarian conifers, angiosperms and Cheirolepidiaceae, while other groups of plants like ferns and the needle-leaved conifers were preferred to a lesser extent (Gee, 2011).

7. Systematic palynology

Division Dinoflagellata (Bütschli, 1885) Fensome et al. (1993)
Subdivision Dinokaryota Fensome et al., 1993
Class Dinophyceae Pascher, 1914
Subclass Peridiniphycidae Fensome et al., 1993
Order Peridiniales Haeckel, 1894
Suborder Peridiniineae Autonym
Family Peridiniaceae Ehrenberg, 1831
Subfamily Deflandreoideae Bujak and Davies, 1983

Genus *Isabelidinium* (McIntyre, 1975) Lentin and Williams (1977)
Type species: *Isabelidinium korogonense* (Cookson and Eisenack, 1958) Lentin and Williams (1977)

Isabelidinium microarmum subsp. **bicavatum**, subsp. nov.
Fig. 2A–H

Derivation of name. Named after its distinctly bicavate cyst.
Holotype. Sample P232D, slide 2, EF co-ordinates C41 (Fig. 2A–C).
Paratype. Sample P232D, slide 4, EF co-ordinates L18, (Fig. 2E–G).
Repository. Palynological collection of the Department of Geology, "Al. I. Cuza" University of Iaşi, Romania.
Type locality. The western part of Densuş, Ştei Valley (northwestern Haţeg Basin), southern Carpathians, Romania.
Type stratum. Upper Member of the Răchitova Formation (lower to lower upper Campanian).
Diagnosis. A subspecies of *Isabelidinium microarmum* characterized by its bicavate and subrectangular cyst and its endophragm and periphragm appressed in the equatorial region. Simple intercalary archeopyle formed from loss of 2a plate.
Description. The bicavate cyst is of intermediate size and has a subrectangular pericyst, a subcircular endocyst with flattened apical and antapical surfaces and equal-sized apical and antapical pericoels. The cyst is convex in the equatorial region and has developed shoulders. Apical horn rounded to blunt, left antapical horn acuminate and right antapical horn reduced. The endophragm thin (~1 μm thick) and smooth to slightly scabrate and the periphragm thin (~1 μm thick) and smooth with miniscule spines (0.5–2 μm length) are closely appressed in the equatorial region. The spines on the periphragm are irregularly distributed on the apical area (mainly the apical horn and shoulders) and the antapical area (mainly the antapical horns). The tabulation is peridinioid indicated only by an omegaform intercallary archeopyle resulting from loss of 2a plate. Operculum free.
Dimensions (in μm). Holotype: overall length/width 115/62; central body length/width 89/62. Paratype: overall length/width 101/60; central body length/width 82/60. Range for 13 specimens measured: overall length/width 101(109)115/58(63)66; central body length/width 74(84)89/58(63)66.
Remarks. Isabelidinium microarmum subsp. *bicavatum* subsp. nov. is distinguished from *I. microarmum* (McIntyre, 1975) Bujak and Davies (1983) subsp. *microarmum* (autonym; Fig. 2I, J) mainly by its endophragm and periphragm that are closely appressed in the equatorial region rather than separated. The type material of

I. microarmum was described as having an endophragm and periphragm always distinguishable and was figured by circumcavate cysts by McIntyre (1975, p. 65). Furthermore, this species was mostly illustrated in the literature by circumcavate cysts. The new subspecies has more or less a subrectangular pericyst shape with more developed shoulders and an endocyst with flattened anterior and posterior ends. The new subspecies is erected since it may turn out to constitute a useful stratigraphic marker for the recognition of the lower and lower upper Campanian. *Isabelidinium microarmum* subsp. *microarmum* has a longer stratigraphic range (Santonian–Maastrichtian).
Stratigraphic occurrence. Samples P232D–P229D (lower to lower upper Campanian), Densuş section, Haţeg Basin.

8. Conclusions

The present study discusses the first palynological and palynofacies records from Santonian–Campanian deposits in the Haţeg Basin. In addition, other data related to vegetation, palaeoclimate and palaeoenvironment of the Maastrichtian are outlined. The main conclusions are the following:

(1) The palynomorph assemblages identified in the present study suggest a Santonian age for the Lower Member (its lower part) of the Răchitova Formation, based on key fern spores and dinocyst taxa, and an early to early late Campanian age for its Upper Member, based on biostratigraphic marker taxa, such as the dinocyst species *Isabelidinium microarmum* and the early angiosperm *Longanulipollis* sp. The Sînpetru Formation shows a low content in terrestrial palynomorphs, suggesting a Maastrichtian age, as indicated in previous palynological studies.

(2) The Lower Member of the Răchitova Formation exhibits a high diversity of terrestrial palynomorphs (mainly fern spores, 74–84% of the total palynomorphs), along with subordinated pollen grains and phytoplankton. The abundance of marine palynomorphs increases in the Upper Member of the Răchitova Formation. The commonest taxon of this interval is *Isabelidinium* spp. The low diversity of the Maastrichtian palynomorph assemblage can be related to palaeoenvironmental conditions (continental deposition, strong oxidation of organic matter).

(3) The predominance of terrestrial POM (opaque and translucent phytoclasts, pollen grains and spores, freshwater algae) in the Lower Member (its lower part) of the Răchitova Formation indicates an inner neritic environment, while some palynofacies parameters and the marine AOM identified in the overlying Upper Member suggest a more outer neritic environment, with some periods of slight increase in water depth. It can be assumed that the phytoplankton (mainly peridinioid type) of the Upper Member of the Răchitova Formation, typical of near-shore environments, was transported by palaeocurrents to a distal area of the sedimentary basin. The Sînpetru Formation is interpreted to reflect deltaic to freshwater pond or lake deposits, based on the predominance of translucent phytoclasts (large fragments of spongy tissues), which belong to aquatic plants leaves, as well as occurrences of freshwater algae and hygrophytic fern spores.

(4) The Santonian–Campanian terrestrial palynomorphs reveal a diverse vegetation with elements of subtropical to warm-temperate forests. Ferns, as well as some conifers (i.e., Cheirolepidiaceae), suggest fluvial to coastal habitats, while other terrestrial palynomorphs (e.g., *Araucariacites*,

Pinuspollenites) indicate well-drained and higher altitude areas. Probably this habitat of higher elevation was also preferred by early angiosperms (parent plants of pollen *Trudopollis* spp.), requiring cooler and wetter conditions. The Maastrichtian vegetation can be attributed to lowland or coastal habitats and reveals warm and humid climatic conditions. However, some arid periods during the Maastrichtian are indicated by the presence of conifer pollen (e.g., *Classopollis* sp.). Araucarian and cheirolepidiacean conifers, as well as some angiosperms, were the main food source of herbivorous dinosaurs.

(5) A new subspecies *Isabelidinium microarmum* subsp. *bicavatum* subsp. nov., is described since it is likely to be a possible useful marker for the recognition of the lower to lower upper Campanian.

Acknowledgements

References

Abbink, O.A., Van Konijnenburg-Van Cittert, J.H.A., Visscher, H., 2004. A sporomorph ecogroup model for the Northwest European Jurassic – Lower Cretaceous: concepts and framework. Netherlands Journal of Geosciences/Geologie en Mijnbouw 83 (1), 17–38.

Aleksandrova, G.N., Beniamovskii, V.N., Vishnevskaya, V.S., Zastrozhnov, A.S., 2012. New data on Upper Cretaceous biostratigraphy of the lower Volga region. Stratigraphy and Geological Correlation 20 (5), 426–465.

Antonescu, E., 1973. Asociaţii palinologice caracteristice unor formaţiuni cretacice din Munţii Metaliferi. Dări de Seamă ale Şedinţelor (Paleontologie) 59, 115–169.

Antonescu, E., Lupu, D., Lupu, M., 1983. Corrélation palynologique du Crétacé terminal du sud-est des Monts Metaliferi et des Dépressions de Haţeg et de Rusca Montană. Anuarul Institutului de Geologie şi Geofizică 59, 71–77.

Barrón, E., Peyrot, D., Rodríguez-López, J.P., Meléndez, N., del Valle, R.L., Najarro, M., Rosales, I., Comas-Rengifo, J., 2015. Palynology of Aptian and upper Albian (Lower Cretaceous) amber-bearing outcrops of the southern margin of the Basque-Cantabrian basin (northern) Spain. Cretaceous Research 52, 292–312.

Batten, D.J., 1996. Palynofacies: introduction, 1011–1064. In: Jansonius, J., McGregor, D.C. (Eds.), Palynology: Principles and applications 3. American Association of Stratigraphic Palynologists Foundation, Dallas (TX).

Batten, D.J., 1999. Small palynomorphs, 15–19. In: Jones, T.P., Rowe, N.P. (Eds.), Fossil plants and spores: modern techniques. Geological Society, London.

Bojar, A.V., Grigorescu, D., Csiki, Z., 2005. Palaeoenvironmental interpretation of dinosaur- and mammal-bearing continental Maastrichtian deposits, Haţeg basin, Romania. Geological Quarterly 49, 205–222.

Botfalvai, G., Csiki-Sava, Z., Grigorescu, D., Vasile, Ş., 2017. Taphonomical and palaeoecological investigation of the Late Cretaceous (Maastrichtian) Tuştea vertebrate assemblage (Romania; Haţeg Basin) - insights into a unique dinosaur nesting locality. Palaeogeography, Palaeoclimatology, Palaeoecology 468, 228–262.

Bowman, V.C., Francis, J.E., Askin, R.A., Riding, J.B., Swindles, G.T., 2014. Latest Cretaceous–earliest Paleogene vegetation and climate change at the high southern latitudes: palynological evidence from Seymour Island, Antarctic Peninsula. Palaeogeography, Palaeoclimatology, Palaeoecology 408, 26–47.

Bujak, J.P., Davies, E.H., 1983. Modern and fossil Peridiniineae. American Association of Stratigraphic Palynologists. Contributions Series 13, 203 pp.

Bütschli, O., 1885. Erster Band. Protozoa, 865–1088. In: Bronn's, Dr H.G. (Ed.), Klassen und Ordnungen des Thier-Reichs, wissenschaftlich dargestellt in Wort und Bild, C.F. Winter'sche Verlagsbuchhandlung, Leipzig and Heidelberg.

Carvalho, M.A., Mendonça Filho, J.G., Menezes, T.R., 2006. Palynofacies and sequence stratigraphy of the Aptian–Albian of the Sergipe Basin, Brazil. Sedimentary Geology 192, 57–74.

Carvalho, M.A., Cabral Ramos, R.R., Crud, M.B., Witovisk, L., Kellner, A.W.A., Silva, H.P., Grillo, O.N., Riff, D., Romano, P.S.R., 2013. Palynofacies as indicators of paleoenvironmental changes in a Cretaceous succession from the Larsen Basin, James Ross Island, Antarctica. Sedimentary Geology 295, 53–66.

Carvalho, M.A., Bengtson, P., Lana, C.C., 2016. Late Aptian (Cretaceous) paleoceanography of the South Atlantic Ocean inferred from dinocyst communities of the Sergipe Basin, Brazil. Paleoceanography 31, 2–26.

Catian, G., Scremin-Dias, E., 2015. Phenotypic variations in leaf anatomy of *Nymphaea gardneriana* (Nymphaeaceae) demonstrate its adaptive plasticity. Journal of the Torrey Botanical Society 142 (1), 18–26.

Cookson, I.C., Eisenack, A., 1958. Microplankton from Australian and New Guinea Upper Mesozoic sediments. Proceedings of the Royal Society of Victoria 70 (1), 19–79.

Costa, L.I., Davey, R.J., 1992. Dinoflagellate cysts of the Cretaceous System, 99–153. In: Powell, A.J. (Ed.), A Stratigraphic Index of Dinoflagellate Cysts. Chapman and Hall, London.

Csiki, Z., Grigorescu, D., 2000. Teeth of multituberculate mammals from the Late Cretaceous of Romania. Acta Palaeontololica Polonica 45, 85–90.

Csiki, Z., Ionescu, A., Grigorescu, D., 2008. The Budurone microvertebrate site from the Maastrichtian of the Haţeg Basin – flora, fauna, taphonomy and palaeoenvironment. Acta Palaeontologica Romaniae 6, 49–66.

Csiki, Z., Grigorescu, D., Codrea, V., Therrien, F., 2010. Taphonomic modes in the Maastrichtian continental deposits of the Haţeg Basin, Romania – palaeoecological and palaeobiological inferences. Palaeogeography, Palaeoclimatology, Palaeoecology 293, 375–390.

Csiki-Sava, Z., Vremir, M., Meng, J., Brusatte, S.L., Norell, M.A., 2018. Dome-headed, small-brained island mammal from the Late Cretaceous of Romania. Proceedings of the National Academy of Sciences of the United States of America (PNAS) 115 (19), 4857–4862.

Csontos, L., Vörös, A., 2004. Mesozoic plate tectonic reconstruction of the Carpathian region. Palaeogeography, Palaeoclimatology, Palaeoecology 210, 1–56.

Daly, R.J., Jolley, D.W., 2015. What was the nature and role of Normapolles angiosperms? A case study from the earliest Cenozoic of Eastern Europe. Palaeogeography, Palaeoclimatology, Palaeoecology 418, 141–149.

Dercourt, J., Gaetani, M., Vrielynck, B., Barrier, E., Biju-Duval, B., Brunet, M.F., Cadet, J.P., Casquin, S., Săndulescu, M. (Eds.), 2000. Atlas Peri-Tethys, Palaeogeographical Maps. CCGM/CGMW, Paris, p. 269.

Duringer, P., Doubinger, J., 1985. La palynologie: un outil de caractérisation des faciès marins et continentaux à la limite Muschelkalk Supérieur–Lettenkohle. Science Géologie Bulletin (Strasbourg) 38, 19–34.

Ehrenberg, C.G., 1831. Animalia evertebrata. In: Hemprich, P.C., Ehrenberg, C.G. (Eds.), Symbolae physicae. Pars Zoologica, vol. 1, p. 119, 10 pl., plates issued 1828, unpaginated text issued 1831.

Ercegovac, M., Kostić, A., 2006. Organic facies and palynofacies: Nomenclature, classification and applicability for petroleum source rock evaluation. International Journal of Coal Geology 68, 70–78.

Federova, V.A., 1977. The significance of the combined use of microphytoplankton, spores, and pollen for differentiation of multi-facies sediments, 70–88. In: Samoilovich, S.R., Timoshina, N.A. (Eds.), Questions of Phytostratigraphy 398. Trudy Neftyanoi nauchno-issledovatelskii geologorazvedochnyi Institut (VNIGRI), Leningrad (in Russian).

Fensome, R.A., Taylor, F.J.R., Norris, G., Sarjeant, W.A.S., Wharton, D.I., Williams, G.L., 1993. A classification of fossil and living dinoflagellates, vol. 7. Micropaleontology Press Special Paper, 351 pp.

Fensome, R.A., Nøhr-Hansen, H., Williams, G.L., 2016. Cretaceous and Cenozoic dinoflagellate cysts and other palynomorphs from the western and eastern margins of the Labrador–Baffin Seaway. Geological Survey of Denmark and Greenland Bulletin 36, 143 pp.

Gee, C.T., 2011. Dietary options for the sauropod dinosaurs from an integrated botanical and paleobotanical perspective, 34–56. In: Klein, N., Remes, K., Gee, C.T., Sander, P.M. (Eds.), Biology of the Sauropod Dinosaurs: Understanding the Life of Giants. Indiana University Press, Bloomington.

Góczán, F., Siegl-Farkas, Á., 1990. Palynostratigraphical zonation of Senonian sediments in Hungary. Review of Palaeobotany and Palynology 66, 361–377.

Grigorescu, D., 1992. Nonmarine Cretaceous formations of Romania, 142–164. In: Mateer, N., Pen-Ji, C. (Eds.), Aspects of Nonmarine Cretaceous Geology. China Ocean Press, Beijing.

Grigorescu, D., 2010. The Latest Cretaceous fauna with dinosaurs and mammals from the Haţeg Basin – A historical overview. Palaeogeography, Palaeoclimatology, Palaeoecology 293, 271–282.

Grigorescu, D., Melinte, M.C., 2001. The stratigraphy of the Upper Cretaceous marine sediments from the NW Haţeg area (South Carpathians, Romania). Acta Palaeontologica Romaniae 3, 153–160.

Grigorescu, D., Csiki, Z., Vasile, Ş., 2010. Cretacicul superior în facies continental din Ţara Haţegului, 123–199. In: Otiman, P.I., Grigorescu, D., Enache, M., Bogdan, A. (Eds.), Conservarea geo- şi biodiversităţii şi dezvoltarea durabilă în Ţara Haţegului - Retezat. Editura Academiei Române.

Haeckel, E., 1894. Systematische Phylogenie. Entwurf eines natürlichen Systems der Organismen auf Grund ihrer Stammesgeschichte, I. Systematische Phylogenie der Protisten und Pflanzen, Berlin, 400 pp.

Halamski, A.T., Kvaček, J., Vajda, V., 2016. Late Cretaceous (Campanian) leaf and palynoflora from southern Skåne, Sweden, 207–230. In: Kear, B.P., Lindgren, J., Hurum, J.H., Milàn, J., Vajda, V. (Eds.), Mesozoic biotas of Scandinavia and its Arctic territories, vol. 434. Geological Society, London, Special Publications (1).

Ioannides, N.S., 1986. Dinoflagellate cysts from Upper Cretaceous – Lower Tertiary sections, Bylot and Devon Island, Antarctic Archipelago. Geological Survey of Canada, Bulletin no. 371, 99 pp.

Ioannides, N.S., McIntyre, D.J., 1980. A preliminary palynological study of the Caribou Hills outcrop section along the Mackenzie River, District of Mackenzie. Geological Survey of Canada, pp. 197–208. Paper no. 80-1A.

Juhász, M., 1975. Lycopodiaceae spores from Lower Cretaceous deposits of Hungary. Acta Biologica Szegediensis 21 (1–4), 21–34.

Kedves, M., Herngreen, G.F.W., 1981. Palynology of the stratotype of the Maestrichtian and the Gulpen Formation, ENCI section, Maastricht, The Netherlands. Pollen et Spores 22, 483–544.

Kirsch, K.H., 1991. Dinoflagellatenzysten aus der Oberkreide des Helvetikums und Nordultrahelvetikums von Oberbayern. Münchner Geowissenschaftliche Abbandlungen A(22), 306 pp.

Lebedeva, N.K., 2006. Dinocyst biostratigraphy of the Upper Cretaceous of Northern Siberia. Paleontological Journal 40 (5), 604–621.

Lebedeva, N.K., Kuz'mina, O.B., 2018. Palynostratigraphy of the Upper Cretaceous and Paleogene Deposits in the South of Western Siberia by Example of Russkaya Polyana Boreholes, Omsk Trough. Stratigraphy and Geological Correlation 26 (1), 80–108.

Lentin, J.K., Williams, G.L., 1977. Fossil dinoflagellate genus *Isabelidinium* nom. nov. Palynology 1, 167–168.

May Lindfors, S., Csiki, Z., Grigorescu, D., Friis, E.M., 2010. Preliminary account of plant mesofossils from the Maastrichtian Budurone microvertebrate site of the Hațeg Basin, Romania. Palaeogeography, Palaeoclimatology, Palaeoecology 293, 353–359.

McIntyre, D.J., 1975. Morphologic changes in Deflandrea from a Campanian section, District of Mackenzie. N.W.T., Canada. Geoscience and Man 11, 61–76.

Melinte-Dobrinescu, M.C., 2010. Lithology and biostratigraphy of Upper Cretaceous marine deposits from the Hațeg region (Romania): Palaeoenvironmental implications. Palaeogeography, Palaeoclimatology, Palaeoecology 293, 283–294.

Mendonça Filho, J.G., Carvalho, M.A., Menezes, T.R., 2002. Palinofácies, 20–24. In: Dutra, T.L. (Ed.), Técnicas e Procedimentos para o Trabalho com Fósseis e Formas Modernas Comparativas. Unisinos, São Leopoldo.

Michels, F.H., Alves de Souza, P., Premaor, E., 2018. Aptian-Albian palynologic assemblages interbedded within salt deposits in the Espírito Santo Basin, eastern Brazil: Biostratigraphical and paleoenvironmental analysis. Marine and Petroleum Geology 91, 785–799.

Mărgărit, G., Mărgărit, M., 1967. Asupra prezenței unor resturi de plante fosile în împrejurimile localității Densuș (Bazinul Hațeg). Studii și Cercetări de Geologie, Geofizică, Geografie. Serie de Geologia 12 (2), 471–476.

Newman, K.R., 1965. Upper Cretaceous–Paleocene guide palynomorphs from northwestern Colorado, vol. 2. University of Colorado, Studies Series in Earth Sciences, pp. 1–21.

Nopcsa, F., 1905. Zur Geologie der Gegend zwischen Gyulafehérvár, Deva, Ruszkabánya und der Rumänischen Landesgrenze. Mitteilungen aus dem Jahrbuche der Königlichen-Ungarischen Geologischen Reichsanstalt 14, 91–279.

Năstăseanu, S., 1975. Aperçu synthétique sur la géologie des Carpathes méridionales entre le Danube et le Jiu. Bulletin de la Societe Geologique de France 17 (3), 359–368.

Panaiotu, C.G., Panaiotu, C.E., 2010. Palaeomagnetism of the Upper Cretaceous Sânpetru Formation (Hațeg Basin, South Carpathians). Palaeogeography, Palaeoclimatology, Palaeoecology 293, 343–352.

Pascher, A., 1914. Über Flagellaten und Algen. Deutsche Botanische Gesellschaft, Berichte 32, 136–160.

Pellaton, C., Gorin, G.E., 2005. The Miocene New Jersey passive margin as a model for the distribution of sedimentary organic matter in siliciclastic deposits. Journal of Sedimentary Research 75, 1011–1027.

Polette, F., Batten, D.J., 2017. Fundamental reassessment of the taxonomy of five Normapolles pollen genera. Review of Palaeobotany and Palynology 243, 47–91.

Pop, G., 1990. The Hațeg area, 25–42. In: Grigorescu, D., Avram, E., Pop, G., Lupu, M., Anastasiu, N. (Eds.), Guide to excursions, International Symposium IGCP Bucharest, Projects 245 (Nomarine Cretaceous Correlation) and 283 (Tethyan Cretaceous Correlation). Geological Institute of Romania.

Pop, G., Neagu, T., Szasz, L., 1972. Senonianul din regiunea Hațegului (Carpații Meridionali). Dări de Seamă ale Ședințelor (Stratigrafie) 58, 95–118.

Popa, M.E., Kvaček, J., Vasile, Ș., Csiki-Sava, Z., 2014. Maastrichtian monocotyledons of the Rusca Montană and Hațeg basins, South Carpathians, Romania. Review of Palaeobotany and Palynology 210, 89–101.

Popa, M.E., Kvaček, J., Vasile, Ș., Csiki-Sava, Z., 2016. Maastrichtian dicotyledons of the Rusca Montană and Hațeg basins, South Carpathians, Romania. Cretaceous Research 57, 699–712.

Portnyagina, L.A., 1981. Normapolles pollen in Upper Cretaceous and Palaeogene deposits of the Skale zone of the Carpathians. Review of Palaeobotany and Palynology 35, 231–235.

Powell, A.J., 1992. Dinoflagellate cysts of the Tertiary System, 155–252. In: Powell, A.J. (Ed.), A Stratigraphic Index of Dinoflagellate Cysts. Chapman and Hall, London.

Prauss, M.L., 2006. The Cenomanian/Turonian boundary event (CTBE) at Wunstorf, northwest Germany, as reflected by marine palynology. Cretaceous Research 27 (6), 872–886.

Radmacher, W., Mangerud, G., Tyszka, J., 2015. Dinoflagellate cyst biostratigraphy of Upper Cretaceous strata from two wells in the Norwegian Sea. Review of Palaeobotany and Palynology 216, 18–32.

Raine, J.I., Mildenhall, D.C., Kennedy, E.M., 2011. New Zealand fossil spores and pollen: an illustrated catalogue. In: GNS Science miscellaneous series no. 4, fourth ed. http://data.gns.cri.nz/sporepollen/index.htm

Rauscher, R., Doubinger, J., 1982. Les dinokystes du Maestrichtien phosphaté au Maroc. Sciences Geologiques 35 (3), 97–116.

Schiøler, P., Brinkhuis, H., Roncaglia, L., Wilson, G., 1997. Dinoflagellate biostratigraphy and sequence stratigraphy of the Type Maastrichtian (Upper Cretaceous), ENCI Quarry, The Netherlands. Marine Micropaleontology 31, 65–95.

Slimani, H., 2000. Nouvelle zonation aux kystes de dinoflagellés du Campanien au Danien dans le nord et l'est de la Belgique et dans le sud-est des Pays-Bas. Memoirs of the Geological Survey of Belgium 46, 1–88.

Slimani, H., 2001. Les kystes de dinoflagellés du Campanien au Danien dans la région de Maastricht (Belgique et Pays-Bas) et de Turnhout (Belgique): biozonation et corrélation avec d'autres régions en Europe occidentale. Geologica et Palaeontologica 35, 161–201.

Slimani, H., Louwye, S., 2012. New junior synonyms of the Late Cretaceous dinoflagellate cysts *Membranigonyaulax wilsonii* Slimani 1994 and *Turnhosphaera hypoflata* (Yun 1981) Slimani 1994. Palynology 36 (1), 110–115.

Slimani, H., Louwye, S., Dusar, M., Lagrou, D., 2011. Connecting the Chalk Group of the Campine Basin to the dinoflagellate cyst biostratigraphy of the Campanian to Danian in the borehole Meer (northern Belgium). Netherlands Journal of Geosciences 90, 129–164.

Slimani, H., Guédé, K.É., Williams, G.L., Asebriy, L., Ahmamou, M., 2016. Campanian to Eocene dinoflagellate cyst biostratigraphy from the Tahar and Sekada sections at Arba Ayacha, western External Rif, Morocco. Review of Palaeobotany and Palynology 228, 26–46.

Stancu, J., Baltres, A., Cioflica, G., Gheta, N., Moisescu, V., Papaianopol, I., Popescu, D., Popescu, G., 1980. Contribuții la studiul petrografic și paleontologic al depresiunii Hațeg pe baza unor foraje. Dări de Seamă ale Institutului de Geologie și Geofizică 67 (4), 115–136.

Steffen, D., Gorin, G., 1993. Palynofacies of the Upper Tithonian–Berriasian deep-sea carbonates in the Vocontian Trough (SE France). Bulletin Centres Recherches Exploration-Production Elf Aquitaine 17, 235–247.

Stilla, A., 1985. Géologie de la région de Hațeg-Cioclovina-Bănița (Carpates Méridionales). Anuarul Institutului de Geologie și Geofizică 66, 91–179.

Stover, L.E., Evitt, W.R., 1978. Analyses of pre-Pleistocene organic-walled dinoflagellates. Stanford University Publications, Geological Sciences no. 15P, 300 pp.

Săndulescu, M., 1984. Geotectonica României. Editura Tehnică, București, 336 pp.

Tahoun, S.S., Deaf, A.S., Ied, I.M., 2018. The use of cyclic stratigraphic pattern of peridinioid and gonyaulacoid dinoflagellate cysts in differentiating potential thick monotonous carbonate reservoirs: A possible ecostratigraphic tool under test. Marine and Petroleum Geology 96, 240–253.

Therrien, F., 2006. Sedimentary facies, depositional environments, and fluvial system changes in the dinosaur-bearing Sânpetru Formation (Late Cretaceous, Maastrichtian), Romania. Sedimentary Geology 192, 183–205.

Therrien, F., Zelenitsky, D.K., Weishampel, D.B., 2009. Palaeoenvironmental reconstruction of the Late Cretaceous Sânpetru Formation (Hațeg Basin, Romania) using paleosols and implications for the "disappearance" of dinosaurs. Palaeogeography, Palaeoclimatology, Palaeoecology 272, 37–52.

Tyson, R.V., 1995. Sedimentary Organic Matter: Organic Facies and Palynofacies. Chapman and Hall, London, 615 pp.

Țabără, D., Pacton, M., Makou, M., Chirilă, G., 2015. Palynofacies and geochemical analysis of Oligo-Miocene bituminous rocks from the Moldavidian Domain (Eastern Carpathians, Romania): Implications for petroleum exploration. Review of Palaeobotany and Palynology 216, 101–122.

Țabără, D., Slimani, H., Mare, S., Chira, C.M., 2017. Integrated biostratigraphy and palaeoenvironmental interpretation of the Upper Cretaceous to Paleocene succession in the northern Moldavidian Domain (Eastern Carpathians, Romania). Cretaceous Research 77, 102–123.

Vajda, V., Wigforss-Lange, J., 2006. The Jurassic-Cretaceous transition of Southern Sweden − palynological and sedimentological interpretation. Progress in Natural Science 16, 31–38.

Vajda, V., Pesquero Fernández, M.D., Villanueva-Amadoz, U., Lehsten, V., Alcalá, L., 2016. Dietary and environmental implications of Early Cretaceous predatory dinosaur coprolites from Teruel, Spain. Palaeogeography, Palaeoclimatology, Palaeoecology 464, 134–142.

Valdés, J., Sifeddine, A., Ortlieb, L., Pierre, C., 2004. Interplay between sedimentary organic matter and dissolved oxygen availability in a coastal zone of the Humboldt Current System; Mejilones Bay, northern Chile. Marine Geology 265, 57–166.

Van Helmond, N.A.G.M., Sluijs, A., Sinninghe Damsté, J.S., Reichart, G.-J., Voigt, S., Erbacher, J., Pross, J., Brinkhuis, H., 2015. Freshwater discharge controlled deposition of Cenomanian−Turonian black shales on the NW European epicontinental shelf (Wunstorf, North Germany). Climate of the Past 11, 495–508.

Van Itterbeeck, J., Markevich, V.S., Codrea, V., 2005. Palynostratigraphy of the Maastrichtian dinosaur and mammal sites of the Râul Mare and Bărbat valleys (Hațeg Basin, Romania). Geologica Carpathica 56 (2), 137–147.

Versteegh, G.J.M., 1994. Recognition of cyclic and non-cyclic environmental changes in the Mediterranean Pliocene; A palynological approach. Marine Micropaleontology 23, 147–183.

Wall, D., Dale, B., Lohmann, G.P., Smith, W.K., 1977. The environment and climatic distribution of dinoflagellate cysts in modern marine sediments from regions in the North & South Atlantic Oceans and adjacent seas. Marine Micropalaeontology 2, 121–200.

Wang, Y., Mosbrugger, V., Zhang, H., 2005. Early to Middle Jurassic vegetation and climatic events in the Qaidam Basin, Northwest China. Palaeogeography, Palaeoclimatology, Palaeoecology 224, 200–216.

Williams, G.L., Bujak, J.P., 1985. Mesozoic and Cenozoic dinoflagellates, 847–964. In: Bolli, H.M., Saunders, J.B., Perch-Nielsen, K. (Eds.), Plankton stratigraphy. Cambridge University Press, Cambridge.

Williams, G.L., Brinkhuis, H., Pearce, M.A., Fensome, R.A., Weegink, J.W., 2004. Southern Ocean and global dinoflagellate cyst events compared: index events

for the late Cretaceous-Neogene, 1–98. In: Exon, N.F., Kennett, J.P., Malone, M.J. (Eds.), Proceedings of the Ocean Drilling Program. Scientific Results, vol. 189.

Willingshofer, E., Andriessen, P., Cloetingh, S., Neubauer, F., 2001. Detrital fission track thermochronology of Upper Cretaceous syn-orogenic sediments in the South Carpathians (Romania): inferences on the tectonic evolution of a collisional hinterland. Basin Research 13, 379–395.

Appendix A. Supplementary data

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