Dinoflagellate cysts and palynofacies across the Cretaceous-Paleogene boundary interval of the Vrancea Nappe (Eastern Carpathians, Romania)

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A palynological study of uppermost Maastrichtian to Lower Paleocene deposits from a stratigraphic section of the Vrancea Nappe (Eastern Carpathians), reveals the presence of diverse and well-preserved dinoflagellate cyst assemblages. The biostratigraphic interpretation of these dinocyst assemblages suggests that (1) the Cretaceous-Paleogene boundary lies within a ~8 m thick sedimentary interval, between the Lepșa Formation (uppermost Maastrichtian) and Putna-Piatra Uscață Formation (Lower Danian), based on the Last Appearance Datum of latest Maastrichtian markers such as *Peroziopina cretaeum* and *Polynodinium cf. grallator* and on the First Appearance Datum of Danian markers such as *Senonisphaera inornata*, *Xenocodium lubricum*, *Tectatodinium rugulatum* and *Eisenackia circumtubulata*, and (2) a discontinuity between the two formations. The palynofacies analysis from this geological section indicates an abundance of continental organic matter (mainly opaque phytoclasts), deposited in a distal setting of the sedimentary basin. The occurrences in the palynological assemblage of some oceanic dinocyst taxa such as *Impagidinium* and *Pteridinium* suggest the same depositional environment for the geological formations analysed.

Key words: Vrancea Nappe, dinoflagellate cyst biostratigraphic, palynofacies, Cretaceous-Paleogene boundary interval.

INTRODUCTION

The Cretaceous-Paleogene (K-Pg) boundary is recognized as representing one of the greatest mass extinction events in the last 500 Ma. The impact on the Earth of a large asteroid (Alvarez et al., 1980), intense volcanic activity, sea level fluctuations and climatic changes (Courtilliot et al., 1986; Courtilliot, 1990) are presently recognized as the causes of the global mass extinctions of most marine and terrestrial biota at the end of the Cretaceous. Among these causes, the Chicxulub impact in northern Yucatan (southern Mexico) is widely accepted as the primary cause for this Cretaceous-Paleogene extinction event (65 Ma) while the Deccan volcanic activity in western India is also considered to be a principal cause (Keller, 2008; Keller et al., 2009).

In contrast to the terrestrial fauna (dinosaurs), as well as most aquatic organisms (calcareous planktonic foraminifera, nannoplankton, etc), organic-walled dinoflagellate cyst taxa did not undergo a mass extinction across the K-Pg boundary (Benson, 1976; Hansen, 1977; De Coninck and Smit, 1982; Hultberg, 1985; Firth, 1987; Brinkhuis and Zachariasse, 1988; Moshkovitz and Habib, 1993; Habib et al., 1996; Gedl, 2004; Slimani et al., 2010). Biostratigraphical studies of this boundary based on the dinoflagellate cysts have been made at several Tethyan (Brinkhuis and Zachariasse, 1988; Gedl, 2004; Egger and Mohamed, 2010; Slimani et al., 2010, 2016; Mohamed et al., 2012, 2013; M’Hamdi et al., 2013; Mohamed and Wagreich, 2013; Slimani and Toufiq, 2013; Guédé et al., 2014) and boreal (Hansen, 1977; Moshkovitz and Habib, 1993; Brinkhuis and Schröder, 1996; Habib et al., 1996; Slimani, 2001; Slimani et al., 2011) geological sections. Other K-Pg sections are from New Zealand (Willumsen, 2004, 2011) in the Southern Hemisphere.

In the Moldavian units of the Eastern Carpathians, where the geological section studied is located, the K-Pg transition was analysed from a palynostratigraphic point of view by Olaru (1978). The author noted that, in the Maastrichtian, the Normapolles group (primitive angiosperms) dominates the palynological assemblages (65–70%), represented by the genera *Complexipollis*, *Trudopolis*, *Plicapollis* and *Oculopolis*. In addition to these palynomorphs, some species of spore (*Leiotriletes tenuis*, *Verrucosispontes quintus*, *Baculatispontes primarius*) and dinoflagellate cysts (e.g., *Hystrichosphaeridium tubiferum*, *Cerodinium diebelii*, *Areoligera cf. senonensis*) were noted. The Paleocene microflora cited from the Izvor Formation recorded a decline of the Normapolles group, the prevalent taxa comprising mono- and dicotyledonous angiosperms (e.g., *Monocolpophytes tranquillus*, *Tricopropollides wallensenensis*, *T. krutzschii*, *T. robustus*), and some pteridophytes and gymno-
sperms. The relative abundance of the dinoflagellate cysts decreases in the Paleocene, compared to that identified in Maastrichtian deposits, the cited species being Cerodinium diabelli, Achnosphera ramillifera, Hystrochsopeaeridium tubiferum and Oligosphaeridium complex (Olaru, 1978). Based on spores and pollen identified, Olaru (1978) inferred a cooling of the climate at the Maastrichtian-Paleocene boundary.

Other biostratigraphical studies of the K-Pg boundary were made based on calcareous nanofossil assemblages from the southwestern part of the Eastern Carpathians (Melinte and Jipa, 2005; Bojar et al., 2009) and on significant foraminiferal assemblages from the central and northern parts of the Moldavidian Units (Ionesi, 1966, 1975; Ion et al., 1982; Guerrera et al., 2012).

The aim of this paper is to describe the dinoflagellate cyst biostratigraphy and palynocytic distribution across the K-Pg boundary interval of the Vrancea Nappe (Cuejdui-Runcu geological section, Eastern Carpathians).

GEOLOGICAL SETTING AND STRATIGRAPHIC FRAMEWORK

In the Eastern Carpathians, the Moldavide Nappe System is divided into the Inner Moldavides (i.e., Teleajen, Macla and Audia nappes), consisting mainly of Cretaceous strata, and the Outer Moldavides (i.e., Tarcău, Vrancea and the Subcarpathian nappes), comprising Cretaceous to earliest Miocene flysch deposits (Sândulescu, 1984; Grasu et al., 1988).

The Vrancea Nappe is structurally interposed between the Tarcău and Subcarpathian nappes and crops out in several tectonic half-windows, including the Bistrița Half-window. The geological cross-section analysed in this paper is located in this tectonic half-window (Fig. 1), more specifically at the confluence of the Cuejdui and Runcu rivers (8 km NW of the city of Piatra Neamț).

This geological section has been previously described, from the lithological and biostratigraphic point of view, by Grasu et al. (1988) and Guerrera et al. (2012). The sedimentary succession identified along the Cuejdui and Runcu rivers is approximately 900 m thick, the lower part being assigned to the Sărata Formation of Early Cretaceous to Late Campanian age (Guerrera et al., 2012).

The Sărata Formation is subdivided into three lithological members: Lower Member (a succession of black shales with turbiditic arenites and conglomerate intercalations); Middle Member (silicified black shales with thin stratified calcarenites and breccias); and Upper Member (sandy marls with green-schists clasts). Upwards, the succession continues with the Lepșa Formation (~115 m thick, Maastrichtian), which consists mainly of grey sandy marls with conglomerates with breccia intercalations. This formation is ended by a slump body (15 m thick), described as an olistostrome, consisting of black shale from the Sărata Formation (Middle Member) deposited on a slope (Guerrera et al., 2012).

Fig. 1. Geological map of the studied area (after Micu, 1976, simplified); lithostratigraphic units and ages after Grasu et al. (1988), Amadori et al. (2012) and Guerrera et al. (2012)
This olistostrome bed is overlain by the Putna-Piatra Uscată Formation (180 m thick; Lower Paleocene–uppermost Ypresian; Grasu et al., 1988; Guerrera et al., 2012), consisting of laminated black shales with limestone intercalations (up to 4–5 m thick), arenites and calcarenites. The geological section along the Runcu River ends with the Bisericani Formation (Priabonian–Lower Rupelian; Amadori et al., 2012).

Biostratigraphical data, based on planktonic foraminifera from the K-Pg boundary interval of the section studied, show that the Lepşa Formation (the middle part) contains Late Maastrichtian taxa such as Globotruncanita stuartii (De Lapparent), Abathomphalus mayorensis (Bolli) and Racemiguembelina fruticosa (Egger) (Guerrera et al., 2012). The micropalaeontological content of the top of this formation is poor, and consists of scarce agglutinated foraminifers; this scarcity may be related to the Cretaceous-Paleogene extinction event. The lower part of the Putna-Piatra Uscată Formation also shows a poor micropalaeontological content, consisting of some earliest Paleocene small globigerinids, such as Subbotina cancellata Blow. According to these biostatigraphical data, Guerrera et al. (2012) placed the K-Pg boundary somewhere near the top of the Lepşa Formation.

MATERIAL AND METHODS

The K-Pg boundary section (coordinates: N 46°59′44.04″; E 26°16′33.45″) investigated in the present paper is located along the Runcu and Cujeiu rivers (Fig. 1). This section exposes ~30 m thick of strata composed of the uppermost part of the Lepşa Formation (Upper Maastrichtian) and the lowermost part of the Putna-Piatra Uscată Formation (Lower Paleocene) (Fig. 2).

In total, six samples were analysed (Fig. 2): two samples (P140, P141) from the Lepşa Formation, one sample (P142) from the olistostrome and three samples from the Putna-Piatra Uscată Formation. The palynological material studied shows low dinocyst diversity, but yielded the most dinocyst biot stratigraphic markers, which are well-preserved and useful for age determinations of the samples analysed.

For palynological and palynofacies analysis, all samples were processed using standard palynological techniques (e.g., Batten, 1999). Approximately 50 g from each sediment sample was treated with HCl (37%) to remove carbonates and HF (48%) to remove the silicate minerals. Denser particles were separated from the organic residue using ZnCl2 with a density of 2.0 g/cm³. The palynological residues were mounted on microscopic slides with glycerine jelly. All samples yielded a palynological assemblage dominated by dinoflagellate cysts, while pollen grains, spores, bryophytes and acritarchs show rare occurrences. Photomicrographs (Figs. 3 and 4) were taken with a digital Leica DFC420 camera mounted on an Leica DM1000 microscope. The taxonomy of the dinoflagellate cyst species follows Dinoflag2 (Fensome et al., 2008) and Slimani et al. (2008). The age determination of deposits from the section analysed was obtained based on dinoflagellate cyst assemblages and their comparison with similar assemblages identified in many Maastrichtian toDanian biostatigraphically calibrated sections from the Northern Hemisphere (see above in the Introduction).

For the palynofacies analysis, the amount of kerogen in the palynological slides was analysed. At least 300–400 organic particles (>15 μm) were counted in each sample, these being included at the three main groups of kerogen constituents proposed by Tyson (1995), Mendonça Filho et al. (2002), Carvalho et al. (2006), and Tabără et al. (2015): namely, palynomorphs group (dinoflagellate cysts, spores, pollen and acritarchs); phytoflagellate group which includes opaque and translucent organic particles derived from terrestrial plants (woody tissues, cuticles, membranes); and Amorphous Organic Matter (AOM) group which includes structureless organic components derived from phytoplankton or degraded higher plant debris.

In the marine environments, the proximal-distal trend is one of the principal controls on kerogen distribution. Several interpretive parameters, based on palynofacies observations, can be used for a detailed palaeoenvironmental analyses, namely: ratio of opaque to translucent phytoflagellate (O:Trans; Steffen and Gorin, 1993; Carvalho et al., 2013) and the continental/marine palynomorphs ratio (C/M; Pellat and Gorin, 2005). Also, onshore-offshore depositional environments and transgressive-regressive trends can be inferred based on a spore-pollen-microplankton (SPM) ternary diagram proposed by Fedorova (1977) and Duringer and Doubinger (1985).

The high relative abundance of translucent particles (e.g., woody tissues) in ancient marine deposits are known to indicate strong terrestrial influx, with deposition in nearshore proximal settings (e.g., fluviodeltaic systems; Tyson, 1995; Carvalho et al., 2013). In contrast, opaque phytoflagellate are derived from the oxidation of translucent particles, being more resistant palynomacerals that can be transported over a long distance without being further degraded. This O:Trans ratio tends to increase in the more distal facies. Large amounts of phytoflagellate can also occur via turbidity currents in deep waters (Habib, 1982; Carvalho et al., 2013). The other parameter used, the C/M ratio (calculated by taking the number of all terrestrial palynomorphs, divided by the number of dinoflagellate cysts), generally decreases offshore.

RESULTS

PALYNOLOGICAL CONTENT

The palynomorph assemblages from the K-Pg section analysed here consist mainly of dinoflagellate cysts (83–100% of the total palynomorphs), except for sample P140, in which a lower percentage (61%) is recorded. A total of 52 dinoflagellate cyst species and subspecies have been recognized; most of the taxa recorded in the Upper Maastrichtian cross the K-Pg boundary and persist into the Danian. This aspect does not indicate a severe extinction of dinoflagellate species across the K-Pg boundary, in contrast to the mass extinction recorded in the planktonic foraminifer assemblages (Paul, 2005; Twitchett, 2006).

Lepşa Formation. The palynological assemblage identified in samples P140 and P141 (Fig. 2) contains dinocyst species such as Palynodinium cf. grallator, Pterodinium cretaceum, Deflandrea galeata, Manuelliella sequelandica, Muratodinium fimbriatum, Cerodinium diebili, Rottnestia wettzeli subsp. wettzeli, Tritthyrodinium evitii, Achomosphaera sagena, Palaeoperidinium pyrophorum, and Phelodinium magnificum (Table 1), commonly used to identify Upper Maastrichtian strata in many areas (see related references mentioned above in the Introduction). Rare Cretaceous reworked specimens such as Cannotheca arenicola have been found in sample P141. Among continental palynomorphs can be listed pteridophyte spores (Deltoidospora toralis, D. psilostomata, Gieichenidites senonicus, Triplosporites sp.), gymnosperms (Podocarpidites sp., Araucaricites sp., Cycadopites sp. and Ephedripites sp.) and early angiosperms (Normapolles).
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Fig. 3. Selected dinocyst species from Runcu section

A – Pterodinium cretaceum (sample P140); B – Xenodinium lubricum (sample P143); C – Hystrichokolpoma bulbosum subsp. bulbosum (sample P144); D – Tectatodinium rugulatum (sample P145); E – Senoniasphaera inornata (sample P143); F – Eisenackia circumtablata (sample P143); G – Deflandrea galeata (sample P141); H – Manumiella seelandica (sample P141); I – Rottneista wetzeli subsp. wetzeli (sample P141); J – Muratodinium fimbriatum (sample P141); K – Glaphyrocysta perforata (sample P143); L – Xenascus sp. (sample P142); M – Cerodinium diebelii (sample P141); N – Hystrichosphaeridium tubiferum (sample P144); O – Achomosphaera alcicornu (sample P145); P – Oligospheridium complex (sample P140); Q – Xenodinium delicatum (sample P145); R – Achomosphaera ramlulifera (sample P144); S – Cordosphaeridium fibrospinosum (sample P144); T – Spiniferites ramosus (sample P141); scale bar 30 μm
From the olistostome above the Lepşa Formation, a single sample (P142) was analysed. The dinoflagellate cyst assemblage is dominated by Spiniferites div. sp., and other taxa such as Cribroperidinium cf. edwardsii, Hystrichodinium cf. pulchrum, Oligosphaeridium buciniferum, Protoellipsodinium cf. clavulum, Xenascus sp. have been identified. Continental palynomorphs have a frequency of 12%, and include some spores (Deltoidospora toralis, Baculatisporites sp.) and rare specimens of Normapolles pollen.

Putna-Piatra Uscată Formation. From the bottom of this formation, three samples were analysed (P143–P145; Fig. 2). The palynological content consists of a high frequency of dinocyst taxa (mainly Spiniferites group, and Xenocodium div. sp.), together with species such as Achomosphaera ramulifera, A. regiensis, A. alicornu, Batiacasphaera rifensis, Hafniaaspera septata, Impagidinium sp., Oligosphaeridium complex, Spiniferella cornuta subsp. cornuta, Cribroperidinium wetzelii, Eisenackia circumtabulata, Senoniasphaera inornata, Tectodinium rugulatum, Xenicodinium delicatulum and X. lubricum (Table 1). The spores identified in the samples analysed have a low frequency (some specimens of Baculatisporites sp., Deltiodospora sp. found in sample P145), and gymnosperm pollen is represented by Pinuspollenites sp. and Cycadopites sp. (Table 1). An acritarch species (Michystridium fragile) occurs in sample P145, while Normapolles pollen is poorly represented in samples P143 and P145.

**PALYNOFACIES DATA**

The quantitative and qualitative analysis of organic particles present in all the samples analysed reveals a predominance of organic matter of continental origin. At the top of the Lepşa Formation (samples P140 and P141), the palynofacies consists of a large proportion of opaque phytoclasts (95–98%), that belong to the inertinite group, and locally small amounts of woody tissues and cuticles can be identified. The palynomorph group is poorly represented (1–2%), generally consisting of dinoflag-
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gellate cysts and a lower frequency of continental palynomorphs (dominantly pteridophyte spores and gymnosperms). The AOM group has a rare occurrence, only some particles of gelified AOM (derived from degraded higher plant debris) being identified.

In the olistostome (sample P142) identified in the geological section, the palynomorphs is generally similar to that inferred from the Lepsa Formation (samples P140 and P141). The opaque phytoclasts show a high percentage (93-95%), to which is added some small granular AOM particles (derived from phytoplankton degradation). The palynomorphs (1%), are represented by various species of dinoflagellate, spores being rarely encountered.

The lower part of the Putna-Piatra Uscatå Formation (samples P143–P145) comprises also a palynomorphs dominated by opaque phytoclasts (98%), some of these phytoclasts being small and rounded. Other phytoclasts such as woody tissues and some biodegraded cuticles are rarely identified. The palynomorphs (1%) are mainly represented by dinoflagellate cysts, in some samples (P144) only phytoclast species being determined.

**INTERPRETATION AND DISCUSSION**

**DINOFLAGELLATE CYST BIOSTRATIGRAPHY**

The stratigraphic distribution of dinoflagellate taxa in the Runcu section is shown in Table 1. The age determination in the geological section analysed is based on the First Appearance Datum (FAD) and Last Appearance Datum (LAD) of significant dinoflagellate species.

**Latest Maastrichtian.** The biostratigraphic interpretation of the dinocyst assemblages, based on the dinocyst bioevents, suggests an Late Maastrichtian age for the top of the Lepsa Formation. Among the species identified in this formation, an important marker taxon is *Pterodinium cretaceum*, which has been named differently (see Slimani et al., 2010; pp. 104), having the LAD in the latest Maastrichtian (Schiller et al., 1993; Roncaglia and Conradini, 1997a; b; Slimani, 2001; Torricelli and Amore, 2003; Slimani et al., 2008, 2010, 2011, 2016; Slimani and Toufiq, 2013; M’Hamdi et al., 2013; Guédé et al., 2014). This species is recorded in a single sample (P140). Also, the species *Palynodinium cf. grallator*, which is another marker for the latest Maastrichtian, is observed in sample P140, the LAD of this species being frequently recorded at top of the Upper Maastrichtian in different geological sections from northern higher latitudes (Hansen, 1977; Schiller and Wilson, 1993; Habib et al., 1996; Schieler et al., 1997; Williams et al., 2004; Slimani et al., 2011), but rarely quoted in the lowermost Danian in low latitudes (Brinkhuis et al., 1998; Gedl, 2004; Slimani et al., 2010; Mohamed et al., 2012; M’Hamdi et al., 2013). *Manumeliai seelandica*, *Deflandra galeata* and *Muradotinum fimbriatum* have been identified in the top of the L epsa Formation (P141 sample). These species have their FAD’s in the Upper Maastrichtian, but may persist up to the Danian in Morocco (Slimani et al., 2010, Guédé et al., 2014), Tunisia (M’Hamdi et al., 2013), the Czech Carpathians (Gedl, 2004) and elsewhere. Another species, such as *Rottnestia wetzelii* subsp. *wetzelii*, which was rarely quoted at the K-Pg boundary from the Northern Hemisphere, was identified from the Upper Maastrichtian of Austria (Mohamed and Wagerich, 2013), and considered as a marker for the Late Maastrichtian in Greenland (Nehr-Hansen, 2012). In the study section of the Runcu River, this species has been identified in almost all samples analysed (above and below the K-Pg boundary). The species that have been recorded both from the top of the Lepsa Formation and from the lower part of the Putna-Piatra Uscatå Formation include *Spiniferites ramosus* (frequent), *Oligosphaeridium complex*, *Hystrichosphaeridium tubiferum* (rare in the Upper Maastrichtian and frequent in Danian), *Achomosphaera ramulifera*, *Hystrichokolpoma bulbosum* subsp. *bulbosum*.

In summary, the FAD’s and LAD’s of all species observed in samples P140 and P141 suggest a latest Maastrichtian age for the uppermost part of the Lepsa Formation, which can be correlated with Hansen’s (1977) *Palynodinium grallator* and Slimani’s (2001) *Hystrichostrogyton conincikii* zones, based on the last occurrence of *Palynodinium cf. grallator*.

The dinoflagellate species identified in the olistostome above the Lepsa Formation indicate a Barremian-Early Maastrichtian age of these deposits, the genus *Xenacus* being an important marker (Williams et al., 1993). Another taxon identified in sample P142 is *Hystrichodinium cf. pulchrurn*, quoted from Campanian-Lower Maastrichtian deposits of the Outer Western Carpathians (Skupien and Mohamed, 2008), the LAD of this species being known in the Early Maastrichtian. Other Cretaceous dinoflagellate cyst taxa are observed in this olistostome such as *Impletosphaeridium? clavulum*, *Hystrichosphaeridium salpingophorum*, *Oligosphaeridium bacinorum*, and *Cribroderidinium cf. edwardsii* (quoted from the Middle Member of the Audia Formation; Tabâra, 2014). The marker taxa previously mentioned indicate a Barremian-Lower Maastrichtian age of the sedimentary deposits analysed from the lower part of the olistostome. The slumping of these deposits suggests significant tectonic activity at the Cretaceous-Paleogene transition, sourcing Barremian-Lower Maastrichtian materials from the Sârata Formation.

**Early Danian.** Dinoflagellate cysts such as *Damasassadunninum californicum*, *Carpatella comuta*, *Senonisphaera inornata* are global Danian index fossils, valuable for the identification of the K-Pg boundary (Drugg, 1967; Gedl, 2004; Williams et al., 2004; Slimani et al., 2010; Slimani and Toufiq, 2013; Mohamed and Wagerich, 2013; Mohamed et al., 2013; M’Hamdi et al., 2013; Guédé et al., 2014). Among these species, only *Senonisphaera inornata* has been identified in the lower part of the Putna-Piatra Uscatå Formation (sample P143). This occurrence suggests that the K-Pg boundary can be placed below the last occurrence of this species and above the last appearance of the Maastrichtian species *Pterodinium cretaceum* and *Palynodinium cf. grallator*, within the interval between samples P141 and P143 (Fig. 2). The stratigraphic range (FAD and LAD) of *Senonisphaera inornata* is restricted to the Early–Middle Danian interval (62.6–64.95 Ma; Hardenbol et al., 1998; Williams et al., 2004; Slimani et al., 2010).

*Eisenacickia circumtabulata* is another important species for the identification of the K-Pg boundary. Its FAD indicates the lowermost Danian in several biostratigraphically calibrated sections such as El Kef in Tunisia (Brinkhuis and Zachariasse, 1988) and Ouled Haddou in Morocco (Slimani et al., 2010; Slimani and Toufiq, 2013). In the section studied, this species first occurs in sample P143, at the same level as *Senonisphaera inornata*.

The dinoflagellate species *Xenicosidinium lubricum* and *Tectadotinum rugulatum*, which have well-documented FADs in the Lower Danian (Hansen, 1977; Hardenbol et al., 1998; Slimani, 2000, 2001), were recorded only in the Putna-Piatra Uscatå Formation (samples P143–P145) and therefore confirm the position of the K-Pg boundary determined above, based on the LAD of *Pterodinium cretaceum* and *Palynodinium cf. grallator*, and the FAD of *Senonisphaera inornata*. Their stratigraphic range in the section studied can be correlated with...
### Table 1

Distribution of palynomorph taxa in the Runcu section

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<th>Age</th>
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<th>Danian</th>
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<td>P140</td>
<td>P141</td>
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<td>Taxa/Samples</td>
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<tr>
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<td>Senoniasphaera cf. rotundata</td>
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<td>Eisenackia circumtabulata</td>
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<td>Glaphyrocysta perforata</td>
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<td>Achomosphaera regiensis</td>
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<td>Pentadinium sp. A</td>
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<td>Xenicodinium delicatum</td>
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<td>Xenicodinium lubricum</td>
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<td>Batiasphaera rifensis</td>
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<td>Hystrichosphearaidium recurvatum</td>
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<tr>
<td>Impelosphaeridium sp.</td>
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<tr>
<td>Kleithriasphaeridium truncatum</td>
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Xenicodinium lubricum Zonule (upper part of the Damassadinium californicum Zone; Hansen, 1977), established in Lower Danian limestones in Denmark. Also, both species (X. lubricum and T. rugulatum) were recorded in Danian deposits in the Caspian Depression by Vasilyeva and Mustav (2012). Carpatella cornuta, the zonal species of the lowermost Danian Carpatella cornuta Zonule (lower part of the Damassadinium californicum Zone; Hansen, 1977) is not recorded in the section studied. The absence of this species might be related to its extreme scarcity or to unfavorable environmental conditions.

The FADs of Achomosphaera allicornu and Xenicodinium delicatum are also indicative of the Lower Danian (Hultberg, 1985; Sliman, 2001; Sliman et al., 2010, 2011; Sliman and Toufiq, 2013; M’Hamdi et al., 2013). Their occurrence in the section studied supports the Danian age of the interval analysed in the Putna-Piatra Uscatá Formation. Other species, previously recorded in Maastrichtian and Danian strata, were identified only in the Putna-Piatra Uscatá Formation. Among these taxa are Batiacasphaera rifensis, Cordosphaeridium fibrospinosum, Críbroperidinium wetzelli, Gliophyrocysta perforata and Operculodinium corradiini.

In summary, all these Maastrichtian and Danian dinocyst event markers suggest that the K-Pg boundary may be placed somewhere between the latest sample analysed (P141) at the top of the Lepşa Formation and the earliest sample analysed (P143) of the base of the Putna-Piatra Uscatá Formation. The presence of the Barremian-Lower Maastrichtian olistostrome (devoid of dinocyst markers of the uppermost Maastrichtian–lowest Danian boundary interval) between the Lepşa and Putna-Piatra Uscatá formations prevent precise localization of the K-Pg boundary in the study section. We also did not observe, as indicated in other studies (see above in the Introduction), any mass extinction of dinocysts in the K-Pg boundary interval of the Runcu section. However, the micropalaeontological content (foraminifers) is poor at the top of the Lepşa Formation (Guerrera et al., 2012) and may suggest consequently a mass extinction of this group close to the K-Pg boundary interval.

The Maastrichtian dinoflagellate assemblage in the section studied shows more similarities with Tethyan assemblages (De Coninck and Smit, 1982; Brinkhuis and Zachariasse, 1988; Slimani et al., 2010, 2016; Mohamed et al., 2012; M’Hamdi et al., 2013) than with Boreal assemblages (Hansen, 1977; Hultberg, 1985; Schiller and Wilson, 1993; Sliman, 2001; Sliman et al., 2011). Compared to the other sections from the Tethyan realm, shows also more similarities with the Maastrichtian dinocysts assemblage from southeastern Czech Republic (Carpathian domain; Gedl, 2004) than with the assemblage from south-east Poland (western part of the East European Platform; Machalski et al., 2016), which was considered to be characteristic of Boreal province, due to the high abundance of the cold water taxon, such as Polyphronodinium grallator. The most important differences observed, compared to the assemblage quoted from the Czech Carpathians, consists in the fact that Polyphronodinium grallator disappears earlier (uppermost Maastrichtian) in the studied section, probably due to different palaeoenvironmental conditions. However, the Danian assemblage is similar to many other assemblages quoted from world-wide, identified both at low and high latitude.
Palynofacies analyses as described by Tyson (1995) comprise an important tool in sedimentology for reconstructing depositional environments. The sedimentary organic matter (also called kerogen) recorded from the formations discussed herein includes a large proportion of continental material, with phytoclasts, pollen grain and spores, as well as a small amount of marine material composed of dinoflagellate cysts and granular AOM.

The kerogen analysed from the Lepșa Formation is composed mainly of opaque phytoclasts that are derived primarily from the oxidation of plant tissue, which was transported over a prolonged period of time (Carvalho et al., 2013). The O:Trans ratio, calculated based on palynofacies data obtained from this geological formation, shows a high value, suggesting a more distal setting, at least outer shelf zone. The same environment is also indicated by the C/M ratio, the latter having a lower value in sample P141 (dinoflagellate cysts prevailing) and slightly higher in sample P140 due to sporomorphs derived from the continental landmass. The occurrences in the Lepșa Formation of some oceanic dinocysts such as Impagidinium and Pterodinium supports the same palaeoenvironmental interpretation. Oceanic dinoflagellate taxa were also recorded in Maastrichtian-Danian deposits from the Czech Carpathians, showing a high frequency in hemipelagic deposits (Gedl. 2004). Nevertheless, the palynological assemblage from the Lepșa Formation also contains some species of the Spiniferites group, which indicates inner-outer neritic environments (Sluijs et al., 2005). This offshore depositional environment inferred for the Lepșa Formation is also suggested by plotting the frequencies of palynomorphs in an SPM ternary diagram (Fig. 5).

The palynofacies recorded from the olistostrome above the Lepșa Formation is generally similar to that inferred from the Lepșa Formation. The organic matter is characterized by a high percentage of opaque phytoclasts and a small amount of granular AOM and dinoflagellate cysts. The O:Trans ratio, as well as the C/M ratio, indicate a more distal facies for these deposits.

The depositional environment of the Putna-Piatra Uscatã Formation (lower part) is very similar to that inferred from the Lepșa Formation. The palynofacies of this formation is dominated by opaque phytoclasts (98%), these organic particles of...

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**Fig. 5.** Spore-pollen-microplankton ternary plot (Federova, 1977; Duringer and Doubinger, 1985) indicating an offshore depositional environment for the deposits analysed

Transmitted light microphotographs of the palynofacies from the samples analysed (scale bar 30 μm): A – opaque phytoclasts of various shapes and sizes, with small amounts of translucent phytoclasts (olistostrome, sample P142); B – a mixed assemblage of opaque phytoclasts and dinocysts (Lepșa Formation, sample P141); C – palynofacies dominated by small opaque phytoclasts (Putna-Piatra Uscatã Formation, sample P143)
ten having small dimensions and rounded shapes (Fig. 5C), as a result of prolonged transport in distal environments (Steffen and Goin, 1983). The dominance of dinoflagellate cysts, compared to the spores-pollen assemblage (Fig. 5, ternary diagram), is indicative of deposition in an offshore environment. Moreover, the occurrences of oceanic dinocysts such as Impagidinium (locally with higher proportions; 15% in sample P144 sample), suggest the same environmental interpretation for the Putna-Piatra Uscață Formation.

CONCLUSIONS

This paper describes biostratigraphical data from the K-Pg boundary interval of the Outer Moldavides (Vrancea Nappe), inferred based on dinoflagellate cyst bioevents, as well as on palynofacies analysis across this boundary interval. The main conclusions are the following:

– the dinocyst assemblage identified in the top of the Leșpa Formation indicates a latest Maastrichtian age. Important biostratigraphic event markers for this age are the LADs of Pterodinium cinctum and Palynomnodium cf. grallator. This interval can be correlated with the latest Maastrichtian Palynomnodium grallator Zone of Hansen (1977) and the Hystrichostrogyt conincki Zone of Slimanı (2001);

– the occurrence of the dinoflagellate cysts Xanascus sp. and Hystrichodinium cf. pulchrum may indicate a Barremian to Early Maastrichtian age for the olistostome disposed above the Leșpa Formation. This slumping event may suggest significant tectonic activity at the Cretaceous-Paleogene transition;

– the dinocyst assemblage recorded in the Putna-Piatra Uscață Formation can be correlated with the Lower Danian Xanodicinium lubricum Zonule of Hansen (1977). The K-Pg boundary lies somewhere within the ~8 m thick strata interval between the top of the Leșpa Formation (sample P141) and the base of the Putna-Piatra Uscață Formation (sample P143), namely between the last occurrence of the Maastrichtian dinocyst markers, such as Pterodinium cinctum and Palynodinium cf. grallator, and the first occurrence of Danian dinocyst markers such as Senoniasphaera inornata, Xanodicinium lubricum,TECTATODINUM NUGULATUM and Eisenackia circumbulata. Unfortunately, the presence of the olistostome between the Leșpa and Putna-Piatra Uscață formations does not allow a more accurate localization of the K-Pg boundary in the section studied;

– the Maastrichtian dinoflagellate assemblage from the Runcu section shows more similarities with Tethyan assemblages, but compared with other assemblages from the same palaeogeographical area (the Western Carpathians and the western part of the East European Platform), some differences in the last appearance and abundance of cold water taxa (e.g., Palynomnodium grallator) can be observed. These small differences in palynomorph distribution are probably related to different palaeoenvironmental conditions. The Danian assemblage from the section studied is similar to many assemblages of the same age previously recorded worldwide;

– palynofacies analysis of the section studied shows an abundance of continental organic matter (mainly opaque phytoclasts belonging to the inertinite group, sometimes with small dimensions and rounded shapes), which could suggest an offshore depositional environment of the sedimentary basin. The presence of some oceanic dinocysts (e.g., Impagidinium, Pterodinium) in the Leșpa and Putna-Piatra Uscață formations, supports the same palaeoenvironmental interpretation.

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REFERENCES


Dinoflagellate cysts and palynofacies across the Cretaceous-Paleogene boundary interval of the Vrancea Nappe...  


APPENDIX 1

Checklist of palynomorph taxa mentioned in the text in alphabetic order. The references to dinocyst species’ authors are given by Fensome et al. (2008). Some species listed in this appendix are presented in Figures 3 and 4.

Dinoflagellate cysts

 Achomosphaera alicornu (Eisenack, 1954) Davey and Williams, 1966 (Fig. 3O)
 Achomosphaera ramulifera (Deflandre, 1937) Evitt, 1963 (Fig. 3R)
 Achomosphaera regniensis Corradini, 1973 (Fig. 4A)
 Achomosphaera sagena Davey and Williams, 1966
 Arealgira senonensis Lejeune-Carpentier, 1938 (Fig. 4B)
 Baltacasaaphera rifensis Slimani, 2008
 Ceradinium diebelen (Alberti, 1959) Lentin and Williams, 1987 (Fig. 3M)
 Ceradinium speciosum (Alberti, 1959) Lentin and Williams, 1987 (Fig. 4D)
 Cordosphaeridium exilimurum Davey and Williams, 1966
 Cordosphaeridium fibrosipinum Davey and Williams, 1966 (Fig. 3S)
 Cribroperidinium cf. edwardsii (Cookson and Eisenack, 1958) Davey, 1969
 Cribroperidinium wetzeli (Lejeune-Carpentier, 1939) Helenes, 1984 (Fig. 4I)
 Deflandrea galeata (Lejeune-Carpentier, 1942) Lentin and Williams, 1973 (Fig. 3G)
 Eisenackia circumtubulata Drugg, 1967 (Fig. 3F)
 Exochosphaeridium cf. majus (Lejeune-Carpentier, 1940) Peyrot, 2011
 Fibrocystra axialis (Eisenack, 1965) Stover and Evitt, 1978
 Gephyrocysta perforata Hultberg and Malmgren, 1985 (Fig. 3K)
 Hafniaasphaera septata (Cookson and Eisenack, 1967) Hansen, 1977
 Hystrichokolpoma bulbosum subs. bulbosum (Ehrenberg, 1836) Morgenroth, 1968 (Fig. 3C)
Hystrichodinium cf. pulchrum Deflandre, 1935
Hystrichosphaeridium recurvatum (White, 1842) Lejeune-Carpentier, 1940
Hystrichosphaeridium salpingophorum Deflandre, 1935
Hystrichosphaeridium tubiferum (Ehrenberg, 1838) Deflandre, 1937 (Fig. 3N)
Impagidinium sp.
Impletosphaeridium sp.
Impletosphaeridium? clavulum Davey, 1969
Kleithriasphaeridium cf. loffrense Davey and Verdier, 1976
Kleithriasphaeridium truncatum (Benson, 1976) Stover and Evitt, 1978
Lingulodinium sp.
Manumiella seelandica (Lange, 1969) Bujak and Davies, 1983 (Fig. 3H)
Muratodinium fimbriatum (Cookson and Eisenack, 1967) Drugg, 1970 (Fig. 3J)
Oligosphaeridium fimbriatum Corradini, 1973 (Fig. 4E)
Oligosphaeridium complex (White, 1842) Davey and Williams, 1966 (Fig. 3P)
Oligosphaeridium pulcherrimum (Deflandre and Cookson, 1955) Davey and Williams, 1966
Oriencedinium centrocarpum (Deflandre and Cookson, 1955) Wall, 1967
Oriencedinium corradini Slimani, 1994 (Fig. 4F)
Palaeocystodinium cf. golzowense Alber ti, 1961
Palaeoperidinium pyrophorum (Ehrenberg, 1838 ex Wetzel, 1933) Sarjeant, 1967 (Fig. 4G)
Palynodinium cf. grallator Gocht, 1970
Pentadinium sp. A (Fig. 4C)
Phelodinium magnificum (Stanley, 1965) Stover and Evitt, 1978
Protoellipsodinium cf. clavulum Davey and Verdier, 1974
Pterodinium cingulatum (Wetzel, 1933) Below, 1981
Pterodinium cretaceum Slimani, 2008 (Fig. 3A)
Rottnestia wetzelii subsp. wetzelii (Deflandre, 1937) Slimani, 1994 (Fig. 3I)
Senonisphaera cf. rotundata Clarke and Verdier, 1967
Senonisphaera inornata (Drugg, 1970) Stover and Evitt, 1978 (Fig. 3E)
Spiniferella cornuta subsp. cornuta (Gerlach, 1961) Stover and Hardenbol, 1994 (Fig. 4H)
Spiniferites multibrevis (Davey and Williams, 1966) Below, 1982
Spiniferites ramosus (Ehrenberg, 1838) Mantell, 1854 (Fig. 3T)
Spiniferites sp.
Systematophora sp.
Tanyosphaeridium xanthiopyxides (Wetzel, 1933) Stover and Evitt, 1978
Tectatodinium rugulatum (Hansen, 1977) McMinn, 1988 (Fig. 3D)
Trithyrodinium evitti Drugg, 1967
Xenascus sp. (Fig. 3L)
Xenicosidinium delicatulum Hultberg, 1985 (Fig. 3Q)
Xenicosidinium lubricum Morgenroth, 1968 (Fig. 3B)

Acritarcha
Microhystridium fragile Deflandre 1948

Pteridophyta
Baculatisporites sp.
Deltoidospora psilostomata Rouse, 1959
Deltoidospora toralis (Leschik, 1955) Lund, 1977
Deltoidospora sp.
Gleicheniidites senonicus Ross, 1949
Triplanosporites sp.

Gymnospermatophyta
Araucariacites sp.
Cycadopites sp.
Ephedriotes sp.
Pinuspollenites sp.
Podocarpidites sp.