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# Palynological and organic geochemical analyses of the Upper Cretaceous Bozeş Formation at Petreşti (southwestern Transylvanian Basin) – biostratigraphic and palaeoenvironmental implications

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A palynological and organic geochemical study of the Upper Cretaceous deposits cropping out in the southwestern part of the Transylvanian Basin (Petreşti section) has been carried out. The samples were collected from the marine Bozeş as well as from the overlying continental Sebeş formations, with main focus on the Bozeş Formation. The recovered palynomorph assemblages are represented mainly by early angiosperm pollen and by fern spores. Phytoplankton taxa are either absent or were recorded only as rare occurrences in the upper part of the Bozeş Formation.

The identified terrestrial palynomorph assemblages document the co-occurrence of taxa from plant communities typical for fluvial to coastal habitats with other palynofloral elements derived from areas of higher altitude and/or cooler–wetter conditions. The occurrence of a diversified Normapolles assemblage including *Trudopollis cuneolis*, *Oculopollis principalis* and *O. praedicatus*, in association with fern spores such as *Klukisporites pseudoreticulatus* and *Vadaszisporites sacali*, supports a mid-late Campanian age for the analyzed section of the marine Bozeş Formation. Palynofacies constituents, combined with organic geochemical data, were used to reconstruct the depositional environments represented in the studied deposits. According to these data, the lower and middle sections of the Bozeş Formation sampled in the Petreşti succession were deposited in a distal, outer neritic area of the Late Cretaceous basin. This outer neritic succession is followed by a nearshore/inner neritic sequence corresponding to the topmost part of the Bozeş Formation, as indicated by the presence of a palynofacies containing lath-shaped opaque phytoclasts mixed with large translucent biostructured phytoclasts.



## 1. Introduction

Upper Cretaceous marine and continental sedimentary successions are widespread in western Romania (i.e. Haţeg Basin, Rusca Montană Basin, southwestern Transylvanian Basin and Apuseni Mountains). The Cenomanian–Campanian marine deposits of these areas have a well-established integrated stratigraphy based on biostratigraphically significant markers, such as calcareous nannoplankton (e.g. Grigorescu and Melinte, 2001; Bălc and Chira, 2002; Chira et al., 2004; Bălc et al., 2007; Melinte-Dobrinescu, 2010; Bălc et al., 2012; Bălc and Zaharia, 2013; Vremir et al., 2014), as well as mollusks and foraminifers (Dimian and Popa-Dimian, 1963; Tomescu et al., 1969; Dincă et al., 1972; Pop et al., 1972; Dincă, 1977; Neagu, 2006). Conversely, only very few palynological studies of the same marine Upper Cretaceous successions are available to date (e.g. Antonescu, 1973; Mogoş, 1992; Ţabără and Slimani, 2019). The assemblages reported so far are dominated by pollen taxa assigned to the Normapolles group (*Longanulipollis*, *Oculopollis orbicularis*, *O.* cf. *semimaximus*, *Suemegipollis*, *Trudopollis*

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div. sp.) and fern spores (*Deltoidospora minor*, *Echinatisporis longechinus*, *Gleicheniidites senonicus*, *Polypodiaceoisporites* div. sp.). On the other hand, phytoplankton taxa are far less common in the same deposits. A Cenomanian–Santonian assemblage with *Cleistosphaeridium heteracanthum, Deflandrea belfastensis*, and *Dinogymnium* div. sp. was reported from the "Deva beds" and the "Bozeş beds", units that occur in the southern part of the Apuseni Mountains (Antonescu, 1973). Meanwhile, species such as *Isabelidinium microarmum, I. acuminatum*, and *Odontochitina operculata* have been described from Upper Santonian–Campanian deposits of the Haţeg Basin (Ţabără and Slimani, 2019).

The mainly Maastrichtian-aged vertebrate-bearing continental strata exposed in different parts of the Transylvanian area (see Csiki-Sava et al., 2016) yielded a palynological assemblage represented exclusively by terrestrial palynomorphs (but see below). Previous palynological studies, focusing mainly on the Haţeg Basin, have identified a palynoflora with numerous fern spore taxa (*Deltoidospora, Laevigatosporites, Polypodiaceoisporites, Leiotriletes,* freshwater ferns), various species of angiosperm pollen (Normapolles group, *Juglandaceae, Myricaceae*), and a minor fraction of freshwater algae (*Chomotriletes fragilis*), indicating lowland, fluvial or coastal habitats and warm climatic conditions (Balteş, 1966; Antonescu, 1973; Stancu et al., 1980; Antonescu et al., 1983; Grigorescu, 1983; Ştiucă, 1983; Van Itterbeeck et al., 2005; Csiki et al., 2008; Ţabără and Slimani, 2019; Botfalvai et al., 2021). The only marine phytoplankton taxon (*Deflandrea* sp.) associated with such continental assemblages were reported by Stancu et al. (1980) from a borehole at Toteşti, in the Haţeg Basin, but due to the recovery condition of the samples yielding these assemblages, their exact stratigraphic position remains uncertain.

Among these Upper Cretaceous deposits, the Maastrichtian vertebrate-bearing continental deposits of the Haţeg Basin have been intensively studied since over a century (e.g. Nopcsa, 1899, 1905, 1923) and yielded several hundreds of fossil specimens, mainly of vertebrates, including dwarf dinosaurs (e.g. Grigorescu, 2010). Synchronous and isofacial continental deposits are also present in other parts of western Romania as well, but these are less richly fossiliferous (e.g. Nopcsa, 1905), although their fossil vertebrate record is steadily improving since the last two decades (e.g. Codrea et al., 2010; Vremir, 2010; Vremir et al., 2015a; Csiki-Sava et al., 2016). In the southwestern part of the Transylvanian Basin (Fig. 1), such continental deposits, assigned to the Sebeş Formation (see Vremir et al., 2015a), yielded important fossil vertebrates such as the robust and double-sickle-clawed dromaeosaurid theropod *Balaur bondoc* (Csiki et al., 2010), the mid-sized azhdarchid pterosaur *Eurazhdarcho langendorfensis* (Vremir et al., 2013), joined recently by its larger kin *Albadraco tharmisensis* (Solomon et al., 2020), and the diminutive kogaionid multituberculate *Barbatodon oardaensis* (Codrea et al., 2014). Significantly, slightly over 10 years ago, a new and important Upper Cretaceous marine-to-continental succession was discovered in the Sebeş–Petreşti area, on southern edge of the southwestern Transylvanian Basin (Codrea et al., 2010; Vremir, 2010). This succession exposes the continuous transition from the deep-water turbiditic deposits assigned to the Bozeş Formation, to the overlying Sebeş Formation deposited in continental facies (Codrea et al., 2010; Vremir et al., 2014, 2015a), thus documenting the withdrawal of marine waters and emergence of this area during the latest Cretaceous. The Petreşti succession also contains several fossil vertebrate-bearing horizons located near, or slightly above, the boundary between the Bozeş and Sebeş formations, thus witnessing the faunal composition of some of the oldest latest Cretaceous continental vertebrate assemblages known from western Romania (Csiki-Sava et al., 2012; Brusatte et al., 2013; Vremir et al., 2014).

Recently, given its key stratigraphic position and important fossil content, our team started a comprehensive multidisciplinary survey of this important succession from Petreşti, aimed to better constrain the timing and paleoenvironmental context of this marine-to-continental transition, and of the emergence of the dwarf dinosaur-bearing Maastrichtian vertebrate assemblages. Here, we report the first results of our research focused mainly on the palynostratigraphy of the marine Bozeş Formation below and near its boundary with the overlying Sebeş Formation. This marine formation has been previously dated either as Turonian–Santonian based on its palynomorph content (Antonescu, 1973), or else as young as late Campanian, for the upper part of formation cropping out in the Petreşti–Arini section (Vremir et al., 2014; see below). We have sampled extensively this succession (see below, Materials and methods), and herewith describe for the first time palynological assemblages recovered from the Bozeş beds cropping out at Petreşti, and discuss their biostratigraphic significance. Moreover, in this study, we also offer novel palaeoenvironmental interpretations for these marine deposits based on their palynofacies, correlated with results of organic geochemistry analyses.

## 2. Geological setting

The vertebrate-bearing Petreşti locality is situated just outside of the northern border of the Sebeş Mountains made up mainly of metamorphic basement units, close to the contact of this mountain range with the Transylvanian Basin (Fig. 1). The larger region that hosts this fossil locality, and extends between Alba Iulia and Sebeş along the middle course of the Mureş River, corresponds to the southwestern corner of the Transylvanian Basin, and is often referred to as the Metaliferi sedimentary area (e.g. Codrea and Dica, 2005). It is characterized by the presence of a thick pile (probably several hundred meters) of uppermost Cretaceous continental deposits, being one of the main areas from western Romania where such deposits yielding important accumulations of continental vertebrates are present (see e.g. Codrea et al., 2010; Csiki-Sava et al., 2016).

The Transylvanian Basin is a post-Cenomanian sedimentary basin covering a basement build by 'mid'-Cretaceous thick-skinned thrusting and nappe emplacement; correlative units of its deeply hidden basement are cropping out in the surrounding uplifted mountain areas of the Eastern and Southern Carpathians (the latter including the Sebeş Mountains), as well as in the Apuseni Mountains. According to Krézsek and Bally (2006), the sedimentary cover of the basin can be subdivided into four megasequences, corresponding to the Upper Cretaceous (rift megasequence), Paleogene (sag megasequence), lower Miocene (flexural megasequence), and middle-upper Miocene (back-arc megasequence), respectively. Deposition of the Upper Cretaceous rift megasequence was controlled mainly by post-orogenic gravitational collapse of the overthickened nappe pile formed during the 'mid'-Cretaceous thrusting events. This megasequence is ended by a latest Cretaceous inversion than led to regional emergence across large parts of the Transylvanian Basin and widespread continental deposition during the lower part of the second, Paleogene-aged megasequence.

The Upper Cretaceous deposits exposed at Petreşti (Figs. 1:11, 2), in an artificial outcrop stretching along the Sebeş River that was created slightly more than a decade ago (Codrea et al., 2010; Vremir, 2010; Csiki-Sava et al., 2012), were formed during, and tellingly illustrate, the main depositional events of the Upper Cretaceous megasequence. The Bozeş Formation, cropping out in the upstream section of the local succession (Fig. 1:2), but in a stratigraphically lower position given the general dip of the beds towards the north-northwest, is made up of marine, dominantly deep-water and turbiditic, flyschoid deposits (Vremir et al., 2014; Fig. 2), mainly grey and dark grey marls (Fig. 2B) with sandstone intercalations that become somewhat more common towards the terminal part of the unit (Fig. 2C). The terminal part of the Bozeş succession at Petreşti shows signs of a more brackish, shallower depositional environment with fossils of benthic invertebrates such as gastropods and corals (Vremir et al., 2014; see also below). The Bozeş Formation corresponds to the deepening stage of the Upper Cretaceous rift megasequence, and was assumed to have a Turonian-Santonian (e.g. Antonescu, 1973), late Santonian–early Campanian (e.g., Bălc et al., 2012), or Santonian–early Maastrichtian (Codrea and Dica, 2005) age in the different parts of the Metaliferi sedimentary area and the neighboring Southern Apuseni Mountains.

The Bozeş Formation is conformably overlain in the Petreşti section by the mainly continental, red-coloured, Sebeş Formation (see Vremir et al., 2015a for discussions concerning this lithostratigraphic unit) that crops out towards the interior of the basin (downstream in the local succession); the transition between the two units appears to be continuous. Unlike the dominantly red-coloured lithology of the unit, the basalmost, transitional part of the Sebeş Formation cropping out at Petreşti retains the dominantly grey-coloured aspect of the Bozeş Formation, but is marked by a coarser, sandy-silty grain size of the deposits (Fig. 2D), and shows a progressive shift towards the typical red-coloured continental beds of the unit (Fig. 2E). The continental Sebeş Formation corresponds to the inversion stage that concludes the first, synrift megasequence, and its deposition may have continued into the early part

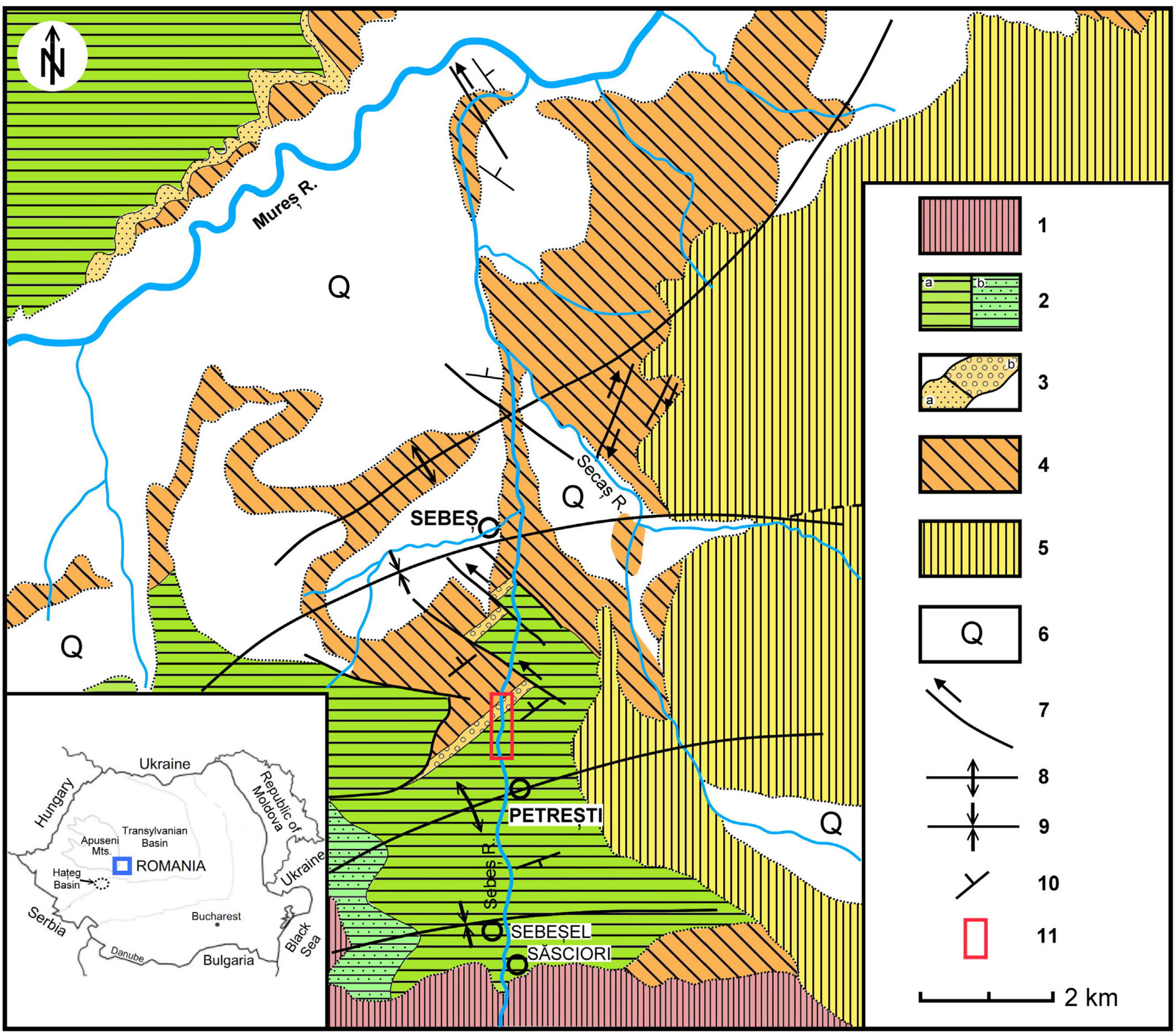


**Fig. 1.** Geological map of the Sebeş-Petreşti area (re-drawn from Vremir et al., 2013, 2014; simplified). Legend: 1 – metamorphic basement (Getic-Supragetic nappe system); 2 – Upper Cretaceous (upper Santonian–upper Campanian) marine deposits (Bozeş Formation - a), with basal, locally developed coal-bearing fluvial-deltaic facies (Santonian "Sebeşel strata" - b); 3 – transitional deltaic (a) or estuarian-brackish (b) facies (top Bozeş Formation); 4 – Upper Cretaceous (uppermost Campanian–Maastrichtian–Paleocene?) continental units (Sebeş Formation); 5 – undifferentiated Miocene and Pliocene marine units (Sîntimbru Formation); 6 - Quaternary cover and terraces; 7 – faults; 8 – anticlines; 9 – synclines; 10 – dip and strike; 11 – location of the studied section.

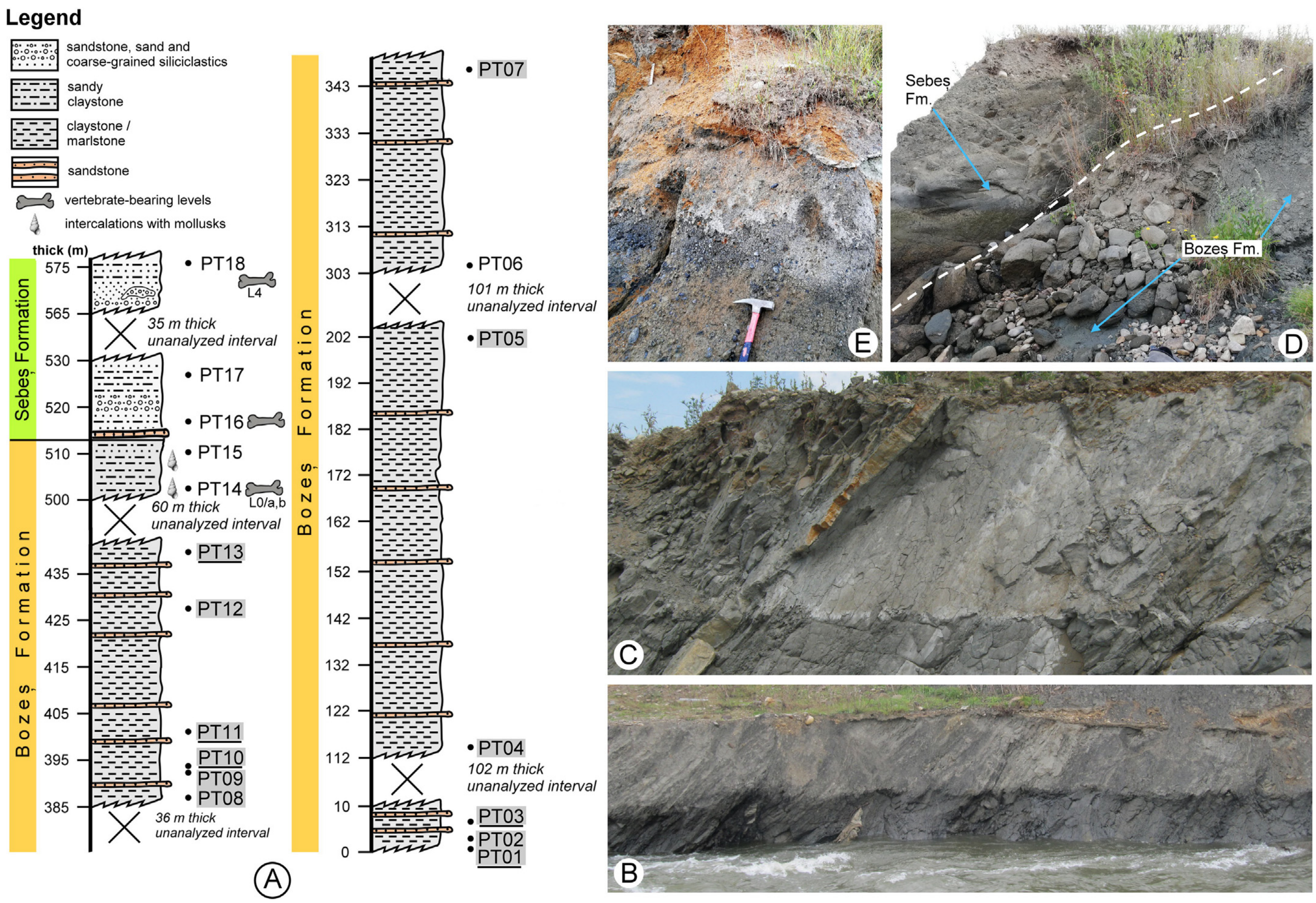


**Fig. 2.** **A**. lithological log and details of the Upper Cretaceous deposits in the Petreşti section; **B**. section from the middle part of the Bozeş Formation, dominated by pelitic rocks; **C**. dark gray marlstones and claystones with sandstone interbeds (upper part of the Bozeş Formation); **D**. the currently recognized boundary (dashed line) between the uppermost, transitional brackish Bozeş Formation and the basalmost, gray sandstones/coarse-grained siliciclastic deposits of the Sebeş Formation; **E**. moderately well sorted, partially oxidized dark-gray sandy-conglomerate, from the lower part of the Sebeş Formation (about 2 m above the sample PT16). Location of vertebrate-bearing levels (L0/a,b and L4) plotted according to Vremir et al. (2014, 2015b). Abbreviations: PT1–PT18 - palynological samples analyzed in the present study (shaded, the samples with palynomorph content; unshaded, barren samples; underlined samples - geochemical analyses).

of the second, sag megasequence. The Sebeş Formation and its correlative units had been generally assumed to have a Maastrichtian age (Vremir et al., 2015a), with deposition starting possibly only during the later part of the early Maastrichtian according to previous interpretations (e.g. Codrea and Dica, 2005), and it is conceivable that it extended into the early part of the Paleogene as well.

## 3. Material and methods

The Petreşti section has been sampled previously in several attempts to document as thoroughly as possible its litho- and biostratigraphy. A first sampling, focused mainly on calcareous nannoplankton, included 33 samples taken from the upper part of the outcropping succession of the marine Bozeş Formation; the results of these first biostratigraphic investigations were reported preliminarily in Csiki-Sava et al. (2012) and detailed subsequently in Vremir et al. (2014). In order to both extend the sampling along the entire outcropping succession as well as increase the sampling density and develop a more comprehensive integrated stratigraphic framework, a second round of sampling took place in June 2017 by a joint Romanian-American team. During this sampling, also focused mainly on the dominantly marine part of the Bozeş Formation, a significantly thicker succession has been sampled, starting from the basal part of the outcropping local succession of this unit, but also extending up into the basalmost, grey-coloured Sebeş Formation. A total of 62 samples were collected in 2017, from which, 18 samples (PT01–PT18; Fig. 2A) were selected for a preliminary organic matter and palynological content assessment, covering as evenly possible the entire sampled stratigraphic interval; of these, 15 samples (PT01–PT15) come from the Bozeş Formation and 3 (PT16–PT18) from the overlying basalmost Sebeş Formation (Fig. 2A). Five of the samples were also used for organic geochemical analyses, aimed at interpreting their depositional environment and the origin of organic matter they contain. The 18 palynological samples were processed following standard palynological preparation techniques described by Batten (1999). Approximately 50 g of rock from each sample 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 palynological residue from each sample was mounted to a slide with glycerine jelly. For this study, a kerogen oxidation procedure was not applied. Identification and quantification of palynomorphs (Figs. 3–5; Appendix A) and palynofacies constituents were carried out using a Leica DM1000 microscope, equipped with a digital camera Leica DFC 420.

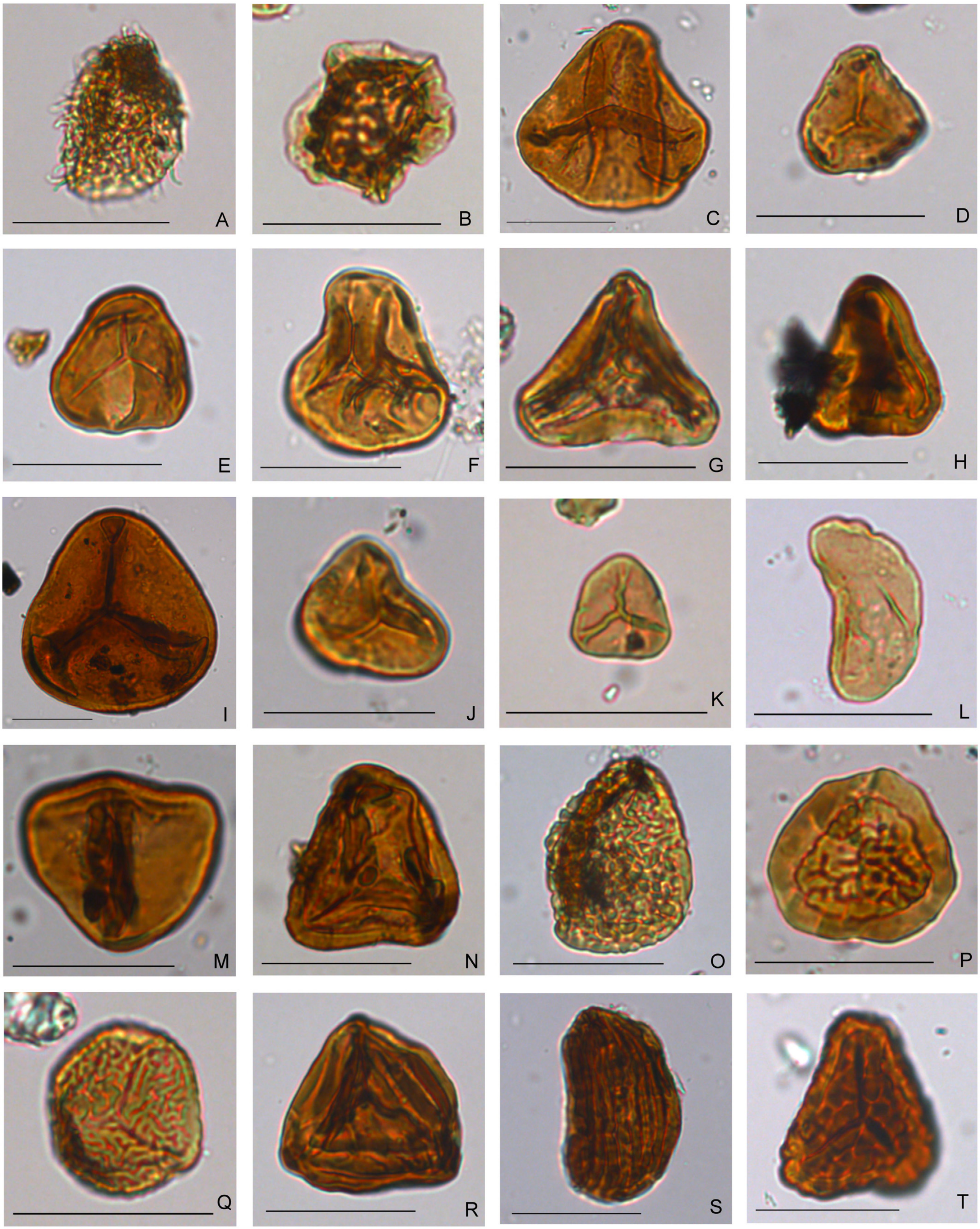


**Fig. 3.** Light photomicrographs of selected phytoplankton taxa and cryptogam spores recorded in the Bozeș Formation (scale bar: 30 μm; the three numbers between brackets are related to samples, palynological slides and England Finder coordinates, respectively). A. *Operculodinium* sp. (PT12, TD/P263, L20-1). B. *Pterodinium* sp. (PT12, TD/P263-2, Q12-1). C. *Deltoidospora australis* (PT08, TD/P259, B24). D. *Deltoidospora rafaeli* (PT09, TD/P260, C11-2). E. *Deltoidospora minor* (PT12, TD/P263-1, D42). F. *Deltoidospora toralis* (PT11, TD/P262,

All palynological and palynofacies slides are kept in the collection of the Geology Department (Slide Nos. TD/P252–TD/P269), „Al. I. Cuza" University of Iaşi.

Palynofacies analysis involved counting the relative abundance of unoxidized palynodebris based on 500 counts per slide. Two main groups of kerogen constituents proposed by Tyson (1995), Mendonça Filho et al. (2002), Ţabără et al. (2021), and Slimani et al. (2021) have been recognized in the studied samples, namely: (I) phytoclasts (opaque and translucent organic particles derived from terrestrial plants), and (II) palynomorphs (pollen, spores, and a small number of specimens assigned to dinoflagellate cysts).

In the marine environment, the proximal–distal trend is one of the principal controls on particulate organic matter (POM) distribution. Several distribution trends of phytoclast types have been used for palaeoenvironmental interpretation (e.g. Tyson, 1993; Mendonça Filho et al., 2011; Radmacher et al., 2020), including: 1. the high proportion of equidimensional opaque phytoclasts that are small-sized and display rounded shapes due to their transport over a prolonged period of time, mainly suggests a distal depositional environment; 2. the high amount of large, lath-shaped opaque phytoclasts represents the result of short-term transport supporting land proximity; 3. the high relative abundance of often large, translucent phytoclasts (e.g. cuticles and woody tissues) indicates a strong terrestrial organic matter influx, and thus this parameter mostly suggests proximal depositional conditions (e.g. fluvio-deltaic systems).

As mentioned, organic geochemical analyses were performed on 5 samples of fine-grained rocks originating from the Bozeş Formation (Table 1). These analyses include measurements of total organic carbon (TOC), total inorganic carbon (TIC) and total sulfur (TS), as well as the investigation of bitumen extracts using gas chromatography–mass spectrometry (GC–MS).

The total carbon (TC), TOC, TIC and TS contents were obtained from approximately 200 mg pulverized whole sample using an Eltra CS-530 Carbon Sulfur Determinator with a TIC module. TC and TIC were determined using an infrared cell detector for $CO_2$ and TS for $SO_2$. TC and TS values were derived from combustion of organic matter in an oxygen atmosphere with simultaneous thermal decomposition of minerals. Determination of TIC was carried out via the reaction of carbonates with 15% warm hydrochloric acid and was equal to 0. The elemental analyzer was calibrated in accordance with Eltra standards. Finally, the total organic carbon content was recalculated for organic matter (TOC = TC − TIC; Table 1).

Bitumen extraction from the samples was performed on powdered samples using a Dionex ASE 350 Accelerated Solvent Extractor (Thermo Scientific) at 70 °C in 34 ml stainless steel cells ($p$ = 10 Mpa; solvent flow = 70 ml/min). These sample extracts were separated from the rock using DCM ($CH_2Cl_2$, dichloromethane) solvent; subsequently, the solvent was evaporated at room temperature and dried extracts weighed to calculate extraction yields (wt.%). The dry residue was diluted in 1.5 ml of DCM and analysed by GC–MS.

GC–MS analyses of the bitumen were carried out using an Agilent 7890A gas-chromatograph equipped with an HP-5 column (60 m × 0.25 mm i.d.) coated with a 0.25 μm stationary phase film, and coupled with an Agilent Technology 5975 mass spectrometer. The experimental conditions were as follows: carrier gas - He; temperature, 50 °C (isothermal for 2 min); heating rate to 175 °C at 10 °C/min, to 225 °C at 6 °C/min and, finally, to 300 °C at 4 °C/min. The final temperature (300 °C) was maintained for 20 min. The mass spectrometer was operated in electron impact ionisation mode at 70 eV and scanned from 50 to 650 da. Data were acquired in full scan mode and processed with Hewlett Packard Chemstation software (for more details, see Zielińska et al., 2020; Ciesielczuk et al., 2021). Good results were obtained only for $n$-alkanes and acyclic isoprenoids. All geochemical analyses were performed in the Institute of Earth Sciences of the University of Silesia in Sosnowiec (Poland).

## 4. Results

### 4.1. Palynological content

From the 18 samples from the Petreşti section analyzed in this study, only 12 samples originating from the lower and middle Bozeş Formation yielded a countable number of palynomorphs (see Appendix 1). Meanwhile, the palynological samples coming from the top of the Bozeş Formation (PT14 and PT15), as well as those collected from the lowermost part of the Sebeş Formation (sampling interval PT16–PT18) were almost sterile as far as organic matter is concerned. The palynoflora recovered from the Bozeş Formation mainly includes cryptogam spores and pollen grains, representing 35 taxa of pteridophytes, 6 taxa of gymnosperms, and 39 taxa of angiosperms. Marine phytoplankton, essentially consisting of dinoflagellate cysts, represents but a small fraction (4 taxa) of the palynological assemblage found in the studied section. A selection of characteristic palynomorphs identified in the Bozeş Formation is illustrated in Figs. 3–5.

The stratigraphic interval covered by samples PT01 to PT13 yielded a well preserved and diverse palynoflora. Among the palynomorphs recorded, the fern spores are the most abundant (40–82% of the total palynomorphs). The most frequently occurring taxa include the representatives of Cyatheaceae (*Deltoidospora minor*, *D. australis*, *D. punctatus*), Polypodiaceae (*Polypodiaceoisporites retirugatus*, *P. granulatus*), Schizaeaceae (*Cicatricosisporites dorogensis*, *C. spiralis*) and Gleicheniaceae (*Gleicheniidites senonicus*). Other frequently identified spore taxa, which generally occur in the upper part of the Bozeş Formation, are *Biretisporites deltoideus*, *Echinatisporis longechinus*, *Klukisporites pseudoreticulatus*, and *Triplanosporites microsinuosus*. Certain taxa with rare occurrences in the Cretaceous deposits of Romania (i.e. *Antulsporites* sp., *Asterisporites radiatus*) show a low frequency in the local palynological assemblage as well. Gymnosperm pollen show a low diversity and only represent a subordinate component of the Petreşti assemblage (up to 11% of the total palynomorphs in some samples). Species such as *Araucariacites australis, Ephedripites multicostatus, Inaperturopollenites dubius*, and *Pinuspollenites* sp. can be listed among the gymnosperm taxa recorded at Petreşti. Angiosperm pollen grains are mostly represented by specimens assigned to the Normapolles group (e.g. *Interporopollenites proporus*, *Oculopollis praedicatus*, *Plicapollis serta*, *Trudopollis fossulotrudens*); these are accompanied by pollen showing affinities with ancestral Juglandaceae (*Subtriporopollenites constans*, *S. anulatus*) which presents a peak (≈ 15%) in the palynological assemblage of the PT12 sample. Other angiosperm taxa such as *Cupuliferoidaepollenites quisqualis*, *Emmapollis* sp. (of typhacean affinities), *Monocolpopollenites* sp. (palm pollen), *Myricipites bituitus*, *Retitricolpites* sp. were occasionally observed throughout the succession.

E8-1). G. *Gleicheniidites senonicus* (PT01, TD/P252-1, B44). H. *Matonisporites* sp. (PT11, TD/P262, F18-1). I. *Biretisporites deltoideus* (PT11, TD/P262-1, C29). J. *Biretisporites potoniaei* (PT13, TD/P264, M11-2). K. *Undulatisporites trigonnus* (PT12, TD/P263, B31). L. *Laevigatosporites ovatus* (PT09, TD/P260-1, L7-2) M. *Triplanosporites microsinuosus* (PT11, TD/P262-2, D24-1). N. *Polypodiaceoisporites retirugatus* (PT12, TD/P263-1, K31-2). O. *Polypodiaceoisporites* sp. (PT03, TD/P254, F28). P. *Polypodiaceoisporites* sp. (PT13, TD/P264-2, R19-1). Q. *Camarozonosporites insignis* (PT12, TD/P263, C28-2). R. *Cicatricosisporites spiralis* (PT12, TD/P263-2, J40). S. *Cicatricosisporites dorogensis* (PT09, TD/P260-1, L3). T. *Trilites* sp. (PT09, TD/P260-2, F31).

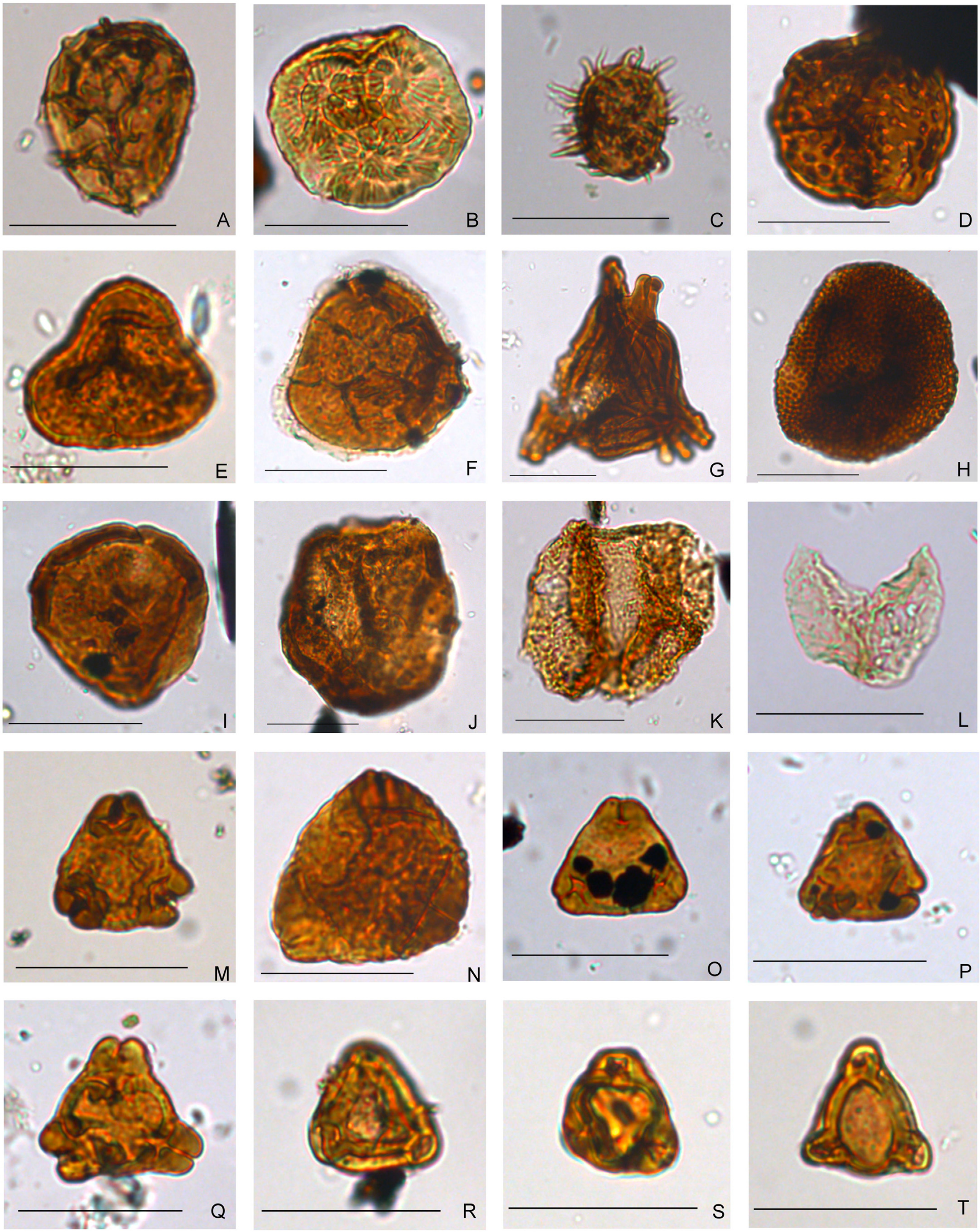


**Fig. 4.** Selected terrestrial palynomorphs (cryptogam spores, gymnosperm and angiosperm pollen grains) recovered from the Bozeş Formation (scale bar: 30 μm; the three numbers between brackets are related to samples, palynological slides and England Finder coordinates, respectively). A. *Lycopodiumsporites clavatoides* (PT12, TD/P263, G30-2). B.

**Table 1**
Bulk geochemical data and ratios based on the distributions of *n*-alkanes and isoprenoids of the analyzed samples from the Bozeş Formation, Petreşti section (for the location of the samples, see Fig. 2A). The *n*-alkane values are derived from GC-MS analysis. TC – Total Carbon; TIC – Total Inorganic Carbon; TOC – Total Organic Carbon; TS – Total Sulfur; Pr – pristane; Ph – phytane.

| Sample | TC (%) | TIC (%) | TOC (%) | TS (%) | *n*-alkanes and acyclic isoprenoids | | |
|---|---|---|---|---|---|---|---|
| | | | | | Pr/$n$-$C_{17}$ | Ph/$n$-$C_{18}$ | Pr/Ph |
| PT01 | 1.193 | 0.525 | 0.668 | 0.504 | 0.80 | 0.39 | 1.91 |
| PT03 | 1.361 | 0.530 | 0.831 | 0.625 | 1.15 | 0.63 | 1.38 |
| PT10 | 1.485 | 0.640 | 0.845 | 0.317 | 0.79 | 0.53 | 1.56 |
| PT11 | 1.201 | 0.425 | 0.776 | 0.310 | 0.64 | 0.35 | 1.62 |
| PT13 | 1.100 | 0.368 | 0.732 | 0.090 | 0.51 | 0.28 | 1.90 |

The phytoplankton includes poorly diversified and badly preserved dinoflagellate cysts. A small number of specimens assigned to *Operculodinium*, *Pentadinium*, *Pterodinium*, and cf. *Cribroperidinium* were recorded in the sampling interval PT11–PT12.

### 4.2. Palynofacies compositions

The kerogen assemblages observed under microscope exhibit a low to moderate preservation state and a content composed exclusively of terrestrial POM. The palynofacies data were derived only for the sampling interval PT01–PT13, as samples from the top of the Bozeş Formation (PT14 and PT15), as well as from the lowermost part of the Sebeş Formation (PT16–PT18) show a very small amount of kerogen. Poor conservation of the organic matter in the PT14–PT18 sampling interval is most probably related to palaeoenvironmental conditions (stronger continental influence during the time of deposition, shallow waters, advanced oxidation of the organic matter due to bacterial degradation; Tyson, 1995; Mendonça Filho et al., 2011).

Three main constituents of POM were recognized, namely: opaque phytoclasts which are predominant in all samples, translucent phytoclasts, and palynomorphs. The distribution of these kerogen constituents identified in the investigated samples is illustrated in Fig. 6. In the lowermost part of the analyzed section (corresponding to samples PT01 and PT02), the opaque phytoclasts show a very high proportion (87–93%), are typically equidimensional and slightly angular in shape, with dimensions of about 25–50 μm (Fig. 6). This interval also contains a minor fraction of fossil resin (4% in sample PT02) derived from conifers, as well as rare small-sized translucent phytoclasts.

A slight change in the palynofacies composition is recorded in the sampling interval PT03–PT10, mainly in the shape and size of the opaque phytoclasts. The proportion of these opaque phytoclasts frequently exceeds 90% of the total kerogen recovered from samples from this interval and most often they have small size (10–30 μm) and a rounded shape (Fig. 6:5). Such "allochthonous" fraction of organic particles are generally considered to be distributed far from their terrestrial source area in marine basins. Occasionally, pollen grains show framboidal pyrite on their surface (Fig. 4O, P), indicating an anoxic environment within the sediments. The palynofacies of the PT03–PT10 sampling interval also includes small amounts of biodegraded woody tissues and a minor fraction of fossil resin.

Within the PT11–PT13 sampling interval, another change in the palynofacies composition was recorded. Here, the proportion of opaque phytoclasts decrease slightly (78–85%), and the composition of organic matter is dominated by a mixture of lath-shaped, often large angular opaque phytoclasts (frequent >100 μm; Fig. 6:1 and 3) and large translucent biostructured phytoclasts represented by woody tissues and cuticles (Fig. 6:2 and 4). Sample PT12 also includes a high content of terrestrial palynomorphs, with some agglomerations of Juglandaceae pollen appearing occasionally on the palynological slides (Fig. 5I).

### 4.3. Geochemical data

The TOC content of the analyzed Bozeş Formation sediments varies between 0.668 and 0.845% (Table 1), ranking these samples as rocks with a fair kerogen content (as defined by Peters and Cassa, 1994). The TS content presents low values in the upper part of the Bozeş Formation (sample PT13, with a value of 0.09%), reaching slightly higher values in the lower part of the studied section (0.504–0.625% in the samples PT01 and PT03, respectively).

The chromatograms of the organic matter recovered from the analyzed Bozeş Formation display prominent saturated hydrocarbon distributions between $n$-$C_{14}$–$n$-C33$n$-alkanes, and dominant pristane (Pr) over phytane (Ph) isoprenoid hydrocarbons (Fig. 7). The *n*-alkanes distribution documents a dominance of low and medium molecular weight compounds (i.e. *n*-C16–*n*-C18), suggesting that the analyzed samples include a certain fraction of marine organic matter derived from phytoplankton (Abeed et al., 2011). The same samples also include a terrigenous land-derived kerogen component as supported by the presence of long-chain *n*-alkanes (*n*-C23–*n*-C29; Sarki Yandoka et al., 2015), but this occurs in lower quantities in the analyzed rocks.

Acyclic isoprenoids (pristane and phytane) occur in variable quantities in all the studied samples. In all instances, pristane values show relatively high concentrations compared to phytane, with Pr/Ph ratios in the range of 1.38–1.91 (Table 1), which suggest that the Bozeş Formation was deposited under suboxic to relatively anoxic conditions (Peters and Moldowan, 1993; Makeen et al., 2015).

## 5. Discussion

### 5.1. Biostratigraphy

Dinoflagellate cysts are most commonly used for palynomorph-based biostratigraphical dating, as these organic marine microfossils represent important biostratigraphic markers for the Upper Cretaceous in the Tethyan realm (Slimani, 2001; Williams et al., 2004). However, the absence, or at most very rare occurrences, of such dinocysts in the studied samples from Petreşti led us to use another group of palynomorphs for our biostratigraphic estimates, namely taxa belonging to the Normapolles group. This type of pollen was derived from early angiosperms (with systematic affinities to the Fagales; Friis et al., 2006) that characterized the "Normapolles Phytogeographic Province" which extended from southern North America through Europe into western Asia during the Late Cretaceous (Vajda and Bercovici, 2014). The high diversity of the Normapolles taxa and their rapid evolution during the Late

*Asterisporites radiatus* (PT12, TD/P263, P38). C. *Echinatisporis longechinus* (PT12, TD/P263-1, I22). D. *Klukisporites pseudoreticulatus* (PT13, TD/P264-1, C36). E. *Concavissimisporites* sp. (PT05, TD/P256, M11). F. *Zlivisporites blanensis* (PT03, TD/P254-1, D29). G. *Appendicisporites cristatus* (PT13, TD/P264, E9). H. *Vadaszisporites sacali* (PT11, TD/P262-2, P27). I. *Classopollis* sp. (PT03, TD/P254-2, M22). J. *Araucariacites australis* (PT13, TD/P264, B25-2). K. *Pinuspollenites* sp. (PT13, TD/P264, R23). L. *Inaperturopollenites hiatus* (PT09, TD/P260-1, F30). M. *Trudopollis spinulosus* (PT12, TD/P263, D11-2). N. *Trudopollis fossulotrudens* (PT13, TD/P264, H27-1). O. *Trudopollis nonperfectus*, with framboidal pyrite (PT03, TD/P254-1, P41). P. *Trudopollis minimus*, with framboidal pyrite (PT03, TD/P254-1, F22). Q. *Trudopollis cuneolis* (PT13, TD/P264-2, G49). R. *Interporopollenites proporus* (PT12, TD/P263-1, I24). S. *Interporopollenites endotriangulus* (PT12, TD/P263-1, L22). T. *Interporopollenites klausii* (PT12, TD/P263, D39-1).

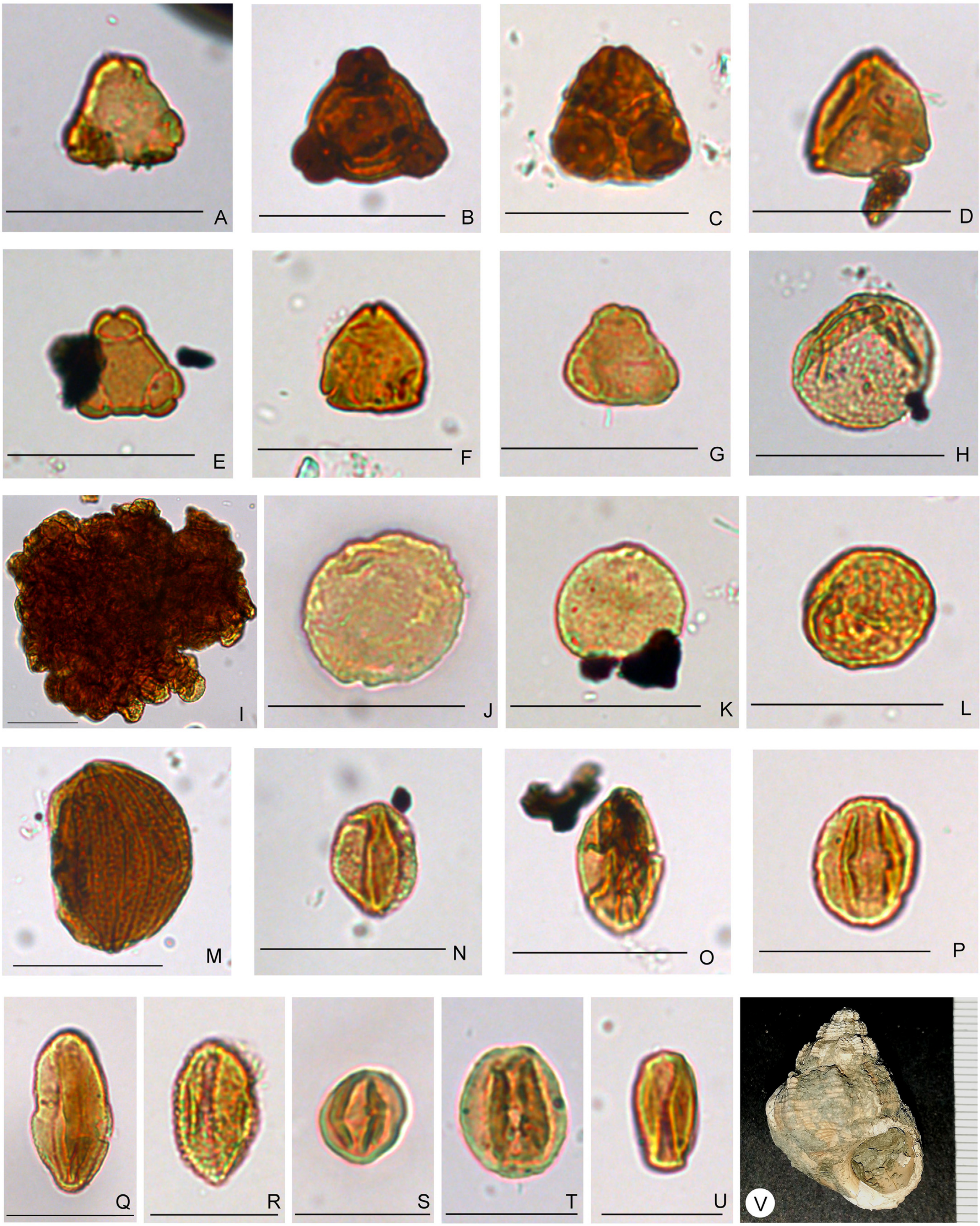


**Fig. 5.** Selected early angiosperm pollen grains and gastropod fauna recorded in the Bozeş Formation (scale bar: 30 μm for A–Q; 20 μm for R–U; the three numbers between brackets are related to samples, palynological slides and England Finder coordinates, respectively). A. *Vacuopollis microconcavus* (PT12, TD/P263, E44). B. *Oculopollis principalis* (PT12,

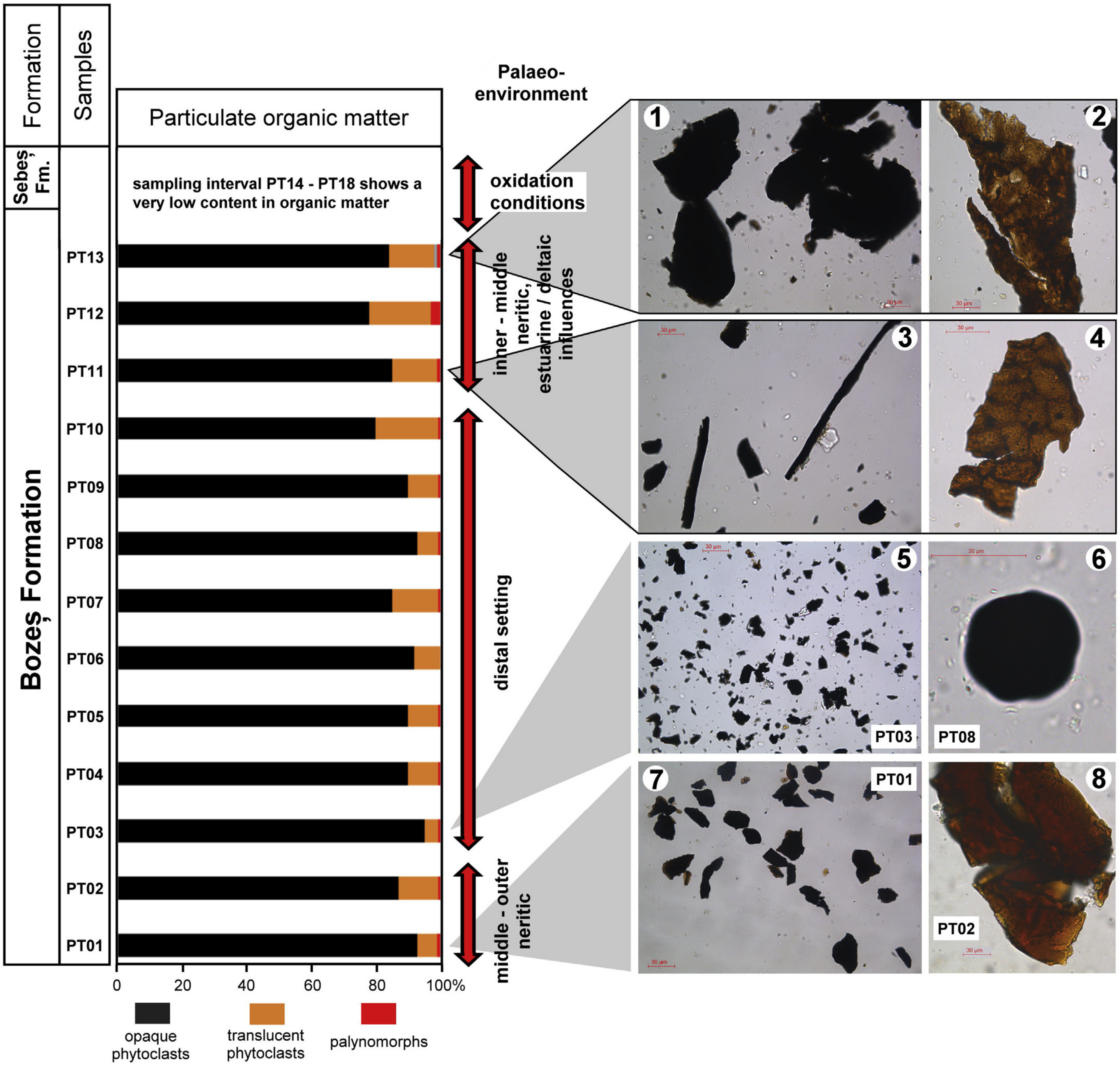


**Fig. 6.** Relative abundances of the particulate organic matter components in the Bozeş Formation, Petreşti section, with specific examples of these POM components (1–8) as well as corresponding palaeoenvironmental interpretations. The POM assemblages recorded at Petreşti include: 1, 2. Large opaque phytoclasts (1) and translucent phytoclast (2) of continental origin (sample PT13); 3, 4. Lath-shaped opaque phytoclasts (3) and large-sized cuticles (4) (sample PT11); 5. Palynofacies dominated by small equidimensional opaque phytoclasts (sample PT03); 6. Rounded opaque phytoclast (sample PT08); 7. Equidimensional and slightly angular opaque phytoclasts (sample PT01); 8. Fossil resin (sample PT02).

Cretaceous makes this group biostratigraphically important. Based on previous studies (Antonescu, 1973; Góczán and Siegl-Farkas, 1990; Siegl-Farkas, 1993; Siegl-Farkas and Wagreich, 1996), several fairly accurate palynostratigraphic schemes of the Upper Cretaceous from Europe are available, and these allow a decent/good correlation with the palynological assemblages (Normapolles taxa) identified in the Petreşti section. Besides the Normapolles-type pollen, certain fern spore taxa were also useful for biostratigraphic age estimates.

The palynoflora recorded in the Bozeş Formation at Petreşti unfortunately contains only a small number of taxa that are commonly known to represent biostratigraphical markers within

TD/P263-1, G41-2). C. *Oculopollis praedicatus* (PT05, TD/P256, P56). D. *Myricipites bituitus* (PT12, TD/P263-2, Q7). E. *Suemegipollis triangularis* (PT12, TD/P263-1, D17). F. *Triporopollenites robustus robustus* (PT05, TD/P256-2, R47). G. *Triatriopollenites* sp. (PT12, TD/P263, F55-1). H. *Emmapollis* sp. (PT09, TD/P260-2, O42). I. Agglomeration of terrestrial palynomorphs, probably *Subtriporopollenites* sp. (PT12, TD/P263-1, R28). J. *Subtriporopollenites subporatus gracillimus* (PT01, TD/P252, B44). K. *Subtriporopollenites anulatus* (PT12, TD/P263-2, J41). L. *Subtriporopollenites constans* (PT12, TD/P263, E51). M. *Trisectoris* cf. *reticulatus* (PT09, TD/P260, F29-1). N. *Retitricolpites* sp. (PT01, TD/P252-1, R19). O. *Tricolpites* sp. (PT01, TD/P252, C45). P. *Tricolporopollenites* sp. (PT12, TD/P263-1, N19). Q. *Fraxinoipollenites constrictus* (PT12, TD/P263, Q22-1). R. *Fraxinoipollenites* sp. (PT12, TD/P263-2, H48). S. *Cyrillaceaepollenites* sp. (PT01, TD/P252, L47). T. *Bacutricolpites constrictus* (PT08, TD/P259-1, D53). U. *Cupuliferoidaepollenites quisqualis* (PT01, TD/P252, M31). V. *Barbotella maestrichtiensis* (scale bar in mm).

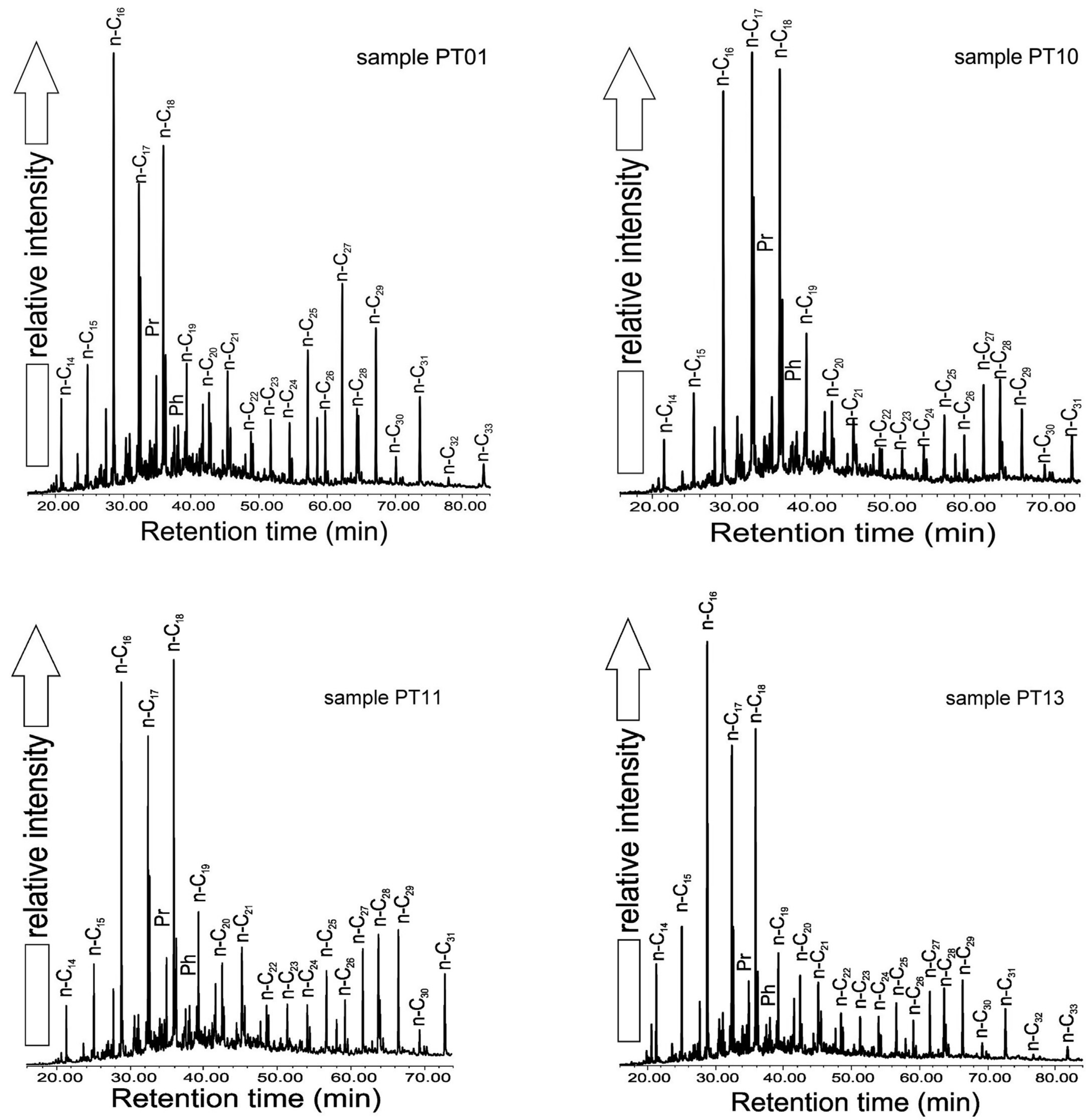


**Fig. 7.** Gas chromatogram–mass spectrometry spectra of saturated hydrocarbons from four selected Bozeș Formation samples.

the Upper Cretaceous. One of the most significant biostratigraphically important taxa identified is *Trudopollis cuneolis* (Fig. 4Q), which is known to range from the late early Campanian up to early Maastrichtian (Polette and Batten, 2017). Moreover, *T. cuneolis* is a typical taxon for the *bajtayi–lenneri* biozone (late Campanian; Fig. 8), according to the palynozonation of the Upper Cretaceous from Hungary (Góczán and Siegl-Farkas, 1990). In the Petrești section, *T. cuneolis* has rare occurrences in samples PT01 and PT13, respectively (Appendix 1), and clearly indicates that the age of the analyzed deposits is not older than late early Campanian.

Two other taxa assigned to the Normapolles group, recorded with a low frequency in the PT05–PT12 interval, are *Oculopollis principalis* and *O. praedicatus*. Both species are generally considered to indicate a Santonian–Campanian age (Pavlishina et al., 2004; Polette and Batten, 2017), but it seems that one of them, *O. praedicatus*, may persist until the early Maastrichtian in the Hațeg area situated to the southwest from our study area, showing occurrences in the basal Densuș–Ciula Formation (Antonescu et al., 1983; Botfalvai et al., 2021). In the Apuseni Mountains area, the Turonian–middle Santonian palynoflora (assigned to “e”

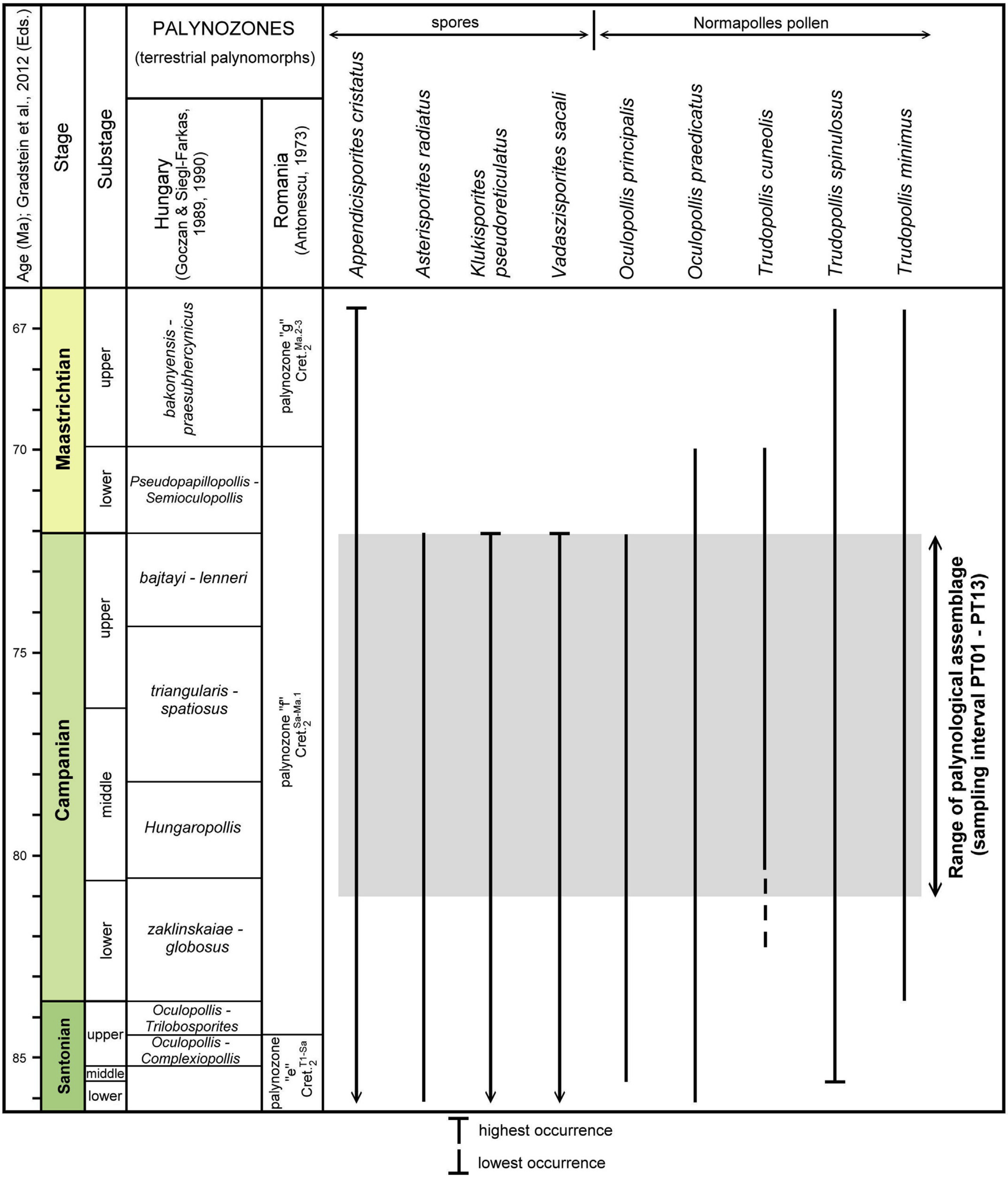


**Fig. 8.** Zonal schemes and ranges of selected Normapolles and spore taxa recovered in the Petreşti section. Correlations with previously published palynozonations from Hungary (Góczán and Siegl-Farkas, 1989, 1990) and Romania (Antonescu, 1973) are shown. Age of the different subunits after Gradstein et al. (2012).

palynozone) includes a high frequency of taxa such as *Oculopollis orbicularis*, *O.* cf. *semimaximus*, and *O.* cf. *maximus* (25–79% of the total palynomorphs), species of this genus decreasing in frequency (only up to 5%) in the younger palynomorph assemblage assigned to the “f” palynozone (uppermost Santonian–lower Maastrichtian) by Antonescu (1973). According to the frequencies of the

*Oculopollis* genus previously recorded in the Turonian—lower Maastrichtian interval in the Upper Cretaceous of the Apuseni Mountains, we can correlate our palynological assemblage identified in the Bozeş Formation at Petreşti with the assemblage assigned to palynozone “f” (sensu Antonescu, 1973; Fig. 8). Moreover, the “f” palynozone of Antonescu (1973) includes several other taxa also present in the Bozeş Formation palynological assemblages from Petreşti. These include taxa such as *Gleicheniidites senonicus*, *Suemegipollis triangularis*, *Trudopollis* div. sp., *Zlivisporites blanensis*, further supporting a good correlation between these two assemblages.

Sample PT12 from the studied section displays a high frequency of various species assigned to *Interporopollenites*, *Plicapollis*, and *Subtriporopollenites* genera (Appendix 1). This composition allows a good correlation with the upper Campanian *Plicapollis—Subtriporopollenites* Assemblage Zone (Siegl-Farkas and Wagreich, 1996) from Hungary, as well as the assemblage of continental palynomorphs recorded in the lower part of the Tercis les Bains section (France), previously dated as late Campanian (Siegl-Farkas, 2001).

Some specimens of Myricaceae pollen (i.e. *Triatriopollenites* sp.; Fig. 5G) shows rare occurrences in the PT01—PT12 interval, this taxon being similar to the one figured in Góczán and Siegl-Farkas (1990; Plate III, Figs. 4—6) and considered to be typical for the lower Campanian *zaklinskaiae—globosus* Assemblage Zone from Hungary. The occurrence of this taxon in slightly younger deposits in southwestern Transylvanian Basin is possible, and could indicate a mid-late Campanian age. Other taxa of the Normapolles group, such as *Trudopollis nonperfectus*, *T. fossulotrudens* and *T. minimus* also occur occasionally in the upper part of the Bozeş Formation deposits sampled at Petreşti (Appendix 1). According to Góczán and Siegl-Farkas (1990), Polette and Batten (2017), and Halamski et al. (2020), these species have a wider biostratigraphic range, namely Coniacian—Maastrichtian, and have been reported previously from both marine and continental Upper Cretaceous deposits of the Haţeg Basin (Ţabără and Slimani, 2019; Botfalvai et al., 2021).

Two fern spores identified at Petreşti, namely *Klukisporites pseudoreticulatus* (Fig. 4D) and *Vadaszisporites sacali* (Fig. 4H), have their highest occurrences at the end of Campanian (Góczán and Siegl-Farkas, 1990; Halamski et al., 2020), therefore the age of the deposits assigned to the Bozeş Formation can be no younger than Campanian. It should be noted that the *Klukisporites pseudoreticulatus* has rare but constant occurrences throughout the studied section of the Bozeş Formation, whereas *Vadaszisporites sacali* was recorded only in sample PT11. The species *V. sacali* has been previously reported from Santonian marine deposits of the Haţeg Basin (Ţabără and Slimani, 2019).

In summary, all the bioevents listed above, supported by the diverse Normapolles pollen taxa and certain fern spores, suggest a mid—late Campanian age for the PT01—PT13 interval sampled from the Bozeş Formation at Petreşti. Unfortunately, the samples collected from the basalmost Sebeş Formation (sampling interval PT16—PT18; Fig. 2A) are palynological barren and thus their age could not be biostratigraphically constrained, containing a very small amount of kerogen due to the dominantly oxidizing conditions during sedimentation.

In the top of the Bozeş Formation (within the uppermost 10—12 m stratigraphic thickness; Fig. 2A), there are several levels that yielded an assemblage of brackish-water gastropods (indeterminate melanopsids and cerithids) and solitary corals (see also Vremir et al., 2014). From this association, a well-preserved gastropod specimen assignable to *Barbotella maestrichtiensis* (Fig. 5V) has been identified. As this taxon has previously been reported from Campanian deposits in Spain (Kiel, 2001), its occurrence at Petreşti would be consistent with our palynology-based age estimate for the Bozeş Formation.

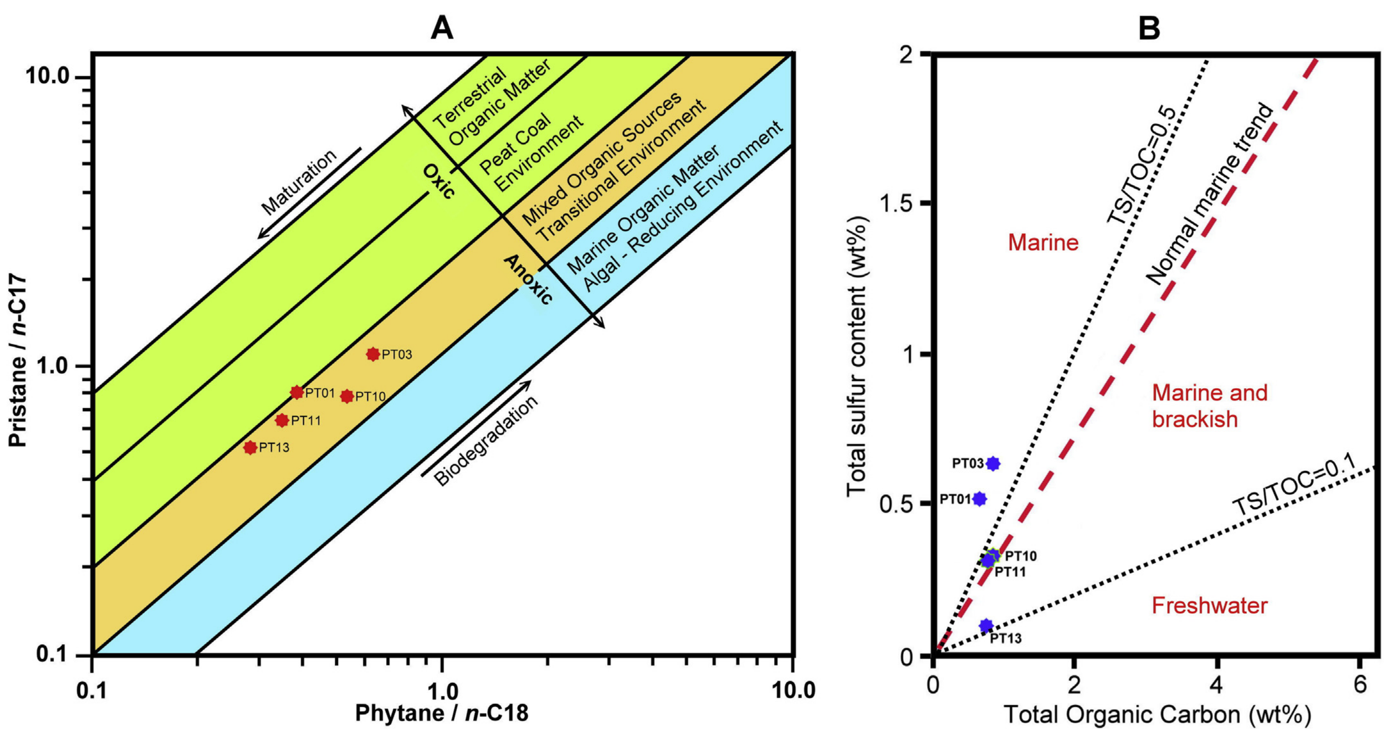


**Fig. 9.** **A**. Cross-plot of phytane/*n*-C18 versus pristane/*n*-C17 organic components measured in the five samples analyzed from Petreşti, indicating the depositional environment and type of organic matter from the analyzed samples (modified after Shanmugam, 1985); **B**. Cross-plot of TOC content against sulfur (TS) content for the same samples. The red dashed line marks the normal marine trend (TS/TOC = 0.36; after Berner and Raiswell, 1983), and the dotted lines delimit the TS/TOC ratios corresponding to freshwater (TS/TOC<0.1), marine and brackish (0.1<TS/TOC<0.5), and marine sediments (TS/TOC>0.5), respectively (after Wei and Algeo, 2020). (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article).

### 5.2. Palaeoenvironmental reconstruction and palaeoclimatic implications

The POM content recorded from the studied interval exhibits a low-to-moderate abundance and includes a large proportion of continental material (opaque and translucent phytoclasts, fossil resin, pollen grains and spores), besides a very small amount of marine material represented by some dinoflagellate cysts.

The kerogen analyzed from samples corresponding to the lower part of the section (PT01–PT02 interval) is mainly composed of equidimensional opaque phytoclasts (87–93%), 25–50 μm in size and with slightly angular shapes, that are derived primarily from the oxidation of terrestrial plant tissue, as well as of translucent phytoclasts. In the overlying PT03–PT10 interval, the proportion of opaque phytoclasts frequently exceeds 90% of the total kerogen, but their dimensions are smaller (10–30 μm) and they frequently show rounded shapes (Fig. 6:5 and 6). The organic geochemistry data obtained for the sampling interval PT01–PT10 (i.e. pristane/*n*-C17 and phytane/*n*-C18 ratios; cross-plot of TOC content vs. sulfur content; Fig. 9) show that the lower and middle part of the Bozeş Formation section investigated at Petreşti contains a mixed organic matter (of terrestrial and marine origin) initially deposited under suboxic to relatively anoxic conditions within a transitional (= inner neritic) environment. The proximal facies outlined for this stratigraphic interval is also confirmed by the recovered palynological assemblages that show proportions of spores ranging from 47% up to 82%. Deposits containing palynological assemblages dominated by fern spores are generally confined to the vicinity of active fluvio-deltaic sources, where low salinities partially suppress the productivity of phytoplankton (Tyson, 1993).

All the samples from the PT01–PT10 interval are devoid of phytoplankton fossils, whereas the interpretation of chromatograms supports a dominance of low and medium molecular weight organic compounds (i.e. *n*-C16 – *n*-C18; Fig. 7) that derive from phytoplankton/algae (Abeed et al., 2011). This apparent incongruence between palynological content and organic geochemistry suggests that the autochthonous marine organic fraction (i.e. phytoplankton) was much rapidly biodegraded compared to the allochthonous, terrestrial one (various phytoclasts, spores and pollen), so that the marine organic component left only its "geochemical signature" on the studied rocks. The cross-plot of TOC content vs. sulfur content (Fig. 9B) also supports the presence of the same open marine conditions for this interval.

The palynofacies composition identified in the lower and especially middle part of the Bozeş Formation section sampled at Petreşti (corresponding to the PT01–PT10 interval) indicates that organic matter initially deposited in a transitional environment (proximal facies) was subsequently transported on the slope to an outer neritic–distal area of the Late Cretaceous basin, as supported by the presence and abundance of the small-sized and rounded opaque phytoclasts (Fig. 6). According to Tyson (1995), Mendonça Filho et al. (2011), and Radmacher et al. (2020), a large proportion of equidimensional, small and rounded opaque phytoclasts point to the presence of a distal depositional environment that is located farther away from the continental source area. Furthermore, observations concerning the size of the opaque phytoclasts, as well as their shape, can be used to roughly estimate the distance of the depositional area from the shoreline (Tyson and Follows, 2000; Jurkowska and Barski, 2017). Our size estimates for the opaque phytoclasts observed in the different samples (see 4.2) indicate a transport distance of the organic particles up to 14–16 km from the shoreline in the case of the basalmost PT01 and PT02 samples, and an even longer transport distance (about 30–35 km) into a more distal area of the basin for the phytoclasts recorded in the PT03–PT10 interval. A similar depositional palaeoenvironment for the Bozeş Formation was previously documented by Chira et al. (2004) and Bălc et al. (2012), who suggested, based on lithological and sedimentological data, that this formation is made up mainly by interbedded claystones and fine sandstones formed in median/distal deep-water turbiditic fan lobes.

The terrestrial palynological assemblage recovered from the Bozeş Formation at Petreşti is similar to that typical to the Upper Cretaceous deposits previously analyzed from the Haţeg Basin and the Apuseni Mountains (Antonescu, 1973; Antonescu et al., 1983; Mogoş, 1992; Van Itterbeeck et al., 2005; Csiki et al., 2008; Ţabără and Slimani, 2019; Botfalvai et al., 2021), revealing the presence of a diversified vegetation with elements of subtropical to warm-temperate forests. The assemblages coming from the PT01–PT10 interval are dominated by hygrophytic fern spores, such as *Deltoidospora*, *Polypodiaceoisporites* and *Gleicheniidites*, and are consistent with plant communities growing in moist lowland (fluvial and/or coastal) habitats, under rather warm climatic conditions (Abbink et al., 2004; Bowman et al., 2014). However, a slightly higher frequency of *Araucariacites* pollen was observed in sample PT08, which suggests a well-drained and higher-altitude habitat, and it was also suggested that this conifer requires cooler temperate conditions (Bowman et al., 2014). The same higher-altitude areas and cooler-wetter conditions were also preferred by some early angiosperms that are regarded as parent plants of *Trudopollis* spp. (Daly and Jolley, 2015), a Normapolles pollen that occurs constantly throughout the analyzed section at Petreşti, but presents a slightly increased frequency in the PT11–PT13 interval. Within the same interval (i.e. in sample PT12), taxa derived from various forest communities such as ancestral Juglandaceae (*Subtriporopollenites* spp., *Plicapollis*) and some Normapolles angiosperms (*Interporopollenites* spp.) are also well represented in the palynological assemblages (Appendix 1). According to Friis et al. (2011) and Daly and Jolley (2015), earliest Cenozoic Juglandaceae taxa from Eastern Europe preferred the warmer and dryer conditions of the lowlands or hilly areas. Therefore, it appears that the Late Campanian plant communities in the southwestern part of the Transylvanian Basin – as recorded by the palynological assemblages identified in the Petreşti section – included both a vegetation type typical of warm climate and lowland habitats, represented by various Juglandaceae and ferns, as well as a Normapolles flora which points to a cooler climate and higher-altitude areas. This record is also interesting as it appears to suggest the beginning of a replacement of Normapolles-producing plants with their modern counterparts (e.g. various Juglandaceae) during the late Campanian in the studied area. Recent research (i.e. Peyrot et al., 2020) outlined the same pattern of replacement of the Normapolles flora with a more derived one, living together in the late Campanian archipelago of Western Europe.

Taken together, the middle-late Campanian palynological assemblages recovered from the Bozeş Formation of the southwestern Transylvanian Basin suggest the existence of various types of plant communities. A hygrophytic vegetation represented by various ferns growing in fluvial and/or coastal habitats was well represented during the middle Campanian. Later, during the late Campanian, this palaeoflora was gradually replaced by a mixed one, consisting of both representatives of lowland habitats (e.g. Juglandaceae, ferns), as well as of a vegetation that characterized higher-altitude areas and cool temperate conditions.

In the upper part of the Bozeş Formation sampled at Petreşti (PT11–PT13 interval), the palynofacies composition changes slightly compared to the one described from the previous interval (PT01–PT10). This part of the succession yielded organic matter dominated by a mixture of lath-shaped, often large opaque phytoclasts (frequently exceeding 100 μm in size; Fig. 6), and large translucent biostructured phytoclasts (woody tissues, cuticles), a palynofacies typical for inner–middle neritic environments, with some estuarine/deltaic influences (Tyson, 1995; Radmacher et al., 2020). All these features are consistent with the geochemical data that indicate a transitional environment for the PT11–PT13 interval (Fig. 9A), as well as the presence of organic matter of brackish–freshwater origin (Fig. 9B). In the same interval, rare occurrences of poorly preserved dinoflagellate cysts (i.e. *Pentadinium* and *Pterodinium*), typical of marine distal areas, have been identified. Their presence in this proximal facies may be related to some upwelling currents.

The top of the Bozeş Formation (corresponding to samples PT14 and PT15) is characterized by the complete absence or else a poor conservation of the kerogen in the rocks, possibly due to the dominantly oxidizing conditions during sedimentation. Indeed, several levels with brackish-water gastropods and corals were also identified in this interval, clearly indicating a strong estuarine and/or deltaic influence near the depositional area. The samples analyzed from the lowermost part of the Sebeş Formation cropping out at Petreşti (PT16–PT18 interval) also displayed a very low content in organic matter. Thus, further detailed palynological sampling from this lithostratigraphic interval (extending from the topmost Bozeş to the basal Sebeş formations) is sorely needed to better constrain the age of this part of the local succession, as well as to better understand the palaeoenvironmental conditions and trends that prevailed during the sedimentation of these oldest vertebrate remain-bearing deposits from the region (see Vremir et al., 2014).

## 6. Conclusions

The palynological study of a 575 m thick Upper Cretaceous sedimentary succession assigned to the Bozeş and basal Sebeş formations that crops out in the Petreşti area (southwestern Transylvanian Basin), combined with palynofacies and organic geochemical analyses, led to the following biostratigraphic and palaeoenvironmental interpretations:

(1) The palynomorph assemblages identified in the present study, the first ones to be reported from the southern part of the Metaliferi sedimentary area, suggest a mid-to-late Campanian age for the marine Bozeş Formation, based on the presence and distribution of key fern spores and Normapolles pollen taxa. The samples analyzed from the overlying continental Sebeş Formation are palynologically barren due to the dominantly oxidizing conditions during the sedimentation of this unit. However, new attempts for other palynological analyses obtained from samples of the basal Sebeş Formation are still sorely needed, for a better biostratigraphic dating of the vertebrate remain-bearing deposits assigned to this formation.

(2) The lower and middle part of the Bozeş Formation cropping out at Petreşti (middle Campanian) is characterized by a palynological assemblage represented mainly by hygrophytic fern spores, a composition that is consistent with plant communities growing in moist lowland habitats and warm climatic conditions. The late Campanian palynological assemblages recorded from the same formation are slightly different, being derived from much more diversified early angiosperm communities, represented by Normapolles-producing plants as well as ancestral Juglandaceae, together with less significant free-sporing plant and gymnosperm communities. This picture of the late Campanian vegetation suggests the co-existence of plants typical for fluvial to coastal areas, along with other palynofloral assemblages derived from higher-altitude areas and cooler–wetter environmental conditions.

(3) Palynofacies analysis of the Bozeş Formation indicates the dominance of terrestrial POM, represented mainly by opaque phytoclasts, sometimes with small sizes and rounded shapes, and less common translucent phytoclasts, pollen grains and spores. These palynofacies characteristics, combined with organic geochemistry data obtained from the lower and middle part of the Bozeş Formation sampled at Petreşti, indicate that organic matter initially deposited in a transitional palaeoenvironment was subsequently transported down the slope to an outer neritic–distal area of the Late Cretaceous basin. The POM assemblages identified from the upper part of the Bozeş Formation are interpreted to reflect inner–middle neritic environments, based on the predominance of lath-shaped, often large opaque phytoclasts, combined with that of large translucent biostructured phytoclasts. In the top of the Bozeş Formation (the uppermost 10–12 m stratigraphic thickness) some intercalations with brackish-water gastropods and corals have been identified, clearly indicating the proximity of the shoreline during their deposition.

(4) The Bozeş Formation from the studied section is devoid of phytoplankton, or else only shows very rare occurrences of this in its upper part. However, GC-MS analyses of the same samples document a dominance of low and medium molecular weight organic compounds (i.e. *n*-C16–*n*-C18) that is usually assumed to derive from phytoplankton/algae. This documents a fairly rapid partial biodegradation of the phytoplankton at the sediment–water interface during the Campanian, as the marine organic component remained preserved only as a “geochemical signature” within the studied rocks.

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## Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.cretres.2022.105148.