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PALYNOSTRATIGRAPHIC AND PALAEOENVIRONMENTAL INVESTIGATIONS OF THE MAASTRICHTIAN FROM OARDA DE JOS (SOUTHWESTERN TRANSYLVANIAN BASIN)

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Abstract. A palynological, palynofacies and organic geochemical investigation of the Upper Cretaceous continental vertebrate site of Oarda de Jos allowed us to constrain its age and to make more detailed inferences about its depositional environment. The recovered palynomorph assemblage is represented mainly by angiosperm pollen and fern spores, alongside rare taxa of gymnosperms. Biostratigraphically significant taxa identified in the assemblage restrict the age of the studies deposits to the later early Maastrichtian. The palynofloral evidence indicates plant communities that mainly preferred higher-altitude areas and cooler-wetter conditions. However, a spore and pollen assemblage which derives from vegetation typical of lacustrine areas or riverbanks also occurs in the studied deposits. The studied palynoflora shows quite significant differences compared to previously published palynological assemblages from the same geological unit (the Sebeș Formation), although from deposits located slightly to the north, at Pâclișa. Organic geochemical data show that certain organic biomarkers such as n-alkanes n-C_{16} to n-C_{18} reach the highest values, and indicate that they may derive from freshwater colonial green algae such as *Scenedesmus*. The palynofacies constituents used to reconstruct the depositional environment suggest an exclusive terrestrial organic matter deposited in a stagnant-water fluvial/lacustrine environment.

Keywords: palynology, organic geochemistry, Late Cretaceous.

INTRODUCTION

Detailed biostratigraphic studies concerning the Upper Cretaceous vertebrate-bearing continental deposits from the southwestern Transylvanian Basin are almost inexistent. The only information was provided previously by Antonescu (1973) and Antonescu et al. (1983) who assigned the "Red Clastic Formation" exposed along Pâclişa Valley, southwest of Alba Iulia (= basal part of the Sebeş, or Șard, Formation) to the upper Maastrichtian, based on the presence of the angiosperm pollen taxon *Pseudopapillopollis praesubhercynicus* which showed a frequency of about 40% of the total identified assemblage. The late Maastrichtian palynological assemblage quoted by Antonescu (1973) from Pâclişa also includes taxa such as *Triporopollenites robustus*, *Interporopollenites proporus*, *Emscheripollis* cf. *gracilis gracilis* and *Suemegipollis triangularis*.

On the left bank of the Mureş River, the Sebeş Formation crops out in several geological sections distributed along the Sebeş River, as well as in the bordering hills such as in the Rîpa Roşie geological reservation (Fig. 1; Codrea et al., 2010a; Vremir, 2010; Vremir et al., 2015). According to Antonescu (1973), a small number of palynological samples taken from the Oarda de Sus and Rîpa Roşie areas proved to be palynologically barren. However, these continental deposits preserve large coaly or silicified tree trunks assigned to *Podocarpus* and the conifer *Telephragmoxylon transsylvanicum* (Antonescu, 1973; Iamandei et al., 2005), as well as fossil seeds of *Mastixia amygdalaeformis* (Givulescu et al., 1995).

Recently, Țabără et al. (2022) analyzed 3 palynological samples collected from the basal Sebeş Formation in the Petreşti section (9.5 km south of the Oarda de Jos outcrop), which also proved to be barren in palynomorphs. Nevertheless, the middle Upper Campanian deposits at Petreşti assigned to the upper part of the underlying marine Bozeș Formation yielded a palynological assemblage represented by various terrestrial palynomorphs such as *Pseudopapillopollis* cf. *praesubhercynicus*, *Trudopollis rusticus*, *Krutzschipollis crassis*, *Oculopollis praedicatus*, *Subtriporopollenites constans*, and rare dinoflagellate cysts represented by *Samlandia* cf. *vermicularia* (Bălc et al., 2024).

The present study aims to contribute novel biostratigraphical data for the Upper Cretaceous continental deposits from the southwestern Transylvanian Basin by focusing on the local succession that crops out near Oarda de Jos locality (Fig. 2), one of the most important vertebrate localities from the Sebeș Formation (e.g., Codrea et al., 2010a; Vremir et al., 2015). Another goal of this research is to improve previous interpretations concerning the depositional environments of the Sebeș Formation at Oarda de Jos – given the special palaeontological importance of this locality (see below) – based on palynofacies data and gas chromatography–mass spectrometry analysis.

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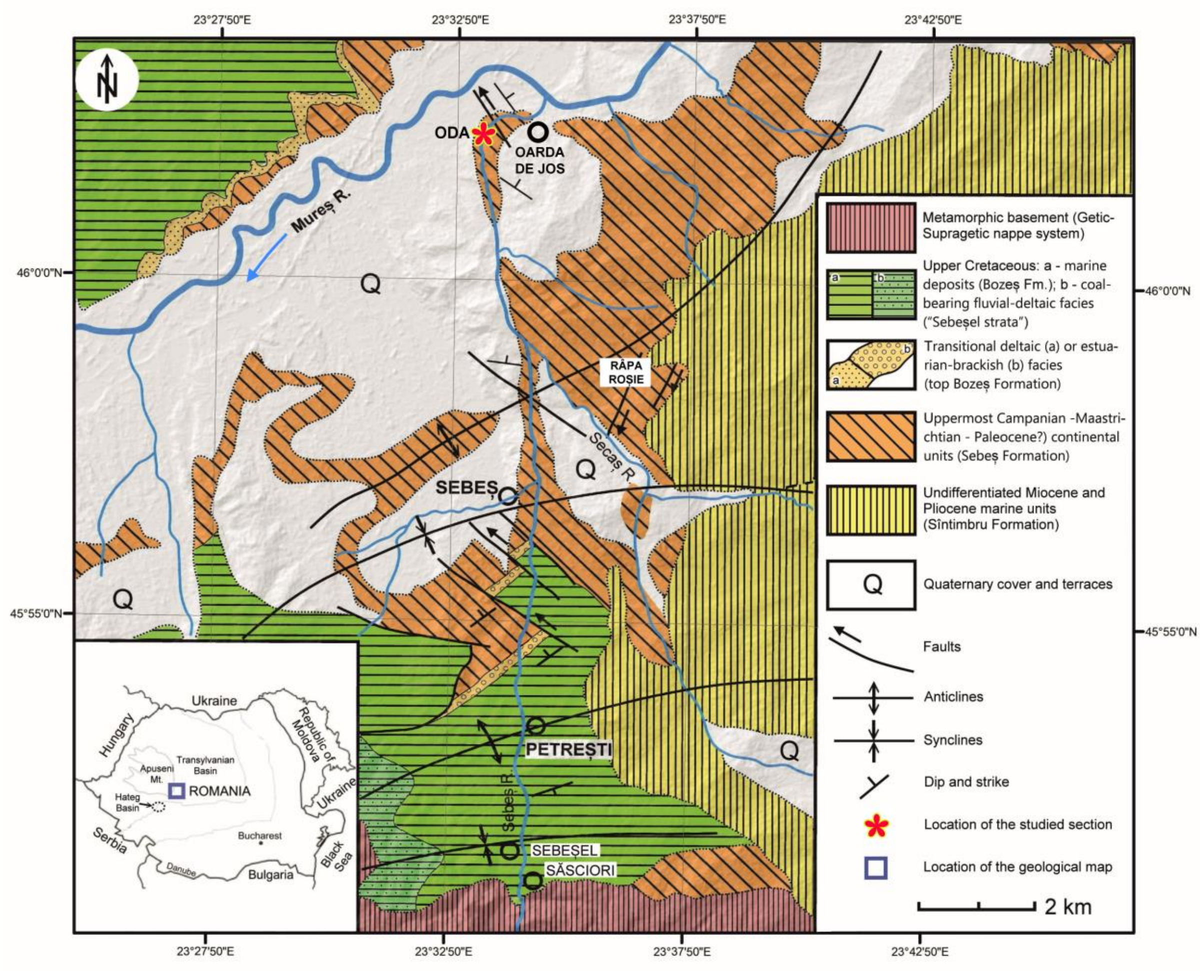

Fig. 1. Geological map of the Sebeș-Oarda de Jos area (re-drawn from Vremir et al., 2013, 2014; simplified).

GEOLOGICAL SETTING

The southwestern corner of the Transylvanian Basin, stretching between north-Alba Iulia to south of Sebeș, hosts one of the most important outcropping areas of uppermost Cretaceous vertebrate-bearing continental deposits from Romania (e.g., Codrea et al., 2010a; Csiki-Sava et al., 2016; Fig. 1), first recognized as such by Nopcsa (1905) and currently grouped into the Sebeș Formation (e.g., Vremir, 2010; Vremir et al., 2015; Csiki-Sava et al, 2016; = Șard Formation, Codrea and Dica, 2005; for a detailed discussion about the local stratigraphic nomenclature, see Vremir et al., 2015). Nevertheless, these deposits -including those cropping out upstream of the Mureș River-Sebeș River confluence near Oarda de Jos (Fig. 1)- had been long considered to represent the Eocene-Oligocene based on their lithofacies (e.g., Koch, 1894); even as late as in 1995, the Oligocene age of the red continental deposits from Oarda de Jos was regarded as uncontested (e.g., Givulescu et al., 1995).

However, by that time, diagnostic vertebrate remains, including a rhabdodontid limb bone, were started to be discovered in the red continental successions from Oarda de Jos (see Vremir et al., 2015); soon, with the intensification of the exploration activities in this area, the relatively richly fossiliferous nature of these deposits had been well established. Furthermore, the taphonomic characteristics and preservation state of these fossils argued for their autochthonous nature, prompting Codrea et al. (2001) to suggest that the hosting deposits must be latest Cretaceous in age based on their correlation with the similarly fossiliferous and undoubtedly uppermost Cretaceous dinosaur beds from the Hațeg Basin (e.g., Nopcsa, 1905, 1915; Grigorescu, 2010; Csiki-Sava et al., 2016). Two main fossiliferous outcropping areas had been recognized near Oarda de Jos, identified as Oarda de Jos A (ODA; Figs. 1, 2) and, slightly more upstream of the first one, Oarda de Jos B (ODB) (Codrea et al., 2010a; Vremir, 2010; Jipa, 2012; Vremir et al., 2015). Although both of these lithologically roughly similar outcrops yielded vertebrate remains, often associated with plant remains, ODA is currently the more important of the two as it is significantly richer in fossil remains (see below) and thus it was chosen as the subject of our palynological investigations; in addition to the two fossiliferous outcrops, an *ex-situ* fossil accumulation (ODS), most probably derived from the top of the local succession, was also reported recently by Solomon et al. (2022a). Based on their relative stratigraphic position, the Oarda de Jos successions and their fossiliferous sites fall into the middle section of the uppermost Cretaceous continental Sebeș Formation (Vremir, 2010; Vremir

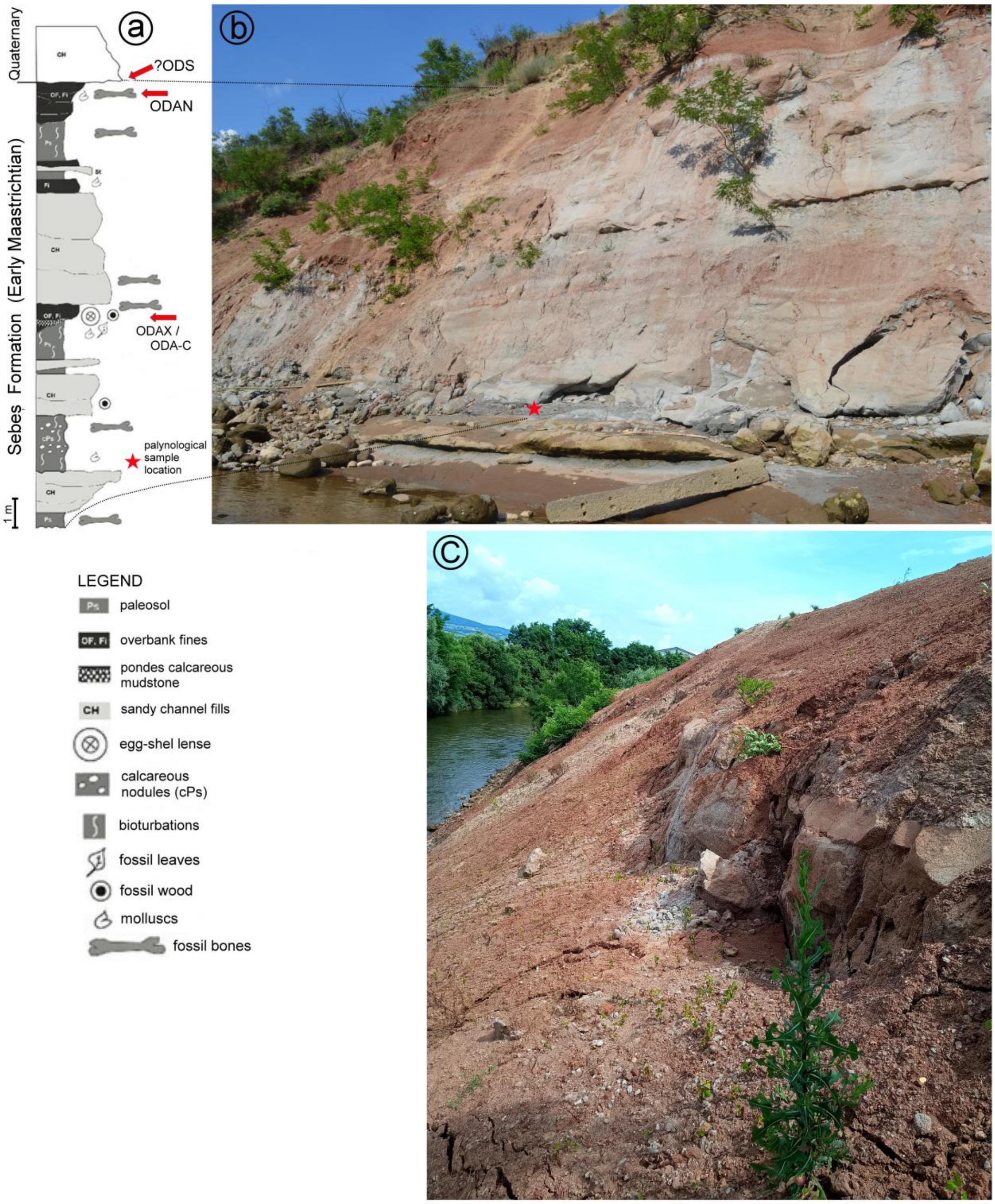

Fig. 2. Lithological column of the Oarda de Jos (ODA) section (**a**.- after Dyke et al., 2012, slightly modified), and images of the ODA site before it was covered with soil (June 2015; **b.**), and after (July 2023; **c.**).

et al., 2015).

The palynologically investigated outcrop (ODA) consists of a succession of mudstones, silty mudstones, sandstones, and pebbly sandstones, with localized thin coal layers in its basal part (Fig. 2) that yielded large coaly or silicified tree trunks, as well as a rich vertebrate assemblage associated with invertebrates and plant microfossils (e.g., Antonescu, 1973; Codrea et al., 2010a, b; Vremir, 2010; Jipa, 2012; Vremir et al., 2015). A certain sedimentological distinctiveness of the Oarda successions – the important presence of quiet-water, 'lacustrine' deposits within the otherwise fluvially dominated Sebeș Formation – had been acknowledged since long (e.g., Codrea et al., 2001).

Indeed, more recent interpretations of the locally exposed beds support the importance of such quiet-water deposits accumulated within small-sized freshwater bodies such as temporary, seasonally active abandoned channels, as well as ponds formed in poorly drained floodplains and/or oxbow lakes (e.g., Codrea et al., 2013a; Solomon et al., 2022a) that were formed within a braided (Codrea et al., 2017) or meandering (Vremir, 2010) river system; occasionally, such beds are hosting thin coaly layers (in the basal part of the section; Vremir, 2010) or ponded calcareous mudstone lenses described as eggshell coquinas (Dyke et al., 2012; Vremir et al., 2015; Fernández et al., 2019). Oxygenation conditions were variable within these standing-water environments, ranging from suboxic, found in seasonally reactivated abandoned channels (represented by light grey-greenish silts, e.g., Jipa, 2012; Codrea et al., 2014; Solomon, 2016) to more anoxic, in true oxbow deposits (grey-bluish mudstones; Solomon et al., 2022a). These drab-colored 'lacustrine' deposits are associated at Oarda de Jos with lithotypes that are more common in the Sebeș Formation such as yellowish grey channel fill sandstones and silty crevasse plays, and brownish-red overbank/floodplain silty mudstones that are often thicker and laterally extensive, compared to the relatively thin and often lens-shaped 'lacustrine' ones. Based on the lithology of the palynologically sampled bed cropping out in the basal-most part of the ODA section, near water level (Fig. 2a, b) it apparently also represents a comparable suboxic standing-water palaeoenvironment. Nevertheless, its larger thickness and more laterally continuous development, together with the reported presence of silicified tree trunks (we were not able to identify such logs in place at the collecting place in the moment of our sampling, although such logs were found, *in situ* or *ex situ* more upstream in the riverbed at a comparable or lower stratigraphic levels) suggests more extensive and permanent water levels in the former depositional environment.

FOSSIL RECORD AND PALAEONTOLOGICAL IMPORTANCE OF THE OARDA DE JOS LOCALITY

As noted, the ODA outcrop – a steep exposure of about 50 in length and 15-19 m in height – represents one of the most important vertebrate occurrences from the continental uppermost Cretaceous of the southwestern Transylvanian Basin. Soon after the identification of the first isolated dinosaur remains in the mid-1990s (Vremir et al., 2015) followed by more rigorous and systematic prospecting of the area, their remains started to accumulate; Codrea et al. (2001) already reported the presence of isolated titanosaur (reported as *Magyarosaurus*), hadrosauroid (presumably *Telmatosaurus*) and rhabdodontid (identified as *Rhabdodon*) dinosaur as well as indeterminate crocodyliform remains, to which Vremir (2004) added that of indeterminate chelonians. The first important vertebrate discovery to be reported from Oarda de Jos was that of a quasi-complete and well-preserved crocodyliform cranium referred by Delfino et al. (2008) to *Allodaposuchus precedens*, a taxon previously erected from largely synchronous deposits of the Hațeg Basin (Nopcsa, 1928); the diagnostic nature and exquisite preservation of the Oarda de Jos specimen later led Narváez et al. (2020) to establish this specimen as the neotype of this basal neosuchian taxon, replacing the former holotype. These mostly isolated macrovertebrate skeletal elements were recovered both from drab-colored, poorly drained as well as from reddish, better-drained floodplain sediments, whereas the coarser channel deposits were less fossiliferous (e.g., Codrea et al., 2010a; Vremir, 2010; Jipa, 2012; Solomon, 2016).

Roughly in the same time period, a ponding, abandoned channel deposit, represented by a 4 m long and maximum 1 m thick lens-shaped body passing laterally into reddish floodplain mudstones (e.g., Codrea et al., 2010a, 2013a), was identified in the upper part of the ODA section that became the main source of vertebrate remains from the local section. This lens (identified as ODAN; Fig. 2a) has yielded, mainly through screen-washing, a very diverse vertebrate assemblage, associated with eggshells, gastropods, crab chelae, and charophytes (e.g., Codrea et al., 2010a, b; Jipa et al., 2010; Jipa 2012; Codrea et al., 2013a; Vremir et al., 2015; see more details below). Although microvertebrates (fish, anurans, albanerpetontids, lizards, chelonians, crocodyliform and dinosaur teeth, multituberculates) dominate the local assemblage, rarer macrovertebrate remains representing crocodyliforms, pterosaurs, as well as titanosaurian, hadrosauroid and rhabdodontid dinosaurs were also reported; based on its reported fossil content as well as preliminary taphonomic investigations (Jipa, 2012), this site can be classified as a high-diversity multitaxic mixed bonebed, and is one major source of information about the palaeobiodiversity of the uppermost Cretaceous Sebeș Formation.

Fish remains from ODAN were first reported by Jipa et al. (2010) and Codrea et al. (2010a, b) who noted the high frequency of lepisosteid remains (teeth, scales), a rather uncommon feature of the fossiliferous assemblages described from the continental uppermost Cretaceous of the Transylvanian area. Subsequently, Codrea & Jipa (2011; see also Jipa, 2012) noted the presence of characiform fish teeth at this site, while more recently, Trif & Codrea (2022) added that of three different morphotypes of indeterminate teleosteans. Based on these accounts, the ODAN fish assemblage ranks among the most diversified ones from the latest Cretaceous Transylvanian landmass; they are also among the numerically best-represented taxa in the ODAN assemblage (Jipa, 2012).

Albanerpetontid remains, too, are relatively common at ODAN, and Jipa (2012) preliminarily suggested the potential presence of two different taxa. Besides the fish remains, anurans make up the most abundant group (Jipa, 2012), and although many of their remains are indeterminate at a lower taxonomic level, the provisional (and then largely unsubstantiated) early report of the presence of the alytid *Paralatonia transylvanica* and that of the bombinatorid *Hatzegobatrachus grigorescui* by

Jipa et al. (2010) had been nevertheless confirmed subsequently by Venczel et al. (2016). Turtle remains are reported at ODAN, but are relatively rare; nevertheless, they seem to be represented by two different taxa, the basal testudine of uncertain affinities *Kallokibotion* and a currently indeterminate pan-pleurodiran dortokid.

Squamates are represented by relatively rare and fragmentary cranial and postcranial remains, from which nevertheless Codrea et al. (2017) recently erected a new barbatteiid taxon, *Oardasaurus glyphis*. Crocodyliforms are again among the best-represented groups in the ODAN assemblage (Jipa, 2012) and display a relatively high taxonomic diversity, with tooth morphotypes similar to *Allodaposuchus*, *Doratodon* and *Acynodon* being reported from here (Jipa, 2012; Codrea et al., 2013a); in general, a high frequency of crocodyliform remains at Oarda de Jos had been frequently noted, including here bite marks as well, probably referable to *Allodaposuchus* as trace-maker (e.g., Codrea et al., 2010a; Jipa, 2012). Pterosaur remains are relatively uncommon at ODAN, but at least some of the remains (jaw fragments, cervical vertebrae) are diagnostic enough to have enabled the erection of a new, large-sized azhdarchid taxon, *Albadraco tharmisensis* (Solomon et al., 2020).

Dinosaurs are represented at ODAN mainly by isolated teeth referred to velociraptorine dromaeosaurids and other indeterminate theropods, as well as to rhabdodontids (*Zalmoxes*), hadrosauroids (*Telmatosaurus*), and indeterminate titanosaurs (Codrea et al., 2010a, b; Jipa et al., 2010; Jipa, 2012); one fragmentary tooth may attest for the presence of nodosaurids (?*Struthiosaurus*) as well (Jipa, 2012), although this specimen may be too fragmentary to be identified with any certainty. However, larger postcranial dinosaur skeletal elements were also recovered from the ODAN lens, represented especially by titanosaur remains (vertebrae, ribs, chevrons, tibia, metatarsal), complementing the relatively large number of dinosaur (titanosaur, rhabdodontid, hadrosauroid) skeletal elements found isolated in other parts of the ODA outcrop (Jipa, 2012). Among the titanosaur remains discovered at ODA (including the ODAN lens) Mocho et al. (2023) has identified two indeterminate caudal vertebral morphotypes, suggesting the possible presence of two different taxa.

Finally, one of the most interesting faunal components at ODAN is represented by multituberculates (Codrea et al., 2012, 2013b); this site yielded the largest amount of multituberculate remains (isolated teeth) known from the entire Transylvanian area (Codrea et al., 2014; Solomon et al., 2022b), a comprehensive sample that allowed the identification and thorough diagnosis of a new, small-sized kogaionid taxon, *Barbatodon oardaensis* (Codrea et al., 2014). The skeletal remains are associated with eggshell fragments referred to Megaloolithidae and ?*Pseudogeckoolithus*, respectively (Codrea et al., 2010a).

Besides the ODAN lens, two other levels from the ODA outcrop proved to be more fossiliferous. Jipa (2012) has reported a vertebrate concentration identified in the middle part of the section (ODAX – Fig. 2a), in a grey-greenish mudstone that yielded turtle shell fragments, a crocodyliform tooth, and eggshell fragments. A more important discovery, coming from about the same stratigraphic level, is represented by a peculiar lens-like (80 x 50 x 20 cm) calcareous mudstone described as an eggshell coquina (ODA-C in Fig. 2a; Vremir, 2010) with a remarkably high (70-80%) content of fragmentary eggshells associated with several quasi-complete eggs as well as with postcranial skeletal remains referable to indeterminate enantiornithine birds (Dyke et al., 2012). These authors interpreted this accumulation as the swept-up remains of an enantiornithin nesting colony deposited in a shallow depression of the floodplain, an accumulation that offers unique insights into enantiornithin nesting behavior (i.e., colonial nesting). Subsequently, Fernández et al. (2019) has shown that besides the enantiornithine eggs and eggshell fragments that make up the bulk of the coquina, other eggshell types (ornithoid, krokolithid, respectively gekkolithid) are also represented in the assemblage, suggesting a mixed nesting association of at least four taxa (including one crocodyliform and one squamate) within the main enantiornithine colony – the earliest known fossil record of such a nesting strategy.

Finally, a fossil accumulation that most probably also originates from the ODA succession (although this is difficult to ascertain due to the *ex-situ* nature of the discovery, within a building site developed on the terrace topping the ODA-ODB cliffs) was reported recently by Solomon et al. (2022a). This accumulation (ODS; tentatively placed in Fig. 2a) has yielded a fossil assemblage that is largely reminiscent of that found in the ODAN lens, with remains of lepisosteid and teleostean fish, indeterminate anurans and squamates, dortokid turtles, crocodyliforms (*Allodaposuchus*, *Doratodon*, ?*Aprosuchus*), as well as indeterminate titanosaurs (see also Mocho et al., 2023) and theropods, associated with gastropods and ostracods. The most outstanding feature of the ODS assemblage is represented by the abundant presence and morphological diversity of seeds and fruits, contrasting with the condition reported in the ODAN lens where charophyte remains are common, but seeds are largely absent, as well as that from a second mammal-bearing diverse microvertebrate assemblage recently reported from the nearby ODB outcrop (ODBL – Codrea et al., 2021; Solomon et al., 2022b) where such plant remains are completely absent. Preservation of these carbonized plant mesofossils is most probably related to the more anoxic sedimentary environment (oxbow lake) reconstructed as the depositional setting of the grey-bluish mudstones sampled at site ODS (Solomon et al., 2022a).

To conclude, the Oarda de Jos locality, and especially the ODA outcrop, is one of the most important, richly fossiliferous localities reported from the uppermost Cretaceous continental Sebeș Formation cropping out in the southwestern corner of the Transylvanian Basin. Its importance is highlighted primarily by the fact that it hosts the type locality (= ODAN lens) of three vertebrate taxa, the small barbatteiid lizard *Oardasaurus glyphis* (Codrea et al., 2017), the large-sized azhdarchid pterosaur *Albadraco tharmisensis* (Solomon et al., 2020), and the small kogaionid multituberculate *Barbatodon oardaensis* (Codrea et al., 2014), as well as the locality of origin of the neotype of the iconic Transylvanian crocodyliform *Allodaposuchus precedens*, the type genus of the European endemic family Allodaposuchidae (Narváez et al., 2020). The importance of this locality is also heightened by its palaeoecological and palaeobiological significance, as it (i) hosts the remnants of the first known enantiornithine nesting colony that also shows the oldest known evidence of mixed nesting strategy (Dyke et al., 2012; Fernández et al., 2019); (ii) documents instances of depositional environments that are otherwise rather rare in the Sebeș Formation (Codrea et al., 2001, 2010a; Vremir et al., 2015); and (iii) records in details the composition of the latest Cretaceous vertebrate assemblages that characterize the middle section of the Sebeș Formation (Vremir et al., 2015; Csiki-Sava et al., 2016). As such, the well-constrained age of this assemblage or further details of the palaeoenvironments represented at Oarda de Jos represent important information that remained largely elusive until now. For example, ever since the establishment of the latest Cretaceous age of these deposits (Codrea et al., 2001), their age remained poorly understood. Codrea et al. (2001), considering that the uppermost Cretaceous continental beds from the Alba Iulia-Sebeș area represent the upper Maastrichtian, implicitly accepted that the Oarda de Jos deposits are also of late (probably late late) Maastrichtian age. Subsequently, they were often reported as belonging generally to the Maastrichtian (e.g., Codrea et al., 2014), an age also supported by the identification of the charophyte taxon *Microchara cristata* in the ODAN lens (Codrea et al., 2013a). Nevertheless, Codrea et al. (2017) gave the age of the ODAN lens as late early Maastrichtian (without further comments or data to support this age assignment) whereas Vremir et al. (2015) suggested a slightly younger, early late Maastrichtian age for the Oarda de Jos successions based on their estimated relative stratigraphic position within the Sebeș Formation succession; finally, Csiki-Sava et al. (2016) placed the Oarda de Jos assemblages into their tier 3 Transylvanian faunal complex assessed to correspond to the late early to early late Maastrichtian time interval.

Unfortunately, recently the beginning of territorial planning activities near/atop of the ODA site led to the almost complete covering of this outcrop with a pile of soil and fragments of allochthonous rocks (Fig. 2c). As such, future palaeontological studies, and especially recovery of new fossil material from this important locality became almost impossible, at least for the near future.

MATERIAL AND METHODS

The sample that yielded the palynological assemblage described in this study was collected in 2015 from a dark grey mudstone bed located in the lowermost part of the ODA outcrop, near the water level (Fig. 2a, b). Approximately 50 g of rock was chemically processed in concentrated HCl (37%) to remove the carbonate particles, which was followed by digestion in concentrated HF (48%) to remove the silicate fraction (Batten, 1999). Denser particles were separated from the organic residue using $ZnCl_2$ with a density of 2.0 g/cm^3. The palynological residue was mounted to a slide with glycerin jelly. Palynomorphs and palynofacies constituents (Figs. 3–6) were photographed using a digital Flexacam C3 camera mounted on a Leica D3000 microscope. The palynological slides are stored in the collection of the Geology Department, "Al. I. Cuza" University of Iași.

Organic geochemistry analysis includes measurements of total organic carbon (TOC), total inorganic carbon (TIC), and total sulfur (TS), as well as the investigations of bitumen extract using gas chromatography–mass spectrometry (GC–MS). These geochemical analyses were performed at the Institute of Earth Science of the University of Silesia in Sosnowiec (Poland).

Palaeoenvironmental evaluation was obtained based on palynofacies constituents (i.e., shape and size of opaque phytoclasts, woody tissues) recovered from the sample, as well as based on the interpretation of geochemical analyses (e.g., cross-plots of phytane/n-C_{18} versus pristane/n-C_{17} components, or TOC content against TS content).

The classification of particulate organic matter (POM) used in this study follows the guidelines of Mendonça Filho et al. (2011) and Aggarwal (2022).

RESULTS

Palynological assemblage

The studied sample yielded a rich and well-preserved terrestrial palynoflora composed of angiosperm and gymnosperm pollen grains, and pteridophyte spores (Table 1). This assemblage includes 62 taxa (22 spores, 9 gymnosperms, and 31 angiosperms), most of these (41 taxa) being also identified in the underlying, somewhat older deposits assigned to the Bozeș Formation at Petreşti (see Ţabără et al., 2022; Bălc et al., 2024); taxa such as *Densoisporites* sp., *Polypodiaceoisporites hojrupensis, Uvaesporites* sp., *Callialasporites dampieri, Pennipollis* cf. *reticulatus* and *Trudopollis hojrupensis* can be listed among those occurring only in the Sebeş Formation. By contrast, the palynological assemblage identified by us from ODA is rather different compared to that reported

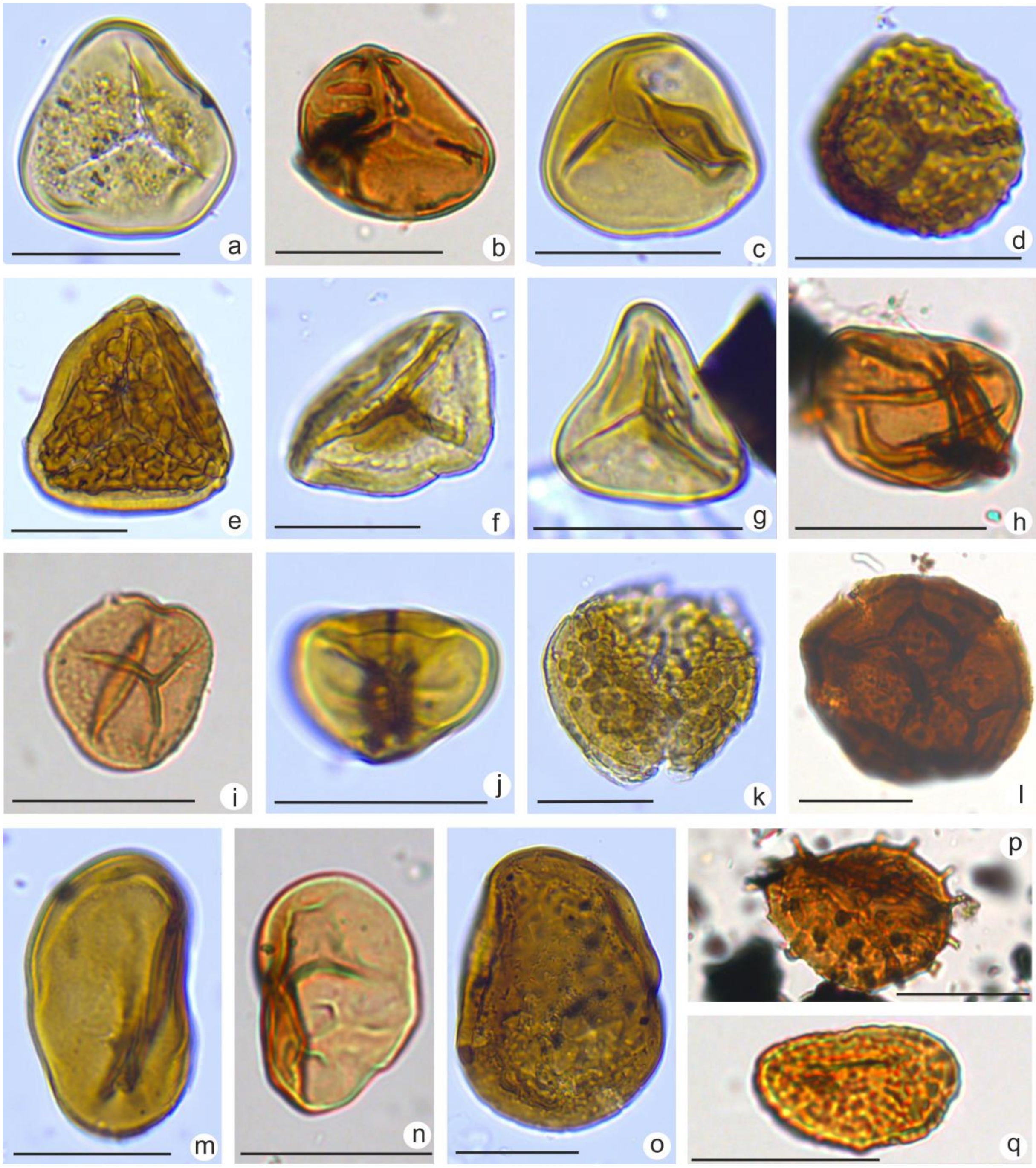

Fig. 3. Terrestrial palynomorphs (cryptogam spores) recovered from the Oarda de Jos sample, uppermost Cretaceous continental Sebeş Formation, (scale bar 30 µm). **a, b.** *Deltoidospora australis*; **c.** *Deltoidospora* sp.; **d.** *Microreticulatisporites uniformis*; **e.** *Polypodiaceoisporites hojrupensis*; **f.** *Densoisporites* sp.; **g.** *Gleicheniidites senonicus*; **h.** *Biretisporites potoniaei*; **i.** *Biretisporites* sp.; **j.** *Triplanosporites microsinuosus*; **k.** *Uvaesporites* sp.; **l.** *Zlivisporites blanensis*; **m.** *Laevigatosporites major*; **n.** *Laevigatosporites ovatus*; **o.** *Laevigatosporites* sp.; **p.** *Neoraistrickia* sp.; **q**. *Polypodiidites secundus.*

by Antonescu (1973) from the basal part of the Sebeş Formation that crops out at Pâclişa (Table 1), as the latter is dominated by *Pseudopapillopollis praesubhercynicus* (40% of the total palynomorphs), whereas this taxon is not recorded at all in the ODA outcrop. We consider that the difference between the two palynological assemblages (ODA and Pâclişa sections) may derive from some different local palaeoenvironmental conditions that existed during the early Maastrichtian in the southwestern corner of the Transylvanian Basin.

Fern spores from the Oarda de Jos outcrop (28% of the total palynomorphs) are dominated by Polypodiaceae (*Polypodiaceoisporites* div. sp.), Cyatheaceae (*Deltoidospora minor, Deltoidospora australis*), Gleicheniaceae (*Gleicheniidites senonicus*), and various other Filicopsids (*Laevigatosporites* div. sp.). Gymnosperm pollen represents a minor component of the Oarda de Jos assemblage (10% of the total

Table 1. Taxonomic list of palynomorphs identified in the Oarda de Jos (ODA) section. * Taxa in common with the Bozeș Formation, Petrești section (Țabără et al., 2022; Bălc et al., 2024); ** Taxa shared with the lower Sebeș Formation, Pâclișa section (Antonescu, 1973).

Taxa	number of specimens		
Pteridophyta			
Baculatisporites sp.	1	*	
Biretisporites potoniaei Delcourt & Sprumont, 1955	1	*	
Biretisporites sp.	1	*	
Deltoidospora minor (Couper, 1953) Pocock, 1970	4	*	
Deltoidospora australis Pocock, 1970	4	*	
Deltoidospora sp.	3	*	
Densoisporites sp.	1		
Echinatisporis sp.	1	*	**
Gleicheniidites senonicus Ross, 1949	4	*	
Gleicheniidites sp.	1	*	
Laevigatosporites ovatus Wilson & Webster, 1946	4	*	
Laevigatosporites major (Cookson, 1947) Krutzsch, 1959	1		
Laevigatosporites sp.	5	*	
Microreticulatisporites uniformis Singh, 1964	1		
Neoraistrickia sp.	1		
Polypodiaceoisporites hojrupensis Kedves, 1980	3		
Polypodiaceoisporites sp.	8	*	
Polypodiidites secundus (Potonié, 1934) Krutzsch, 1963	1		
Punctatisporites sp.	1		
Triplanosporites microsinuosus Pflanzl, 1955	1	*	
Uvaesporites sp.	1		
Zlivisporites blanensis Pacltova, 1961	1	*	
Indeterminable spores (autochthonous)	9		
Gymnospermatophyta			
Araucariacites australis Cookson, 1947	4	*	
Araucariacites sp.	2	*	
Callialasporites dampieri (Balme) Sukh Dev, 1961	3		
Classopollis sp.	4	*	
Cycadopites sp.	2		
Ephedripites sp.	1	*	**
Inaperturopollenites dubius (Potonié & Venitz, 1934) Thomson & Pflug, 1953	1	*	
Inaperturopollenites hiatus (Potonié, 1931) Thomson & Pflug, 1953	1	*	
Inaperturopollenites sp.	3		
Angiospermatophyta			
Aquilapollenites sp.	1		
Bacutricolpites constrictus Pierce, 1961	2	*	
Interporopollenites proporus Weyland and Krieger, 1953	2	*	**

Interporopollenites klausii Kedves, 1980	1	*	
Interpollis sp.	1	*	
Momipites sp.	1		
Monocolpopollenites sp.	1	*	
Myricipites bituitus (Potonié, 1931) Nagy, 1969	3	*	
Myricipites sp.	16	*	
Oculopollis baculatus Pacltová & Krutzsch, 1970	2		
Oculopollis praedicatus (Weyland and Krieger, 1953) emend. Polette and Batten, 2017	2	*	
Oculopollis minoris Krutzsch, 1973	2		
Pennipollis cf. *reticulatus* (Brenner, 1963) Friis et al., 2000	1		
Plicapollis serta Pflug, 1953	2	*	
Suemegipollis triangularis Goczan, 1964	5	*	**
Sparganiaceaepollenites sp.	1		
Subtriporopollenites anulatus Pflug & Thomson, 1953	3	*	
Subtriporopollenites constans Pflug, 1953	12	*	
Subtriporopollenites sp.	3	*	
Tricolpites cf. *sagax* Norris, 1967	4		
Tricolpites amplifissus (Laing, 1975) Ward, 1986	2		
Tricolpites sp.	8	*	**
Tricolporopollenites sp.	1	*	
Triporopollenites robustus subsp. *robustus* Pflug, 1953	1		**
Trudopollis nonperfectus (Pflug in Thomson & Pflug, 1953) Pflug, 1953	18	*	
Trudopollis hojrupensis Kedves, 1979	1		
Trudopollis granulosus Kedves & Hemgreen, 1980	2	*	
Trudopollis minimus Góczán, 1964	7	*	
Trudopollis fossulotrudens (Pflug in Thomson & Pflug, 1953) Pflug, 1953	3	*	
Trudopollis primigenius Krutzsch, 1973	1	*	
Trudopollis sp.	18	*	**

palynomorphs), and is mainly represented by the Araucariaceae (*Araucariacites australis*), Cheirolepidiaceae (*Classopollis* sp.) and Taxodiaceae (*Inaperturopollenites* div. sp.). Angiosperm pollen reaches 62% of the total palynomorph count and is mostly represented by specimens assigned to the Normapolles group (*Trudopollis* div. sp., *Oculopollis* div. sp., *Plicapollis serta*), alongside Myricaceae (*Myricipites* div. sp.) and Juglandaceae (*Subtriporopollenites anulatus, Subtriporopollenites constans*).

Our palynological assemblage includes a series of taxa first mentioned from the Upper Cretaceous of Romania, i.e., *Uvaesporites* sp. (among fern spores), *Callialasporites dampieri* (Araucariaceae), and angiosperm pollen such as *Aquilapollenites* sp., *Tricolpites amplifissus* and *Trudopollis hojrupensis*. Among these taxa, the unexpected occurrence of the *Aquilapollenites* pollen (Fig. 5e) indicates a northern floristic influence, as during the Late Cretaceous, the Aquilapollenites Floristic Province had a northern high-latitude distribution, including Greenland, North America, and northern and eastern Asia (Vajda and Bercovici, 2014).

Palynofacies composition

In the studied sample, the POM observed under the microscope is moderately well preserved, its origin being exclusively terrestrial. Three main constituents of POM were recognized, namely: opaque phytoclasts (~90 %), commonly large in size (50–100 μm) and corroded (Fig. 6c), and sometimes lath-shaped (Fig. 6a, b); translucent

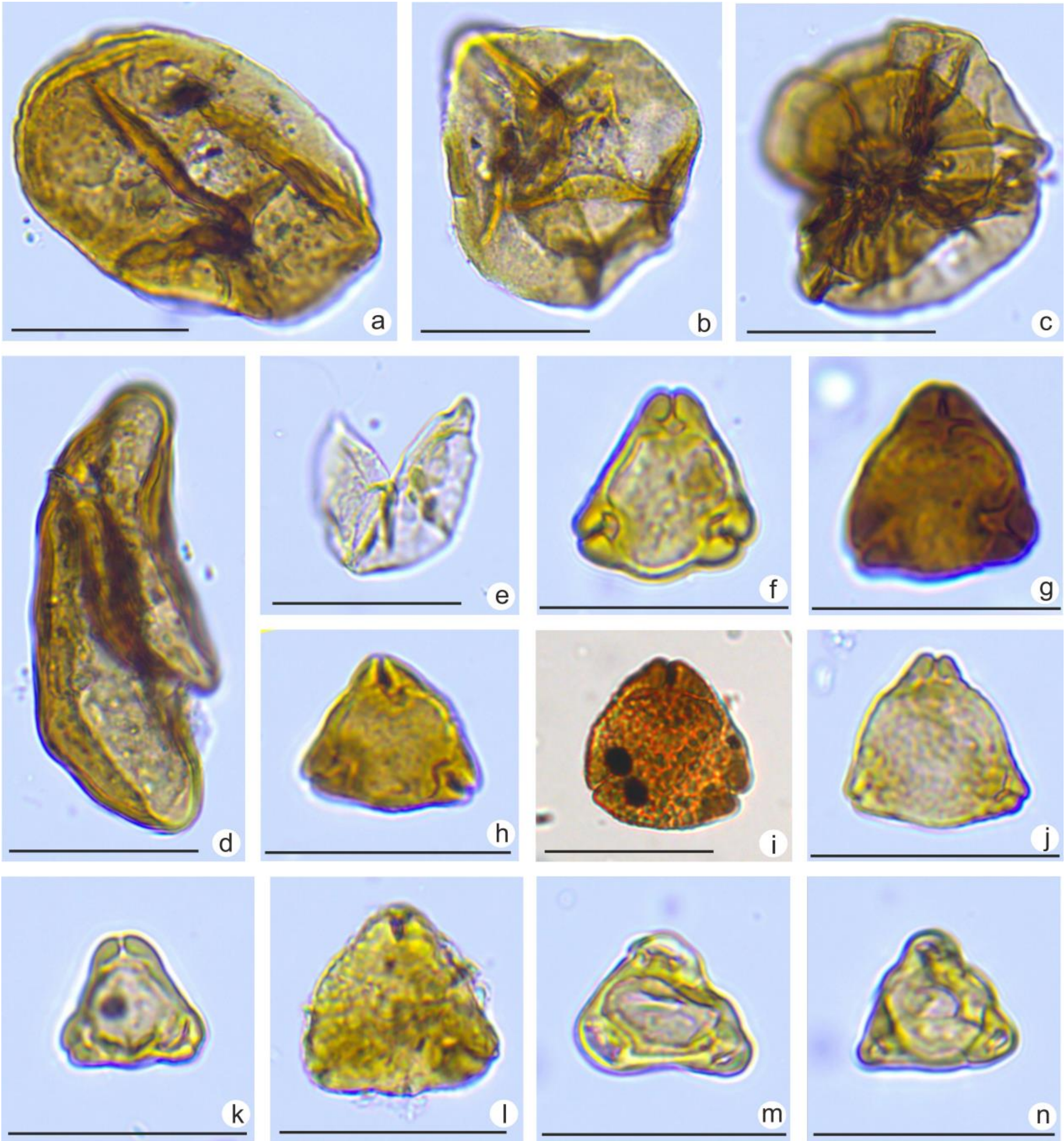

Fig. 4. Gymnosperm and early angiosperm pollen grains recorded in the Oarda de Jos sample, uppermost Cretaceous continental Sebeș Formation (scale bar 30 µm). **a, b.** *Araucariacites australis*; **c.** *Callialasporites dampieri*; **d.** *Cycadopites* sp.; **e.** *Inaperturopollenites* sp.; **f, g.** *Trudopollis nonperfectus*; **h.** *Trudopollis hojrupensis*; **i.** *Trudopollis fossulotrudens*; **j.** *Trudopollis granulosus*; **k.** *Trudopollis minimus*; **l.** *Trudopollis* sp.; **m.** *Interporopollenites proporus*; **n.** *Interporopollenites klausii.*

phytoclasts that are subdominant components (~8–9%) consisting of biodegraded brown woody tissues (Fig. 6d) and small cuticle fragments; and continental palynomorphs that are rare (1–2 % of the total POM), represented mainly by angiosperm pollen and fern spores.

Geochemical data

The results of geochemical analyses (TOC content and GC–MS) are shown in Table 2. The TOC content of the analyzed Sebeș Formation sediment from Oarda de Jos is 0.812%, ranking this sample as a rock with a fair kerogen content (as defined by Peters and Cassa, 1994).

The chromatogram of the organic matter recovered from the rock (Fig. 7a) shows a high concentration of short-chain n-alkanes (n-C_{16} to n-C_{18}), molecular compounds that may derive from freshwater green algae such as *Scenedesmus quadricauda* (Love et al., 2005). On the other hand, long-chain n-alkanes (i.e., n-C_{22} to n-C_{31}) which are considered to be derived from terrestrial plants or emergent macrophytes (Caro Gonzales et al., 2020), occur in a smaller quantity in the studied sample. The carbon preference index (CPI) far exceeds the value of 1 (Table 2), suggesting a freshwater and lacustrine environment (Caro Gonzales et al., 2020), as well as a low thermal maturity of the organic matter included in the

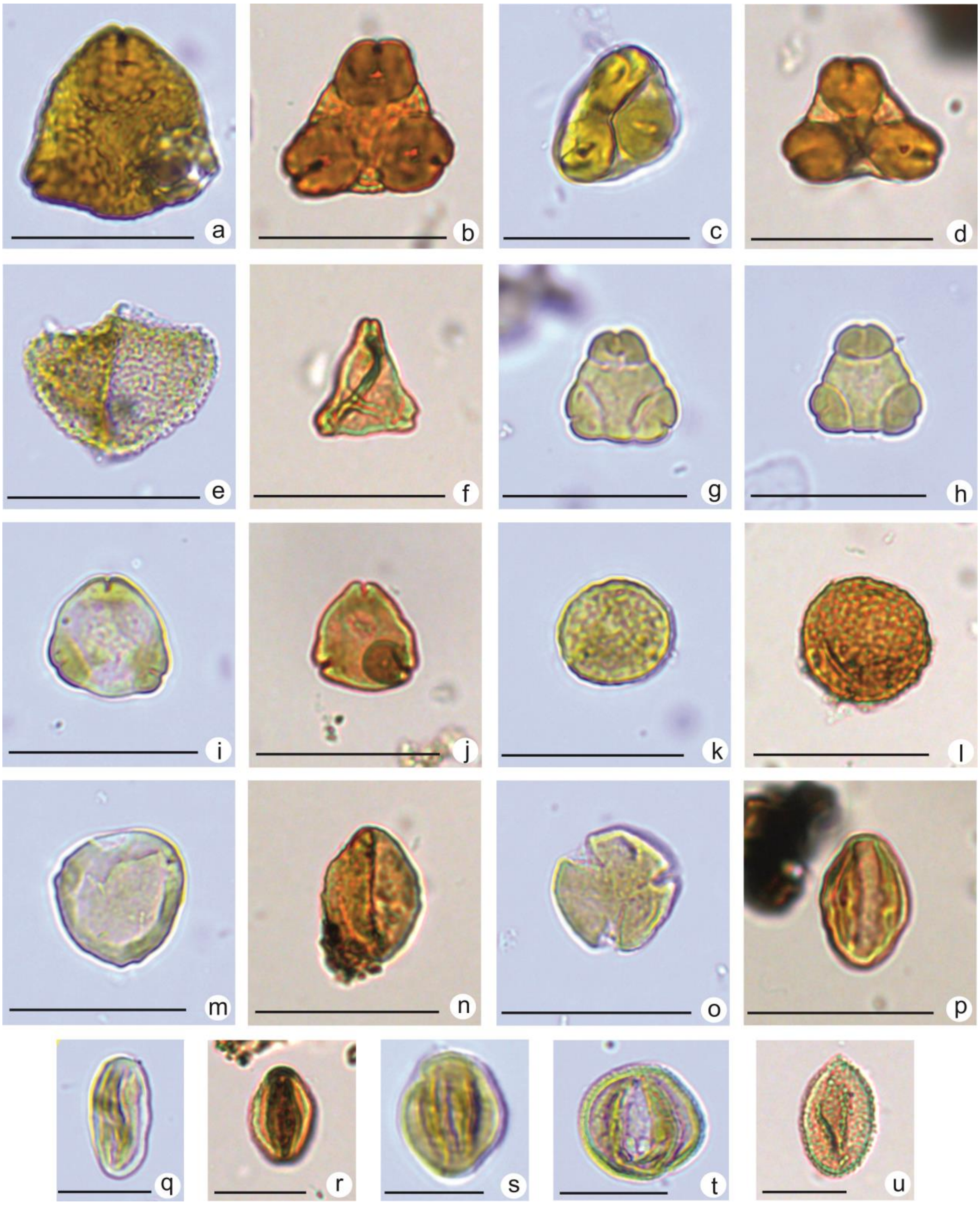

Fig. 5. Early angiosperm pollen taxa identified in the Oarda de Jos sample, uppermost Cretaceous continental Sebeș Formation (a–p: scale bar 30 µm; q–u: scale bar 15 µm). **a.** *Oculopollis praedicatus*; **b.** *Oculopollis baculatus*; **c, d.** *Oculopollis minoris*; **e.** *Aquilapollenites* sp.; **f.** *Plicapollis serta*; **g, h.** *Suemegipollis triangularis*; **i, j.** *Myricipites* sp.; **k, l.** *Subtriporopollenites constans*; m. *Subtriporopollenites anulatus*; n. *Monocolpopollenites* sp.; **o.** *Tricolpites* sp.; **p.** *Tricolporopollenites* sp.; **q, r.** *Tricolpites* sp.; **s.** *Bacutricolpites constrictus*; **t.** *Tricolpites amplifissus*; **u.** *Sparganiaceaepollenites* sp.

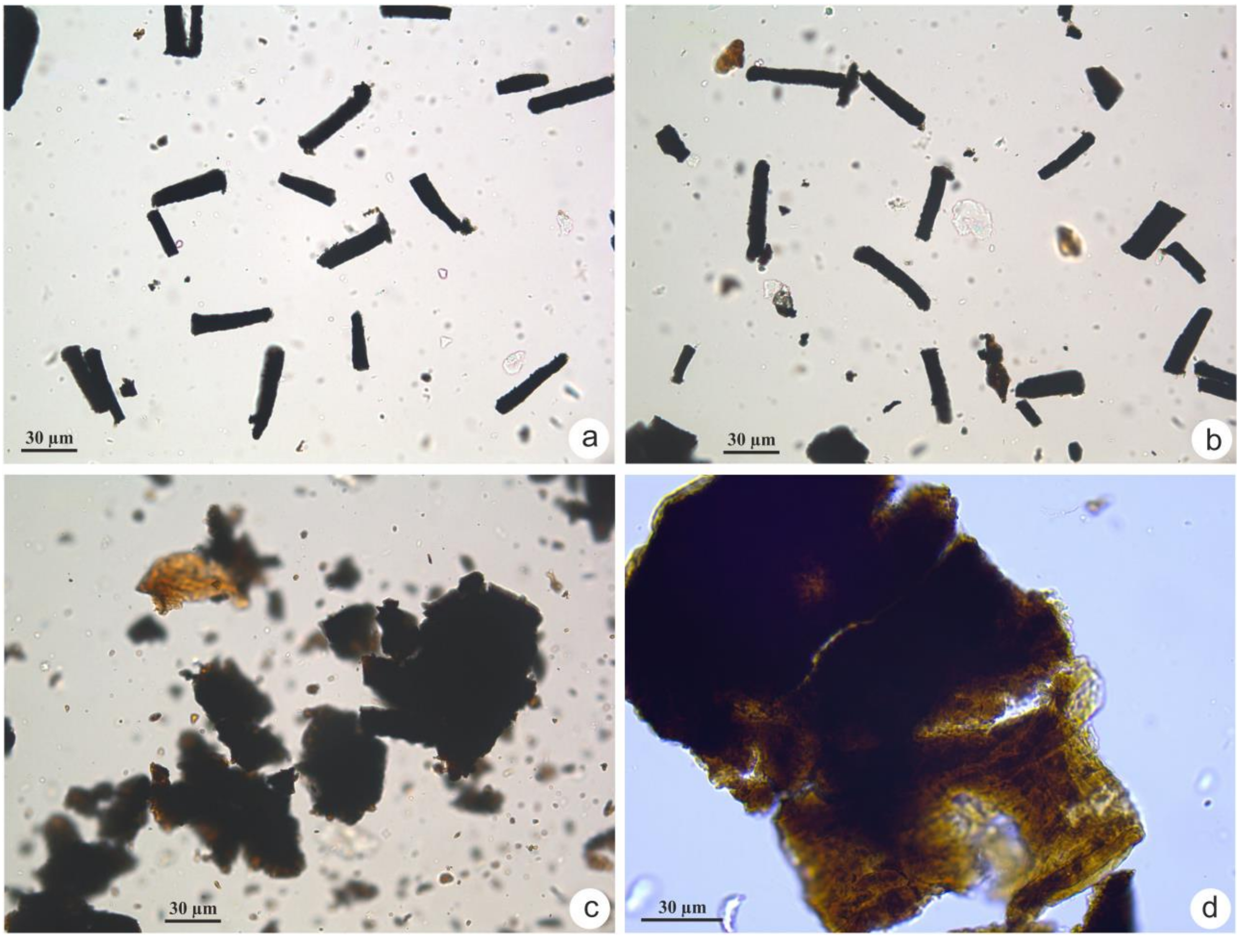

Fig. 6. Photomicrographs of palynofacies components derived from terrestrial plants in the Oarda de Jos sample, uppermost Cretaceous Sebeș Formation. **a, b.** lath-shaped opaque phytoclasts; **c.** large corroded opaque phytoclasts, mixed with translucent phytoclasts; **d.** brown woody tissue with a jellified structure.

Table 2. The geochemical analysis (TOC, TS, n-alkanes and aromatics) of the Oarda de Jos sample.

Sample	TC (%)	TIC (%)	TOC (%)	TS (%)	*n*-Alkanes and acyclic isoprenoids				aromatic hydrocarbon indices		
					Pr/*n*-C_{17}	Ph/*n*-C_{18}	Pr/Ph	CPI (C_{24-34})	MPI-1	MPI-3	MP/P
Oarda de Jos (ODA), Sebeș Form.	1.033	0.221	0.812	0.572	0.57	0.46	1.40	3.51	0.53	1.90	0.66

sampled rocks (Abeed et al., 2011). High CPI values are also related to the increased contribution of land plants and/or of the freshwater chlorophycean algae *Botryococcus braunii* (Bechtel et al., 2012).

The Pr/Ph ratio is one of the most commonly used geochemical parameters and is considered a good indicator of the redox conditions in the original depositional environment (Tissot and Welte, 1984). Organic matter derived mainly from terrestrial plants would be expected to contain a high Pr/Ph ratio of > 3.0 (oxidizing conditions), while low values of the same ratio (< 0.6) indicate anoxic conditions.

The Pr/Ph ratio for the sample here analyzed from the Sebeș Formation deposits from Oarda de Jos has a value of 1.4 (Table 2), suggesting intermediate redox conditions (suboxic environment; Peters and Moldowan, 1993).

DISCUSSIONS

Palynostratigraphy

Certain taxa identified in the ODA sample analyzed here (Fig. 8) provide important information that allows constraining the age of the identified palynoflora.

From the fern spore and angiosperm taxa recorded in the sample, some have previous records that make them biostratigraphically useful. The taxon *Polypodiaceoisporites hojrupensis* (Fig. 3e) has its first occurrence across the Campanian–Maastrichtian boundary in the Tercis les Bains section (France; Siegl-Farkas, 2001; Méon et al., 2001); formerly, it was considered a characteristic taxon for the upper Maastrichtian of Hungary (Góczan and Siegl-Farkas, 1990), and was also reported in younger deposits such as those of Danian age in Denmark (Kedves, 1980). According to our currently available personal observations derived from the survey of uppermost Cretaceous beds of the Haţeg Basin area, it seems that *Polypodiaceoisporites hojrupensis* also occurs there at Vălioara (in the northwestern part of the basin), in continental deposits assigned to the lower Maastrichtian (Botfalvai et al., 2021).

Another useful biostratigraphic marker is *Oculopollis praedicatus* from the Normapolles group (Fig. 5a). This taxon is generally considered to indicate a Santonian–Campanian age (Polette and Batten, 2017), occurring in Upper Campanian deposits in Ukraine (Shevchuk, 2018) and in the southwestern Transylvanian Basin (Ţabără et al., 2022; Bălc et al., 2024), but apparently persists up into the early Maastrichtian in the Haţeg area (Antonescu et al., 1983; Botfalvai et al., 2021) and in the Eastern Carpathians (Ţabără et al., 2023). Rare occurrences of the *Oculopollis* genus have been recorded in lower to mid-Maastrichtian deposits from Nălaţ-Vad, Toteşti and Vălioara from Haţeg Basin (Van Itterbeeck et al., 2005; Csiki et al., 2008), but are absent from the upper Maastrichtian deposits of the Romanian Eastern Carpathians (Ţabără and Slimani, 2017; Ţabără et al., 2017) and the Skale zone of the Ukrainian Carpathians (Portnyagina, 1981).

The taxon *Trudopollis granulosus* (Fig. 4j) was often considered to indicate the late Campanian–Maastrichtian time interval (https://paleobotany.ru/); it is cited both from the uppermost Campanian of the Tercis les Bains section (Antonescu and Odin, 2001) and from the top of the marine Bozeş Formation at Petrești, southwestern Transylvanian Basin, in deposits assigned to the Upper Campanian (Bălc et al., 2024), and now we identify it from the ODA deposits that are clearly overlying stratigraphically the Bozeş beds from Petrești (e.g., Vremir et al., 2015).

The palynological assemblage recovered from the ODA section also contains certain taxa such as fern spores (i.e., *Microreticulatisporites uniformis*) and gymnosperm pollen (*Callialasporites dampieri*) that are frequently reported from the Lower Cretaceous (Juhász, 1975; Schrank, 2017; Mansour et al., 2023; https://paleobotany.ru/), but which appear to have survived until the Santonian–Campanian in Canada, England and Poland (Braman, 2001; Jarvis et al., 2023) and seems to reach the Maastrichtian in the Oarda de Jos area.

The diversity and high frequency (~24% of the total palynomorphs) of *Trudopollis* pollen identified in the Oarda de Jos assemblage would support an early Maastrichtian age for the hosting deposits. According to the stratigraphic distribution of this taxon as recorded in nearby areas such as the Haţeg Basin, the southwestern Transylvanian Basin (Petrești section), and the Eastern Carpathians, this type of pollen has apparently proliferated on the different emergent landmasses that existed in the Carpathian areas during the Campanian and the early Maastrichtian (Ţabără et al., 2023), but became very rare afterwards, around the early/late Maastrichtian boundary, before disappearing entirely from the same area during the late Maastrichtian.

In summary, the known stratigraphic distributions of the taxa listed above, but most importantly the pattern of distribution presented by *Trudopollis* in the circum-Transylvanian areas, suggest an early Maastrichtian age for the analyzed deposits at Oarda de Jos. Moreover, given the stratigraphic position of the ODA section well above the Campanian/Maastrichtian boundary that should be located in the more southerly Petrești section (Vremir et al., 2014, 2015; Bălc et al., 2024), this age assessment can be probably further refined to the later part of the early Maastrichtian. Accordingly, our results support the assessment provided by Codrea et al. (2017) for the age of the ODAN lens (and, thus, for the ODA outcrop overall, considering the reduced stratigraphic thickness of the exposed succession – about 17 m; Fig. 2a), of late early Maastrichtian, while being somewhat younger that those suggested by Vremir et al. (2015) and Codrea et al. (2001), respectively. Finally, it is worth noting that our new age constraints are also concordant with the biochronologic tier attributed by Csiki-Sava et al. (2016) to the ODA vertebrate assemblages based on their assumed relative stratigraphic position.

Palaeoenvironmental reconstruction

The palynofacies assemblage identified in the studied ODA sample provides further important insights into the former depositional conditions, as the various components of kerogen show a well-defined trend useful in palaeoenvironmental assessments (Tyson, 1995; Aggarwal, 2022). The high relative abundance of woody tissues and large cuticles, combined with the presence of lath-shaped opaque phytoclasts and the exclusive occurrence of terrestrial palynomorphs (spores and pollen), is often used to indicate a freshwater environment with low energy setting within the proximal part of a fluvial/lacustrine system, as well as a short-term transport of the vegetal material (Boulter, 1994; Aggarwal et al., 2019; Radmacher et al., 2020; Aggarwal, 2022). The palynofacies of the lower Maastrichtian deposits from Oarda de Jos, characterized precisely by the dominance of large opaque phytoclasts, sometimes of

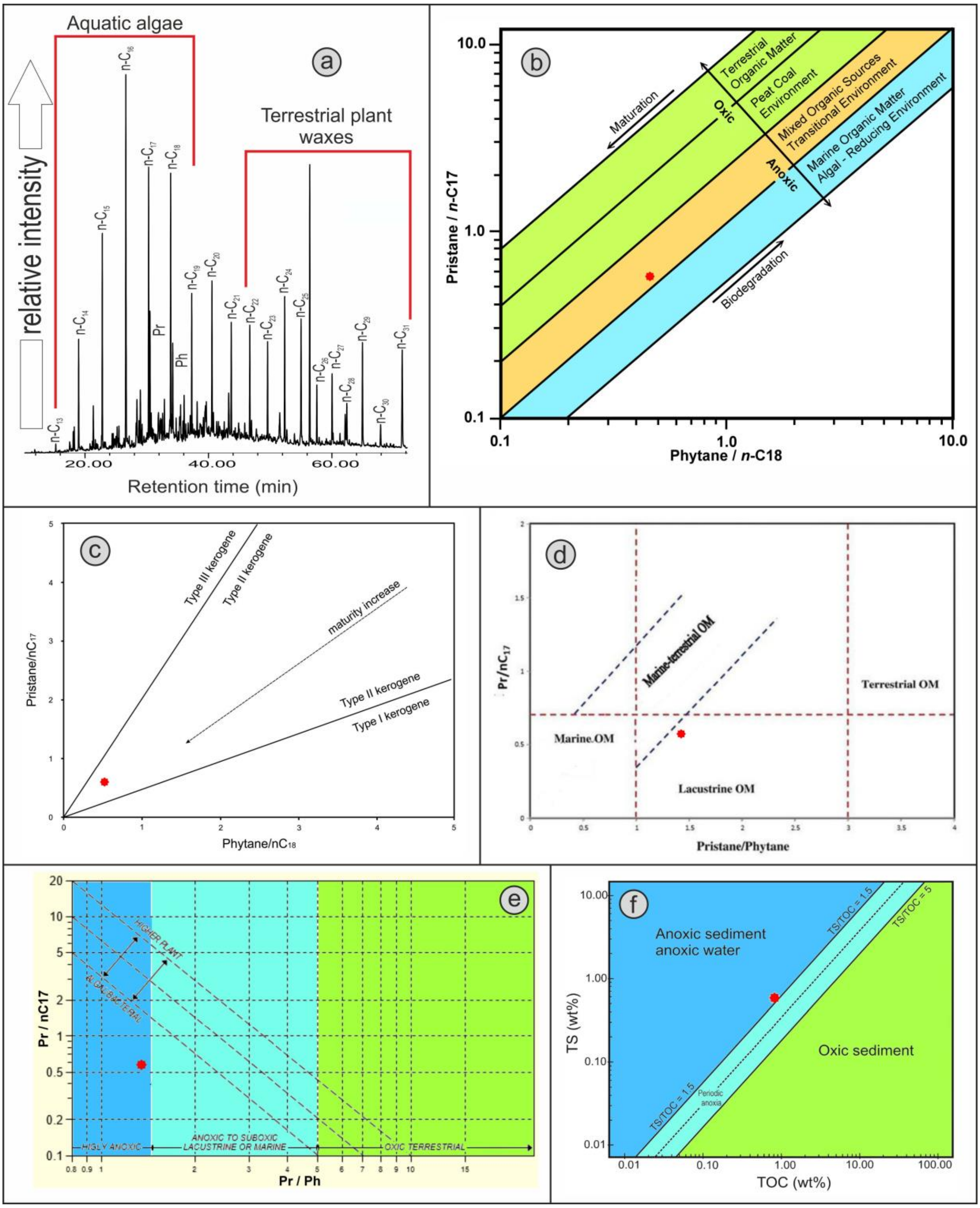

Fig. 7. Gas chromatogram–mass spectrometry spectra from the Oarda de Jos sample, uppermost Cretaceous continental Sebeș Formation (**a**), and diverse cross-plots: **b**, **c.** - phytane/*n*-C_{18} versus pristane/*n*-C_{17} (b - after Shanmugam,1985; c - after Dziadzio and Matyasik, 2021), **d**, **e.** - Pr/Ph versus Pr/ *n*-C_{17} (d - after Yelwa et al., 2022; e. - after Zahra et al., 2015), **f.** - TOC versus TS (after Pontes et al., 2021), indicating the type of organic matter and depositional environment.

lath-shaped forms, mixed with translucent brown phytoclasts, and with exclusively terrestrial palynomorphs, is thus clearly suggestive of a quiet-water fluvial/lacustrine environment, thus offering independent support for a similar interpretation of the sampled bed based on its sedimentological characteristics, as well as of a short-distance transport of these organic components. Therefore, our interpretation largely agrees with the previous palaeoenvironmental assessments provided by Codrea et al. (2001, 2010a, 2013a, 2017; see also Jipa, 2012; Trif & Codrea, 2021) for the ODA section, while also providing useful information that allows further refinement of these assessments.

Organic biomarkers are a valuable complement to palynofacies studies because their calibration using modern examples provides a means for detailed palaeoenvironmental reconstruction. Our geochemical data (especially those concerning the n-alkanes which are

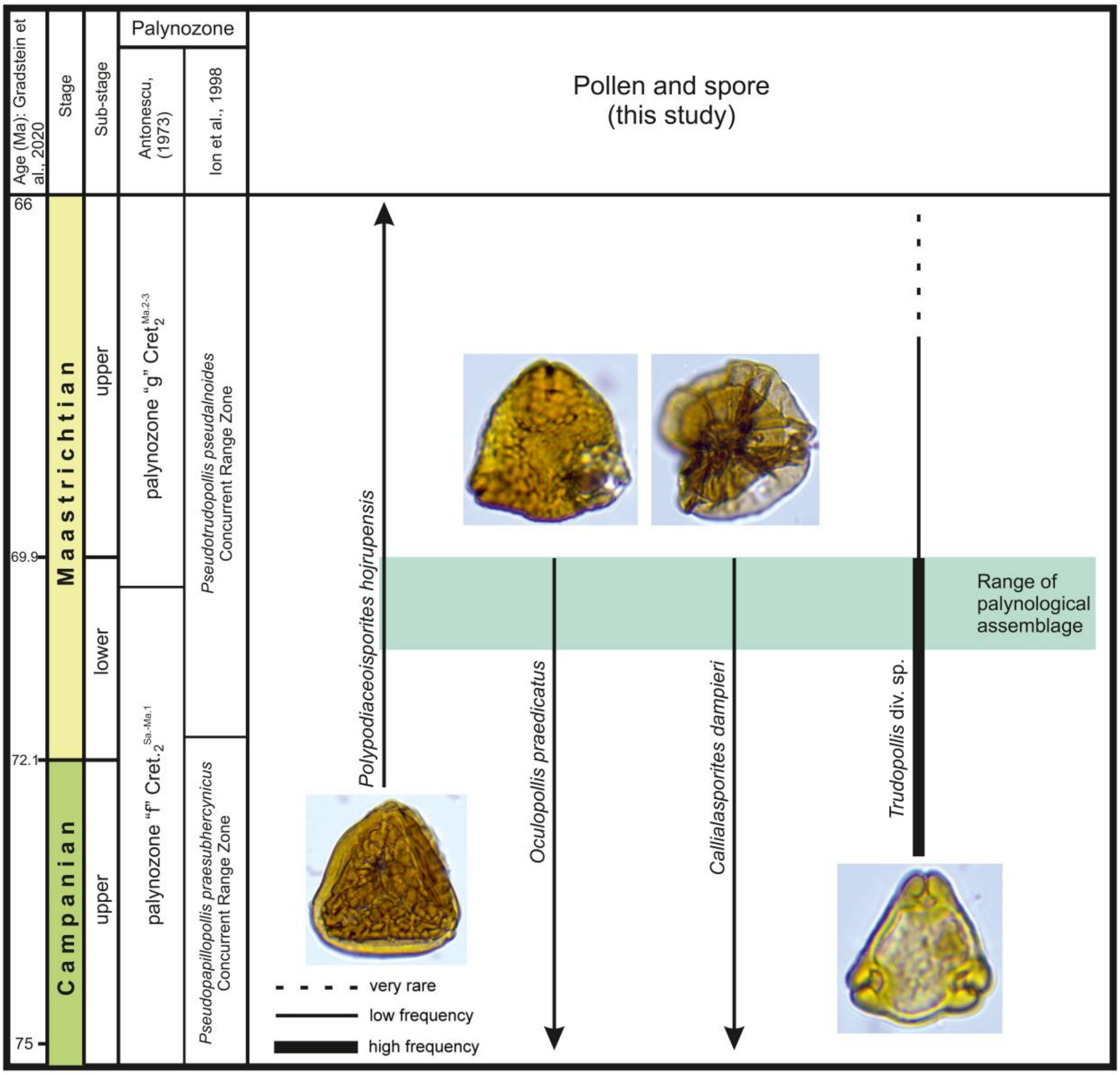

Fig. 8. Local schemes and ranges of selected pollen and spore taxa recovered in the Oarda de Jos section.

"molecular fossils" that preserve the original carbon structure from former living organisms; Shalaby et al., 2020) clearly support that the deposition of the studied sediments from Oarda de Jos took place in a lacustrine setting (Fig. 7d, e), under anoxic (Fig. 7e, f) to suboxic conditions according to the Pr/Ph ratio of 1.4 (Yandoka et al., 2015) – these inferences are in good accordance with indications derived from the general lithofacial characteristics of the sampled deposit (a dark grey mudstone). The Pr/n-C_{17} versus Ph/n-C_{18} ratios also reveal a mixed kerogen type II (Fig. 7b, c), including both continental/terrestrial and aquatic organic matter, the latter most likely of lacustrine origin (Fig. 7d). Furthermore, the identified biomarkers are mainly represented by short-chain n-alkanes (n-C_{13} to n-C_{20}; Fig. 7a) that are usually considered to originate from an autochthonous algal/bacterial organic matter (Kostova et al., 2022), with a predominance of the n-C_{16} to n-C_{18} n-alkanes (Fig. 7a) that may derive from taxa such as the freshwater colonial green algae *Scenedesmus* (Love et al., 2005), a taxon that was already identified in Cretaceous deposits (Willard and Ruppert, 2023). However, freshwater algae such as *Scenedesmus* or *Botryococcus* have not been identified in our palynological assemblage from Oarda de Jos, as it is well known that biodegradation acts more quickly on aquatic-sourced organic matter (phytoplankton and bacteria) than on terrestrially sourced organic matter (lignin and cellulose) of vascular plants (Valdon et al., 2023). Therefore, the aquatic organic component remained preserved only as a "geochemical signature" within the studied rocks and can be revealed only by geochemical analysis. The CPI value of 3.51 suggests a low thermal maturity of the kerogen recovered from the studied sample (Abeed et al., 2011). Remarkably, although the ODA succession was cited previously as exhibiting examples of widespread lacustrine sedimentation within the Sebeș Formation (e.g., Codrea et al., 2001, 2010a), most of the specifically discussed lithons suggesting stagnant-water depositional environments (e.g., ODAN lens, ODS ex-situ hosting sediment, ODAX level, eggshell coquina limestone lens; Codrea et al., 2010a, b, 2013a, 2017; Dyke et al., 2012; Jipa, 2012; Trif & Codrea, 2021; Solomon et al., 2022a) were identified as temporarily active abandoned channel fills, small ponds or oxbow lakes, which are all characterized by spatially restricted geometries, or else generally as poorly drained floodplain deposits. As noted above (Geological setting), the particular spatial development and lithofacies of the palynologically sampled bed from the basal part of the ODA succession was already suggestive of a more permanent standing water body. Interpretation of the geochemical markers discussed previously appears to offer independent support for the identification of such a more permanent lacustrine depositional setting with suboxic to anoxic redox regime both in the water column itself as well as within the bottom sediments, and characterized by the development of a rich algal community that is usually suggestive of nutrient-rich conditions.

On the other hand, despite the overall dominance of the lacustrine organic matter as suggested by organic geochemistry, the analyzed ODA palynological assemblage is dominated by the angiosperm pollen *Trudopollis* spp. belonging to the Normapolles group, this taxon reaching ~24% of the total palynomorphs. According to Friis et al. (2011) and Daly and Jolley (2015) this type of Normapolles pollen comes from parent plants such as *Manningia* that preferred higher-altitude areas and cooler-wetter conditions; the same palaeoenvironmental conditions are also suggested by the presence of the *Araucariacites* gymnosperm pollen (Bowman et al., 2014), another moderately common pollen type from the assemblage. Together, these occurrences would indicate the presence of such higher-altitude areas in the vicinity of the ODA depositional area during the later part of the early Maastrichtian. Meanwhile, other palynomorphs identified at ODA such as hydrophytic fern spores (*Deltoidospora*, *Polypodiaceoisporites* and *Gleicheniidites*), as well as Myricaceae (*Myricipites* div. sp.) and *Sparganium* pollen, indicate lowland areas occupied by various plant communities that grew along river banks or around lakes; these are probably more suggestive of the composition of the vegetation that covered the immediate proximity of the depositional environment reconstructed here for the palynologically sampled bed from Oarda de Jos.

CONCLUSIONS

The Sebeș Formation deposits outcropping near Oarda de Jos were investigated using palynological and palynofacies analyses, as well as organic geochemistry characteristics (TOC content and GC–MS analyses).

Our survey represents only the second report of a palynological assemblage from the uppermost Cretaceous continental Sebeș Formation (acquired after a lengthy gap of 50 years), and the first such investigation concerning the middle-upper part of this fossiliferous unit. The significance of our study is further augmented by the fact that Oarda de Jos is one of the most important vertebrate-bearing localities from the Sebeș Formation, including it being the (neo)type locality of several taxa endemic to the latest Cretaceous Hațeg Island, including here a lizard, a crocodyliform, a pterosaur, and a multituberculate. The main conclusions of our research can be summarized as follows:

- age-diagnostic non-marine palynological markers recovered from Oarda de Jos, such as *Polypodiaceoisporites hojrupensis*, *Oculopollis praedicatus* and *Trudopollis granulosus*, support an early (possibly late early) Maastrichtian age for these deposits – somewhat older than considered previously in several publications. This age assessment is also supported by the high frequency of *Trudopollis* pollen identified in the studied outcrop, as this taxon is known to have proliferated in the Carpathian areas during the Campanian and the early Maastrichtian, but declined severely towards the late Maastrichtian.
- the palynofacies analysis revealed an organic matter assemblage made up of phytoclasts and palynomorphs of exclusively terrestrial origin, and deposited in a quiet, shallow fluvial/lacustrine environment. Various other parameters such as CPI, Pr/Ph ratio, and TOC vs. TS content show that the organic matter recovered from the sampled bed has a low thermal maturity and was deposited under anoxic to partially suboxic conditions within a lacustrine setting, such a palaeoenvironment providing the necessary conditions for the good degree of preservation of the palynomorphs described and interpreted in this study. This interpretation is also supported by organic biomarkers, i.e., the high values of the n-alkanes $n\text{-}C_{16}$ to $n\text{-}C_{18}$, which derive most probably from freshwater colonial green algae such as *Scenedesmus* that were thriving in this stagnant and nutrient-rich water body.
- the palynological assemblage itself is dominated by Normapolles pollen, which derives from vegetation that preferred mainly higher-altitude areas and cooler-wetter conditions of the Hațeg Archipelago, suggesting that such areas were present in the neighborhood of the reconstructed standing-water depositional environments from the Oarda de Jos alluvial plain. However, lowland-specific plant communities that grew along river banks or around lake shores are also well represented in the local palynological assemblage, indicating the type of vegetation that existed in the immediate proximity of the algae-infested lakes.

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