



The palynology and palynofacies of the Miocene deposits from the Subcarpathian Nappe (Ciritei Quarry, Eastern Carpathians)

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Abstract

The present study focuses on the palynological assemblage and palynofacies of the Upper Burdigalian – Lower Badenian deposits from the Subcarpathian Nappe. The assemblage of aquatic microfossils indicates an inner neritic setting with normal water salinity, while the continental vegetation consists of taxa originating from swampy areas (*Taxodium*, *Myrica*, palms), hilly areas of low and medium altitude (*Quercus*, *Fagus*, *Carya* a.o.), and high altitude areas populated by various gymnosperms. The palynofacies of these deposits is characterized by the predominance of continental phytoclasts (coaly opaque particles and translucent fragments), indicating deltaic or lagoon environments.

Keywords: palynology, palynofacies, Lower – Middle Miocene, Subcarpathian Nappe.

Introduction

The Subcarpathian Nappe represents the outermost unit of the Moldavids from the Eastern Carpathians, being composed, mostly, of Lower and Middle Miocene deposits developed in molassic and/or schlier lithofacies (Săndulescu, 1984).

From a structural point of view, the Subcarpathian Nappe is separated into three tectonic subunits (digitations), namely (from west to east): the Măgurești-Perchiu digitation, the Pietricica digitation, and the Valea Mare digitation (Săndulescu et al., 1980; Săndulescu,

1984). The formation of the Subcarpathian Nappe, as well as that of the folded formations within it, took place during the Moldavian tectogenesis (intra-Sarmatian; Dumitrescu and Săndulescu, 1968).

Geological setting

The geological formations included in the Pietricica digitation (Subcarpathian Nappe) were deposited within the Eocene – Badenian range (Grasu et al., 1999), and, in the study area, they are in direct westerly contact with the Vrancea Nappe (Fig. 1A).

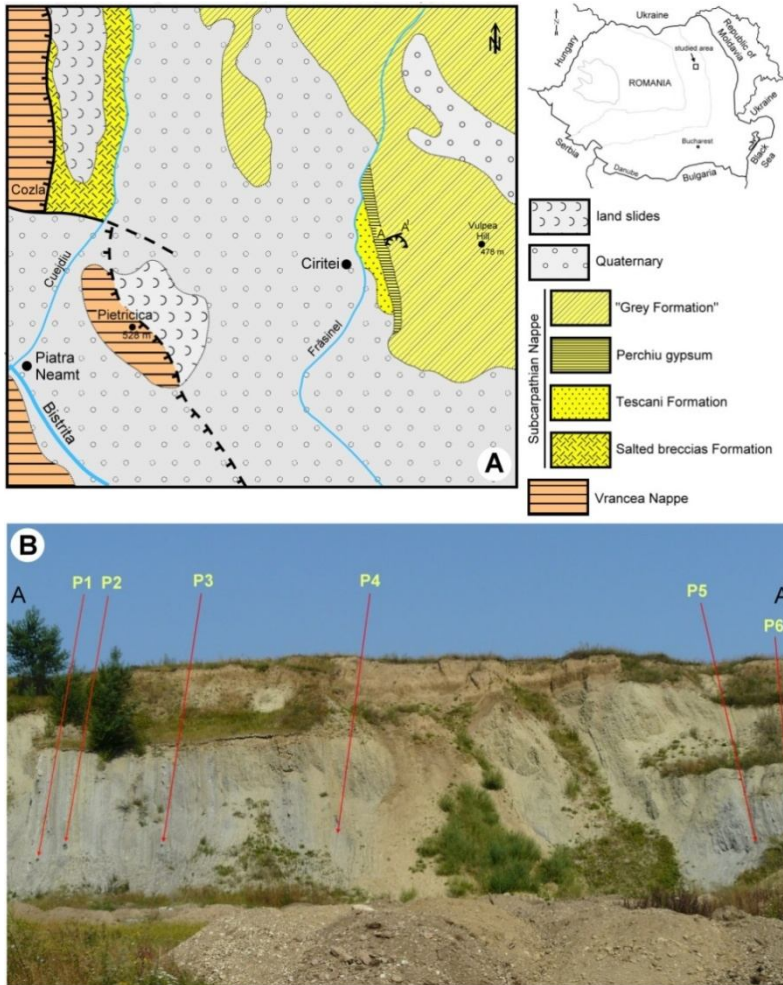


Fig. 1 A – Geological sketch map of the Subcarpathian Nappe from the Ciritei Quarry area – Piatra Neamț (after the geological map 1:50000, Piatra Neamț sheet); B – The “Grey Formation” from the Ciritei Quarry, with location of the samples analyzed. The position of the outcrop is illustrated in Fig. 1A (the A-A' section).

The oldest sedimentary deposits are assigned to the Eocene (the Bisericani Formation) and the Oligocene (Lower melilites and bituminous marls), these formations being similar to those of the Vrancea Nappe. Over this, are disposed in the discontinuity of the sedimentation the Pietricica Conglomerates, represented by massive conglomerate

with lithoclasts of paleozoic “Green Schists” (Dobrudjan type), Jurassic and Eocene limestone, and quartzites (Mărușeanu, 1985; Grasu et al., 1999). The thickness of these conglomerates ranges between 300 and 800 m, as the detrital material comes from foreland sources, its transportation having been carried out by a paleoriver in great alluvial fans, and

their age is Burdigalian (Grasu et al., 1999; Mărunțeanu, 1999). In the continuity of sedimentation, over the Pietricica Conglomerates, is disposed Tescani Formation with Middle and Upper Burdigalian age (Mărunțeanu, 1999). Lithologically, in the lower part of this formation, coarser turbidite (microconglomerates, massive coarser sandstones) alternating with lutite have been identified, while, in the upper part, gray (sometimes reddish) clays or marls are prevalent (Grasu et al., 1999). The next lithostratigraphic units is the Grey Schlier Formation (sensu Mărunțeanu, 1999), which displays great lithologic variation (clays, marls, sandstone, gypsum in the form of lenses or beds, tuffs). Within this succession, certain lithostratigraphic marker levels were distinguished (Olteanu, 1953; Grasu et al., 1999), namely: at the bottom, the Perchiu Gypsum and the Valea Calului Marls (represented by reddish clays) are found, while, in the upper part, the Stufu Gypsum is present. Between the Perchiu Gypsum and the Valea Calului Marls, a sedimentary succession composed of gray marls alternating with sandstones, called the “Grey Formation” (Grasu et al., 1999), is located. The age of the Grey Schlier Formation is Late Burdigalian – Lower Badenian (Mărunțeanu, 1999; Grasu et al., 1999). The sedimentological studies

carried out on this formation suggest the alternation of continental and marine sedimentations, in a seashore environment.

Over these deposits, the Badenian sedimentary sequence is represented by Răchitașu Formation, containing glauconitic sandstone with *Lithothamnium*, marls with *Globigerina*, dacitic tuffs and tuffites, followed, in the upper part, by an Evaporitic Level.

The aim of the present paper is to analyze the vegetation and paleoenvironment of the Lower – Middle Miocene limit from the Subcarpathian Nappe, and to establish a palynofacies based on the rocks analyzed.

Materials and methods

1. Samples location and outcrop description

From a lithostratigraphic point of view, the Ciritei Quarry has revealed the upper part of the Tescani Formation, overlain by the Perchiu Gypsum, with a thickness of about 75 m. The evaporitic deposits are followed by the “Grey Formation,” which crops out about 80 m and consists of an alternation of gray clay with sandstone intercalations displaying wave undulations (Fig. 1B; Fig. 2). The position of this strata is approximately vertical. The samples analyzed in the present paper were collected from these clays (Fig. 1B).



Fig. 2 Alternations of grey clays and sandstones in the “Grey Formation” (details).

2. Organic matter analysis

The six clay samples were processed using standard palynological techniques (e.g., Batten, 1999). They were treated with HCl (37%) so as to remove the carbonates, and HF (48%) in order to remove the silicate minerals. The separation of palynomorphs was performed with centrifugal action, using ZnCl₂ with a density of 2,00 g/cm³ as heavy liquid. The microscopic slides were obtained using glycerine jelly as mounting medium. The description of organic matter (paly-nofacies analysis) was carried out according to the classification proposed by Tyson (1995), Mendonça Filho et al. (2002) and Carvalho et al. (2006), namely: the *phytoclast group*, which includes all fragments derived from terrestrial plants (cuticles, tracheids, black woody tissue, charcoal); the *paly-nomorph group* (spores, pollen, dino-flagellates); the *Amorphous Organic Matter (AOM) group*, which refers to all particulate organic components that appear structureless under the light microscope (phytoplankton and bacterially-derived AOM, higher plant resins and amorphous products of the diagenesis of macrophyte tissue).

The kerogen types were determined based on their optical aspect under the microscope (Combaz, 1980; Suárez-Ruiz et al., 2012; Mendonça Filho et al., 2012).

The method used for palaeoclimatic estimation is the "Coexistence Approach" (CA), described by Mosbrugger and Utescher (1997).

Results and interpretation

1. Palynology

The palynological assemblage identified in the six samples collected from the "Grey Formation" is dominated by continental palynomorphs (fern spores, angiosperms and gymnosperms), while species of phytoplankton (dinoflagellate cysts, Tab. 1) are subordinate.

Dinoflagellate species are more numerous in sample P1. Among them, we could list *Homotryblium aculeatum*, *Cleistosphaeridium* sp., *Thalassiphora pelagica* and *Spiniferites ramosus*. *Homotryblium* div. sp. and *Spiniferites*

ramosus indicate the inner-outer neritic setting of the sedimentary basin (Dale, 1996; Sluijs et al., 2005), while the presence of *Homotryblium aculeatum* species (which displays high process length; see Plate I, Fig. 2) demonstrates a normal water salinity (De Vernal et al., 1989). A low-oxygen shelf environment can be assumed based on the presence of *Thalassiphora pelagica* (Pross and Schmiedl, 2002), however, in the profiles analyzed, have not identified a high frequency for this species. The age of the deposits studied is difficult to specify based on the dino-flagellate species identified. *Homotryblium* div. sp. are cited throughout the entire Early Paleocene-Middle Miocene stratigraphic interval (Iakovleva et al., 2001; Brinkhuis, 1994), in Romania being also frequently mentioned in the Oligocene of the Eastern Carpathians (Țabără, 2010) and the Volhynian of the Moldavian Platform (Chirilă and Țabără, 2010). *Thalassiphora pelagica* is a species frequently cited in Eocene-Oligocene deposits (Olaru, 1978; Köthe and Piesker, 2007; Gedl, 2005, 2013), the last occurrence of this taxon being during the Lower Burdigalian (the D16b biozone, Köthe and Piesker, 2007). We believe that this species may have persist up to the Upper Burdigalian.

Continental vegetation (ferns, angiosperms and gymnosperms) is well represented within the palynological assemblage identified (Tab. 1). Based on it, the following biotops can be reconstructed:

- the existence of a swampy area is proven by the presence of *Taxodium*, *Myrica*, various ferns, palms, and *Typha*. However, at the same time, we can also infer, based on pollen of Chenopodiaceae, a local saline swamp environment that emerged due to marine regression. According to Slamková (1999), the pollen of Chenopodiaceae derived from herbaceous halophytic vegetation developed in interfluvial areas. This type of pollen was frequently encountered in all the samples analyzed.

- the low and medium altitude areas were covered by a riparian forest, characterized by *Engelhardtia*, *Alnus* and a mixed mesophytic forest with *Quercus* div. sp., *Fagus*, *Tilia*, *Carya* and *Ulmus*.

Tab. 1 Palynological assemblage identified within the “Grey Formation” (Ciritei Quarry)

Taxa	P1	P2	P3	P4	P5	P6
Phytoplankton						
<i>Homotryblum aculeatum</i> Williams 1978	1					
<i>Tythodiscus</i> sp.	2	1	1	2		1
<i>Cleistosphaeridium</i> sp.	1					
<i>Thalassiphora pelagica</i> (Eisenack 1954) Eisenack & Gocht 1960	1					
<i>Spiniferites ramosus</i> (Ehrenberg 1838) Mantell 1854				1		
Pteridophyta						
<i>Laevigatosporites haardti</i> (Potonie et Ven. 1934) Th. et Pflug 1953 subsp. <i>haardti</i> Krutzsch 1967	1					
<i>Polypodiaceoisporites</i> sp.	1			2	2	
<i>Leiotriletes wolffi brevis</i> Krutzsch 1962		1				
<i>Leiotriletes microlepioidites</i> Krutzsch 1962			1			
<i>Toripunctisporis lusaticus</i> Krutzsch 1962		1				
<i>Echinatisporis bockwitzensis</i> Krutzsch 1963		1				
<i>Echinatisporis</i> sp.					1	
<i>Baculatisporites</i> sp.			1			
<i>Verrucatosporites</i> sp.				1		
<i>Intrapunctatosporis</i> cf. <i>lusaticus</i> Kr. & Sontag 1967				1		
Gymnospermatophyta						
<i>Pityosporites</i> sp.	24	9	20	27	20	16
<i>Pityosporites microalatus</i> (Pot. 1931) Th. et Pf. 1953	9	2	2	2		4
<i>Pityosporites alatus</i> (Pot. 1931) Th. et Pf. 1953	3					
<i>Pityosporites labdacus</i> (Pot. 1931) Th. et Pf. 1953	4	2	1	2	3	
<i>Pityosporites minutus</i> (Zaklinskaja 1957) Krutzsch 1971	1	1	2	2		
<i>Podocarpidites libellus</i> (Pot. 1931) Krutzsch 1971	1					
<i>Podocarpidites podocarpoides</i> (Thg. 1958) Krutzsch 1971	1					
<i>Podocarpidites piniverrucatus</i> Krutzsch 1971	1					
<i>Podocarpidites</i> sp.	2					1
<i>Cedripites miocaenicus</i> Krutzsch 1971		1				
<i>Cedripites</i> sp.					1	
<i>Inaperturopollenites hiatus</i> (Pot. 1931) Th. et Pf. 1953	1	1	1			1
<i>Inaperturopollenites concedipites</i> (Wodehouse 1933) Krutzsch 1971			1		1	1
<i>Inaperturopollenites</i> sp.	4	1	2	3	1	1
<i>Ephedripites</i> sp.	1					
<i>Zonalapollenites</i> sp.			1			
<i>Sciadopityspollenites serratus</i> (Pot. et Ven. 1934) Thiergart 1937					1	

Taxa	P1	P2	P3	P4	P5	P6
Angiospermatophyta. Monocotyledonatae						
<i>Monocolpopollenites</i> sp.						1
<i>Typha</i> sp.		1				
Angiospermatophyta. Dicotyledonatae						
<i>Tricolporopollenites microhenrici</i> (Pot. 1930) Krutzsch 1960	1					1
<i>Tricolporopollenites henrici</i> (Pot. 1931) Krutzsch 1960			1			
<i>Tricolporopollenites microreticulatus</i> (Pf. et Th.) Th. et Pf. 1953				1		
<i>Tricolporopollenites</i> sp.		1		1		
<i>Quercopollenites petrea</i> Nagy 1969	1					
<i>Quercopollenites</i> sp.	1		2		1	
<i>Tricolpopollenites liblarensis</i> (Th. 1950) Th. et Pf. 1953 subsp. <i>liblarensis</i>			1			
<i>Tricolpopollenites liblarensis</i> (Th. 1950) Th. et Pf. 1953 subsp. <i>fallax</i> (Pot. 1934) Th. et Pf. 1953						1
<i>Faguspollenites</i> sp.	1			1		
<i>Intratropipollenites instructus</i> (Pot. 1931) Th. et Pf. 1953	1					
<i>Intratropipollenites</i> sp.			1			
<i>Engelhardtoidites microcoryphaeus</i> (Pot. 1931) Th. et Thierg. ex Potonié 1960	4	5	1	1	2	
<i>Myricipites bituitus</i> (Pot. 1931) Nagy 1969	1		2			
<i>Myricipites</i> sp.	3		1	1	1	
<i>Momipites punctatus</i> (Pot. 1931) Nagy 1969	1			1		
<i>Alnipollenites verus</i> (Pot. 1931) Pot. 1934			1			
<i>Alnipollenites</i> sp.		1				
<i>Caryapollenites simplex</i> (Pot. 1931) Krutzsch 1960	1		1		1	
<i>Chenopodipollis multiplex</i> (Weyland et Pflug 1957) Krutzsch 1966	4	2	2	2	1	1
<i>Ulmipollenites</i> sp.	1					
<i>Compositoipollenites</i> sp.		1	1	1	1	2
? <i>Scabiosaepollenites</i> sp.	1		1		1	

- the high-altitude forest, represented by various species of *Pinus*, *Tsuga* and *Cedrus*, corresponds to approximately 40 – 50% of the palynological assemblage. It occupied the higher areas of the Eastern Carpathians, located in the western part of the sedimentary basin during the Upper Burdigalian – Lower Badenian (Fig. 3).

Compared to the Lower Burdigalian

microflora from the Gura Șoimului Formation (Bistrița-Râșca Half-Window; Țabără and Popescu, 2012), a taxonomic similarity can be observed between the two palynological assemblages. Yet, within the sedimentation of the stratigraphic sequence analyzed in the present paper (Upper Burdigalian), the coniferous forest (mainly *Pinus*) is better represented, both quantitatively and qualitatively.

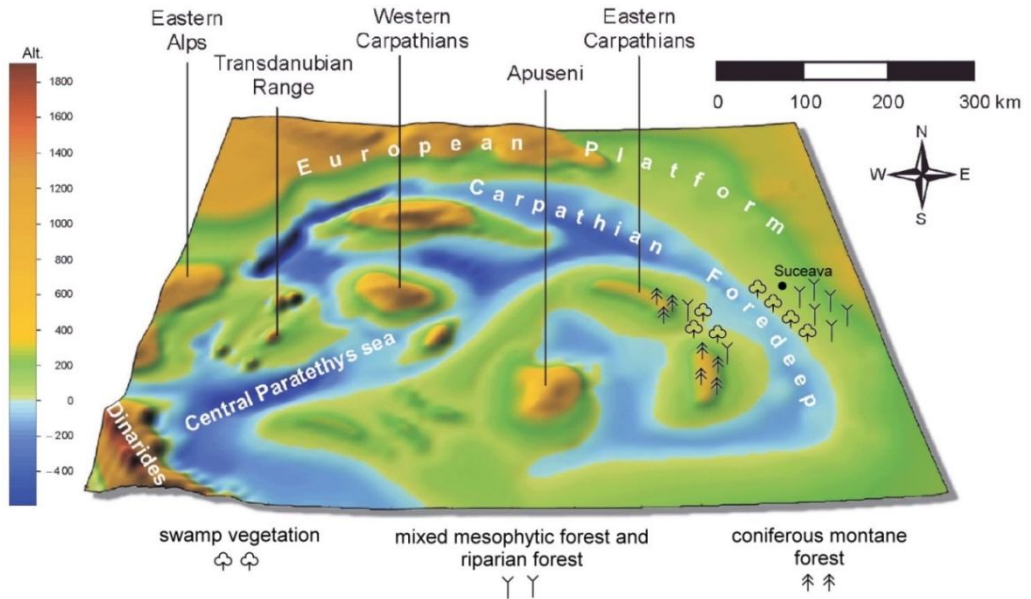


Fig. 3 Palaeogeographic sketch map of the Central and Eastern Paratethys during the Upper Burdigalian (after Kvaček et al., 2006), with reconstruction of the plant communities in the studied area.

The palaeoclimatic parameters calculated using the “Coexistence Approach” for the palynological assemblage of the “Grey Formation” are the following:

Mean annual temperature:	min. 15.6°C <i>Engelhardtia microcoryphaeus</i> max. 18.4°C <i>Cedripites miocaenicus</i>
Mean annual precipitation:	min. 892 mm <i>Leiotriletes microlepidoidites</i> max. 1281 mm <i>Inaperturopollenites hiatus</i>
Mean temperature of the coldest month:	min. 9.6°C <i>Leiotriletes microlepidoidites</i> max. 12.5°C <i>Cedripites miocaenicus</i>
Mean temperature of the warmest month:	min. 24.7°C <i>Engelhardtia microcoryphaeus</i> max. 28.1°C <i>Intratripopollenites instructus</i>

2. Palynofacies analysis

The microscopic analysis of the organic matter from the samples analyzed has allowed the recognition of three groups of organic constituents of the kerogen (phytoclads, palynomorphs and AOM), as follows:

- the percentage of phytoclads (of total kerogen). Phytoclads prevail in all the samples analyzed. They have a frequency of

approximately 80% in sample P1, their proportion increasing progressively up to 97% in sample P6 (collected at the top of the outcrop). These phytoclads, which represent a source of continental organic matter, consist mainly of coaly opaque particles (Plate III, Fig. 1), translucent fragments (woody tissue or tracheids; Plate III, Fig. 3, 4), and yellow-brown particles of smaller sizes. Generally,

large amounts of phytoclast particles are deposited by rivers in estuarine, deltaic and lagoon environments (Carvalho et al., 2006).

- the percentage of AOM (of total kerogen). The percentage of AOM ranges between 1-2% (in sample P6) and about 15% (in sample P1). Granular AOM (marine origin; Plate III, Fig. 5) is more frequent in the samples analyzed, being often identified as granules, and frequently associated with small coaly fragments. Rarely, the kerogen analyzed contains brown gelified AOM (Plate III, Fig. 2), derived from terrestrial organic matter degraded by bacteria.

- the percentage of palynomorphs (of total kerogen). The palynomorphs viewed in palynological slides do not exceed 1-2% of the total kerogen. Predominant are gymnosperms (*Pinus* div. sp.), to which are added subordinated spores of ferns, angiosperms and some dinoflagellate cysts. The Thermal Alteration Index (TAI) revealed by continental palynomorphs is usually 2, rarely 2+, indicating an immature stage of organic matter for hydrocarbon generation.

Conclusions

The present paper presents the palynological content and palynofacies of the "Grey Formation" identified in the Cırteii Quarry (Subcarpathian Nappe). Its main conclusions are the following:

- the palynological assemblage is dominated by taxa originating from continental vegetation. Among these, a higher proportion corresponds to gymnosperms (*Pinus* div. sp.). A swamp area (*Taxodium*, *Myrica*, ferns, *Typha*), as well as hilly areas populated by mixed mesophytic forest (*Quercus* div. sp., *Fagus*, *Carya*, *Tilia* a.o.), have also been documented. A saline swamp that emerged due to marine regression, populated by halophytic herbaceous vegetation (Chenopodiaceae), can also be inferred. Aquatic species (dinoflagellates) are poorly represented within the palynological assemblage, indicating a inner neritic setting with normal water salinity (*Homotryblium aculeatum*), or, locally, even

poorly-oxygenated shelf areas (*Thalassiphora pelagica*).

- the palaeoclimatic parameters during the sedimentation of this formation are the following: a mean annual temperature of 15.6–18.4°C, mean annual precipitation of 892–1281 mm, mean temperature of the coldest month 9.6–12.5°C, and a mean temperature of the warmest month between 24.7 and 28.1°C.

- the age of the sedimentary deposits analyzed is difficult to specify based on the palynological assemblage. *Homotryblium* genus is quoted within the Early Paleocene - Sarmatian range, whereas *Thalassiphora pelagica* is known from the Eocene-Oligocene up to the Lower Burdigalian. This species may have persisted up to the Upper Burdigalian.

- the analysis of the palynofacies has shown a predominance of continental phytoclasts (80–97% of the kerogen extracted from the rocks), and AOM up to 15%. The large amount of continental organic particles characterizes the estuarine, deltaic or lagoon environments of the sedimentary basin.

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PLATE CAPTIONS

Plate I

1. *Thalassiphora pelagica* (Eisenack 1954) Eisenack & Gocht 1960
2. *Homotryblium aculeatum* Williams 1978
3. *Tytthodiscus* sp.
4. *Cleistosphaeridium* sp.
5. *Polypodiaceoisporites* sp.
6. *Laevigatosporites haardti* (Potonie et Ven. 1934) Th. et Pflug, 1953 subsp. *haardti* Krutzsch 1967
7. *Leiotriletes wolffii brevis* Krutzsch 1962
8. *Leiotriletes microlepidoidites* Krutzsch 1962
9. *Echinatisporis bockwitzensis* Krutzsch 1963
10. *Verrucatosporites* sp.
11. *Baculatisporites* sp.
12. *Podocarpidites libellus* (Pot. 1931) Krutzsch 1971
13. *Podocarpidites piniverrucatus* Krutzsch 1971
14. *Pityosporites alatus* (Pot. 1931) Th. et Pf. 1953
15. *Pityosporites labdacus* (Pot. 1931) Th. et Pf. 1953
16. *Pityosporites microalatus* (Pot. 1931) Th. et Pf. 1953
17. *Ephedripites* sp.
18. *Cedripites miocaenicus* Krutzsch 1971
19. *Zonalapollenites* sp.
20. *Inaperturopollenites hiatus* (Pot. 1931) Th. et Pf. 1953
21. *Inaperturopollenites concedipites* (Wodehouse 1933) Krutzsch 1971

Plate II

1. *Sciadopityspollenites serratus* (Pot. et Ven. 1934) Thierngart 1937
2. *Intratropollenites instructus* (Pot. 1931) Th. et Pf. 1953
3. *Engelhardtoidites microcoryphaeus* (Pot. 1931) Th. et Thierng. ex Potonié 1960
4. *Quercopollenites petrea* Nagy 1969
5. *Faguspollenites* sp.
6. ? *Scabiosaepollenites* sp.
7. *Chenopodipollis multiplex* (Weyland et Pflug 1957) Krutzsch 1966
8. *Caryapollenites simplex* (Pot. 1931) Krutzsch 1960
9. *Tricolporopollenites microhenrici* (Pot. 1930) Krutzsch 1960
10. *Tricolporopollenites henrici* (Pot. 1931) Krutzsch 1960
11. *Momipites punctatus* (Pot. 1931) Nagy 1969
12. *Myricipites bituitus* (Pot. 1931) Nagy 1969
13. *Compositoipollenites* sp.
14. *Tricolpopollenites liblarensis* (Th. 1950) Th. et Pf. 1953 subsp. *liblarensis*
15. *Ulmipollenites* sp.
16. *Alnipollenites verus* (Pot. 1931) Pot. 1934
17. *Tricolporopollenites microreticulatus* (Pf. et Th.) Th. et Pf. 1953

Plate III

1. Lath-shaped opaque coaly particles.
2. Representative palynofacies assemblages from the “Grey Formation” of the Ciritei Quarry: opaque phytoclasts (red arrow), woody tissue (blue arrow), gelified AOM (green arrow).
3. Tracheid.
4. Brown woody tissue (terrigenous phytoclast) displaying fibrous structure.
5. Particle of granular AOM in association with opaque phytoclasts and pollen.

Plate I

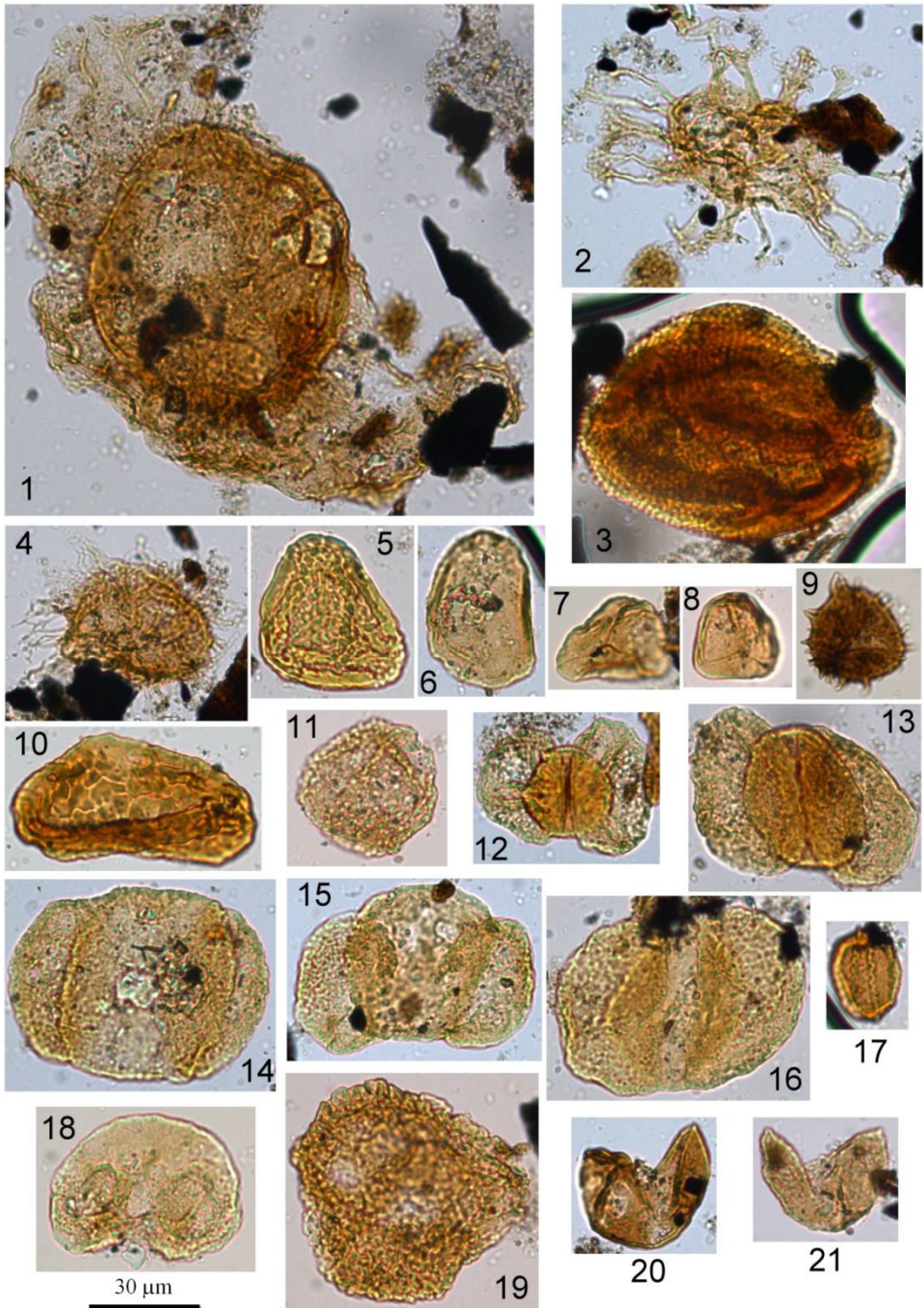


Plate II

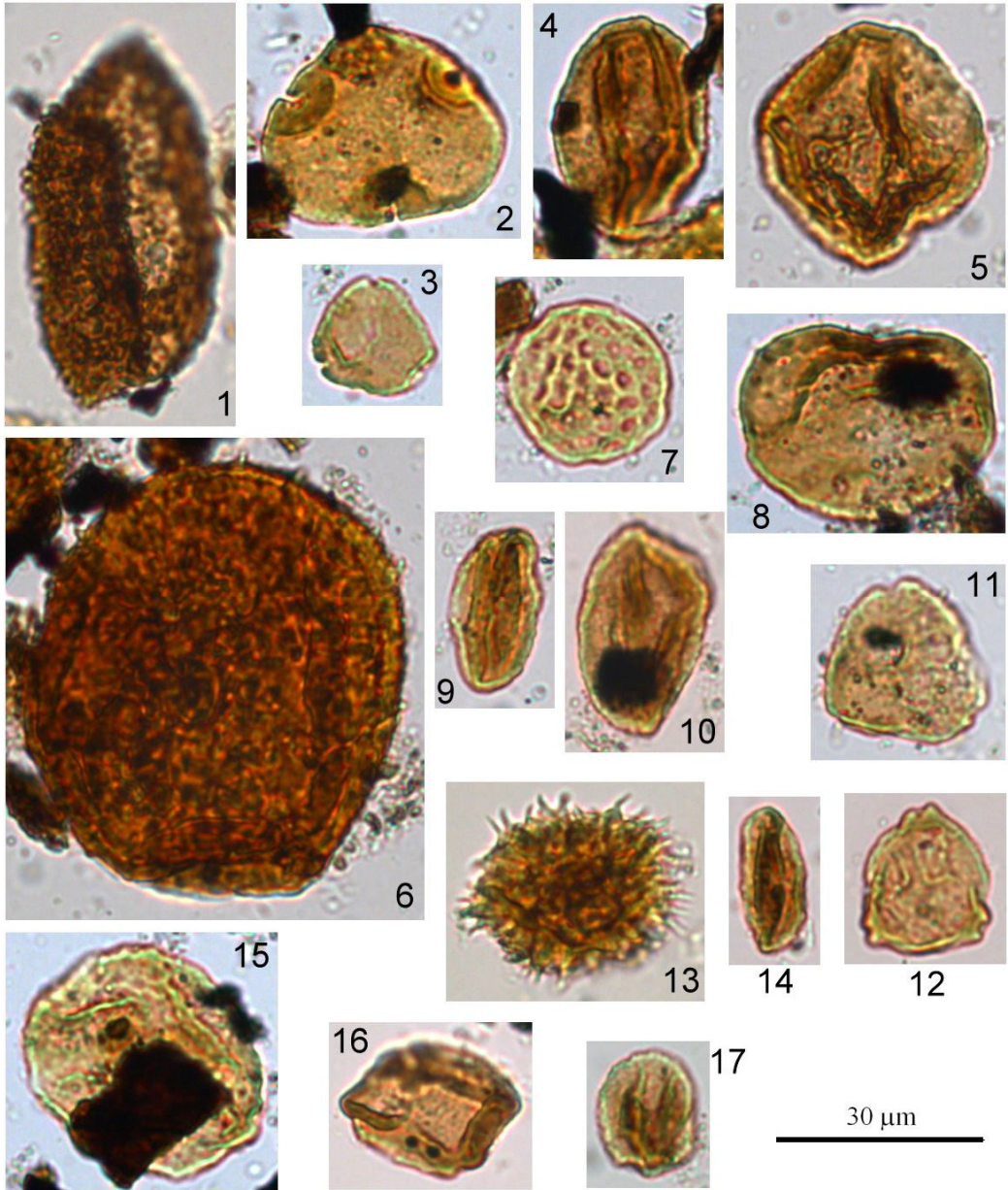


Plate III

