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Palynostratigraphy of the Maastrichtian dinosaur- and mammal sites of the Râul Mare and Barbat Valleys (Haţeg Basin, Romania)

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Abstract: The palynomorph associations of the Upper Cretaceous dinosaur-bearing sediments of three different sites (Pui, Toteşti-baraj and Nălaţ-Vad) within the Haţeg Basin show a great similarity with the palynomorph associations of the stratotypes of the Densuş-Ciula and Sânpetru Formations. The absence of volcanoclastic layers places the sediments within the Sânpetru Formation. Palynological evidence indicates a Maastrichtian age of the vertebrate sites studied. The age can be refined to the Early-Late Maastrichtian boundary interval based on the good correlation with the lower Rogancian (France), the lower Garumnian (Spain) and the Gulpen Formation (Maastrichtian stratotype, The Netherlands). The ancient vegetation, dominated by ferns and bryophytes with disperse flowering plants and gymnosperm trees, is indicative for a subtropical climate. Freshwater ferns flourished in the floodplain ponds. For the first time, the megaspore genus *Ghoshispora* is recorded in Europe.

Key words: Maastrichtian, Southern Carpathians, Romania, Haţeg Basin, palynology.

Introduction

Uppermost Cretaceous (Campanian-Maastrichtian) vertebrate assemblages are well known and documented from eastern Asia and western North America. In Europe contemporary faunas have been described from southern France, Spain and Portugal (Le Loeuff 1991). With the exception of Laño (Pereda Suberbiola et al. 2000), the material collected at these localities is scarce and fragmentary and mammals appear to be particularly rare, especially multituberculates, which are currently only known in Europe from the Haţeg Basin. The Upper Cretaceous fauna recovered from the Haţeg Basin, Romania is one of the most diverse and best preserved of these European assemblages (Weishampel et al. 1991; Grigorescu et al. 1999). In the present study, the palynomorph associations of the sediments at Toteşti-baraj, Nălaţ-Vad, and Pui confirm the correlation with the Sânpetru Formation and clarify the age of these important vertebrate sites. The first Upper Cretaceous multituberculate tooth (an incisor) in Europe was found in the Sânpetru Formation in the Sibisel Valley (Grigorescu 1984), followed by the first molars in the Barbat Valley at the Pui site (Radulescu & Samson 1986; Grigorescu & Hahn 1987). The sediments exposed at Pui are classically attributed to the Sânpetru Formation (Grigorescu & Anastasiu 1990, p. 53). Recently two new sites have been discovered in the Râul Mare Valley (Fig. 1): Toteşti-baraj (Codrea et al. 2002) and Nălaţ-Vad (Smith et al. 2002). These sites have yielded numerous well-preserved mammal teeth together with dinosaur egg nests and dinosaur bones. On older geological maps of the Haţeg Basin, exposures of Upper Cretaceous continental sediments within the Râul Mare Valley are not indicated (Grigorescu 1983). On the basis of the regional geological framework, the new Râul Mare sites have been tentatively attributed to the Sânpetru Formation. The similar vertebrate assemblages seem to confirm this hypothesis.

Stratigraphic setting of the Maastrichtian non-marine deposits of the Haţeg Basin

Two Maastrichtian continental formations (Fig. 1) crop out in the Haţeg Basin (Grigorescu & Anastasiu 1990), the Sânpetru Formation (in the central-southern part) and the Densuş-Ciula Formation (in the northwestern part). The latter is divided into three members and contains several volcanoclastic intercalations, while the first is undivided and devoid of such material. Both have yielded a rich dinosaur fauna. For the Densuş-Ciula Formation, all the fossils have been recovered from the middle member. The upper member is barren and therefore its age is uncertain, although Grigorescu & Anastasiu (1990) and Grigorescu (1992) assumed a Paleogene age based on the absence of dinosaur fossils. The lower part of this formation rests unconformably on Upper Cretaceous marine deposits. So the possible age of the lower and middle members of the Densuş-Ciula Formation is limited to an interval between the age of the underlying marine deposits and the extinction of

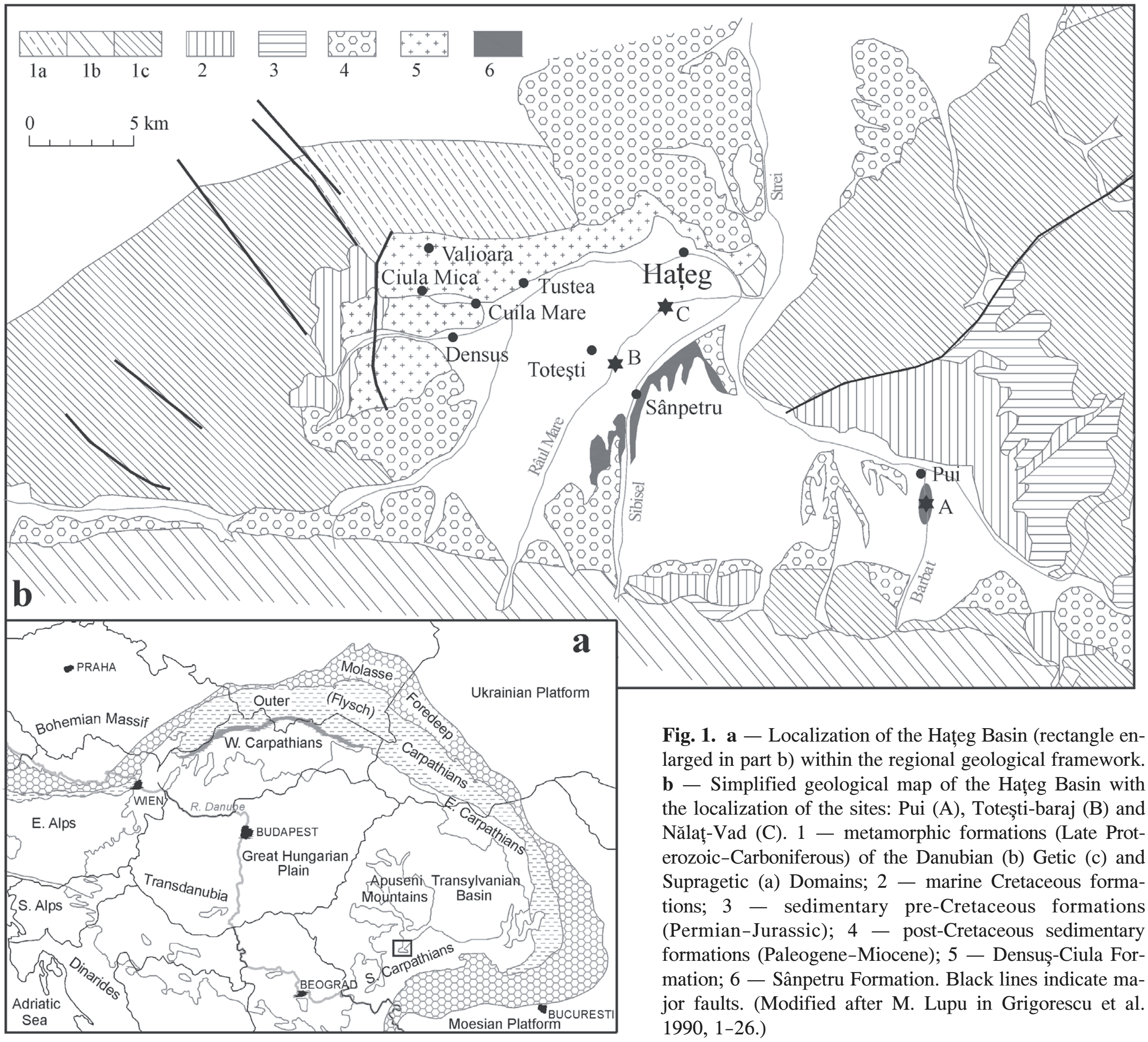

Fig. 1. **a** — Localization of the Haţeg Basin (rectangle enlarged in part b) within the regional geological framework. **b** — Simplified geological map of the Haţeg Basin with the localization of the sites: Pui (A), Toteşti-baraj (B) and Nălaţ-Vad (C). 1 — metamorphic formations (Late Proterozoic–Carboniferous) of the Danubian (b) Getic (c) and Supragetic (a) Domains; 2 — marine Cretaceous formations; 3 — sedimentary pre-Cretaceous formations (Permian–Jurassic); 4 — post-Cretaceous sedimentary formations (Paleogene–Miocene); 5 — Densuş-Ciula Formation; 6 — Sânpetru Formation. Black lines indicate major faults. (Modified after M. Lupu in Grigorescu et al. 1990, 1–26.)

the dinosaurs at the Cretaceous/Paleogene (K/P) boundary. The lower contact of the Sânpetru Formation is not exposed and therefore its stratigraphic position is more complicated. The Sânpetru Formation and the middle member of the Densuş-Ciula Formation have been correlated on the basis of their dinosaur fauna and the age of both formations has always been treated together. Antonescu et al. (1983) described the freshwater gastropods and palynomorph taxa (Table 2) recovered from the stratotypes of both units and this study provided further proof for the correlation of the two stratigraphic units.

In the past, the marine sediments underlying the Densuş-Ciula Formation have been estimated as rising up to the Early Maastrichtian on the basis of foraminifer evidence (Grigorescu & Anastasiu 1990; Pop et al. 1990). Taking into account the Early Maastrichtian age of the underlying marine sediments and the presence of *Pseudopapilopollis praesubhercynicus* in the palynomorph associations (Antonescu et al. 1983), the dinosaur-bearing deposits have previously been attributed to the Late Maastrichtian (Grigorescu & Anastasiu 1990; Grigorescu 1992). Both arguments have proven unreliable and have been refuted by Lopez-Martinez et al. (2001). Firstly, there is a continuous succession of palynomorph taxa across the K/P boundary in the Tethys region, therefore ages should be based on assemblages rather than marker species. With the repositioning of the Campanian-Maastrichtian boundary and new calibrations, the foraminiferal data of the Haţeg Basin were in need of revision. Indeed, recently the underlying marine sediments have been dated with calcareous nannoplankton as latest Campanian (Grigorescu & Melinte 2001; Grigorescu & Csiki 2002). On the basis of paleomagnetic data, Panaiotu & Panaiotu (2002) suggested a Lower Maastrichtian age (Chron 31r, 68.7–71.0 Ma) for the entire Sânpetru Formation.

Material and methods

During two different field campaigns, samples of organic rich sediments were collected at the Pui (5 samples), Toteşti-baraj (10 samples) and Nălaţ-Vad (6 samples) sites (Figs. 1, 2). Nine samples in total have yielded palynomorphs; the other samples were barren. The dark-coloured sediments at the Râul Mare sites yielded rich palynomorph associations. The red-coloured sediments at the Pui site were all barren, only the coarse-grained channel deposits, green in colour, have yielded poor palynomorph associations.

Palynological techniques were applied to approximately 50 g of sediment per sample and involved treatment with cold 25% HCl, digestion for two days in HF (40%), followed by repeated hot baths (80 °C) in 25% HCl. The samples were rinsed to neutrality between each step. No oxidation, heavy liquid separation or ultrasonic treatment was applied. All residues were homogenized by stirring and sieved through nylon filters with a mesh size of 15 µm. For sample NVD 7 rich in megaspores, subsamples were sieved through 30 µm filters in order to concentrate the megaspores. Both fractions were stained with Safranin O and mounted with glycerine jelly. Relative abundances were calculated from specimen counts from the 15 µm slides. One or two slides from the 30 µm fraction were scanned for rare species or especially well-preserved specimens. Photographs were taken on a ZEISS Axioskop-2 light microscope equipped with a Sony DSC-S75 camera.

Results

Toteşti-baraj and Nălaţ-Vad

The investigated samples have yielded rich, well-preserved and diversified palynomorph associations (see Table 1 for a counted list of taxa, Fig. 3). Spores dominate the associations (70–90 %), while gymnosperms and angiosperm pollen occur in smaller quantities. Smooth trilete and monolete spores like *Leiotriletes, Cyathidites, Laevigatosporites* dominate the assemblage. *Osmundacidites, Polypodiaceoisporites* and *Gleicheniidites* occur frequently. Bryophyte spores like *Sphagnumsporites* and *Selaginella* are common. The most dominant gymnosperm is *Taxodiaceaepollenites hiatus*, while bisaccate pollen grains occur only in low numbers. The angiosperm associations consist of Normapolles (a.o. *Nudopollis, Oculopollis, Trudopollis*) and Postnormapolles (a.o. *Subtriporopollenites, Triatriopollenites*) type of pollen grains. The angiosperm pollen are very diverse without a true dominance of one of the taxa. One of the samples (Table 1, NVD 7) has yielded an interesting assemblage of megaspores of *Ghoshispora* and *Azolla* (Fig. 4). In spite of their similar morphological characteristics, the *Ghoshispora* specimens show a distinct difference in size. They can be divided into a large (ca. 125 µm) and a small (ca. 50 µm) form (Fig. 4). Both forms have been attributed to *Ghoshispora bella*, as the size of this species is highly variable (Srivastava 1971).

Pui site

Only one sample from green channel deposits was productive and yielded a very poor palynological assemblage (Table 1), both in number of taxa and in number of specimens. Only the taxa with a relatively high abundance rate in the other samples have been observed at the Pui site. In spite of the low number of counted specimens (Table 1), the assemblage shows the same trends as for the other sites. Spores dominate the assemblage, gymnosperm pollen occur relatively frequently while angiosperm pollen are rare.

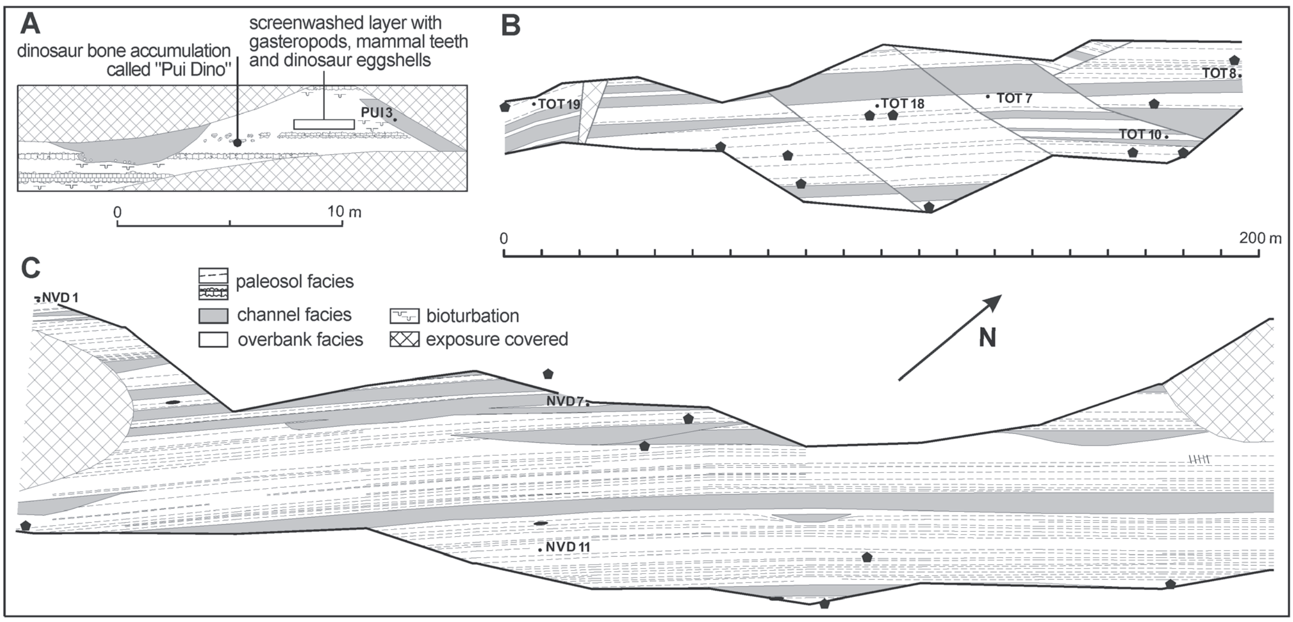

Fig. 2. Schematic view of the exposures at Pui (**A**), Toteşti-baraj (**B**) and Nălaţ-Vad (**C**) with the location of the palynological samples (associations given in Table 1), black pentagons and ellipses indicate the vertebrate fossils.

Table 1: Palynomorph associations (samples indicated on Fig. 2, * indicates the species in common with the Gulpen Formation (according to Kedves & Herngreen 1980).

		Pui/3		NVD/1		NVD/7		NVD/11		TOT/7		TOT/8		TOT/10		TOT/18		TOT/19	
Spores		**22**	**56.4**	**204**	**71.8**	**233**	**74.9**	**187**	**74.5**	**18**	**13.6**	**190**	**72.5**	**71**	**62.8**	**316**	**90.3**	**444**	**89.2**
Acanthotriletes sp.																		2	0.4
Adiantum mirum Chlonova, 1960								1	0.4										
Anapiculatisporites dawsonensis Reiser et Williams, 1969	*			1	0.4														
Appendicisporites sp.																		2	0.4
Appendicisporites tricornitatus Weyland et Greifeld, 1953												1	0.4					3	0.6
Azolla sp.						29	9.3												
Baculatisporites comaumensis (Cookson) Potonié, 1956																		1	0.2
Balmeisporites sp.																		1	0.2
Ceratosporites equalis Cookson et Dettmann, 1958				3	1.1														
Cicatricosisporites dorogensis Potonié et Gelletich, 1933	*			5	1.8	4	1.3	6	2.4			11	4.2	1	0.9	47	13.4	34	6.8
Cicatricosisporites furcatus Deak, 1963												2	0.8					3	0.6
Cicatricosisporites sp.				1	0.4														
Cicatricosisporites subrotundus Brenner, 1963	*											1	0.4						
Cingutriletes cf. *C. clavus* (Balme) Dettmann, 1963								1	0.4										
Chomotriletes fragilis Pocock, 1962				3	1.1	2	0.6	1	0.4			2	0.8			3	0.9	3	0.6
Chomotriletes sp.				7	2.5							1	0.4						
Concavisporites junctus (Kara-Murza) Semenova, 1970																1	0.3		
Concavissmisporites asper (Bolchovitina) Pocock, 1964				3	1.1			1	0.4							3	0.9		
Converrucosisporites proxigranulatus Brenner, 1963	*			1	0.4														
Cyathidites australis Couper, 1953				3	1.1	3	1.0	7	2.8			20	7.6	5	4.4	8	2.3	10	2.0
Cyathidites minor Couper, 1953		4	10.3	36	12.7	21	6.8	56	22.3	6	4.5	14	5.3	22	19.5	110	31.4	100	20.1
Densoisporites perinatus Couper, 1958	*					2	0.6												
Densoisporites velatus Weyland et Krieger, 1953				5	1.8									1	0.9	3	0.9	5	1.0
Dyctiophyllidites harrisii Couper 1953																1	0.3	1	0.2
*Echinatisporites levidensis (*Balme) Srivastava, 1972																2	0.6		
Foraminisporis asymmetricus (Cookson et Dettmann) Dettmann, 1963																		1	0.2
Foveosporites canalis Balmé, 1957																		1	0.2
Foveosporites cenomanicus (Chlonova) Schvetzova, 1976						1	0.3	1	0.4										
Foveosporites sp.																2	0.6		
Gabonisporites labyrintus Srivavastava, 1972				3	1.1	5	1.6					11	4.2						
Ghoshispora bella (Kondinskaya) Srivastava, 1978						29	9.3												
Gleicheniidites circinidites (Cookson) Dettmann, 1963	*			8	2.8	4	1.3					2	0.8			1	0.3	1	0.2
Gleicheniidites dicarpoides Grigoryeva, 1961				4	1.4														
Gleicheniidites laetus (Bolchovitina) Bolchovitina, 1968				13	4.6	5	1.6	1	0.4			6	2.3					2	0.4
Gleicheniidites rasilis (Bolchovitina) Bolchovitina, 1968				1	0.4														
Gleicheniidites senonicus Ross,1949				6	2.1									2	1.8				
Gleicheniidites sp.		1	2.6					2	0.8							1	0.3		
Gleicheniidites triplex (Bolchovitina) Krutzsch, 1959								2	0.8							1	0.3		
Hamulatisporites rugulatus (Couper) Srivastava, 1972				1	0.4											2	0.6		
Heliosporites kemensis (Chlonova) Srivastava				4	1.4	8	2.6									4	1.1	1	0.2
Intrapunctatosporis sp.		1	2.6																
Klukisporites notabilis Srivastava, 1972						13	4.2					1	0.4						
Klukisporites variegatus Couper, 1958				2	0.7											6	1.7	1	0.2
Klukisporites visibilis (Bolchovitina) Pocock, 1962								4	1.6										
Kuylisporites lunaris Cookson et Dettmann, 1958																1	0.3		
Laevigatosporites major (Verbitskaja) Zhang Q.B., 1984																		1	0.2
Laevigatosporites ovatus Willson et Webster, 1946		5	12.8	22	7.7	20	6.4	24	9.6	2	1.5	4	1.5	16	14.2	38	10.9	100	20.1
Laevigatosporites ovoideus Takahashi, 1961				10	3.5											3	0.9		
Leiotriletes rotundiformis Bolchovitina, 1956																1	0.3	1	0.2
Leiotriletes sp.		6	15.4	33	11.6	34	10.9	57	22.7	10	7.6	52	19.8	20	17.7	37	10.6	89	17.9
Leptolepidites bullatus (Van Hoeken- Klinkenberg) Srivastava, 1972																2	0.6		
Leptolepidites verrucatus Couper, 1953				10	3.5	7	2.3	1	0.4			5	1.9					6	1.2
Liburnisporites adnacus Srivastava, 1972				1	0.4							5	1.9					4	0.8
Matonisporites equiexinus Couper, 1958																1	0.3		
Matonisporites sp.																		2	0.4
Neoraistrickia sp.																		1	0.2
Neoraistrickia truncata (Cookson) Potonié, 1956	*					2	0.6												
Nevesisporites radiatus (Chlonova) Srivastava, 1972						1	0.3									2	0.6	1	0.2
Ophioglossum sp.								1	0.4										
Osmundacidites sp.																4	1.1	11	2.2
Osmundacidites wellmanii Couper, 1953		1	2.6	5	1.8	3	1.0	6	2.4			16	6.1			9	2.6	9	1.8
Polycingulatisporites reduncus (Bolchovitina) Playford et Dettmann, 1965				1	0.4	7	2.3					1	0.4						
Polypodiaceoisporites cyclocingulatus Krutzsch, 1967				1	0.4			6	2.4										
Polypodiaceoisporites potoniei Kedves, 1961																		1	0.2
Polypodiaceoisporites variabilis Pacltova, 1970		4	10.3									15	5.7	3	2.7	9	2.6	23	
Polypodiidites speciosus (Harris) Archangelsky, 1972																1	0.3		
Retitriletes rotundiformis (Kara-Murza) Krutzsch, 1963						3	1.0									2	0.6	5	1.0
Rouseisporites reticulatus Pocock, 1962				1	0.4	5	1.6	2	0.8			2	0.8					4	0.8
Rouseisporites sp.																		1	0.2
Schizaeoisporites cicatricos Sole de Porta, 1972	*							5	2.0							10	2.9	2	0.4
Selaginella intertexta Krasnova, 1961				1	0.4														
Selaginella sp.												15	5.7						
Sphagnumsporites antiquasporites (Wilson et Webster) Potonié, 1956																		2	0.4
Sphagnumsporites sp.				5	1.8	3	1.0							1	0.9	1	0.3		
Sphagnumsporites psilatus (Ross) Couper, 1957												1	0.4						
Spinatisporites sp.								1	0.4									8	1.6
Todisporites minor Couper, 1958																		1	0.2
Todisporites sp.								1	0.4										
Triletes bettianus Srivastava, 1972	*			2	0.7	5	1.6												
Tuberosisporites sp.	*			2	0.7	17	5.5					2	0.8						

Table 1: *Continuing.*

		Pui/3		NVD/1		NVD/7		NVD/11		TOT/7		TOT/8		TOT/10		TOT/18		TOT/19	
Gymnosperms		**12**	**30.8**	**40**	**14.1**	**39**	**12.5**	**53**	**21.1**	**47**	**35.6**	**62**	**23.7**	**18**	**15.9**	**17**	**4.9**	**37**	**7.4**
Abiespollenites editus (Chlonova) Chlonova, 1976		1	2.6																
Abietinaepollenites sp.										2	1.5								
Alisporites aequalis Mädler, 1964		2	5.1	3	1.1														
Alisporites bilateralis Rouse, 1959	*			4	1.4	6	1.9	5	2.0							1	0.3		
Alisporites bisaccus Rouse, 1959																		1	0.2
Araucariacites sp.				3	1.1	1	0.3	3	1.2									1	0.2
Cedripites parvisaccatus (Sauer) Krutzsch, 1971				2	0.7	3	1.0	5	2.0	6	4.5			1	0.9				
Cedruspollenites sp.		1	2.6																
Classopollis classoides (Pflug) Pocock et Jansonius, 1961	*					1	0.3	1	0.4			5	1.9			3	0.9		
Classopollis sp.		1	2.6															3	0.6
Ginkgocycadophytus sp.		2	5.1	5	1.8	4	1.3	4	1.6			3	1.1	5	4.4	2	0.6	3	0.6
Inaperturopollenites sp.								1	0.4										
Piceapollenites sp.										21	15.9			5	4.4			1	
Pinuspollenites sp.		5	12.8	3	1.1	14	4.5	9	3.6	12	9.1	15	5.7	2	1.8	2	0.6	12	2.4
Podocarpidites ellipticus Cookson, 1947						1	0.3					2	0.8						
Podocarpidites multessimus (Bolchovitina) Pocock, 1962	*			5	1.8														
Taxodiaceaepollenites hiatus (Potonié) Kremp, 1949				15	5.3	9	2.9	25	10.0	6	4.5	37	14.1	5	4.4	9	2.6	16	3.2
		Pui/3		**NVD/1**		**NVD/7**		**NVD/11**		**TOT/7**		**TOT/8**		**TOT/10**		**TOT/18**		**TOT/19**	
Angiosperms		**5**	**12.8**	**40**	**14.1**	**39**	**12.5**	**11**	**4.4**	**67**	**50.8**	**10**	**3.8**	**24**	**21.2**	**17**	**4.9**	**17**	**3.4**
Atlantopollenites choffatii Diniz, Kedves et Simoncsics, 1977				1	0.4														
Coryluspollenites sp.										12	9.1		0.0	2	1.8			1	0.2
Echimonocolpites minutus Salard-Cheboldaeff, 1978				1	0.4	3	1.0					2	0.8						
Elytranthe striatus Couper, 1953		1	2.6															1	0.2
Hofkeripollenites capsula (Pflug) Kedves et Hergreen, 1980	*													5	4.4	7	2.0	2	0.4
Hofkeripollenites triangulus Kedves et Hergreen, 1980	*			1	0.4														
Interpollis microsupplingensis Krutzsch, 1961										1	0.8								
Interpollis supplingensis (Pflug) Krutzsch, 1961	*			1	0.4	3	1.0							1	0.9				
Interpollis cf. *velum* Krutzsch, 1961	*									1	0.8								
Interporopollenites sp.				5	1.8	11	3.5	1	0.4							2	0.6		
Liliacidites sp.														1	0.9				
Maestrichtipollenites concavus Kedves et Hergreen, 1980	*											1	0.4						
Minorpollis maestrichtiensis Kedves et Hergreen, 1980	*					1	0.3									1	0.3		
Nudopollis apertus (Pflug) Pflug, 1953	*			1	0.4														
Nudopollis minutus Zaklinskaja, 1963	*					5	1.6									1	0.3		
Nudopollis terminalis (Thomson et Pflug) Pflug, 1953	*			2	0.7														
Oculopollis minoris Krutzsch, 1973	*			2	0.7							5	1.9			1	0.3		
Oculopollis sp.																1	0.3	2	0.4
Platycarya sp.																1	0.3	1	0.2
Plicapollis conserta Pflug, 1953	*			2	0.7	1	0.3												
Plicapollis serta Pflug, 1953	*					1	0.3											3	0.6
Plicapollis cf. *silicatus* Pflug, 1953	*											1	0.4						
Pompeckjoidaepollenites platoides (Pflug, 1953) Krutzsch, 1967																1	0.3		
Portniaginaepollenites maestrichtiensis Kedves et Hergreen, 1980	*									1	0.8								
Portniaginaepollenites minor Kedves et Hergreen, 1980	*									1	0.8								
Quercites sparsus (Martynova) Samoilovich, 1961								4	1.6										
Retitricolpites georgensis Brenner, 1963		1	2.6																
Retitricolpites sp.								1	0.4										
Subtriporopollenites constans Pflug, 1953	*					2	0.6			2	1.5								
Subtrudopollis sp.						2	0.6												
Subtrudopollis subtrudens (Pflug) Krutzsch, 1967	*					2	0.6												
Thomsonipollis magnificus (Thomson et Pflug) Krutzsch, 1960																		1	0.2
Triatriopollenites aroboratus Pflug, 1953				10	3.5														
Triatriopollenites bituites (Potonié) Thomson et Pflug, 1953	*			4	1.4					30	22.7								
Triatriopollenites confusus Zaklinskaya, 1963										2	1.5			1	0.9			1	0.2
Triatriopollenites lubomirovae (Gladkova) Kedves, 1974	*			5	1.8	1	0.3			14	10.6								
Triatriopollenites roboratus Pflug, 1953	*	1	2.6	1	0.4														
Tricolpites hians Stanley, 1965								1	0.4					2	1.8				
Tricolpites microreticulatus Boltenhagen et Potonié, 1965		1	2.6																
Tricolpites reticulatus Cookson, 1947																		1	0.2
Tricolpites sp.		1	2.6	1	0.4	3	1.0	1	0.4							1	0.3	1	0.2
Tricolpites vulgaris (Pierce) Srivastava, 1969								1	0.4										
Tricolporopollenites sp.												1	0.4						
Triporopollenites cretacicus Kedves et Herngreen, 1980	*					1	0.3			1	0.8								
Triporopollenites sp.								1	0.4	2	1.5			1	0.9	1	0.3		
Trudopollis maestrichtiensis Kedves et Herngreen, 1980	*			3	1.1													2	0.4
Trudopollis cf. *parvotrudens* Pflüg, 1953	*							1	0.4										
Trudopollis sp.						3	1.0							10	8.8				
Ulmoideipites tricostatus Anderson, 1960														1	0.9				
Vacuopollis sp.	*																	1	0.2
Total		**39**	**100.0**	**284**	**100.0**	**311**	**100.0**	**251**	**100.0**	**132**	**100.0**	**262**	**100.0**	**113**	**100.0**	**350**	**100.0**	**498**	**100.0**

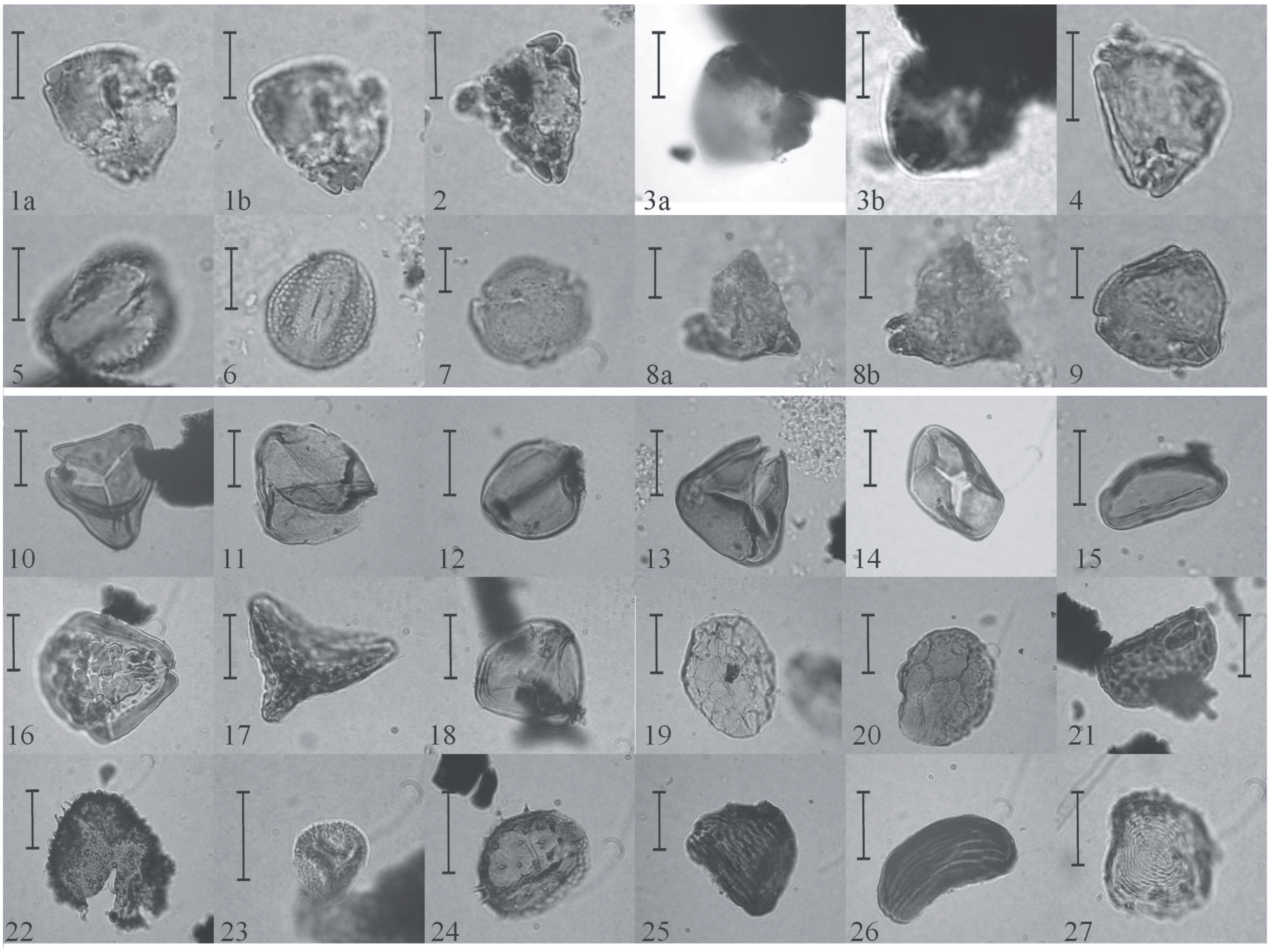

Fig. 3. 1 — *Hofkeripollis capsula* (Toteşti, slide 18/1). **2** — *Nudopollis minutus* (Toteşti, slide18/1). **3** — *Oculopollis minoris* (Toteşti, slide 18/1). **4** — *Minorpollis maestrichtiensis* (Toteşti, slide 18/1). **5** — *Retitricolpites* sp. (Nălaţ-Vad, slide 11/1). **6** — *Quercites sparsus* (Nălaţ-Vad, slide 11/1). **7** — *Tricolpites vulgaris* (Nălaţ-Vad, slide 11/1). **8** — *Trudopollis* cf. *parvotrudens* (Nălaţ-Vad, slide 11/1). **9** — *Triatriopollenites confusus* (Toteşti, slide 19/2). **10** — *Cyathidites australis* (Toteşti, slide 19/3). **11** — *C. australis* (Toteşti, slide 19/1). **12** — *Cyathidites minor* (Toteşti, slide 19/1). **13** — *C. minor* (Nălaţ-Vad, slide 11/1). **14** — *Leiotriletes rotundiformis* (Toteşti, slide19/3). **15** — *Laevigatisporites ovatus* (Nălaţ-Vad, slide 11/1). **16** — *Polypodiaceoisporites variabilis* (Toteşti, slide 18/1). **17** — *Gleicheniidites triplex* (Toteşti, slide 18/1). **18** — *G. circinidites* (Toteşti, slide 18/1). **19** — *Retitriletes rotundiformis* (Toteşti, slide 18/1). **20** — *Rouseisporites reticulatus* (Toteşti, slide 19/3). **21** — *Polypodiidites speciosus* (Toteşti, slide 18/1). **22** — *Echinatisporites levidensis* (Toteşti, slide 18/1). **23** — *Sphagnumsporites antiquasporites* (Toteşti, slide 19/2). **24** — *Heliosporites kemensis* (Toteşti, slide 19/3). **25** — *Cicatricosisporites dorogensis* (Toteşti, slide 19/3). **26** — *Schizaeoisporites cicatricos* (Toteşti, slide 18/1). **27** — *Chomotriletes fragilis* (Toteşti, slide 18/1). (Figs.1–9 scale bar = 10 μm; Figs.10–27 scale bar = 20 μm).

Interpretation

Correlation

Due to the lack of quantative data, it is difficult to compare the list (Table 2) of Antonescu et al. (1983) with the data of the present paper. These authors describe the associations from the stratotypes of the Sânpetru and Densuş-Ciula Formations as follows: smooth trilete microspores of the type *Leiotriletes* and *Dictyophyllidites* are dominant, followed by spores with a cingulum like *Polypodiaceoisporites*, disaccate pollen are nearly absent while *Inaperturopollenites* are frequent, pollen of the Normapolles and Postnormapolles group form the foundation of the association. These characteristics apply to the palynomorph associations of the different sites (Table 1, see previous section). *Cicatricosisporites* occurs frequently while Antonescu et al. (1983) indicate that these types of spores are rare in the stratotype sections. Generally the angiosperm taxa observed in this study are very similar to those recognized by Antonescu et al. (1983), although *Pseudopapilopollis praesubhercynicus*, considered by the same authors as an important marker, has not been observed in the studied samples. In spite of these differences, the palynomorph associations allow the correlation of the three sites with the middle member of the Densuş-Ciula Formations and Sânpetru Formation. The absence of volcaniclastic material clearly places the sediments studied within the Sânpetru Formation.

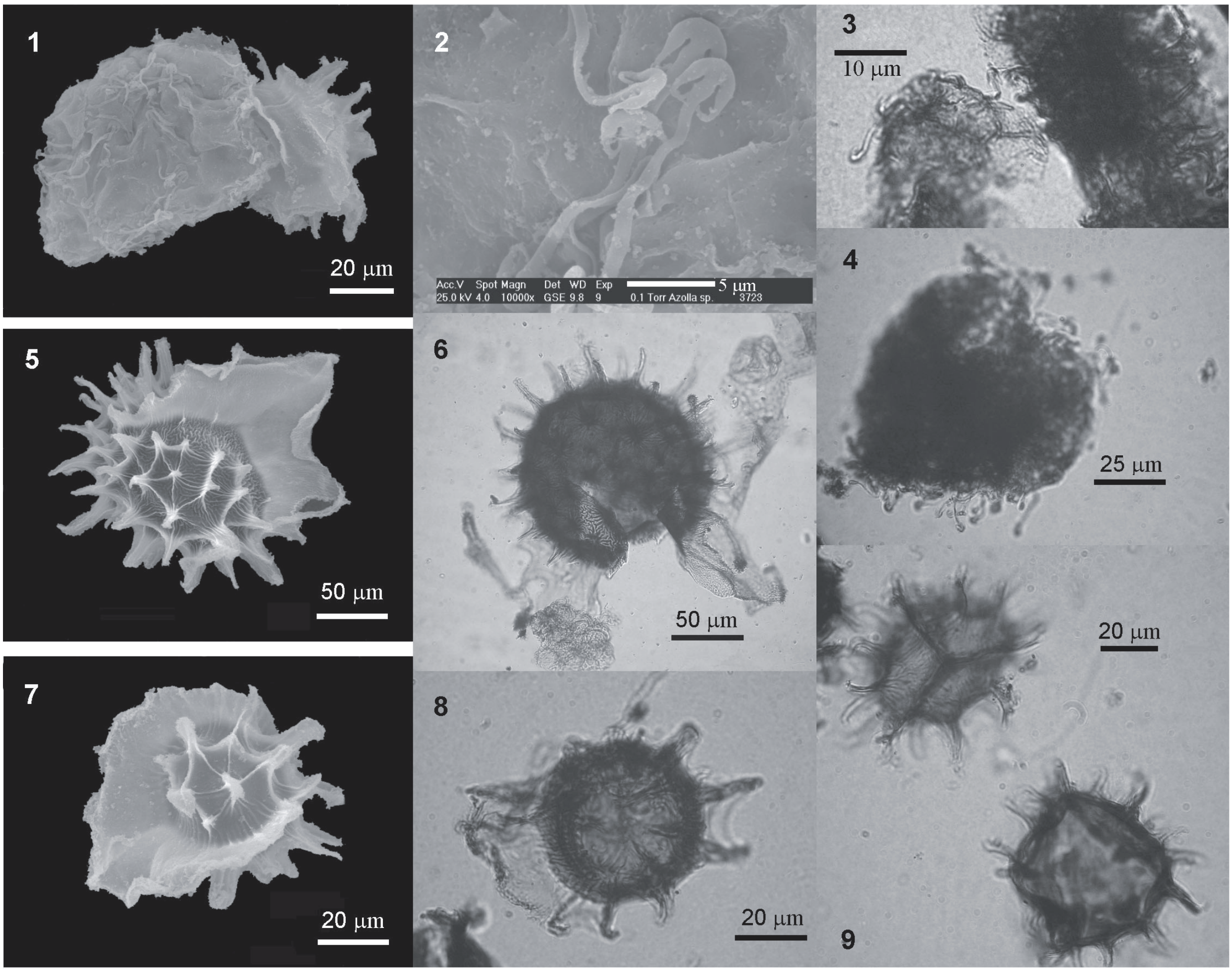

Fig. 4. Megaspores (Nălaţ-Vad)**. 1–2** — *Azolla* sp. with detail of glochidia, SEM. **3–4** — *Azolla* sp. **5** — *Ghoshispora bella* (large), SEM. **6** — *Ghoshispora bella* (large). **7** — *Ghoshispora bella* (small), SEM. **8–9** — *Ghoshispora bella* (small).

Biostratigraphy

The extant genus *Azolla* is known in the fossil record since the Late Cretaceous. From this period, the genus is well-known from Campanian and especially Maastrichtian strata of North America (Batten & Kovach 1989, 1990).

Ghoshispora bella has been recorded from Senonian-Danian deposits (Kondinskaya 1966) and the Maastrichtian of North America: from the Whitemud Formation, Alberta, Canada (Srivastava & Binda 1969), the Edmonton and the Mary River Formation, Alberta, Canada (Snead 1969), the Hell Creek Formation, Montana, U.S.A. (Norton & Hall 1967) and the Lance Formation, Wyoming (Farabee & Canright 1986). Although Srivastava (1971) considers *G. bella* a valuable stratigraphic marker for Maastrichtian strata, Gunther & Hills (1972) observed it throughout the Brazeau Formation (Campanian-Maastrichtian), Alberta, Canada and Speelman & Hills (1980) observed it in the Pakowki, Foremost and Oldman Formations (Santonian-Campanian), Alberta, Canada; therefore the stratigraphic range of this species has to be extended into the Santonian. The megaspore genus *Ghoshispora* has never been recorded in Europe before.

The presence of the genera *Interpollis* and *Nudopollis* clearly place the studied dinosaur-bearing strata within the Maastrichtian (Goczan et al. 1967).

The spore assemblage, rich in taxa and dominated by Cyatheaceae, Gleicheniaceae, Schizaceae, resembles the palynozone A of Ashraf & Erben (1986), which occurs in the lower Rognacian and the lower Garumnian (regional stages of the Early Maastrichtian). With the new positioning of the Campanian–Maastrichtian boundary (Odin & Lamaurelle 2001), the age of the lower Rognacian has been revised as Late Campanian-Early Maastrichtian (Garcia & Vianey-Liaud 2001; Cojan et al. 2003).

Portniaghina (1971, 1973, 1981) established a palynological zonation for the flysh deposits of the Skale Zone of the Carpathians. Campanian and Early Maastrichtian palynozones are characterized by abundant Normapolles grains. Campanian associations are dominated by forms with long annuli and oculi. The Early Maastrichtian associations are characterized by the absence of typical Campanian taxa like *Lusatipollis* and *Longanulipollis*, by the presence of *Convexipollis* and by a variety of species of *Interporopollenites*, *Plicapollis*, *Pseudopapilopollis* and *Trudopollis*. Upper Maastrichtian deposits

Table 2: Palynomorph taxa from the stratotypes of the middle member of the Densuş-Ciula Fomation (Ciula locality), of the Sânpetru Formation (Sibişel locality) (Antonescu et al. 1983) and Toteşti borehole (Stancu et al. 1980).

Sibişel

Convexipollis cf. *convexigerminalis* Krutzsch, 1967
Oculopollis cf. *baculotrudens* (Pflug) Zaklinskaya, 1963 cf.
Oculopollis sibiricus Zaklinskaya, 1963
Papilopollis? spp.
Plicapollis cf. *conserta* Pflug, 1953
Pseudopapillopollis praesubhercynicus (Goczan) Goczan, 1967

Toteşti

Callidasporites sp.
Carnisporites granulatus Schulz
Cyathidites minor Couper, 1953
Dictyophyllidites equiexinus (Couper) Dettmann, 1963
Leiotriletes maxoides Krutzsch
Plicifera delicata (Bochovitina) Bolchovitina, 1968
Polycingulatispotites reduncus (Bolchovitina) Playford et Dettmann, 1965
Triporoletes asper Srivastava, 1972
Oculopollis semimaximus Krutzsch
Oculopollis orbicularis Goczan, 1964
Plicapollis serta Pflug, 1953
Suemeghipollis triangularis Goczan, 1964
Concentricystes sp.
Deflandrea sp.

Ciula

Azolla sp.
Cicatricosisporites spp. (rare)
Corrugatisporites toratus Weyland et Greifeld, 1953
Dictyophyllidites spp.
Echinatisporites longechinus Krutzsch, 1959
Laevigatosporites spp.
Leiotriletes spp.
Polypodiisporites spp.
Polypodoaceoisporites spp.
Spore type B
Triletes sp.
Triporoletes cf. *tornatilis* Srivastava, 1972
Triporoletes spp.
Zlivisporites blanensis Pacltova, 1961
Inaperturopollenites sp.
cf. *Comptonia* sp.
cf. *Engelhardtioidites* sp.
Interporopollenites cf. *gracilis* Krutzsch, 1960
Interporopollenites proporus Weyland et Greifeld, 1953
Liliacidites sp.
cf. *Minorpollis* sp.
Oculopollis cf. *baculotrudens* (Pflug) Zaklinskaya, 1963
Oculopollis cf. *orbicularis* Goczan, 1964
Papilopollis spp.
Pistillipollenites sp.
Plicapollis cf. *conserta* Pflug, 1953
Plicapollis cf. *pseudoexcelsus* (Krutzsch) Krutzsch, 1961
Pseudoculopollis sp.
Pseudopapilopollis praesubhercynicus (Goczan) Goczan, 1967
Pseudoplicapollis peneserta (Pflug) Krutzsch, 1967
Semioculopollis praedicatus (Weyland et Krieger) Krutzsch, 1967
Spermatites spp.
Subtriporopollenites aff. *constans* Pflug, 1953 subsp. 1 & 2
Suemeghipollis triangularis Goczan, 1964
Tricolpites sp.1 & 2
"*Tricolporites* sp."
Tricolporopollenites spp.
Trudopollis ex gr. *imperfectus* (Pflug) Pflug, 1953
Trudopollis? spp.
Vacuopollis sp.

have yielded associations where species of *Extratripotopollenites*, *Subtriporopollenites*, *Tetrapollis* and *Trudopollis* are more abundant and older Normapolles taxa like *Quedlinburgipollis* and some species of *Oculopollis* are absent. On the basis of these characteristics, the continental sediments of the Haţeg Basin show a good correlation with the Maastrichtian strata of the flysch deposits of the Skale Zone of the Carpathians.

Antonescu et al. (1983) used *Pseudopapilopollis praesubhercynicus* to correlate the strata of the Haţeg Basin with the Upper Maastrichtian strata of Hungary. The absence of this taxon makes the correlation with the Senonian sediments of Hungary less clear. According to Goczan & Siegl-Farkas (1990), *Subtriporopollenites constans* is a characteristic species of the Hungarian Upper Maastrichtian and therefore, in spite of the absence of *P. praesubhercynicus* in our samples, the correlation with the *Palaeostomocystis bakonyensis*-*Pseudopapillopollis praesubhercynicus* Assemblage Zone, characteristic for the Hungarian Upper Maastrichtian, is maintained. In the new integrated biostratigraphy for the Romanian Cretaceous (Ion et al. 1998), Antonescu considers *P. praesubhercynicus* as the marker species of the uppermost Lower Campanian to the lowermost Lower Maastrichtian. Due to the absence of any of the marker-species, the associations studied (Table1) could not be fitted into the zonation as proposed by Ion et al. (1998). Further comparison with Romanian palynomorph associations of Maastrichtian age is impossible due to the lack of published data (Antonescu 2000, p. 9).

The palynological assemblage of the Maastrichtian stratotype (Kedves & Herngreen 1980), more precisely of the Lixhe and Lanhaye Members of the Gulpen Formation is very similar to the associations of the Romanian sites. Both associations have 23 angiosperm taxa in common on the species level (indicated with * in Table 1). Both members have been dated as early Late Maastrichtian (Jagt 2002).

On the basis of the arguments given above, the dinosaur-bearing sediments are considered to be Maastrichtian in age. The good correlation with the early Rognacian and the Lixhe Member of the Gulpen Formation, shows that the age of the three analysed sections can probably be refined to the Early–Late Maastrichtian boundary interval. The palynological evidence presented here corroborates the interpretation of the paleomagnetic data of Panaiotu & Panaiotu (2002), who place the Sânpetru Formation within the 31r-magnetochron (68.7–71.0 Ma).

Paleoenvironment

As stated earlier, the palynomorph association of the sites studied shows a good correlation with palynozone A of the lower Rognacian (Ashraf & Erben 1986). On the basis of the botanical affinities of the observed taxa, these authors demonstrated a tropical to subtropical evidence for this palynozone. The same line of reasoning can be applied on the dinosaur-bearing sediments of the Haţeg Basin. The presence of calcrete paleosols has been demonstrated for the sections studied in the present paper by Van Itterbeeck et al. (2004) and for other sections in the Haţeg Basin by Grigorescu & Anastasiu (1990) and Grigorescu & Csiki (2002). According to Mack & James (1994), these type of paleosols are characteristic of the dry subtropical climatic zone. Thus the climate, during the deposition of the dinosaur-bearing sediments of the Haţeg Basin, is interpreted as subtropical.

This climatic interpretation is supported by the presence of the *Azolla* and *Ghoshispora* megaspores. *Azolla* is a free floating water fern in freshwater ponds and lakes in a perennially to seasonally wet tropical to warm-temperate habitats (Yi et al. 2003). *Ghoshispora bella*, also a freshwater fern (Kondinskaya 1966), is frequently found together with *Azolla* (Srivastava 1971) and thus indicative of similar ecological conditions. These megaspores together with freshwater algae like *Chomotriletes* (= *Concentricystes*) clearly prove that the sediments of sample NVD7 were deposited in a freshwater pond. Indeed, based on sedimentology, these sediments have been interpreted as abandoned channel deposits (Van Itterbeeck et al. 2004).

Exposures of Upper Cretaceous continental sediments were not reported in the Râul Mare Valley prior to the discovery of the Toteşti-baraj and Nălaţ-Vad sites (Codrea et al. 2002; Smith et al. 2002). They were reported, however, from the subsurface (Stancu et al. 1980) with data on their palynological content (Table 2). The dinoflagellate cyst *Deflandrea* sp. is mentioned from the borehole sediments but has not been found in the outcrop samples. This type of cyst is known from lagoonal, estuarine and brackish water sediments (Powell et al. 1996, p. 170; Stover et al. 1996, p. 716) and therefore the continental environments of the dinosaur sites were located close to the ancient shoreline.

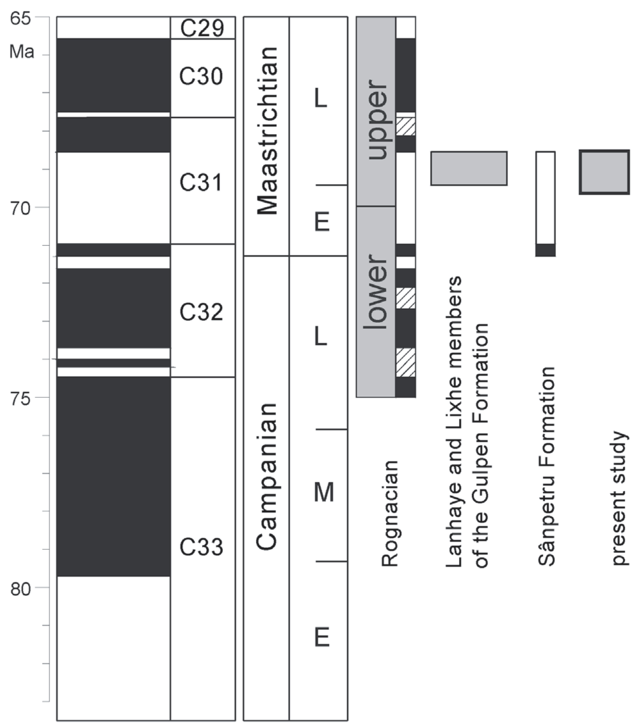

Fig. 5. Summary diagram with the Campanian and Maastrichtian geochronology and magnetostratigraphy (Gradstein et al. 1995) with the age and magnetostratigraphy of the Rognacian (Galbrun 1997; Garcia & Vianey-Liaud 2001), the age of the Lixhe and Lanhaye members (Jagt 2002), the magnetostratigraphy of the Sânpetru Formation (Panaiotu & Panaiotu 2002) and the estimated age of the Barbat and Râul Mare sites.

Conclusions

The palynomorph associations of three important vertebrate sites (Pui, Toteşti-baraj and Nălaţ-Vad) perfectly match the characteristics of the palynology of the stratotypes of the Densuş-Ciula and Sânpetru Formations as given by Antonescu et al. (1983). The absence of volcanoclastic layers typical of the Densuş-Ciula Formation, clearly places the studied sediments within the Sânpetru Formation.

The associations show a good correlation with palynozone A as described by Ashraf & Erben (1986) from the lower Rognacian (France) and lower Garumnian (Spain) (Late Campanian–Early Maastrichtian). There is also a good correlation with the palynomorph associations of the Maastrichtian stratotype (Kedves & Herngreen 1980). On the basis of these correlations and the general taxonomic composition of the associations (Fig. 5), the age of the vertebrate sites from the Râul Mare and Barbat Valleys is estimated as Maastrichtian and can be refined to the Early/Late Maastrichtian boundary interval. The palynological data corroborates the age estimations for the Sânpetru Formation of Panaiotu & Panaiotu (2002).

According to the palynology, the ancient vegetation can be characterized as an open vegetation dominated by ferns and bryophytes with some disperse flowering plants and a few gymnosperm trees under a subtropical paleoclimate. In the floodplain ponds, freshwater ferns with megaspores like *Azolla* and *Ghoshispora* flourished.

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