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PALEOENVIRONMENTAL RECONSTRUCTION OF LATEST CRETACEOUS DINOSAUR-BEARING FORMATIONS OF ROMANIA: PRELIMINARY RESULTS

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Rezumat

Reconstituiri de paleomediu pentru formațiunile purtătoare de dinozauri din Romania: rezultate preliminare

Paleomediile în care dinozaurii şi alte organisme contemporane lor au trăit pot fi reconstituite studiind contextul stratigrafic, sedimentologic şi paleopedologic a trei dintre localitățile Cretacic târzii purtătoare de dinozauri, aparținând la două formațiuni distincte: Formațiunea de Sânpetru (valea Sibişelului şi valea Râului Bărbat) din Bazinul Hațeg şi partea superioară a Stratelor de Bozeş din apropierea localității Vințu de Jos, din Depresiunea Transilvaniei.

Echipa formată din cercetători ai celor două instituții îşi propune de asemenea să determine intervalul de timp reprezentat de aceste depozite cât şi poziția limitei Cretacic/Terțiar în coloanele stratigrafice, acolo unde există.

Abstract

The paleoenvironments in which dinosaurs and other contemporaneous organisms lived can be reconstructed by studying the stratigraphic, sedimentologic, and paleopedologic contexts of three latest Cretaceous dinosaur-bearing localities, pertaining to two distinct formations (Sânpetru Formation in the Hațeg Basin and Vințu de Jos strata in the Transylvanian Depression). In the Sibişel Valley, the Sânpetru Formation is characterized by relatively thin sandstone-dominated fining-upward sequences, shallow and narrow channel-shaped sandstone bodies, limited variability of paleocurrent direction, and weakly-developed, drab-colored paleosols with an increase in the abundance of redoximorphic features (mottles) up-section. Combined with the concentration of fossil remains in sandy fossiliferous pockets interpreted as abandoned channels, these features suggest deposition in a rapidly changing, aggrading bedload-dominated system, such as braided streams, where the watertable probably reached surface expression for a significant (25-50%) part of the year. However, the occurrence of mottles higher in the section indicates fluctuation in watertable level and a transition to a

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better-drained floodplain. Along the Bărbat River, fining-upward sequences of the Sânpetru Formation differ in being dominated by red mudstone and fine sandstone. Channel deposits are usually thin and exhibit a moderate variability of paleocurrent direction. Paleosols exhibit well-developed horizons containing carbonate nodules, slickensides, mottles, and fossil remains. These features suggest deposition in a rapidly aggrading and avulsing, mixed- to suspension-load dominated fluvial system, possibly meandering rivers. The paleosols were probably formed under a semi-arid to arid climate as suggested by the carbonate nodules, but the occurrence of mottles and slickensides indicate that wetter conditions did occur, possibly related to seasonal precipitation. The continental deposits exposed near the village of Vințu de Jos ("Bozeş Strata") consist in thick fining-upward sequences dominated by pedogenically-modified red mudstones. Carbonate nodules are ubiquitous in these deposits, rarely constrained within a well-defined horizon but occasionally forming well-cemented caliche layers. Paleosols, which appear to have a high smectitic content, also contain rhizocretions, slickensides, and fossil remains; mottles are extremely rare. Laterally extensive sandstone sheets dissect the thick overbank deposits; thick and wide channel-shaped sandstone bodies as well as inclined heterolithic strata, formed by point bar migration, are occasionally present. All these features suggest deposition in a rapidly aggrading, suspension-load dominated system, such as meandering rivers. The paleosols record semi-arid to arid climatic conditions with alternating wet-dry periods and a relatively low watertable that rarely fluctuated on the floodplain. Preliminary paleomagnetic analyses of the Sânpetru Formation (Sibişel Valley) reveal that, if the K/T boundary is located in the upper part of the section, the basal most deposits may be as old as early to middle Maastrichtian.

INTRODUCTION

Fossiliferous continental deposits of Late Cretaceous (late Maastrichtian?) age are well known from the Southern Carpathians, Transylvania, southwestern Romania. The Densuş-Ciula and Sânpetru formations, both found in the Hațeg Basin, and the Vintu de Jos strata, from the Transylvanian Depression (Fig. 1), have yielded remains of dinosaurs, pterosaurs, crocodilians, turtles, and multituberculates for over a century (NOPCSA, WEISHAMPEL, GRIGORESCU, and others), thus producing one of the most diverse and best preserved latest Cretaceous dinosaurian fauna of Europe (WEISHAMPEL et al. 1991; WEISHAMPEL and JIANU, in press). In one of these sequences (the Sânpetru Formation) dinosaur remains, otherwise common, are reportedly absent from the last 200 m of the section, and Paleogene bivalves and gastropods are found above that level, which have led paleontologists to suggest that continuous deposition occurred across the Cretaceous/Tertiary boundary (LAUFER 1925; WEISHAMPEL et al. 1991; GRIGORESCU 1992). Unfortunately, this possibility has yet to be confirmed by independent methods, such as magnetostratigraphy and geochronology, and no detailed paleoenvironmental study of the deposits has been published in nearly two decades (GRIGORESCU 1983).

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Here, we present preliminary results from fieldwork conducted in the Haţeg Basin during the summers of 2000-2001 by the Johns Hopkins University - Muzeul Civilizaţiei Dacice şi Romane (Deva) collaboration team. The goals of this renewed collaboration are to: 1) construct composite stratigraphic sections for the Sânpetru Formation (both along the Sibişel and Bărbat Rivers) and Vinţu de Jos strata; 2) determine the time interval represented by these deposits and establish the position of the K/T boundary (if present) in the sections, and; 3) study the sedimentologic setting and faunal composition of fossil localities and correlate each of them to the composite sections in order to determine the nature of the biodiversity and paleoenvironmental changes that occurred in the latest Cretaceous of Romania.

This research is particularly timely because López-Martinez et al. (2001) have recently claimed that the Transylvanian deposits may not be late Maastrichtian in age and, therefore, could not record the latest Cretaceous extinction of dinosaurs. The question as to whether the reported disappearance of dinosaurs (and possibly other taxa) from the Transylvanian deposits, or the decrease in abundance of their remains, can alternatively reflect a preservational bias (possibly due to a change in depositional setting), a regional extinction event (due to local causes) prior to the K/T boundary, or an extinction contemporaneous with the worldwide mass extinction observed at the K/T boundary requires immediate elucidation.

GEOLOGY

Four rock formations of Late Cretaceous age are exposed in the Southern Carpathians: 1) the Densuş-Ciula Formation; 2) the Sânpetru Formation; 3) the Rusca Montană Formation, and; 4) strata exposed in proximity of Vintu de Jos (Fig. 1). Both the Densuş-Ciula and the Sânpetru formations are found in the Haţeg Basin, an intramontane post-orogenic basin. These formations are thought to be contemporaneous on lithostratigraphic and paleontological bases (at least to some extent; see ANTONESCU et al. 1983; WEISHAMPEL et al. 1991; GRIGORESCU 1992, and references therein). The Rusca Montană Formation, part of the post-orogenic Rusca Montană Basin, is located west of the Haţeg Basin and is considered in part contemporaneous to it on the basis of pollen, flora, and freshwater gastropods (ANTONESCU et al. 1983). The Vinţu de Jos strata are found approximately 50 km to the NE of the Haţeg region. Some authors have suggested, on the basis of similar dinosaurian fauna and palynology (IANOVICI et al. 1976; ANTONESCU et al. 1983), that these strata may be contemporaneous with the Haţeg Basin formations.

The stratigraphy and paleontology of the Densuş-Ciula and Rusca Montană formations have been the subject of extensive studies (e.g. BALTES 1966; DINCA et al. 1972; DUŞA and BARILA 1973; DINCĂ 1977; POP and PETRESCU 1983; STRUTINSKI 1986; GRIGORESCU et al. 1990a,b; GRIGORESCU 1992, 1993; PĂTRAŞCU et al. 1993; GRIGORESCU et al. 1994; CSIKI and GRIGORESCU 1998, 2000). However, exposures of these formations are limited (often as small outcrops along

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creeks) and located far from each other, precluding the construction of a reliable composite section. Furthermore, Dr. Dan Grigorescu and collaborators from the University of Bucharest have been conducting fieldwork and documenting the few exquisite outcrops for several years (GRIGORESCU et al. 1990; GRIGORESCU 1992; GRIGORESCU et al. 1994; CSIKI and GRIGORESCU 1998, 2000). For these reasons and to prevent overlapping and repetitive research, the Densuş-Ciula and Rusca Montană formations will not be considered in this project. Instead, the focus will be on the Sânpetru Formation and the Vințu de Jos strata.

The Sânpetru Formation

Exposed in the central part of the Hațeg Basin, the Sânpetru Formation is the best exposed and most fossiliferous of the Late Cretaceous Transylvanian formations. About 2,500m thick (Fig. 2; NOPCSA 1905), the Sânpetru Formation consists of laterally continuous, medium- to fine-grained, red and green terrigenous deposits with lenticular conglomeratic beds. Along the Sibişel River, where the best and stratigraphically highest outcrops of the Sânpetru formation are exposed (Fig. 2), two members are recognized: a lower member in which pyroclastic material is an important matrix component and red clays are common; and an upper member with abundant conglomeratic beds, more common andesitic tuffites, and the red clays are replaced by gray-blackish clays in the section (GRIGORESCU 1983, 1992; WEISHAMPEL et al. 1991). Depositional interpretations of the Sânpetru Formation have varied from an exclusively lacustrine environment (NOPCSA 1905), to braided streams in a distal alluvial fan setting (GRIGORESCU 1983; Weishampel et al. 1991), to a meandering fluviolacustrine system (GRIGORESCU 1992). The generally coarser upper member is inferred to represent an increase in uplift and erosional rates due to subduction along the Tethyan margin of the continent (BURCHFIEL 1980; GRIGORESCU 1983; WEISHAMPEL et al. 1991; WILLINGSHOFER 2000).

Fossil remains discovered in the Sânpetru Formation along the Sibişel River represent the best-preserved and most diverse Late Cretaceous fauna of Europe (WEISHAMPEL et al. 1991; WEISHAMPEL and JIANU, in press). Disarticulated remains of chelonians, dinosaurs (theropods, ornithopods, sauropods, and ankylosaurs), pterosaurs, squamates, crocodilians, and multituberculates have been recovered from these deposits and studied for over a century (NOPCSA 1897, 1900, 1902a,b, 1904, 1915, 1923, 1928, 1929; GRIGORESCU and KESSLER 1980; JIANU 1992, 1994; WEISHAMPEL et al. 1993; WEISHAMPEL and JIANU 1996, in press; JIANU and WEISHAMPEL 1997; CSIKI and GRIGORESCU 1998, 2000; BUSCALIONI et al. 2001). GRIGORESCU (1983) proposed an ecosystem model for the Sânpetru fauna, in which specific taxa preferably inhabited distinct habitats, but did not explain how these conclusions were reached. Recently, CSIKI (1995) recognized evidence of habitat partitioning amongst Sânpetru dinosaurians. Sânpetru freshwater gastropods and pollen are similar to those found in the Densuş-Ciula Formation (ANTONESCU et al. 1983) and macrofloral remains, although rare (fragmentary ferns and palm trees), suggest a subtropical climate (ANTONESCU et al. 1983;

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GRIGORESCU 1992). It is in the last 200m of Sânpetru Formation exposed along the Sibişel River that dinosaur remains are allegedly absent and Paleocene gastropods found, thus suggesting continuous deposition across the K/T boundary (LAUFER 1925; WEISHAMPEL et al. 1991; GRIGORESCU 1992).

About 15km to the southeast of the Sibisel Valley, red sandstones and conglomerates outcropping in the bed of the Bărbat River, near the village of Pui, have been attributed to the lower member of the Sânpetru Formation on the basis of lithological and paleontological similarities (Fig. 2; NOPCSA 1905; GRIGORESCU et al. 1985). However, direct correlation of strata between the two sites is thus far impossible. Even though exposure is limited, an extremely diverse fauna, including gastropods, fishes, amphibians, turtles, squamates, crocodilians, dinosaurs, and multituberculates, has been recovered from these deposits (NOPCSA, 1905; GRIGORESCU et al. 1985; RĂDULESCO and SAMSON 1986; GRIGORESCU and HAHN 1987; CSIKI and GRIGORESCU 1998, 2000).

Although sedimentologic and taphonomic studies have been conducted for the exposures along the Sibişel River (GRIGORESCU 1983), no stratigraphic nor paleopedologic work has ever been published on the Sibişel outcrops, and a strong geologic framework is still lacking for the Barbat deposits. The main obstacles that have deterred scientists from building composite stratigraphic sections consist of hazardous outcrops, limited exposure (due to vegetation along the Sibişel River and to Quaternary cover along the Bărbat River), and the great thickness of the Sânpetru Formation. However, the preliminary results present here demonstrate that composite sections and detailed sedimentologic and paleopedologic studies of these deposits can be done.

The Vințu de Jos strata

Approximately 50 km to the north-east of the Hațeg Basin, south-east of the Trascău Mountains, near the towns of Alba Iulia and Vințu de Jos, continental red beds of Maastrichtian age are exposed (ANTONESCU 1973; ANTONESCU et al. 1983). Ranging in thickness from several tens of meters to 1,500 m, these deposits are part of the Transylvanian Depression, a structure that was formed by tectonic subsidence due to the Carpathian orogenies. These strata, sometimes referred to as the "Bozeş Strata" (IANOVICI et al. 1976), consist of red mudstones and tuffaceous sandstones and conglomerates, deposited in a fluviolacustrine setting (GRIGORESCU 1992).

Both vertebrate and plant remains have been recovered from these strata. Remains of gastropods, chelonians, ornithopods, theropods, ankylosaurs, and a possible dinosaur tracksite have been discovered (NOPCSA 1905; GRIGORESCU 1987; JIANU, pers. obs.). Floral diversity, as indicated by microspores, pollen, and macrofossils, was extremely high and included charophytes and palm trees (ANTONESCU 1973; ANTONESCU et al. 1983; GRIGORESCU 1992). As stated above, the Vințu de Jos strata have been correlated, on the basis of faunal and floral assemblages, with the continental sequences exposed in the Hațeg and Rusca Montană basins (ANTONESCU 1973; ANTONESCU et al. 1983).

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Thus far, the stratigraphy and sedimentology of the Vințu de Jos strata have not been the subject of any detailed investigation. Since they are contemporaneous with the Sânpetru Formation, a study of the paleoenvironments represented by these deposits is essential to gain a better understanding of the latest Cretaceous Transylvanian biotas and any changes that may have occurred near the K/T boundary. A composite stratigraphic section of the outcrops situated near Vințu de Jos has already been reconstructed (see below) and detailed paleopedologic and sedimentologic studies can now be conducted.

PRELIMINARY RESULTS

The stratigraphic complexity of continental deposits always presents a major obstacle to any detailed study of vertebrate faunas, paleoenvironments, and evolutionary trends. It is therefore necessary to: 1) have a strong stratigraphic control over the deposits, through the use of composite stratigraphic sections of the Sânpetru Formation (both along the Sibişel and Bărbat Rivers) and Vințu de Jos strata; 2) determine the time interval represented by these deposits and establish the position of the K/T boundary in the section, via geochronology and magnetostratigraphy; and, 3) study the sedimentologic setting and faunal composition of fossil localities and correlate each of them to the composite sections, via megascopic, microscopic, and geochemical studies. To attain these objectives, collaboration between the Functional Anatomy and Evolution Program of the Johns Hopkins University (Baltimore, Maryland, U.S.A.) and Ms. CORALIA-MARIA JIANU of the Muzeul Civilizației Dacice şi Romane, Deva (Romania), has been established. The fieldwork permits required have been obtained from the Romanian Academy of Science (Bucharest) through Ms. JIANU and Dr. SILVIA BURNAZ. Fieldwork has been conducted during the summers 2000 and 2001 and preliminary results obtained during these two field seasons are presented here.

1. Composite stratigraphic sections

A strong stratigraphic control over the fossiliferous localities and paleoenvironmental indicators (paleosols and fluvial sequences) is necessary to recognize any changes (i.e. in fluvial system, hydrology, climate, biodiversity) occurring through space and time; such control can be gained from composite stratigraphic sections of the different formations.

To construct the composite sections for the different formations, local stratigraphic sections are measured along the steep slopes and cliff faces of the foothills of the Southern Carpathians, some reaching heights of nearly 70m and slopes in excess of 45^{o}. Local sections are correlated to each other in the field by laterally tracing recognizable beds; when the marker beds can no longer be recognized, at a distance ranging usually from a few tens to hundreds of meters, a second section is then measured. This method ensures a precise and accurate way of correlating each measured section in order to reconstruct the composite section (see THERRIEN et al. 2000).

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As part of the preliminary work, complete composite sections for the Sânpetru Formation, as exposed along the Bărbat River near Pui, and the Vințu de Jos strata have been constructed. A composite section for the exposures along the Sibişel River, also pertaining to the Sânpetru Formation, is under way but, due to the extreme thickness of these deposits, is not yet complete.

Sânpetru Formation – Sibişel River

The Sânpetru Formation is moderately well exposed along the Sibişel River (45°32.62'N 22°54.57'E), which flows north through the tall Southern Carpathian foothills. Although vegetation cover is abundant, it is possible to physically trace laterally continuous beds from one location to another. It may be that the great thickness of exposed strata (possibly close to 1000 m), the numerous covered intervals, and the steepness of the hills previously hindered detailed stratigraphic work in the area. Nevertheless, a composite stratigraphic section is necessary to document any paleoenvironmental and/or biodiversity changes, especially since it is toward the top of the formation that the K/T boundary is thought to be located (Fig. 2), and one of us (F.T.) has so far constructed such a composite section for the basal most 175 m of outcrop (Figs. 2 and 3). The section was measured with a Jacob staff and by taking under consideration the strike and dip of the strata, approximately 23°N and 36° to the northwest respectively.

Sânpetru Formation – Bărbat River. Exposures of the Sânpetru Formation near Pui are limited to the Bărbat River bed and to abandoned channels where the river has eroded through the superficial Quaternary deposits (45°30.70'N 23°05.69'E). Consequently, detailed study of the stratigraphy and sedimentology (at the cm scale) can only be achieved when the water level is low, which is probably one of the reasons why no composite stratigraphic section of this area has been compiled until now.

Previously estimated at a thickness of 200 m (GRIGORESCU et al. 1985), the present composite section reveals that the total thickness of the deposits exposed along the Bărbat River is approximately 102 m (Fig. 4). The current thickness was obtained by measuring units using a Jacob staff and by taking under consideration the strike and dip of the strata, approximately 090°N and 14° to the south respectively.

Vințu de Jos strata

These strata are exposed in the hills on the north shore of the Mureş River. Due to limited exposures and the distance between outcrops, no composite section of the entire formation has ever been measured. Although only representing the uppermost part of the sequence, we present here a composite stratigraphic section for the visible outcrops (i.e. not covered by vegetation) near the village of Vințu de Jos (Fig. 5).

Outcrops can be seen on two hills (eastern and western) at the base of the Metaliferi Mountains, approximately 1 km distant from one another. For this reason, two composite sections, one for each hill (easternmost 46°01.78'N 23°30.02'E, westernmost 46°00.63'N 23°28.53'E), have been

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measured using a Jacob staff and by taking under consideration the strike and dip of strata, approximately 350^{o}N and 25^{o} to the east respectively.

2. Determination of the age of the strata

Two means of determining the age and time interval represented by the strata will be used: magnetostratigraphy and radiometric dating.

Magnetostratigraphy

Paleomagnetic analyses have been conducted in the past on Haţeg and Rusca Montană deposits (PĂTRAŞCU and PANAIOTU 1990; PĂTRAŞCU et al. 1993), but solely for the purpose of determining the paleogeographic position of the Haţeg Basin. No attempt was made to use magnetostratigraphy as a dating method, which may be primarily related to the lack of stratigraphic control over the deposits. By constructing composite stratigraphic sections of the Sânpetru Formation, it will be possible to follow a tight sampling method (one sample every five meters of section) and establish the magnetostratigraphy of these deposits. When possible, samples will be drilled as oriented one-inch cores. However, for poorly-cemented sediments we will take oriented hand samples. Paleomagnetic samples will be analyzed using either AF or thermal demagnetization to obtain directional results for magnetostratigraphic interpretation. Magnetic susceptibility, ARM, IRM, and hysteresis properties will be measured to determine the magnetic mineralogy and demagnetization behavior of the various facies. Magnetization components will be assessed using Zijderveld plots.

Dr. JOHN KING from the Graduate School of Oceanography – University of Rhode Island (Narragansett, Rode Island, U.S.A.) has agreed to analyze the samples collected. For preliminary study, 29 oriented samples were collected at 5-meter intervals from the Sânpetru Formation (Sibişel Valley, Fig. 3) and analyzed for paleomagnetic properties. These preliminary results demonstrate that a reliable magnetostratigraphy can be obtained. Twenty oriented hand-samples were AF demagnetized at 5.0 mT steps between 0 - 100 mT. Stable results were obtained from 17 of the 20 samples. A preliminary magnetostratigraphy from the Sânpetru Formation is shown in Figure 2b. All paleomagnetic studies were done on an automated 2G-755R U-channel system. Thermal demagnetization was done with a Schonstedt thermal demagnetizer.

When considered in their stratigraphic context, they provide a means to establish the time interval spanned by the deposits. If the K/T boundary is really located in the uppermost part (around the 800m-level) of the Sibişel outcrops, then the preliminary results suggest that the basalmost 175m-interval of the section might be early-to-middle Maastrichtian.

Radiometric dating

Even though deposits from the Sânpetru Formation have been known to be derived, at least in part, from volcanic material for nearly a century (NOPCSA 1905; GRIGORESCU 1983, 1992; WEISHAMPEL et al. 1991), no radiometric analysis has ever been done to establish their absolute age. Even in the case of the Densuş-Ciula Formation, which contains lava flows, ash falls, and reworked

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volcanic material, relative age of the deposits has always been determined by biostratigraphy, mostly on the basis of palynology and similarity of the faunal assemblage with other European faunas.

The presence of dispersed alleged volcanic material in the matrix of sandstone offers the possibility of obtaining primary volcanic minerals for radiometric dating purposes. In the Sânpetru Formation (Sibişel River outcrops) and the Vințu de Jos strata, sandstone and mudstone layers with a good potential for preserving such minerals were sampled for preliminary analysis. Macroscopically, these layers are characterized by being rich in muscovite and by containing angular feldspar grains and, occasionally, small mudclasts.

As preliminary research, four layers from the Sânpetru Formation (Sibişel Valley, Fig. 3) were sampled. Dr. ROLAND MUNDIL from the Berkeley Geochronology Center (Berkeley, California, U.S.A.) has agreed to analyze the samples collected. Unfortunately, none of the samples turned out primary volcanic minerals in sufficient quantity for radiometric dating, but future work is planned to assess to feasibility of sampling appropriate strata (R. MUNDIL, pers. comm., 2001). Geochronology can have a significant impact on this project as when the dated sandstones will be reported in their respective position in the composite sections, a strong temporal control over those sections will be established.

3. Paleoenvironments and faunal assemblages

Once a strong spatial and temporal control has been established over the continental deposits (goals 1 and 2), it will be possible to investigate the nature of the biodiversity and paleoenvironmental changes that occurred during the Late Cretaceous, and especially in the last 200m of the Sânpetru Formation. By studying the sedimentology and stratigraphy of the formation, we will be able to identify changes in depositional and fluvial settings which, when considered in their temporal context, might be correlated to Carpathian tectonics or climatic events (e.g. BURCHFIEL 1980; WILLINGSHOFER 2000). Furthermore, insights into the prevailing paleoclimatic, paleoenvironmental, and paleohydrologic conditions in which vertebrates lived can be gained through a detailed study of paleosol micromorphology and geochemistry (e.g. BOWN and KRAUS 1981a,b; RETALLACK 1983; FASTOVSKY and MCSWEENEY 1987; FEAKES and RETALLACK 1988; MCCARTHY et al. 1998; THERRIEN and FASTOVSKY 2000).

Paleosol micromorphology (i.e. clay coatings, redoximorphic features, carbonate nodules, matrix birefringence, slickensides) and geochemistry (i.e. oxides and trace elements content, clay-mineral composition) can reveal which pedogenic processes (i.e. eluviation, illuviation, gleyization) were active in these ancient soils and help in the identification of paleosol horizons (or paleosol sequences). Since pedogenic processes are dependent on the prevailing climatic conditions, they are useful paleoenvironmental indicators (FASTOVSKY and MCSWEENEY 1987). By comparing paleosol sequences at similar correlated stratigraphic levels, it will be possible to interpret and

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document local variations as differences in habitat (e.g., THERRIEN and FASTOVSKY 2000). Global pedogenic differences occurring across various stratigraphic levels may also represent a paleoenvironmental trend through time preserved in the geologic record. Comparison of paleosols from the two continental sequences under study will reveal similarities and differences in the habitats frequented by dinosaurs and other taxa, which is relevant to the cause(s) of dinosaur disappearance in the last 200m of section in the Sânpetru Formation.

Although the latest Cretaceous faunas of Romania have been extensively studied for their systematic (taxonomic), paleoecological, and paleobiogeographic implications, relatively little has been done in terms of biodiversity changes. In fact, the only comparisons of faunal composition at distinct stratigraphic levels were done at a crude level only (base of the formation versus higher in the formation; e.g., GRIGORESCU 1983). No detailed study of biodiversity trends has ever been published in spite of the quantity of material recovered. This can potentially be due to the lack of stratigraphic control over some of the fossiliferous localities, whether it be the exact stratigraphic position of the localities or their position relative to one another, and the lack of appropriate record of the faunal assemblages discovered (some date back to the late 19th and early 20th century). Hence, this situation prevents any detailed study biodiversity change through time and space. In order to establish a baseline for the study of patterns of faunal change through the sections, known fossiliferous localities for which faunal assemblages have been documented, as well as new discoveries that will be made while constructing the composite sections, will be compiled and integrated in the composite section of their respective formation. This will be done by physically correlating each locality in the field, by laterally tracing marker units (for example, sandstone beds), to the closest measured section used to construct the composite stratigraphic sections, thus conferring an accurate stratigraphic position of the locality as well as a time constraint on its age, provided by the absolute ages of the underlying and overlying volcanic layers and magnetostratigraphy.

Information on the vertebrate assemblages (taphonomy and composition) discovered at each fossil locality and on the paleoenvironmental setting in which the bones are preserved (sedimentology and paleopedology) will be gathered in the field and from the literature when possible. By comparing fossil assemblages at similar correlated stratigraphic levels, it will be possible to study faunal variability across the latest Cretaceous landscape and, possibly, interpret the differences in terms of taphonomy and habitats (CSIKI 1995). The stratigraphic succession of fossiliferous localities within the formations will also reveal whether patterns of change in biodiversity can be observed. In turn, it might be possible to determine if these changes in biodiversity coincided with paleoenvironmental changes and, with the aid of the dating methods described above, if these changes were rapid or gradual, synchronous or diachronous across Romania, and if the disappearance of dinosaurians in the uppermost 200m of the Sânpetru Formation coincide with their worldwide extinction at the K/T boundary.

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As preliminary work, a macroscopic study of the sedimentology, stratigraphy and paleopedologic features has been conducted and the results are presented below. Samples for petrological and micromorphological (thin-sectioning), and geochemical analyses (X-ray fluorescence spectrometry [XRF] and X-ray diffraction [XRD]) have also been collected and analyses are underway (THERRIEN, in prep.).

Sânpetru Formation – Sibişel River

This section consists of stacked "cyclothems" (*sensu* GRIGORESCU 1983) – repetitive fining-upward sequences defined as a basal greenish conglomeratic sandstone overlain by green-gray or reddish brown sandy siltstone and mudstone (Fig. 3). These cyclothems are generally 1m thick, but thickness varies widely (from 0.5m to 5m). The sandstone beds are laterally extensive and shallow and narrow channel-shaped scours are preserved locally. Although generally hard to see, large-scale trough and tabular cross-stratifications with gravel imbrication are present. Coal fragments are common in the sandstones. Paleocurrent indicators exhibit very limited amount of variability, generally between 25^{o}N and 50^{o}N. Channel deposits constitute a significant part of these cyclothems, often as thick or thicker than the fine material portion. The latter only rarely preserve relict sedimentary structures in the form of parallel laminations.

In the lower quarter of the composite section, the siltstones and mudstones are predominantly green and weakly bioturbated, rarely exhibiting root traces and burrows. When present, the roots are often preserved as coal filaments of various sizes. Carbonate nodules are rare to absent in this part of the section. These deposits represent hydromorphic (gleyed) paleosols, depleted in iron, and suggest impeded drainage and reducing condition due to prolonged water saturation periods (25-50% of the year; DANIELS et al. 1971). Red coloration gradually appears up section, due to the appearance of redoximorphic features (iron mottles) in the gleyed matrix. The fine material passes from green to predominantly red through the section, with local occurrence of green mudstones and color zonation appearing in the red deposits. Carbonate concretions are commonly found in these deposits, although some may have a diagenetic origin as they are found in channel deposits preserving sedimentary structures. The mudstones exhibit few root traces, burrows, mottles, and, farther up-section, color zonation, all suggesting pedogenic alteration. Gleyed matrices and redoximorphic features (mottles) are associated with poorly drained paleosols with a high, but fluctuating water table, as mottles are formed under the associated alternation in oxidizing and reducing conditions (e.g., VEPRASKAS 1992).

The redder mudstones, a color due to the abundance of iron oxides (MCBRIDE 1974), represent better-drained and oxidizing conditions. The color zonations represent horizon differentiation within paleosols, probably representing a greater degree of maturity (e.g., BOWN and KRAUS 1981a). Furthermore, since each paleosol sequence is relatively thin, the profile may reflect the alteration of very few stacked flood deposits (*contra* thick composite paleosols; see BIRKELAND 1974; RETALLACK

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1983; KRAUS and BOWN 1986) and provide an unbiased record of the changes in the paleoenvironments of the Sânpetru deposits.

Fragmentary, isolated vertebrate remains are commonly found in the overbank deposits but high concentration of dissociated remains occur, although less frequently, in shallow sandstone lenses. These have been termed "fossiliferous pockets" by GRIGORESCU (1983), which are typical for high-energy, rapidly shifting fluvial systems where fossil remains are preferentially accumulated in abandonned channels (see BEHRENSMEYER and HOOK 1992).

The combination of sedimentologic features – shallow, narrow channel-shaped scours; predominance of large-scale trough cross-stratification in sandstones; limited amount of variability in paleocurrent direction; low proportion of overbank deposits relative to channel deposits; preservation of sedimentary structures and the sandy nature of overbank deposits; the weak development of pedogenic features – suggests deposition in a rapidly changing, aggrading bedload-dominated system, such as braided streams (SCHUMM 1968; CANT 1978; COLLINSON 1978; ETHRIDGE and SCHUMM 1978; JACKSON 1978; BRIDGE 1985), conclusion in agreement with GRIGORESCU's (1983) interpretation.

Within the basal most 150m of section, a clear paleoenvironmental trend from wet habitats to better-drained, drier habitats is also indicated.

Sânpetru Formation – Bărbat River

The stratigraphy and sedimentology of the deposits exposed near Pui differ markedly from even the basalmost Sânpetru strata exposed along the Sibişel River (*contra* NOPCSA 1905 and GRIGORESCU et al. 1985). The section consists of fining-upward sequences dominated (usually a few meters thick) by red mudstones and very fine sandstones occasionally dissected by relatively thin (1m or less) brown to light green conglomeratic sandstone units (Fig. 4). The latter, interpreted as channel deposits, are generally structureless, but occasionally exhibit trough cross-stratifications and gravel imbrication with high variability in paleocurrent direction (from 35^{o}N, through 0^{o}N, to 335^{o}N).

The fine material often exhibits bioturbation, root traces, mottling, carbonate nodules, slickensides, and color zonation, which are interpreted as evidence of pedogenic alteration of overbank deposits. The matrix of the paleosols is consistently red and red-to-purple mottles are occasionally present. Although the red color indicates predominant oxidizing conditions (MCBRIDE 1974), the rare occurrence of mottles suggest that alternating reducing-oxidizing conditions did occur due to fluctuation of the groundwater levels. Carbonate nodules occur in discrete horizons within the stratigraphic section and occasionally well-cemented horizons, interpreted as illuvial calcic (Bk) horizons and caliche layers. These pedogenic features are known to form when pluvial water transporting carbonates in solution evaporates before reaching the water table, such as in highly seasonal or semi-arid climates (GOUDIE 1973, 1983; REEVES 1976; BLODGETT 1988). This interpretation is supported by the occurrence of slickensides in the deposits, indicating seasonal wetting and drying and associated shrinking and swelling of clays (e.g. DUDAL and ESWARAN 1988;

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WILDING and TESSIER 1988). Other evidence for paleosol differentiation includes the dark red horizons that occur throughout the section. Usually possessing a gradational inferior border, these dark red horizons are highly bioturbated, contain slickensides, and consistently occur at the top of paleosol profiles. Furthermore, abundant vertebrate fossil remains occasionally occur in those red horizons (see below). Although geochemical analyses and micromorphological investigation are necessary to interpret the nature of these red horizons, macroscopic features suggest that they may be illuvial B horizons or, potentially, well-preserved A horizons.

At least two microvertebrate localities have been discovered near Pui, one by the University of Bucharest and the second by the Babeş-Bolyai University of Cluj Napoca. In addition, dissociated vertebrate elements have also been recently discovered (a perfectly preserved sauropod vertebra, C.M. JIANU, pers. obs. 2000). All of these remains come from overbank deposits and, at least for the sauropod vertebra and other abundant unidentified remains, are preserved in dark red paleosol horizons.

Even though large-scale sedimentary structures (i.e. inclined heterolithic strata, IHS) were not observed, the variability in paleocurrent direction, the predominance of overbank deposits over channel deposits, and the repetitive nature of those sequences suggest sedimentation in a rapidly aggrading and avulsing, mixed to suspension-load dominated fluvial system, possibly meandering rivers (COLLINSON 1978; JACKSON 1978; BRIDGE 1985). The associated floodplain environment was relatively dry but underwent seasonal water table level fluctuations under a semi-arid to seasonal climate.

Consequently, this detailed sedimentological study casts doubt on the validity of previous claims (NOPCSA, GRIGORESCU, see above) that these outcrops can be correlated to the basal member of the Sânpetru Formation exposed along the Sibişel River solely on the basis of lithological similarity (in this case, color). Although they are contemporaneous, the Bărbat deposits represented here probably reflect distal environments to those of the Sibişel Valley outcrops, although to which precise member of the latter cannot be determined at present.

Vințu de Jos strata

The stratigraphy and sedimentology of the Vințu de Jos strata is reminiscent of the outcrops exposed along the Bărbat River. The sections consist of thick fining-upward sequences dominated by red and brown mudstones with laterally extensive brown and light green sandstone sheets (Fig. 5). In places, deep channel-shaped sandstone bodies are preserved and trough cross-stratification is the dominant sedimentary structure in these deposits. Sedimentary structures indicate extremely variable paleocurrent directions, ranging from 45°N, through 0°N, to 184°N. At least two occurrences of IHS, one in each section, are observed in the Vințu de Jos strata: one of which consists of fining-upward conglomerate-sandstone couplets and the other fining-upward sandstone-mudstone couplets. Although IHS are known from a variety of depositional environments, the orthogonal

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orientation of paleocurrent indicators (gravel imbrication and small-scale trough cross-stratification) relative to the dip of the IHS suggests that they represent lateral accretion surfaces of a migrating point bar (ALLEN 1965; JACKSON 1978; COLLINSON 1978; BRIDGE 1985; THOMAS et al. 1987).

The mudstone exposures in the field have a shrink-and-swell texture, suggesting a significant smectitic content. They are generally structureless and exhibit bioturbation, carbonate nodules, rhizocretions (carbonate crust accumulating around roots in semi-arid to arid environments; RETALLACK 1990), slickensides, and color zonation, all indicating pedogenic alteration; however, only rarely do these paleosols contain mottles. The paleosol sequences are often very thick and characterized by horizons with gradational boundaries and carbonate nodules not constrained within well-defined horizons. These lines of evidence suggest that episodic deposition of material occurred concurrently with pedogenesis, thus contributing to the formation of thick paleosol profiles (composite paleosols and compound pedogenesis; see BIRKELAND 1974; RETALLACK 1983; KRAUS and BOWN 1986). The occurrence of calcic horizons and rhizocretions suggests that evaporation was important, such as in a semi-arid to arid climate. Both the abundance of slickensides and the potentially high smectitic content reflect alternating wet and dry periods. However, the paucity of mottles in the paleosol profiles indicates that the water table rarely reached high levels on the floodplain.

Fossil remains are preferentially preserved in overbank deposits: disarticulated theropod and turtle remains, and petrified wood have been discovered in dark red horizons interpreted as a paleosol (see below) while an associated ankylosaur skeleton has been retrieved from a mudstone overlying a sandstone sheet by a team from the Babeş-Bolyai University of Cluj Napoca (C.M. JIANU, pers. com. 2000).

The great thickness of overbank deposits relative to channel deposits, the presence of IHS, and the great variability of paleocurrent suggest that the Vințu de Jos strata were deposited primarily in a rapidly aggrading, suspension-load dominated system, most assuredly by meandering rivers (ALLEN 1965; JACKSON 1978; COLLINSON 1978; BRIDGE 1985; THOMAS et al. 1987). The paleosols indicate that a semi-arid climate with seasonal precipitation prevailed and that the water table level generally remained low.

SIGNIFICANCE AND CONCLUSION

The ongoing research has great potential to document paleoenvironmental and biodiversity changes in the latest Cretaceous of Romania. The three study areas have been shown to represent different paleoenvironments and give a view as to how contemporaneous faunas adapted to these differences (see also CSIKI 1995). Furthermore, paleoenvironments have been shown to change through the Sânpetru Formation section, which offer the potential to study the ways in which the fauna reacted to the shifting conditions.

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Only with the strong spatial and temporal control over the stratigraphic sequences imparted by the composite sections, geochronological dates, and magnetostratigraphy will it be possible to make strong claims about the biodiversity and paleoenvironmental changes that occurred in the Late Cretaceous of Romania. Once all the known fossil localities are correlated to the closest section used to build the composite stratigraphic sections, it will be possible to determine not only how the faunal assemblages changed through time, but also whether these changes coincided with paleoenvironmental shifts, and what their nature might be.

Even though the study areas are thought to be contemporaneous on palynological and paleontological grounds, the time interval represented by each is still unclear. The degree of temporal overlap between each stratigraphic section so far is unknown and may, in fact, be very limited. Determining the time span represented by each stratigraphic sequence will give insight on the temporal range of the Romanian faunas and on the synchronicity of biodiversity changes.

Finally, the absolute and relative ages of these deposits will reveal whether the K/T boundary is preserved in the continental sequences of Romania and point toward its location. If the continental deposits are not of latest Maastrichtian age, then we will have documented the earlier disappearance of dinosaurians in Romania (prior to the K/T boundary), or at least the decrease in abundance of their remains, in such a way that sheds light on biotic and paleoenvironmental events that took place at the end of the Mesozoic in a tectonically very active and highly complex peri-Tethyan region of central Laurasia. However, if the K/T boundary is present and can be located, it will represent one of the very few terrestrial sections that preserve this time interval in the world. As a consequence, it will be possible to compare the recorded paleoenvironmental and biodiversity changes with those observed in the only other well-documented, contemporaneous continental sequence in the world, the Hell Creek

Formation of western North America

The biodiversity trend could reveal whether the dinosaurian extinction pattern in eastern Europe was sudden or gradual (e.g., SHEEHAN et al., 1991, 2000; SHEEHAN and FASTOVSKY, 1992; ARCHIBALD 1996, 2000), while paleoenvironmental reconstructions, made on the basis of paleosols and fluvial deposits, could indicate if dramatic environmental changes (such as hydrologic and fluvial system changes), similar to those observed in North America (e.g., FASTOVSKY and MCSWEENEY, 1987) occurred at the end of the Cretaceous. This would finally provide the essential information required to compare the tempo and mode of extinction and recovery following a major mass extinction event on a global scale.

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FIGURE CAPTIONS

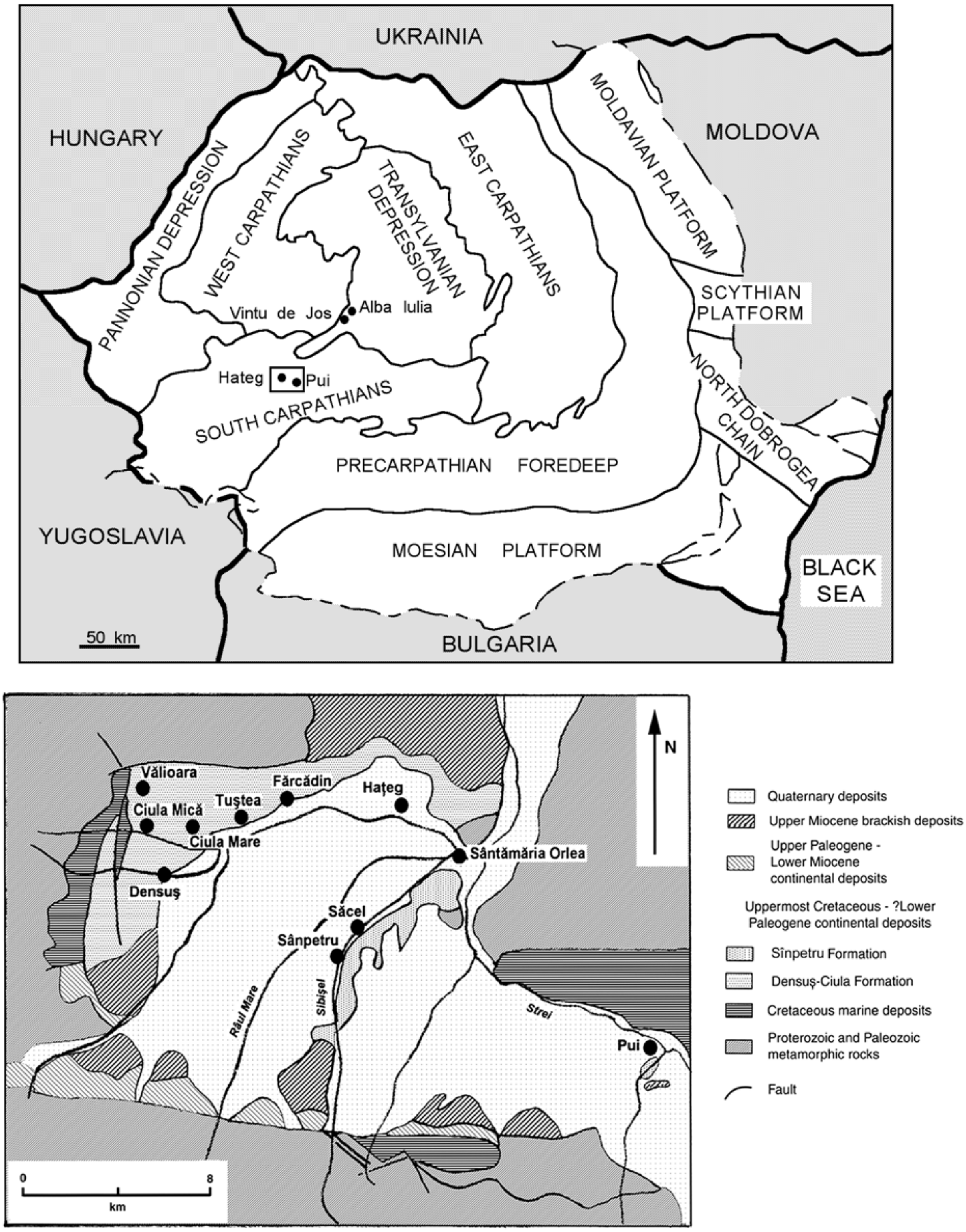

Fig. 1. Map of Romania with major tectonic "provinces." Haţeg Basin is shown in greater detail. Modified from Grigorescu (1992) and Weishampel and Jianu (in press).

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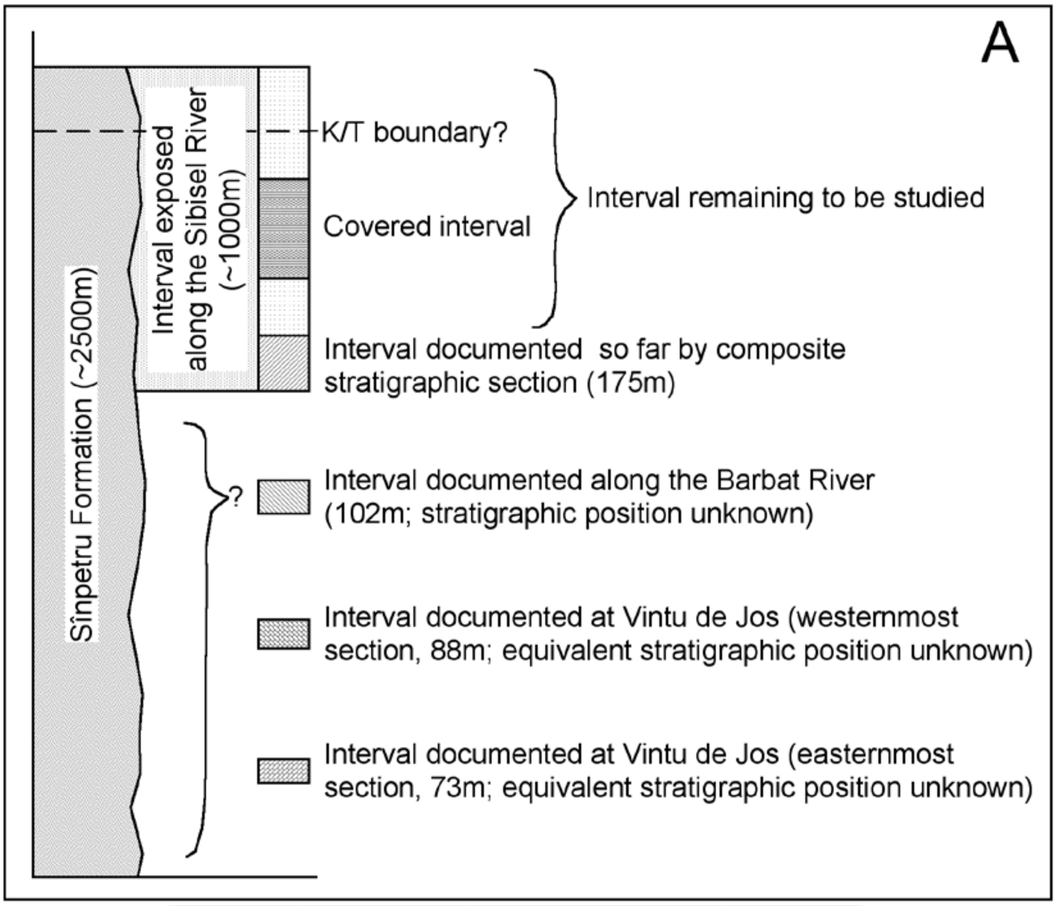

B

Sample	Strike of Arrow	Dip of Arrow	Polarity	Comments
MAG 24	195	14	?	NG
MAG 29	317	06		
MAG 28	221	26		
MAG 27	218	41		
MAG 26	277	00		
MAG 25	202	23		
MAG 23	209	33		
MAG 3	251	23		
MAG 21	020	19		NG
MAG 20	209	32		Intermediate
MAG 19	232	23		
MAG 18	182	02		NG
MAG 17	226	33		
MAG 2	230	33		
MAG 14	226	28		
MAG 12	228	36		
MAG 9	276	31		
MAG 7	231	53		
MAG 6	260	47		
MAG 4	061	59		

Fig. 2. Schematic stratigraphic section of the Sânpetru Formation with relative position of studied interval (A). Preliminary results of paleomagnetic analyses conducted in measured composite section of the Sânpetru Formation along the Sibişel River (B; see Figure 3). Unstable samples are labelled NG.

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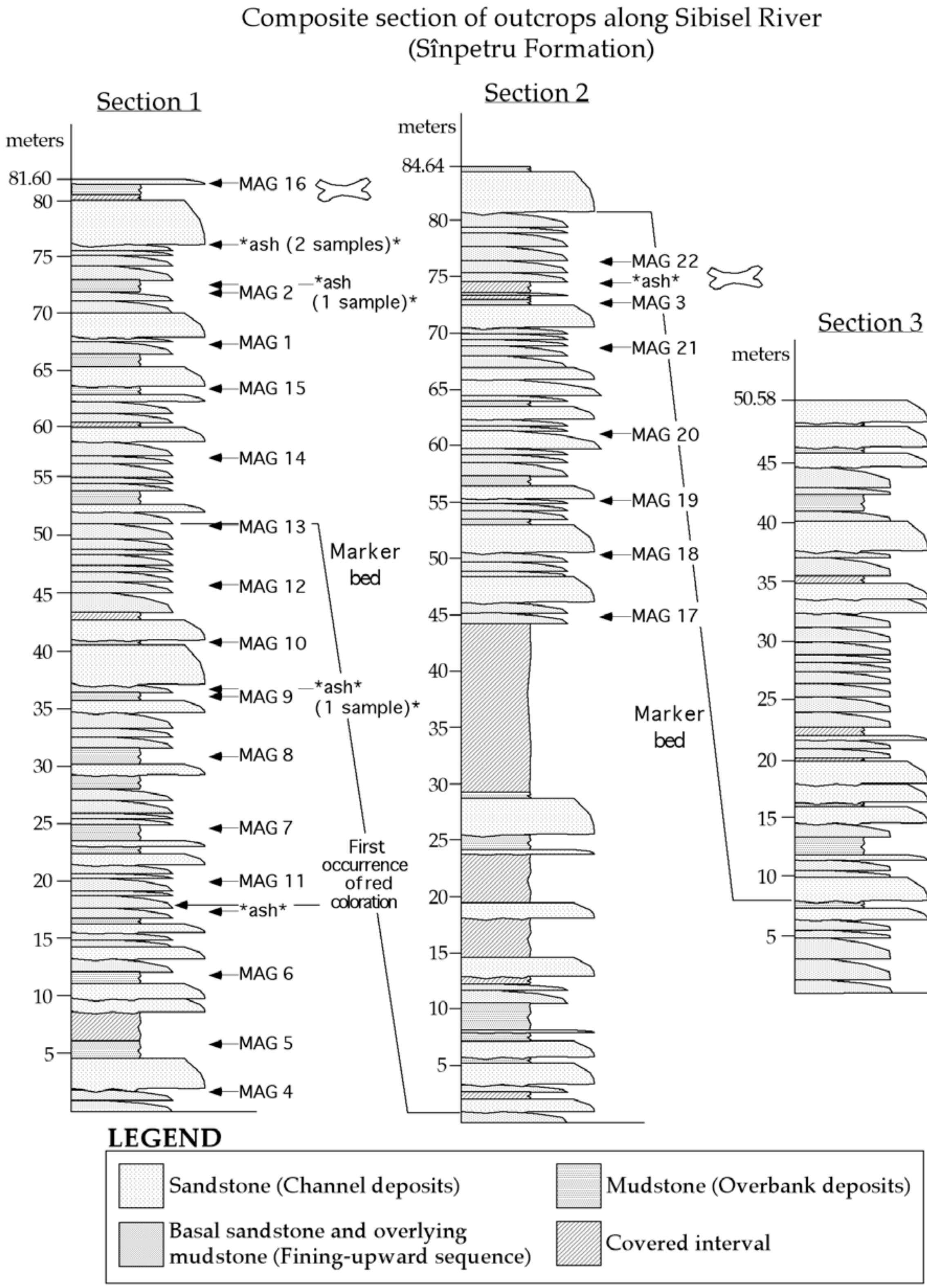

Fig. 3. Composite section of the Sânpetru Formation as exposed along the Sibişel River, near Sânpetru. Stratigraphic position of samples collected for magnetostratigraphy, possible volcanic ash layers, and fossil sites is indicated on section.

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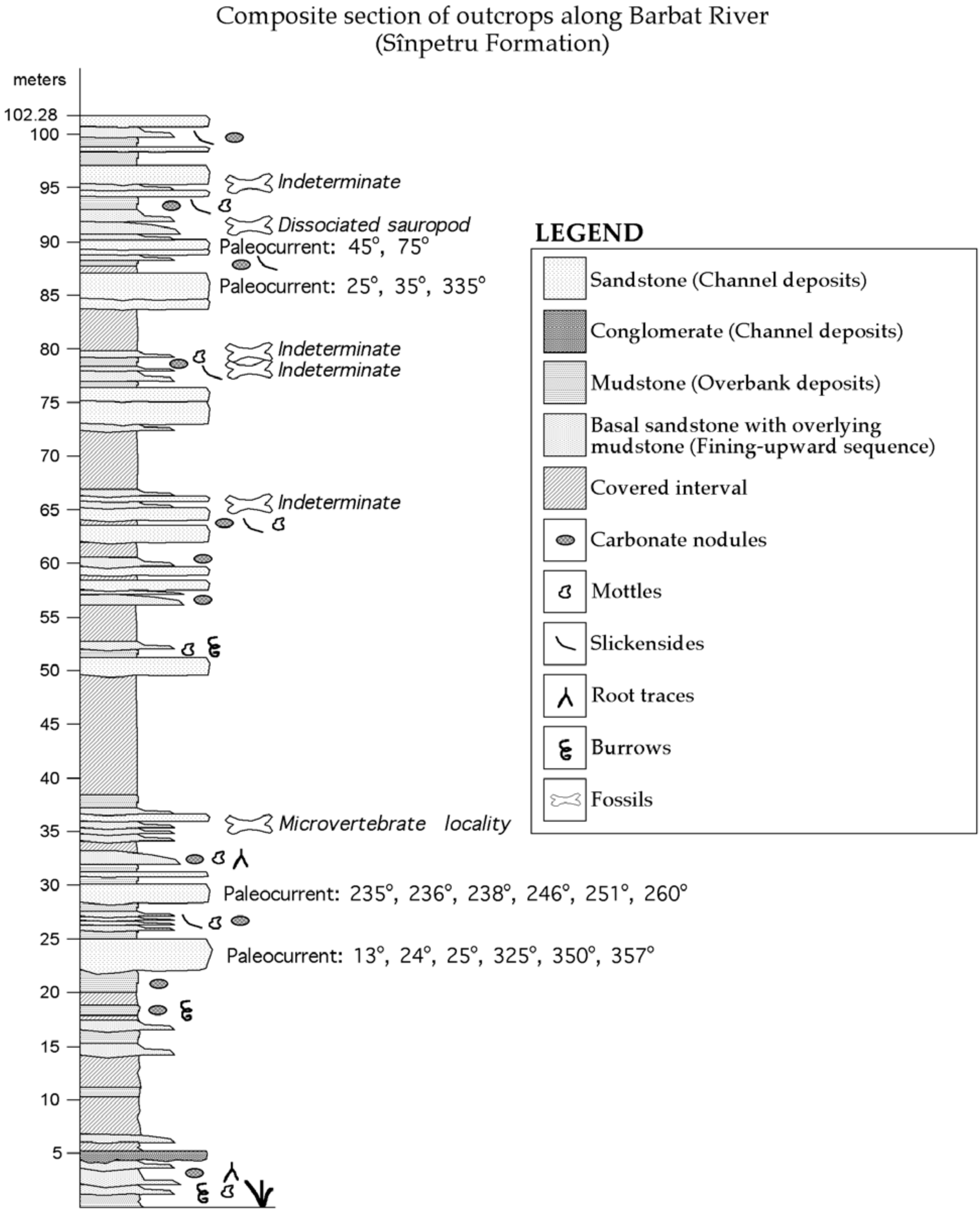

Fig. 4. Composite section of the Sânpetru Formation as exposed along the Bărbat River, near Pui.

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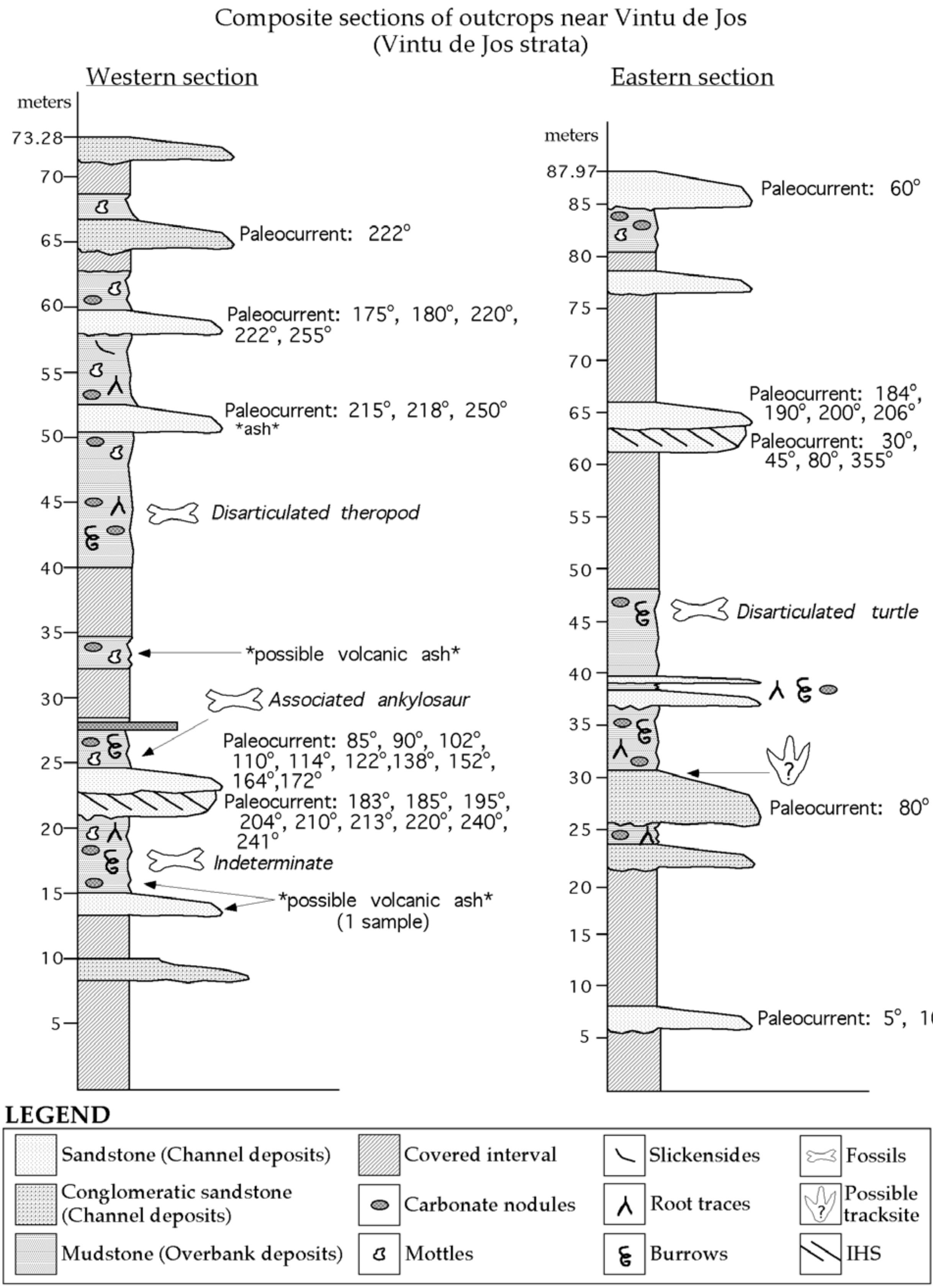

Fig. 5. Composite sections of the Vințu de Jos strata.

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