Available online at www.sciencedirect.com

SCIENCE DIRECT®

Palaeogeography, Palaeoclimatology, Palaeoecology 218 (2005) 15–56

PALAEO

www.elsevier.com/locate/palaeo

Palaeoenvironments of the latest Cretaceous (Maastrichtian) dinosaurs of Romania: insights from fluvial deposits and paleosols of the Transylvanian and Haţeg basins

François Therrien*

Center for Functional Anatomy and Evolution, Johns Hopkins University-School of Medicine, Baltimore, Maryland, United States

Received 12 August 2004; received in revised form 6 December 2004; accepted 7 December 2004

Abstract

A diverse Maastrichtian dinosaur-dominated fauna is known from the Red Continental Strata of the Transylvanian Basin and the Densuş-Ciula Formation and Pui beds of the Haţeg Basin, western-central Romania. Sedimentological and palaeopedological studies of these deposits provide insights into the prevailing palaeoenvironmental and palaeoclimatic conditions at the end of the Cretaceous. The Red Continental Strata and Pui beds are dominated by red mudstone sequences and exhibit highly variable palaeocurrent direction. Inclined heterolithic strata with palaeocurrent indicators orientated perpendicular to the dipping strata are also present in channel deposits of the Red Continental Strata. All these features suggest deposition by meandering rivers. Although red mudstones are abundant in the Densuş-Ciula Formation, this formation differs from the aforementioned formations in containing thick sandstone beds displaying sedimentary structures typical of braided stream deposits and characterized by low variability of palaeocurrent direction. These features indicate deposition in a low-sinuosity fluvial system.

Paleosols of the three studied formations are characterized by the presence of carbonate nodules closely associated with iron oxides, rhizocretions, and slickensides; mottles and indurated calcareous horizons are occasionally present in paleosols of the Red Continental Strata and Pui beds. These features are indicative of a climate characterized by seasonal precipitation in which evapotranspiration exceeded precipitation, and where the watertable fluctuated during the year. Dark red, noncalcareous paleosols also occur occasionally in the Pui beds, representing leached profiles that developed on sandier parent material. The geochemical composition of all paleosols studied indicates that palaeoprecipitation was less than 1000 mm/year, which is significantly lower than estimates inferred from the tropical palaeoflora of the region (1300–2500 mm/year). This apparent incongruence in paleoprecipitation estimates can be explained by the fact that tropical plants can live in warm, monsoonal climates if they have access to sufficient quantity of water during the dry seasons to satisfy their metabolic needs.

Comparison of the studied formations to the famous contemporaneous Sânpetru Formation of the Haţeg Basin confirms similarity of palaeoclimatic conditions. However, palaeoenvironmental and taphonomic conditions differ. Whereas the Sânpetru Formation comprises a mosaic of wetlands and moderately-drained floodplains in which areas of impeded drainage were

---

* Currently: NSERC Postdoctoral Fellow, Royal Tyrrell Museum of Palaeontology and Department of Biological Sciences -University of Calgary, Alberta, Canada TOJ 0Y0. Tel.: +1 403 823 7707; fax: +1 403 823 7131.

E-mail address: francois.therrien@gov.ab.ca.

doi:10.1016/j.palaeo.2004.12.005

predominant, the Red Continental Strata, Densuş-Ciula Formation, and Pui beds represent moderately- to well-drained floodplain settings. Although the Pui beds have long been assumed to pertain to the Sânpetru Formation on the basis of palaeontological and superficial lithological similarities (i.e., red colour), comparison of the results of the detailed palaeoenvironmental studies suggests that the Pui beds are distinct from the Sânpetru Formation and may warrant their own formational recognition (Bărbat Formation). Finally, fossil preservation conditions in the Sânpetru Formation indicate concentration of remains by hydraulic processes on wet floodplains (lenticular bonebeds or "fossiliferous pockets") while those of the other three formations suggest attritional mortality assemblages preserved in dry paleosol profiles. Such taphonomic differences must be considered carefully in palaeoecological studies of the Maastrichtian dinosaurian fauna of Romania.

Keywords: Dinosaur; Romania; Maastrichtian; Paleosol; Palaeoenvironmental reconstruction; Palaeoclimate; Tethys

1. Introduction

Several dinosaur-bearing formations of Maastrichtian age are known from Romania, but few detailed palaeoenvironmental studies have been conducted. The Sânpetru (or Sînpetru) Formation of the Haţeg Basin, famous for its diverse dinosaur-dominated fauna that consists of sauropods, ornithopods, theropods, ankylosaurs, pterosaurs, crocodilians, squamates, chelonians, fishes, amphibians, and multituberculates (Nopcsa, 1897, 1899, 1900, 1901, 1902a,b, 1904, 1915, 1923a,b, 1928, 1929; Grigorescu and Kessler, 1980; Grigorescu et al., 1985, 1999; Radulescu and Samson, 1986, 1996; Grigorescu and Hahn, 1987; Weishampel et al., 1991, 1993, 2003; Jianu, 1992, 1994; Csiki, 1995; Weishampel and Jianu, 1996; Jianu and Weishampel, 1997; Csiki and Grigorescu, 1998, 2000; Buffetaut et al., 2002; Folie et al., 2002; Smith et al., 2002; Venczel and Csiki, 2003), has received the most attention (Grigorescu, 1983; Therrien, 2004; Van Itterbeeck et al., 2004). Palaeoenvironmental reconstruction of the Sânpetru Formation exposed along the Sibişel River indicates that the lower half of the section accumulated in a shifting mosaic of wetlands and drier floodplains in a subhumid climate characterized by alternating wet and dry periods (Therrien, 2004).

Even though important palaeontological discoveries, either in the form of dinosaur nests or rich macro- and microfossil assemblages, have been made in red strata exposed near the town of Pui and in the Densuş-Ciula Formation (Haţeg Basin, Hunedoara County), and in deposits referred to as the Red Continental Strata (southwestern Transylvanian Basin, Alba County; Fig. 1), little work has been conducted to document the palaeoenvironmental conditions in which dinosaurs are preserved. Because the lithological characteristics of these units differ markedly from the type locality of the Sânpetru Formation exposed along the Sibişel River (e.g., Grigorescu, 1983; Therrien, 2004), palaeoenvironmental reconstruction of these units documents the diversity of dinosaur habitats present in Romania during the Maastrichtian and gives insight into taphonomical differences that may be of palaeoecological significance. Detailed sedimentological and palaeopedological studies of these units are essential to improve our understanding of the poorly-known continental palaeoenvironments and palaeoclimatic conditions that prevailed in the northern Mediterranean Tethys prior to the terminal Cretaceous extinction.

2. Geologic setting

During the Late Cretaceous, Romania was situated in the tectonically active region of the northern Mediterranean Tethys Ocean. The collision of at least three microcontinents, Apulia, Rhodope, and Moesia, which began in the Albian, produced the first orogenic phase of the Southern Carpathians and the Apuseni Mountains (Fig. 2; e.g., Sanders, 1998; Willingshofer, 2000; Willingshofer et al., 2001; also see Csontos and Vörös, 2004). In the early Maastrichtian, the compressive forces responsible for the rise of the orogen ceased, resulting in the collapse of the orogen and formation of a series of extensional basins. Depending on the position of each basin relative to sea level, continental and/or marine depositional environments

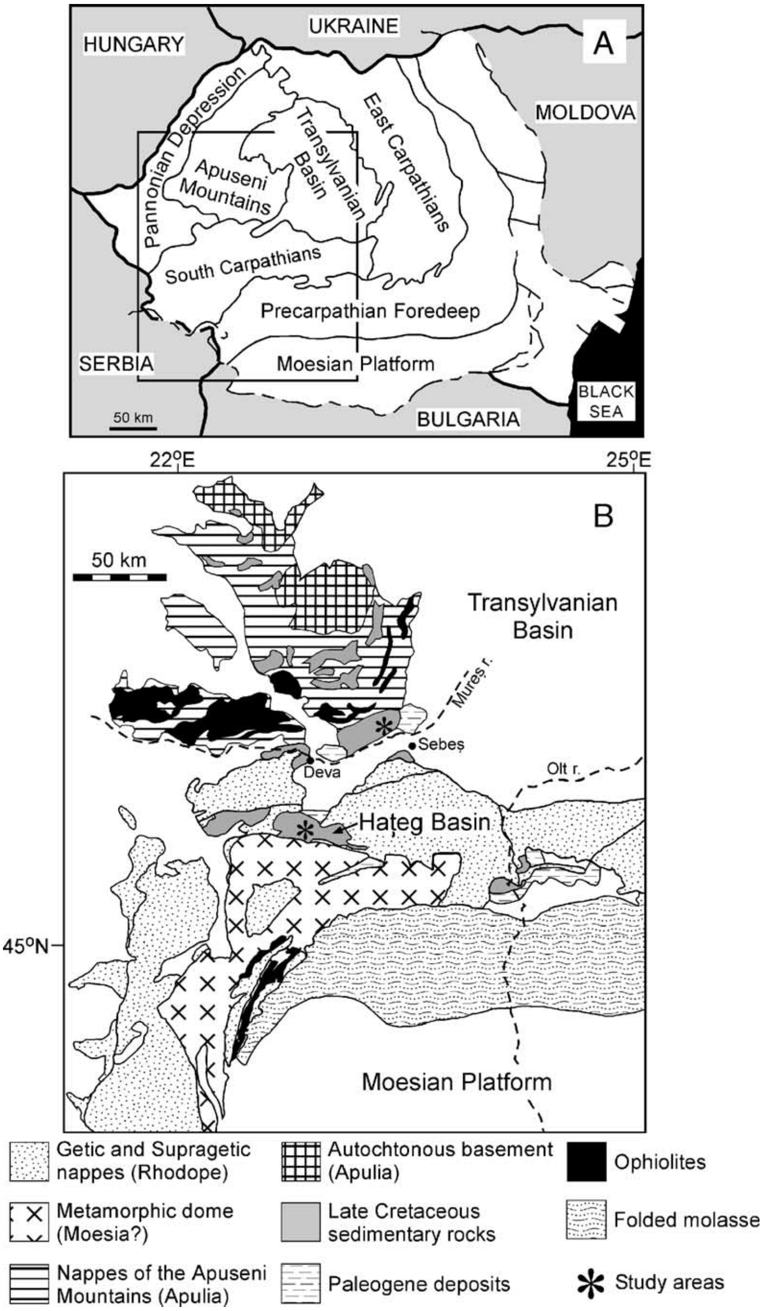

Fig. 1. Transylvanian and Hațeg basins, Romania. (A) Maastrichtian continental deposits are found near the Apuseni Mountains and Southern Carpathians of western-central Romania. The boxed area is detailed in (B). Modified from Grigorescu (1992). (B) Geologic map of the Apuseni Mountains and Southern Carpathians. The Maastrichtian dinosaur-bearing strata studied are located at the southern extremity of the Apuseni Mountains near Vurpăr and in the Hațeg Basin of the Southern Carpathians. Modified from Burchfiel and Bleahu (1976), Schmid et al. (1998), Sanders (1998), Willingshofer (2000), and Willingshofer et al. (2001).

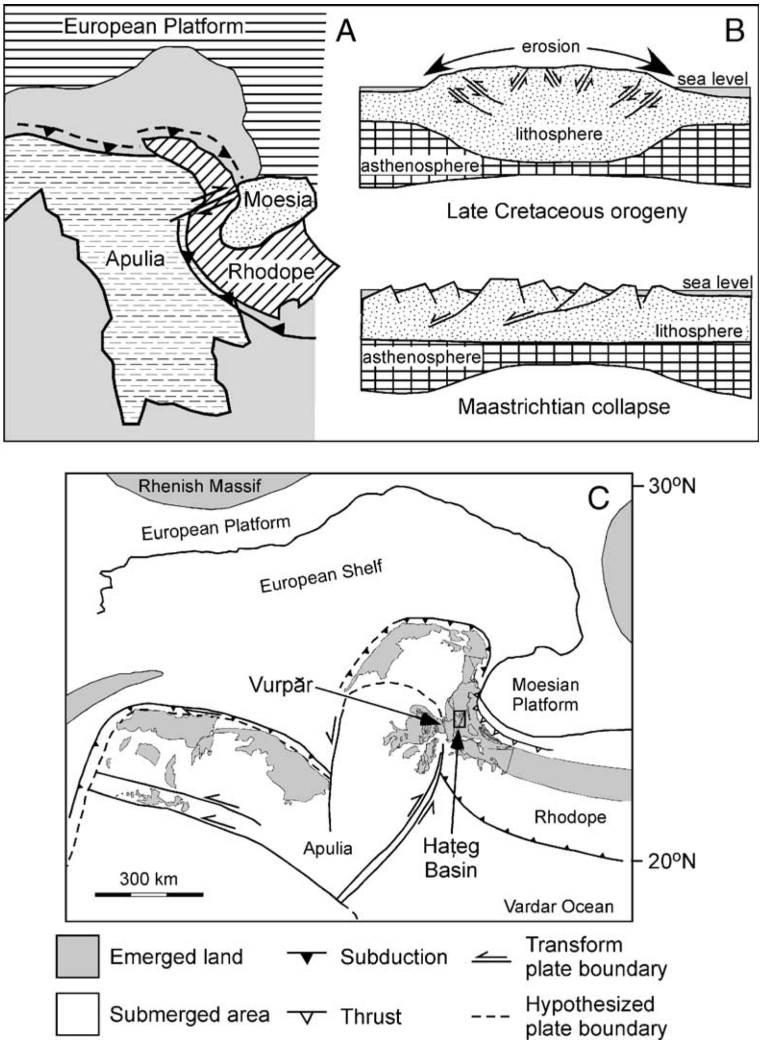

Fig. 2. Southern Carpathian orogen during the Maastrichtian. (A) Schematic reconstruction of the tectonic units present in the northern Mediterranean Tethys region during the Late Cretaceous. The collision of the microcontinental plates Apulia, Rhodope, and Moesia resulted in the formation of the Southern Carpathian orogen. Modified from Sanders (1998). (B) Schematic reconstruction of the Carpathian collision. Compressive forces during the Late Cretaceous produced the uplift and deformation of the orogen. In the Maastrichtian, compressive forces ceased and the orogen collapsed, forming extensional intramontane basins. Marine invasion occurred in basins that were located below sea level and had a connection to the sea; continental sedimentation occurred in the others. Modified from Sanders (1998). (C) Maastrichtian palaeogeography of the northern Mediterranean Tethys region. The Southern Carpathian orogen, although technically not an island, was isolated from the European Platform by shallow and deep marine basins. The Haţeg Basin, a post-orogenic, extensional basin within the Southern Carpathian orogen, and Vurpăr were situated between 20° and 30°N. Based on Sanders (1998), Willingshofer (2000), and Stampfli et al. (2001).

were established (Sanders, 1998; Willingshofer, 2000; Willingshofer et al., 2001).

Continental dinosaur-bearing strata are found in the western half of the Haţeg Basin and in the southwestern corner of the Transylvanian Basin (Fig. 1). Within the Haţeg Basin, fluviolacustrine depositional systems produced the Sânpetru and Densuş-Ciula formations. The Sânpetru Formation, a nearly 2500-m-thick sequence of which a 1000-m interval is exposed along the Sibişel River, is generally subdivided into a lower member, where red clays are common and allegedly containing disseminated pyroclastic material (but see

Therrien, 2004), and an upper member characterized by abundant conglomerates and a lack of red clays (Grigorescu, 1983, 1992; Weishampel et al., 1991). This formation was deposited as a poorly channelized braidplain or in a distal alluvial fan setting (Grigorescu, 1983, 1992; Weishampel et al., 1991; Grigorescu and Csiki, 2002; Therrien, 2004). The Densuş-Ciula Formation, nearly 4000 m in thickness, is subdivided into a lower member rich in coarse volcaniclastic material, a fossiliferous middle member of finer sediment poor in volcaniclastic material, and a non-fossiliferous upper member devoid of volcaniclastic material. This formation records deposition by alluvial fans and braided streams interspersed with pulses of volcanic activity (Anastasiu, 1991; Grigorescu, 1992; Grigorescu et al., 1994; Grigorescu and Csiki, 2002). Sixty kilometers north-east of the Haţeg Basin, outcrops dominated by red mudstones are exposed along the southeastern margin of the Apuseni Mountains between the villages of Vurpăr and Pâclişa on the north shore of the Mureş River and along the northern margin of the Southern Carpathians near Sebeş (Fig. 1). This lithological unit has been informally referred to as the "red detritic facies" by Antonescu (1973) and Antonescu et al. (1983), "Vinţ strata (molasse)" by Burchfiel and Bleahu (1976), "lower red bed formation" by Vremir and Codrea (2002), and "Vinţu de Jos strata" by Therrien et al. (2002) (erroneously considered part of the "Bozeş Strata" by the latter and Weishampel et al., 2003). Because the locality of Vinţu de Jos is mentioned in the literature in association with other rock formations (e.g., Antonescu, 1973), the nomenclature used by Therrien et al. (2002) to refer to this lithological unit could create confusion and is therefore replaced by "Red Continental Strata" to reflect the precedence of Antonescu (1973). This unit, which presumably attains 2500 m in thickness, was deposited in a fluviolacustrine setting (Nopcsa, 1905; Antonescu, 1973; Grigorescu, 1992; Codrea et al., 2001, 2002a; Vremir and Codrea, 2002). Although the various Romanian formations cannot be lithostratigraphically correlated to each other, they are contemporaneous based on identical faunal and floral fossil assemblages (Nopcsa, 1905; Antonescu et al., 1983; Grigorescu et al., 1985; Grigorescu, 1992). These formations have long been considered late Maastrichtian in age (e.g., Antonescu, 1973; Antonescu et al., 1983; Weishampel et al., 1991; Grigorescu, 1992; Grigorescu and Csiki, 2002) but recent studies revealed that they might rather be of early to middle Maastrichtian age (López-Martínez et al., 2001; Panaiotu and Panaiotu, 2002; Therrien, 2004; Van Itterbeeck et al., in press).

Palaeogeographic reconstructions of the Mediterranean Tethys locate the Southern Carpathian-Apuseni complex in the tropics during the Maastrichtian (Fig. 2). Structural studies (e.g., Willingshofer, 2000) and palaeomagnetic analyses of sedimentary deposits (Patrascu and Panaiotu, 1990; Panaiotu and Panaiotu, 2002) indicate that the region was situated between 20° and 30° North latitude. This conclusion is further supported by the presence of tropical plant species in fossil assemblages (Tuszon, 1913; Baltes, 1966; Givulescu, 1966; Mărgărit and Mărgărit, 1967; Givulescu, 1968; Duşa, 1974; Petrescu and Duşa, 1980, 1982a,b; Antonescu et al., 1983; Pop and Petrescu, 1983; Iamandei and Iamandei, 1997). Palaeoclimatic inferences made on the basis of the Romanian palaeoflora suggest a warm, tropical climate (mean annual temperature 22–24 °C) with abundant (1300–2500 mm/year) yet seasonal precipitation. However, the distribution of rudist reefs (Voigt et al., 1999), fossil plants and phosphorite deposits along the northern Tethyan margin (Horrell, 1991), computer simulations of the Maastrichtian climate (Bush, 1997), and the study of paleosols from the Sânpetru Formation exposed along the Sibişel River (Therrien, 2004), reveal that evapotranspiration was greater than precipitation and that a strong monsoonal climate prevailed.

3. Methods

Three localities known to preserve abundant fossil material were studied: (1) the red beds of Pui, exposed in the Bărbat River 15 km southeast of the Sibişel Valley and historically assigned to the Sânpetru Formation on the basis of superficial lithological similarities (Fig. 3; Nopcsa, 1905; Grigorescu et al., 1985, 1999; Grigorescu, 1992), (2) the Tuştea locality of the middle member of the Densuş-Ciula Formation (Fig. 3; Grigorescu et al., 1994), and (3) the red beds exposed near Vurpăr on the north shore of the Mureş River (Fig. 1). Because each locality will be compared to the typical exposures of the Sânpetru Formation along the Sibişel River (Therrien, 2004), for the sake

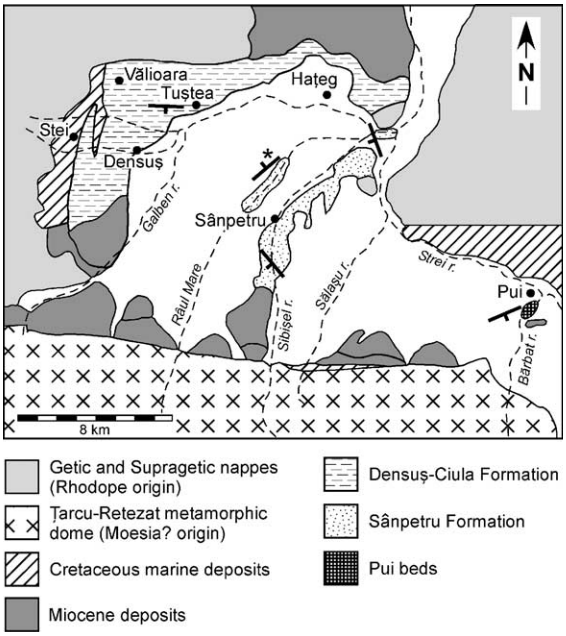

Fig. 3. Geologic map of the western half of the Haţeg Basin where the Densuş-Ciula Formation, Pui beds, and Sânpetru Formation are exposed. Deposits of the Sânpetru Formation are found along several rivers in the Haţeg Basin, but the best outcrops afford nearly 1000 m of exposure along the Sibişel River, south of the village of Sânpetru. The attitude of the strata (strike and dip) is reported for various rock exposures in the Haţeg Basin; all were measured by the present author except for the one indicated by an asterisk "*", which was reported by Codrea et al. (2002b) and Smith et al. (2002). Strata attitude: Densuş-Ciula Formation exposed at Tuştea (092°N, 14° to the south); Pui beds (067°N, 14° to the south); northern exposure of the Sânpetru Formation on the eastern bank of Raûl Mare near Hateg (136°N, 55° to the west); Sânpetru Formation exposed along the Sibişel River (142°N, 45° to the west); and Raûl Mare deposits* (220–230°N, dip: 75–80° to the northwest). Based on Weishampel et al. (1991) and Grigorescu (1992).

of simplicity the term "Sânpetru Formation" will refer specifically to the type exposures of that formation along the Sibişel River, while "Pui beds" will refer to the outcrops of the Bărbat River. Except for the Densuş-Ciula Formation and, recently, a short interval of the Pui beds (Van Itterbeeck et al., 2004), none of these localities has been subjected to detailed sedimentological and palaeopedological analysis.

Stratigraphic sections were measured for all available outcrops. Sections were correlated to one another by physically tracing beds (i.e., walking along the marker beds between sections) or, when impossible, by calculating the thickness of covered intervals (via a Jacob-staff approach) in order to construct composite stratigraphic sections. This method assumes that no vertical displacement (i.e., faults) occurs within the intervening covered interval. As no faults were observed in the studied outcrops, this approach is considered valid. Each rock unit was described in terms of sedimentary structures and/or pedological features. The thickness of strata and palaeocurrent orientation, determined from clast imbrication and cross-stratification, were corrected for the attitude (strike and dip) of the formations.

The compositional mode of channel deposits was evaluated through point-counting analysis of one typical sandstone layer (medium sand, except for Pui sample which was fine sand) from each locality. Light mineral proportions were obtained by counting a total of at least 300 points from three of the four corners of each thin section. Minerals included within phaneritic lithic fragments were counted as the type of lithoclast (rock type) in which they occur rather than as their respective mineral constituents (i.e., quartz, feldspars; Decker and Helmold, 1985; Johnsson et al., 1991; von Eynatten and Gaupp, 1999; Garzanti and Vezzoli, 2003, contra Gazzi–Dickinson counting method, Ingersoll et al., 1984). The compositional categories recognized in the sandstones are monocrystalline quartz, undulose quartz, polycrystalline quartz, k-feldspar, plagioclase, and various lithic fragments (Table 1). The sandstone compositions were plotted on Qt–F–L and Qm–F–Lt ternary

Table 1
Results of point count analysis conducted on sandstones of the Red Continental Strata, Densuş-Ciula Formation, and Pui beds

Sample	Quartz (mono)	Quartz undulose	Quartz (poly)	K-feldspar	Plagioclase	Muscovite	Chlorite	Biotite	Metapelite 2	Metapelite 3	Metapelite 5	Metafelsite 2	Metafelsite 3
Vurpăr	1296	994	1106	361	20	109	41	33	–	–	–	–	–
Tuştea	26	299	431	38	22	31	2	16	60		7	–	13
Pui	390	1221	1033	833	105	180	–	4	–	61	–	131	101

Metamorphic rock categories after Garzanti and Vezzoli (2003).

diagrams and compared to compositional modes of sandstones from the Sânpetru Formation exposed along the Sibişel River (Therrien, 2004).

Samples were collected from selected paleosols, generally one or two samples per recognized horizon, for petrographic and geochemical analyses. Forty thin sections were prepared in order to document paleosol micromorphology under petrographic microscope (10–400× magnification) following the terminology of Bullock et al. (1985). The abundance of major and trace elements in various paleosol horizons was determined through X-ray fluorescence spectroscopy (XRF); the analysis was conducted on a Phillips 2404 spectrometer by Dr. Stan Mertzman at the Department of Earth and Environment, Franklin and Marshall College. Because the geochemical composition of the parent material(s) was unknown, these results were converted into molecular weathering ratios to evaluate the pedogenic processes in the ancient soils (see Feakes and Retallack, 1988; Retallack, 1997).

4. Features of Romanian paleosols

Paleosols of the Pui beds, Densuş-Ciula Formation (Tuştea locality), and Red Continental Strata (Vurpăr) are generally moderately- to well-developed (see Retallack, 1997). Some of the key pedogenic features observed in these paleosols, as well as their interpretation, are outlined below.

4.1. Colour of paleosols

In the Pui beds and Red Continental Strata, paleosols are brown to red in colour (10R 4/6 to 7.5YR 4/4), although drab-coloured (light green) root traces and mottles are present (see below). Thin purple intervals (7.5R 3/2) are present locally in the Red Continental Strata. In the Densuş-Ciula Formation, brown to red paleosols are clearly most abundant, but gray intervals are also occasionally found. The various colours of paleosol horizons reflect the concentration of iron and manganese compounds present in the matrix, which is controlled in part by the predominant palaeoenvironmental and palaeoclimatic conditions (e.g., McBride, 1974; Blodgett et al., 1993; Schwertmann, 1993; Yang et al., 2001; Atchley et al., 2004). The red colouration of paleosols is produced by the abundance of iron oxides, primarily hematite, accompanied by a low organic content. The red and brown colours are formed under oxidizing conditions and represent well-drained environments.

4.2. Mottles (redoximorphic features)

Mottles are localized ferruginous accumulation or depletion within the paleosol groundmass. These features are formed by the translocation of iron within the soil profile under alternating reducing and oxidizing conditions associated with a fluctuating watertable (Vepraskas, 1992; Vepraskas et al., 1994). In the Pui and Vurpăr paleosols, mottles occur as small (<5 mm) to large (>15 mm), irregular to circular features dispersed within pedogenic horizons or as elongate features surrounding root traces; in contrast, mottles are absent in the Tuştea paleosols. When present, mottles can be very prominent or extremely difficult to distinguish from the matrix depending on their degree of development. They vary in colour from red (7.5R 5/6) to strong brown (7.5YR 4/6) with occasional purplish tints (5R 3/1 or 10R 3/2). In thin section, most mottles consist of moderately to strongly impregnated groundmass areas characterized by gradational boundaries with the surrounding matrix, although orthic pedofeatures with distinct boundaries are occasionally present.

Light greenish gray (5GY 7/1 to 5GY 6/1) reduction haloes are widespread in paleosols of the Red Continental Strata, Densuş-Ciula Formation, and

Metafelsite 4	Metafelsite 5	Zircon	Apatite	Garnet	Felsic intrusive	Andesite	Marble	Chert	Glass	Corundum	Qt/F+L ratio	Qp/F+L ratio
–	–	1	26	2	86	109	131	187	18	–	7.31	2.64
18	57	1	5	–	108	295	–	14	–	8	1.51	0.87
–	–	3	15	–	127	10	–	237	–	1	2.34	1.03

Pui beds; interestingly, these features are absent in the Sânpetru Formation. Reduction spots vary in size and in shape: they can be circular or elongate, follow structures such as bedding planes, infilled cracks or roots, contain a carbonaceous or calcareous core, and overprint pedogenic features and ichnofossils. Generally, these features are formed after soil burial (Mykura and Hampton, 1984; Hofmann et al., 1987; Hofmann, 1990; Panhuys-Sigler et al., 1996).

4.3. Microstructures and fabric of paleosol groundmass

Peds are natural aggregates of soil matrix produced by the shrinking and swelling of clays induced by alternating wet and dry soil conditions and root activity. Subangular blocky peds, often broken by fissures or slickensides (Fig. 4A), are present in paleosols of the Densuş-Ciula Formation and Red Continental Strata. No peds were observed in the Pui beds, although this absence could be an artifact related to the poor quality of the outcrops and the limited number of samples collected.

The microstructure of the soil matrix is characterized by the alignment of clay particles, which produces birefringence in cross-polarized light, termed b-fabric (Bullock et al., 1985). Just as in Sânpetru paleosols, the most common b-fabrics recognized in the studied paleosols are granostriations (Fig. 4B), parallel striations (Fig. 4C), stipple-speckled and mosaic speckled. However, reticulate striations and cross-striations (Fig. 4D) also were observed in paleosols of the Densuş-Ciula Formation and Red Continental Strata. Striated b-fabrics are elongate birefringent zones of simultaneous extinction formed by the alignment of clay particles in response to tensile and compressive stresses in the soil induced by wetting and drying cycles (Brewer, 1964). Speckled b-fabrics consist of randomly-oriented, equidimensional clay units found in isolation (stipple-speckled) or in domains of simultaneous extinction (mosaic speckled) that are formed during the early stages of pedogenesis (Bullock et al., 1985). Undifferentiated groundmasses, characterized by a poorly developed or absent b-fabric, are found in very weakly developed pedogenic horizons.

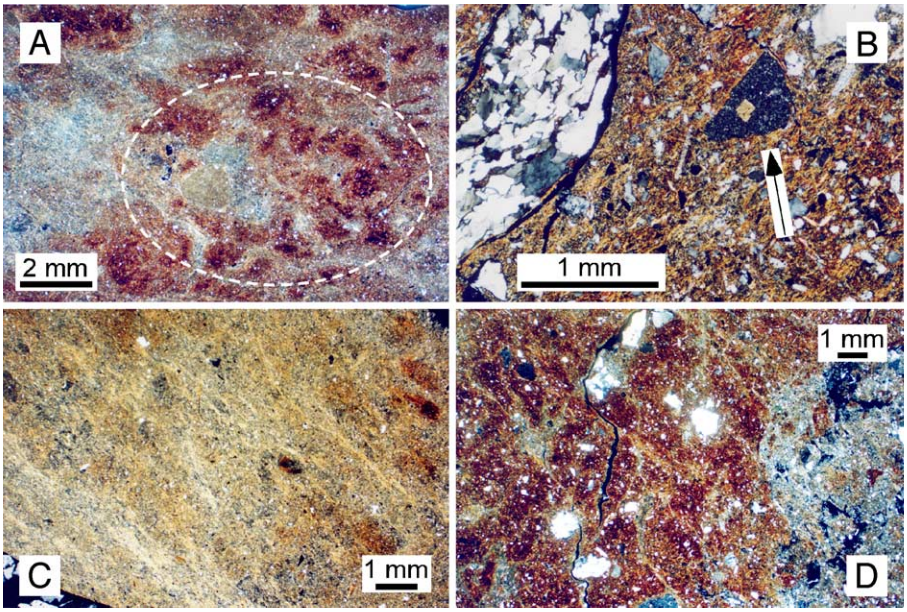

Fig. 4. Microstructures of the Maastrichtian paleosols of Romania. (A) Subangular blocky ped dissected by fractures and slickensides. Photomicrograph in polarized light. (B) Granostriated b-fabric consists of haloes of birefringent clays surrounding clasts. Such features are formed by shrink-and-swell stresses in the soil. Photomicrograph in polarized light. (C) Striated b-fabric is the alignment of birefringent clays under shrink-and-swell stresses. Photomicrograph in polarized light. (D) Cross-striated b-fabric produced by the intersection of various birefringent clay lineations. Photomicrograph in polarized light.

4.4. Carbonate accumulation

Carbonate accumulation is a diagnostic feature of nearly all paleosols studied. Carbonate accumulation around roots, called rhizocretions, are found occasionally at Tuştea and Vurpăr. These features are generally small, not exceeding 25 mm in diameter. However, carbonate nodules equivalent to type 2 caliche of Gile et al. (1966) and Birkeland (1985) are ubiquitous in the paleosols of all three formations. These nodules occur in mudstones and siltstones, although they are occasionally found in sandy material. Carbonate nodules range generally in size from 0.1 mm to 60 mm, although irregular masses up to 200 mm in diameter are found in Tuştea paleosols (Fig. 5A). Microscopically, carbonate nodules are micritic with occasional sparite veins or fissures infilled by groundmass. Intergrowth of carbonate and iron oxides is common (Fig. 5B) and occasionally results in the formation of carbonate nodules with ferruginous growth rings (Fig. 5C).

In the Pui paleosols, numerous laterally continuous calcareous horizons consisting of carbonate nodules and internodular fillings developed in mudstone sequences, equivalent to the type 3 caliche (plugged horizon) of Gile et al. (1966) or type 4 caliche (coalesced nodules) of Birkeland (1985; Fig. 6A). In the Red Continental Strata, a single similar calcareous horizon was observed in a thin sandstone bed that locally preserves sedimentary structures (Fig. 6B). Microscopically, this unit comprises abundant micritic carbonate nodules embedded in a calcite-cemented groundmass. Many nodules display iron oxide intergrowths, while others exhibit very well developed growth rings of light and dark brown micrite (Fig. 6C).

Carbonate nodules form generally in subhumid to arid climates where precipitation is insufficient to remove carbonate from the soil. Translocation of carbonate is accomplished by rainwater percolating through the soil. Because evapotranspiration exceeds precipitation in those climates, meteoric water evaporates before reaching the watertable, which results in the precipitation of dissolved carbonates at the average depth of rainfall penetration (Goudie, 1973, 1983; Reeves, 1976; Blodgett, 1988; Retallack, 1994). Initially, carbonates precipitate as filaments and coatings but with time will form nodules (Bk horizon) and impermeable horizons (K horizon; Gile et al., 1966; Birkeland, 1985). Intergrowth of carbonate nodules and iron oxides is common in soils formed in climates characterized by alternating wet and dry periods, as carbonate precipitates under dry conditions while iron is mobile under reduced soil conditions (e.g., Courty and Fédoroff, 1985; Retallack, 1997). Finally, calcareous rhizocretions have been documented to form under dry conditions, when the microenvironment surrounding the roots is alkaline and favors carbonate accumulation (see Retallack, 2001).

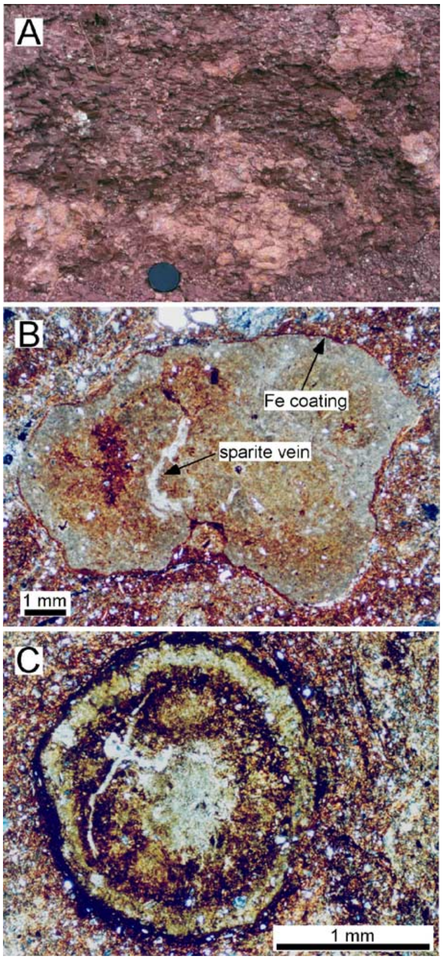

Fig. 5. Carbonate accumulation in the Maastrichtian paleosols of Romania. (A) Carbonate nodules and masses in a calcic (Bk) horizon of a Tuştea paleosol. Lens cap for scale (5 cm). (B) Micritic carbonate nodules displaying sparite veins, intergrowth of iron oxides, and ferruginous coating. Photomicrograph in polarized light. (C) Compound pedogenic carbonate nodule displaying ferruginous growth rings. Such combination indicates periodic alternations of oxidizing and reducing conditions in the soil. Photomicrograph in polarized light.

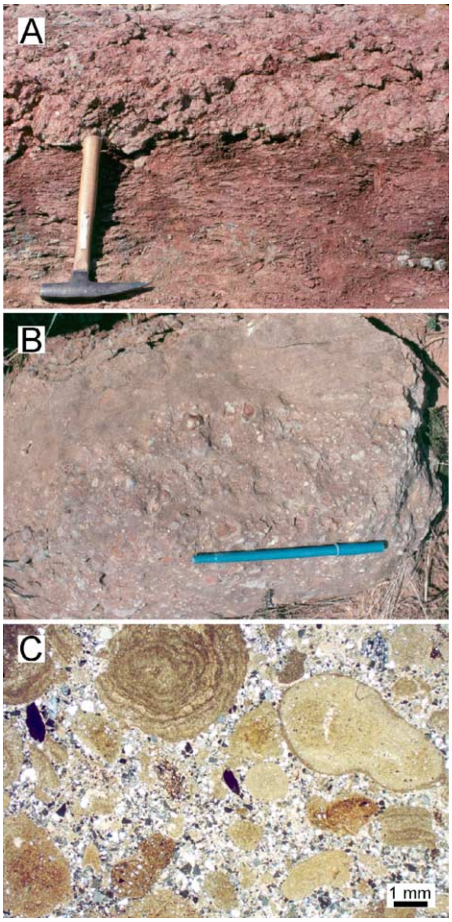

Fig. 6. Indurated calcareous layers (caliche) in the Maastrichtian paleosols of Romania. (A) Typical indurated layer found in Pui beds, consisting of coalesced carbonate nodules. Hammer for scale. (B) Indurated calcareous layer in Red Continental Strata. Carbonate nodules and cement have developed in a stratified sandstone bed (visible in upper right corner of sample). Pen for scale (15 cm). (C) Microscopic structure of the Red Continental Strata caliche. Micritic carbonate nodules bathe in a calcite-cemented groundmass. Numerous nodules display iron oxide intergrowths while others exhibit very well developed growth rings of light and dark brown micrite. These concentric rings reflect (possibly seasonal) fluctuation in the growth rate of carbonate nodules. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

4.5. Ferruginous pedofeatures

Ferruginous pedofeatures are common in the paleosols of the three localities, indicating that eluviation and illuviation of iron were significant pedogenic processes in these paleosols. Iron accumulation occurs in the form of thin (0.01–0.1 mm), red coatings and hypocoatings surrounding clastic grains, carbonates nodules, and root traces (Figs. 5B and 7A–B). Occasionally, iron oxides form cappings, bridges, and link cappings on clastic grains (Bullock et al., 1985). Ferruginous pedofeatures are indicative of repetitive wetting and drying cycles within soils, as they are formed when conditions fluctuate from reducing to oxidizing, prompting the precipitation of iron oxides (Pimentel et al., 1996; PiPujol and Buurman, 1997; Retallack, 2001). Thus, rainfall must have been important, at least seasonally, in Romania during the Maastrichtian.

4.6. Clay illuviation

Traces of clay illuviation are pervasive in the paleosols of Pui, Vurpăr, and Tuştea. Illuviated clays form thin (0.01–0.1 mm) coatings on clastic grains, root and void walls, or infill fissures (Fig. 7C–D). Most clay coatings appear as oriented, birefringent clay particles lining pore walls or surrounding clastic grains and carbonate nodules. Infilled voids generally display very subtle laminations, as inferred from the extinction pattern of clays in polarized light.

Abundant and well-developed illuvial clay features indicate that periods of substantial precipitation characterized the Maastrichtian climate of Romania. Such pedofeatures are formed when clays are physically transported by meteoric water percolating through the profiles and deposited as coatings when soils dry (McKeague, 1983).

4.7. Slickensides

Pedogenic slickensides are much more common in paleosols of the Pui beds, Densuş-Ciula Formation, and Red Continental Strata than in the Sânpetru Formation exposed along the Sibişel River (see Therrien, 2004). They are found in red and brown horizons, although they do not form pseudoanticline structures typical of modern vertisols. In thin section, slickensides appear as striated b-fabric, the alignment of highly birefringent clays being produced by the tensional and compressional stresses induced by seasonal wetting and drying of

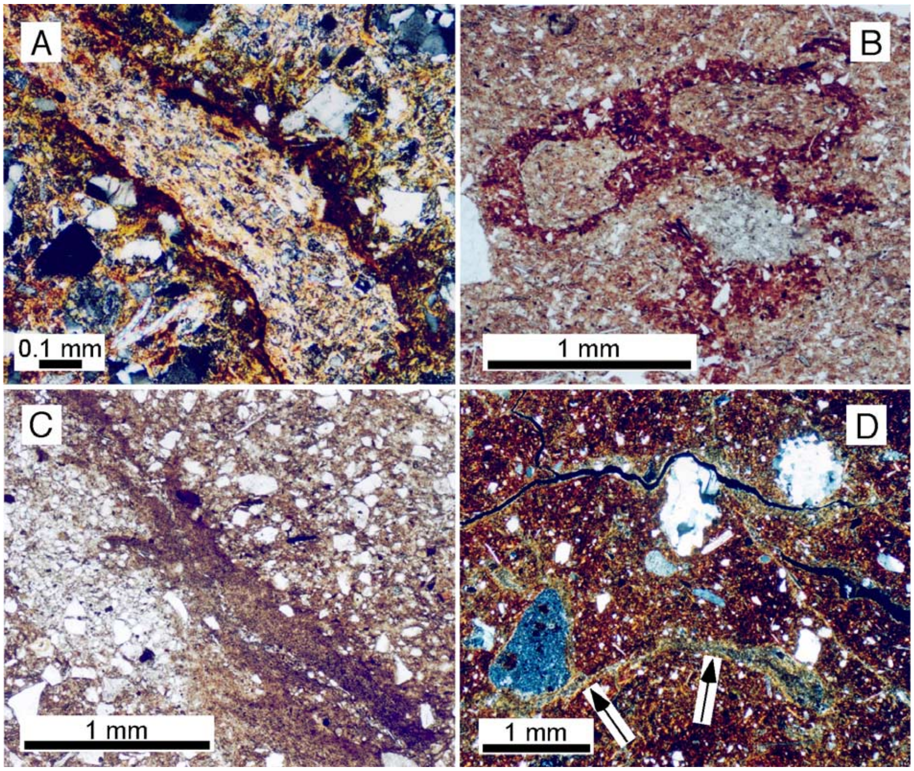

Fig. 7. Illuvial features in the Maastrichtian paleosols of Romania. (A) Longitudinal section through an infilled channel, possibly of a root, displaying a well-developed ferruginous hypocoating. Photomicrograph in polarized light. (B) Cross-section through infilled channels, possibly of roots, displaying well-developed ferruginous hypocoatings. Photomicrograph in plane light. (C) Clay accumulation in the form of coating along the wall of a fissure. Photomicrograph in plane light. (D) Clay accumulation in the form of coatings along the walls of fissures and around clastic grains. Photomicrograph in polarized light.

the soil (e.g., Dudal and Eswaran, 1988; Wilding and Tessier, 1988).

4.8. Bioturbation

Root traces and burrows are common in the studied paleosols. They appear as channels filled with mud- to sand-sized clastic particles and other debris that infiltrated from the surface. Root traces are fine (1–3 mm in diameter), vertically oriented, branching features that generally do not exceed 10 cm in length. Drab-haloed root traces, sometimes surrounded by red ferruginous hypocoatings, are abundant in Pui paleosols but slightly less so in the Red Continental Strata and Densuş-Ciula Formation. Burrows are generally visible in outcrop when infilled by material distinct from the surrounding groundmass or when cemented, appearing as small (1–3 mm in diameter) elliptical tubules. In thin section, burrows display a crescentic to chaotic internal fabric due to the disruption of the groundmass by burrowing invertebrates. Contrary to what was observed in the Sânpetru Formation (Therrien, 2004), deeply-penetrating root traces and burrows were not observed in the Pui, Tuştea, and Vurpăr paleosols.

4.9. Paleosol profile recognition

The periodic deposition of sediment by flood events results in the superposition of paleosol profiles. Because pedogenesis can occur across lithological boundaries, recognition and interpretation of pedogenic horizons can be complicated. In the Densuş-Ciula Formation and Red Continental Strata, thick uninterrupted intervals of pedogenically-modified mudstone are common. Paleosol horizons within those intervals are often very thick (cumulative pedogenesis) or display features indicating that different pedogenic processes modified the parent material (compound pedogenesis), reflecting the periodic incorporation of small quantities of material to the profile (see Birkeland, 1974; Kraus and Bown, 1986; Kraus, 1999).

Pedogenic horizons are identified on the basis of macro- and micromorphological features. The recognition of A horizons in paleosol profiles is generally speculative as organic matter is rarely preserved in oxidizing environments. However, pedogenic horizons characterized by a high degree of bioturbation, the absence of illuvial features (e.g., clay or iron coatings, carbonate nodules), geochemical depletion, and a position above illuvial horizons are interpreted as A horizons (see Therrien and Fastovsky, 2000). Horizons displaying accumulation of calcium carbonate in the form of nodules are identified as Bk horizons. Horizons characterized by laterally continuous carbonate layers are interpreted as K horizons. When illuvial clay features, such as clay coatings on grains or along root walls and streaked b-fabrics created by pore-linings, are common and well-developed in a given horizon, it is interpreted as a Bt horizon. Horizons exhibiting poorly developed clay or carbonate accumulation or only minor traces of illuviation were interpreted as Bw horizons. Occasionally, horizons lacking illuvial features and exhibiting little weathering were present in paleosol profiles; such horizons were interpreted as parent material or C horizons.

5. Palaeoenvironmental reconstruction of dinosaur-bearing formations

5.1. Red Continental Strata, Vurpăr

A discontinuous series of exposures is present along a rural road near the village of Vurpăr. Composite stratigraphic sections were compiled for the outcrops of two hills located near the base of the Apuseni Mountains: a western section (46°00′ 32″N 23°28′ 41″E) and an eastern section (46°01′ 47N 23°30′ 01″E; Fig. 8). It was impossible to correlate the two sections to each other because of the great distance (~6 km) separating them and the fact that strata dip in opposite directions (strike 317°N, dip 25° north and strike 129°N, dip 40° south, respectively), suggesting that the sections may be located on opposite limbs of a syncline.

5.1.1. Fluvial system

The Red Continental Strata are dominated by intervals of pedogenically-modified red and brown mudstones interrupted by laterally extensive brown and light green sandstone sheets (Fig. 8). Sandstone layers vary between 0.5 m to 3 m in thickness, comprise very fine to very coarse sand, and are generally single-storied. Local channel-shaped scours occur but are only partially preserved, thus preventing accurate determination of width/depth ratios. Small- to large-scale trough cross-stratification is the most common sedimentary structure in sandstones. Some beds preserve exclusively horizontal laminations (Fig. 9A). Measurement of palaeocurrent direction reveals a high degree of interchannel variability, exceeding 180°. Overall, palaeocurrent measurements (n=42) indicate southward flow (southwest through southeast; Fig. 8), away from the nearby southern Apuseni Mountains.

Several sedimentary structures indicate that lateral accretion was an active process in the channels of the Red Continental Strata. Two sandstone beds, one in each section, display steeply inclined surfaces oriented perpendicular to the palaeocurrent direction. In the western section, shallowly inclined (4°, corrected for dip but not for compaction) conglomerate-sandstone couplets are found within a fining-upward sandstone interval (86 cm thick, corrected for dip) overlying trough cross-stratified channel deposits (73 cm thick, corrected for dip; Fig. 9B). The 2 cm-thick pebble-to-cobble conglomerate laminae, alternating with 10-cm-thick sandstone units, become finer and thinner up-profile and updip, a feature commonly observed in lateral accretion deposits (Thomas et al., 1987). Within the conglomerate laminae, pebbles are imbricated perpendicular to the dip of the laminae. Codrea et al. (2001) described and interpreted this interval as tabular cross-stratification deposited on lateral accretion surfaces of a migrating sandbar, suggesting deposition in braided streams. However, the structures are also similar to inclined heterolithic strata (IHS) described from numerous ancient and modern fluvial deposits and interpreted as point bar deposits (Allen, 1965; Collinson, 1978; Jackson, 1978; Bridge, 1985; Thomas et al., 1987). In the eastern section, an 84-cm-thick (corrected for dip) interval of shallowly inclined (7°,

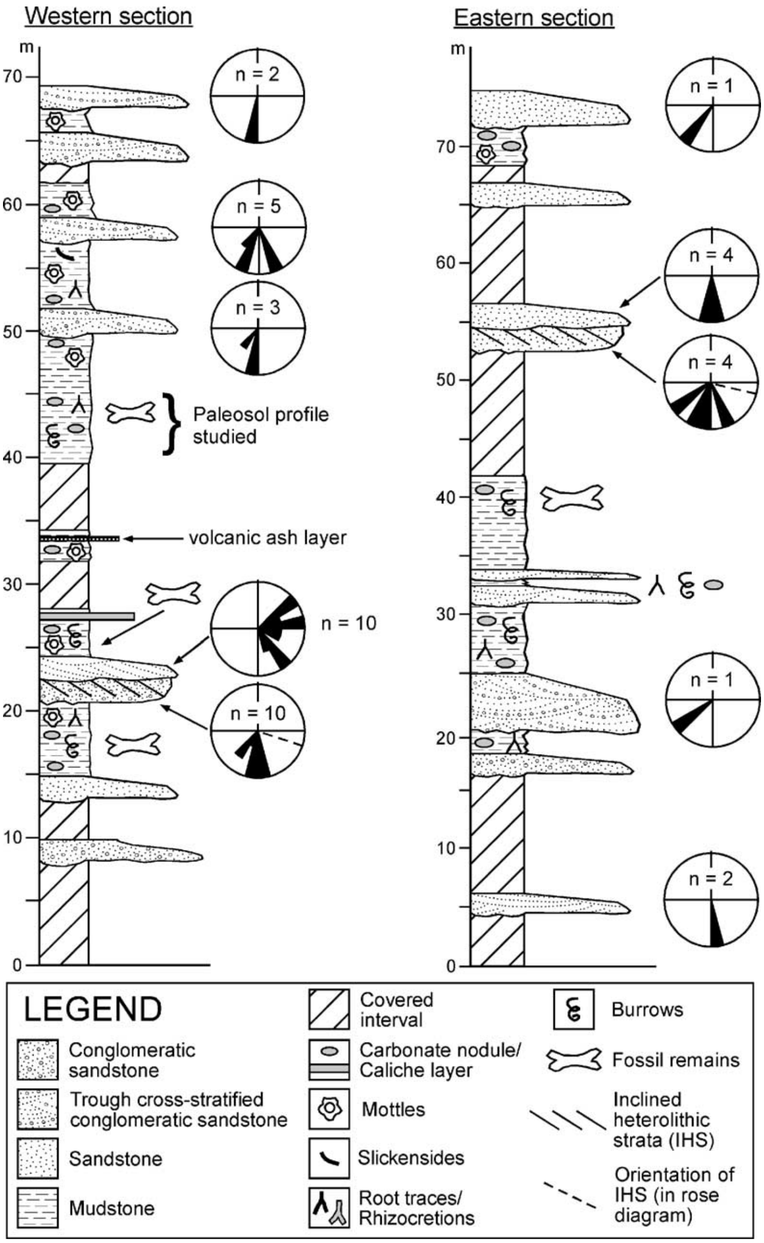

Fig. 8. Composite stratigraphic sections of the Red Continental Strata near Vurpăr (Transylvanian Basin, Alba county). Total thickness of western and eastern sections is 69.32 m and 73.46 m, respectively. Pedogenic features characterizing the red paleosols and the stratigraphic location of fossil finds are indicated. The rose diagrams, reflecting the palaeocurrent direction measured in various channel deposits, indicate that high-sinuosity rivers flowing primarily southward formed the deposits.

corrected for dip but not for compaction) light green sandstone and red sandy mudstone couplets overlies 105-cm-thick trough cross-stratified channel deposits. While the thickness of the red mudstone interval remains relatively constant in the sequence (~5 cm), the thickness of the green sandstone intervals decreases upward from 25 cm to 7 cm (Fig. 9C), a phenomenon commonly reported in lateral accretion deposits (Tho-

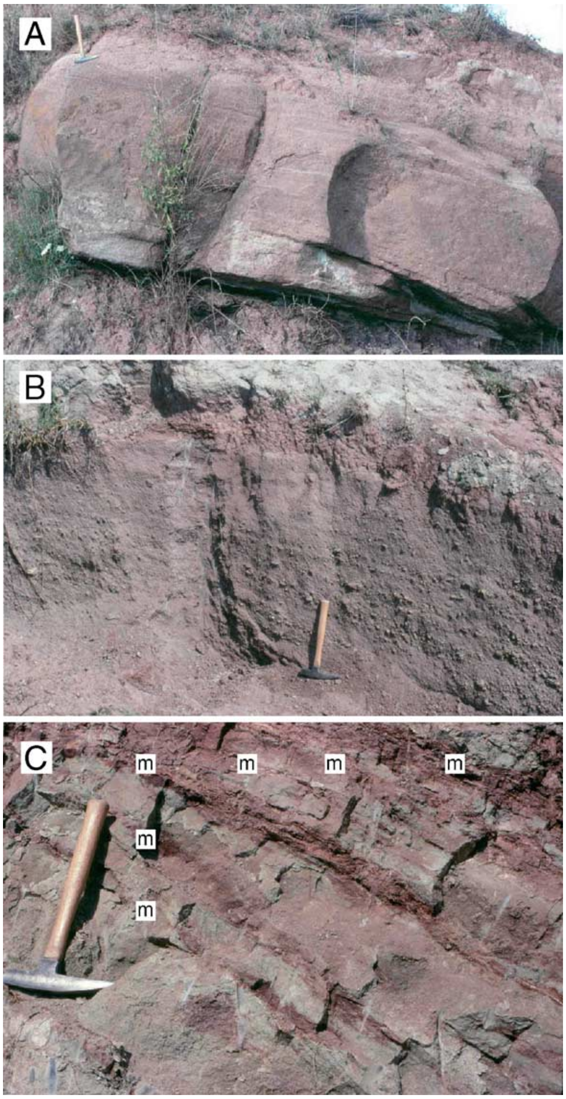

Fig. 9. Sedimentary structures in Red Continental Strata channel deposits. (A) Horizontal to low-angle stratification in sandstone sheet. Hammer for scale (upper left corner). (B) Inclined heterolithic strata (IHS) consisting of conglomerate-sandstone couplets in channel deposits of the western section. The conglomerate intervals become finer and thinner up-dip, typical of lateral accretion units. The clasts in the conglomerate intervals are imbricated perpendicular to the dip of the IHS. Hammer for scale. (C) Sandstone–mudstone couplets of the IHS present in channel deposits of the eastern section. Although the thickness of the red mudstone intervals (labeled "m") remains relatively constant in the sequence, the thickness of the green sandstone intervals decreases upward, as often observed in lateral accretion deposits. Sedimentary structures preserved in the sandstone and mudstone intervals indicate that palaeoflow was perpendicular to the dip of the strata. Hammer for scale. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

mas et al., 1987). Internal sedimentary structures preserved in the couplets, in the form of small-scale trough cross-stratification, indicate that palaeocurrent was perpendicular to their dip. Even though the overall architecture of this interval is reminiscent of levee deposits, the perpendicular orientation of the couplets to the direction of palaeoflow rather suggests that they were produced by lateral accretion within a channel. Similar inclined sandstone–mudstone couplets with internal sedimentary structures are preserved in numerous ancient and modern fluvial deposits interpreted as point bar deposits (Allen, 1965; Collinson, 1978; Jackson, 1978; Bridge, 1985; Thomas et al., 1987).

The sandstones of the Red Continental Strata are moderately to poorly sorted lithic wackes, composed primarily of angular to subrounded monocrystalline and polycrystalline quartz, potassium feldspars, and igneous rock fragments (Table 1). Angular andesite clasts and glass shards are common in these sandstones, suggesting that volcanic rocks were present in the source area. Furthermore, the discovery of a thin volcanic ash layer of andesitic composition in the western section (Fig. 8), supports the hypothesis of synchronous volcanic activity during deposition of the Red Continental Strata. Indeed, Maastrichtian banatitic intrusions, related to the subduction of oceanic crust, are found in the Apuseni Mountains and Southern Carpathians (see Kräutner et al., 1984; Anastasiu, 1991; Berza et al., 1998; Sanders, 1998; Willingshofer, 2000; Csontos and Vörös, 2004). Comparison of compositional modes reveals that the Red Continental Strata are compositionally distinct from the Sânpetru Formation: the studied sandstone is richer in monocrystalline quartz, with high Qt/F+L and Qp/F+L ratios (Suttner and Dutta, 1986), and richer in lithic fragments than the Sânpetru sandstones (Fig. 10). These results indicate that the composition of the source area for the Red Continental Strata was different from the source area of the Sânpetru Formation. Whereas the Sânpetru rivers drained a metamorphic core complex (Ţarcu-Retezat Mountains), the ancient rivers near Vurpăr drained the southern Apuseni Mountains, which consist of crystalline, ophiolitic, and sedimentary nappes (Burchfiel and Bleahu, 1976; Sandulescu et al., 1978; Sanders, 1998; Willingshofer, 2000).

While the Red Continental Strata fluvial system is generally floodplain-dominated, the abundance of

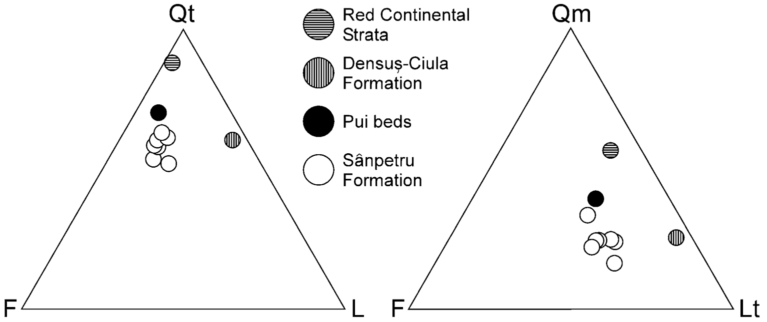

Fig. 10. Composition ternary diagrams for sandstones of the Red Continental Strata, Densuş-Ciula Formation, and Pui beds. These sandstones are compared to sandstones of the Sânpetru Formation (Therrien, 2004). Sandstones of the Red Continental Strata and Densuş-Ciula Formation are different from those of the Sânpetru Formation, being richer in quartz and lithic fragments, respectively; thus the provenance of the material found in these formations was different. The source area for the Red Continental Strata was the southern Apuseni Mountains, which consist of crystalline, ophiolitic, and sedimentary nappes, while sediment of the Densuş-Ciula Formation was derived from the Poiana Ruscă Mountains, part of the Getic/Supragetic crystalline and sedimentary nappes associated with andesitic intrusions and volcanism. The composition of the Pui and Sânpetru sandstones is very similar. The slightly higher quartz content of the Pui sandstone relative to those of the Sânpetru Formation could be due to the finer grained nature of the studied sample; thus Pui and Sânpetru sediments were probably derived from a similar source area, the metamorphic dome of the Ţarcu-Retezat Mountains.

mudstones in vertical sequences does not necessarily reflect deposition by meandering rivers. Although high-sinuosity fluvial systems are generally associated with thick overbank deposits, numerous meandering river deposits preserve little mudstone in their stratigraphic sequences (see Jackson, 1978) and recent

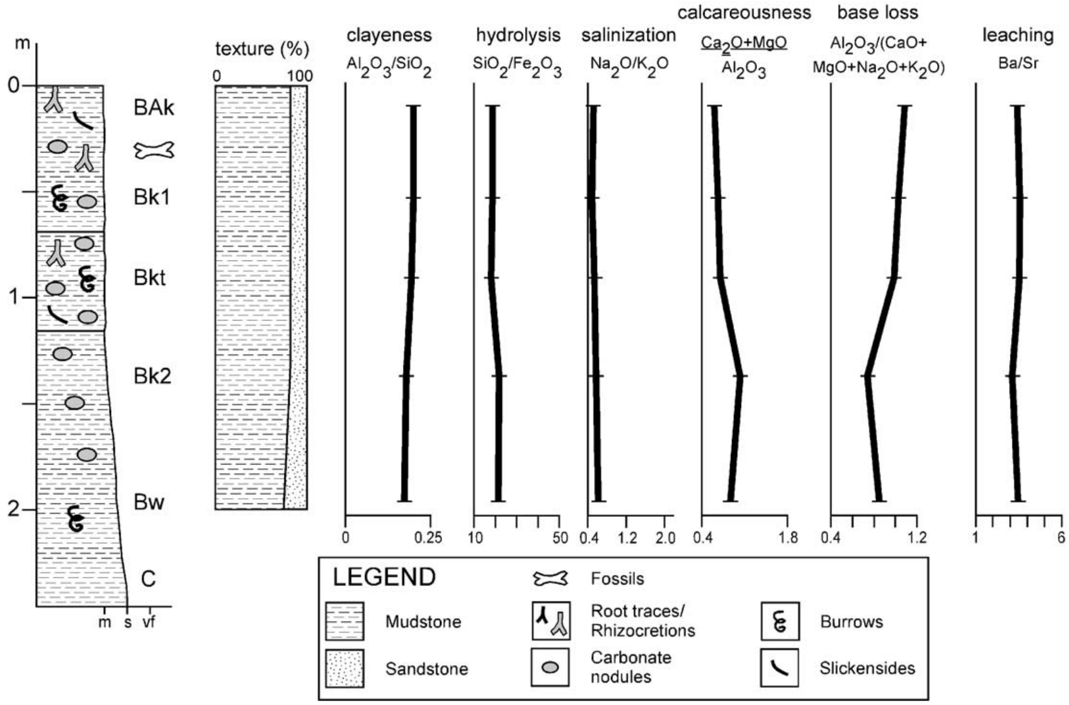

Fig. 11. Typical paleosol profile of the Red Continental Strata. This brown-to-red paleosol contains carbonate nodules, rhizocretions, and slickensides. The various molecular weathering ratios reflect a distinct geochemical trend through the profile, indicating that the pedogenic horizons are well-differentiated. The textural index reveals that the profile consists predominantly of mudstone.

Table 2
Characteristics of the paleosols of the Red Continental Strata, Densuş-Ciula Formation, and Pui beds

Depth (cm)	Horizon	Lithology	Matrix color	Redoximorphic features	B-fabric	Carbonates	Notes
Red Continental Strata, Vurpăr (location of paleosol: 42 m from base of western section; 46°00′36″N 023°28′36″E)							
0–34	BAk	Sandy mudstone	10R 3/4 (brownish red)	None	Stipple speckled with striations and granostriations	Rare small nodules, common rhizocretions (1 cm diameter); Microscopy: micritic with sparite veins, ferruginous intergrowths	Intense bioturbation; slickensides; clay and iron coatings; localized zones of Fe depletion or concentration; theropod bones found in this unit
34–69	Bk1	Sandy mudstone	10R 3/4 (brownish red)	None	Mosaic speckled with numerous striations	Few small nodules, common rhizocretion (1 cm diameter); Microscopy: micritic, some occasionally form coatings on ferruginous pedofeatures	Bioturbation; slickensides; clay and iron coatings; localized zones of Fe depletion or concentration
69–116	Bkt	Sandy mudstone	5YR 3/4 (reddish brown)	None	Mosaic speckled with numerous striations	Common small to medium nodules, some rhizocretions or cemented burrows; Microscopy: micritic, ferruginous intergrowths	Bioturbation; slickensides; broken subangular blocky peds?; clay and iron coatings; localized zones of Fe depletion or concentration
116–188	Bk2	Sandy mudstone	7.5YR 4/4 (brown)	None	Stipple speckled with some striations and granostriations	Common to abundant small to medium nodules; Microscopy: micritic, ferruginous intergrowths	Bioturbation; slickensides?; some iron coatings
188–213	Bw	Sandy mudstone	7.5YR 4/4 (brown)	None	Stipple speckled with striations and occasional granostriations	Microscopic nodules; micritic, rare sparite inclusions	Bioturbation; slickensides?; localized zones of Fe depletion or concentration
213–228	C	Sandy siltstone					
Densuş-Ciula Formation, Tuştea (location of paleosol: 7.91m from base of section)							
0–33	Bw	Sandy mudstone	2.5YR 3/4 (reddish brown)	None	Striated	Common small to large nodules and masses; Microscopy: micritic and sparitic masses present	Bioturbation; slickensides; some clay illuviation
33–72	Bk(t?)	Sandy mudstone	2.5YR 3/4 (reddish brown)	None	Striated and granostriations	Abundant small to large nodules and masses; Microscopy: micritic, most have diffuse margins; ferruginous intergrowths	Bioturbation; slickensides; clay and iron coatings
72–97	2ABk	Sandy mudstone	2.5YR 3/4 (Reddish brown)	None	Striated and granostriations	Common small to large nodules and masses; Microscopy: micritic and sparitic masses present	Intense bioturbation; slickensides?; some clay coatings

Table 2 (*continued*)

Depth (cm)	Horizon	Lithology	Matrix color	Redoximorphic features	B-fabric	Carbonates	Notes
97–150	2Bk	Sandy mudstone	2.5YR 3/6 (reddish brown)	None	Stipple speckled with striations and granostriations	Few small to large nodules and masses; Microscopy: mostly micritic, occasional sparite inclusions, diffuse margins, ferruginous intergrowths	Bioturbation; slickensides, iron coatings, occasional clay coatings
150–171	2Bt	Sandy mudstone	2.5YR 3/6 (reddish brown)	None	Striated	None or rare	Bioturbation; slickensides, clay and iron coatings; abundant cracks filled by chaotically-organized material
Nesting horizon, Tuştea (location of paleosol: 1.29m from base of section)							
0–21	Bw	Very sandy mudstone	10R 3/4 (reddish brown)	None	Stipple speckled and granostriations	None	Bioturbation; some clay and iron coatings
21–29	C?	Conglomeratic lithic arenite (crevasse splay deposit)					Laterally discontinuous deposit, extends laterally into carbonate-cemented layer
29–63	2Bk	Very sandy mudstone	2.5YR 2.5/4 (reddish brown)	None	Striated	Few small to large nodules and masses, diffuse margins	Bioturbation; some clay and iron coatings
63–80	2CBk	Very sandy mudstone	2.5YR 2.5/4 (reddish brown)	None	Undifferentiated	Rare small to large nodules and masses, diffuse margins	Bioturbated, rare poorly developed clay coatings
Pui beds (location of paleosol: 94.90 m from base of section; 45°30′16″N 23°05′38″E)							
0–5	BAt	Muddy sandstone	7.5R 3/6 (red)	Few, small, diffuse, and irregular; 10R 3/2	Some striations and granostriations, but mostly silasepic (sandy groundmass)	None	Bioturbation; clay and iron coatings; may contain slickensides; abrupt lower boundary
5–18	Bt	Muddy sandstone	10R 3/6 (red)	Few, medium to large, diffuse, and irregular; 10R 3/2	Striations and granostriations, but mostly silasepic (sandy groundmass)	None	Bioturbation; clay and iron coatings; may contain slickensides; clear lower boundary
18–27	Bw	Muddy sandstone	10R 3/6 (red)	None	Mostly silasepic (sandy groundmass)	None	Bioturbation; few clay and iron coatings; may contain slickensides; gradual lower boundary
27–39	BC	Muddy sandstone	10R 3/4 (brownish red)	None	Mostly silasepic (sandy groundmass)	None	Bioturbation; rare iron coatings

The descriptive colour written in parentheses indicates the apparent colour of the horizon in outcrops. The location of the paleosol refers to the stratigraphic level from the base of the specified section at which the studied profile is found.

models of braided stream alluvium reveal that the quantity of overbank deposits can also be significant in low-sinuosity fluvial systems (Bentham et al., 1993; Mack and James, 1993). However, the preponderance of mudstones, the high variability of palaeocurrent direction, and the presence of IHS interpreted as point bar deposits together suggest that the Red Continental Strata were deposited by a high-sinuosity fluvial system that carried a significant suspended load.

5.1.2. Paleosols

The mudstone intervals preserved near Vurpăr represent cumulative paleosol profiles built by the episodic addition of sediment to the developing profile (Figs. 8 and 11; Table 2). Although they may vary in maturity, the paleosols of the Red Continental Strata all formed in a palaeoenvironment subject to alternating wet and dry periods. Pedogenic features, when considered by themselves, do not indicate if the alternation between wet and dry periods occurred on a seasonal, annual, or longer periodicity. However, when considered in combination with a palaeoflora, suggestive of annual variation in precipitation, the alternations can be inferred to have occurred seasonally. Slickensides are common in Vurpăr paleosols although pseudoanticlines, complex concave shrink-and-swell features formed in vertisols (e.g., Wilding and Tessier, 1988; Marriott and Wright, 1993; Caudill et al., 1996; Wright et al., 2000), were not observed. Preliminary results of X-ray diffraction analysis reveal that smectite is present in these paleosols; pedogenic smectite is known to form in climates subject to seasonal precipitation. All paleosols display carbonate accumulation, generally in the form of rhizocretions and carbonate nodules occurring in well-defined calcic (Bk) horizons (Fig. 11; Table 2), and an indurated K horizon is developed in a thin sandstone bed in the western section (Fig. 8). Such calcareous features develop in arid to subhumid climates where evapotranspiration exceeds precipitation. Indurated K horizons are usually indicative of greater soil maturity, although the occurrence of a single K horizon in a sandstone bed suggests that the greater porosity of the bed may be responsible for accelerating its development (Gile et al., 1966; Birkeland, 1985). The presence of slickensides, smectite, fractured carbonate nodules cemented by sparite, and closely associated carbonate nodules and ferruginous oxides (see above) indicates alternating wet and dry periods. The presence of mottles in some paleosols reveals that soil conditions varied occasionally from oxidizing to reducing. Finally, the association of vertic features (slickensides), carbonate nodules, and redoximorphic features (mottles) in these paleosols suggests that the climate was subhumid (500–760 mm/year; Royer, 1999, 2000; Khadkikar et al., 2000).

The geochemical composition of Vurpăr paleosols also suggests that a strongly seasonal subhumid climate prevailed. Recently, Sheldon et al. (2002) derived equations correlating specific geochemical properties of Bw and Bt horizons of various types of paleosols to the climatic conditions under which they formed (precipitation range 200–1600 mm/year). Namely, they correlated the chemical index of alteration without potash and molecular ratio of bases/alumina with mean annual precipitation (MAP) and molecular ratio of potash and soda to alumina with mean annual temperature (MAT) in the following manner:

$$\mathrm{MAP} = 221e^{0.0197(100*\mathrm{Al_2O_3}/[\mathrm{Al_2O_3}+\mathrm{CaO}+\mathrm{Na_2O}])} \qquad (1)$$

$$\mathrm{MAP} = 14.265*(100*\mathrm{Al_2O_3}/[\mathrm{Al_2O_3}+\mathrm{CaO}+\mathrm{Na_2O}]) - 37.632 \qquad (2)$$

$$\mathrm{MAP} = -259.34\ln([\mathrm{MgO}+\mathrm{CaO}+\mathrm{Na_2O}+\mathrm{K_2O}]/\mathrm{Al_2O_3}) + 759.05 \qquad (3)$$

$$\mathrm{MAT} = -18.516*([\mathrm{K_2O}+\mathrm{Na_2O}]/\mathrm{Al_2O_3})+17.298 \qquad (4)$$

Although Sheldon et al. (2002) cautioned that these relationships may not give accurate results for paleosols with near-surface carbonate accumulation, Retallack (2004) and Sheldon and Retallack (2004) applied them to paleosols possessing calcic horizons at a depth of 50 cm or deeper. These relationships were also applied to the Maastrichtian paleosols of Romania and care was taken to include at least one paleosol per formation that either possessed only a deep calcic horizon (Red Continental Strata, Densuş-Ciula Formation) or lacked carbonate accumulation altogether (Pui beds, Densuş-Ciula Formation).

Following Sheldon et al.'s (2002) equations, the geochemical properties of the Bw and Bt horizons of two distinct Vurpăr paleosols were used to estimate palaeoprecipitation and palaeotemperature of the Maastrichtian climate (Table 3). The results suggest that annual rainfall varied between 708 and 853 mm while mean annual temperatures were around 11.5–11.7 °C. These estimates are significantly lower than those suggested by the Maastrichtian tropical flora occurring in the Red Continental Strata and other contemporaneous Romanian deposits, which presumably required abundant precipitation (1300–2500 mm; Fig. 17) and high mean annual temperatures (22–24 °C; Antonescu, 1973; Petrescu and Duşa, 1982a; Pop and Petrescu, 1983; Iamandei and Iamandei, 1997). These divergences initially appear incompatible. However, Horrell (1991) interpreted the Romanian floral assemblage as living in a warm climate characterized by highly seasonal precipitation, where periods of abundant precipitation alternate with periods of limited precipitation (e.g., India, southeastern Asia). Tropical plants can live in such climates if they have access to water during the dry seasons, either from the surface or groundwater, or if the reduced amount of rainfall is sufficient to satisfy their metabolic needs. Petrescu and Duşa (1982a,b) and Pop and Petrescu (1983) also inferred seasonality of precipitation on the basis of the contemporaneous macroflora preserved in the Rusca Montană Basin, although they estimated abundant palaeoprecipitation (at least 1300 mm/year). The anomalously low MAT estimates derived from paleosols are also an artifact of seasonal precipitation. The geochemical estimation method relies on the amount of sodium and potassium oxides (relative to aluminum oxides) present in the soil. Under a warm seasonal climate, K-rich minerals are less easily weathered and (Na-rich) evaporites may form due to the reduced amount of precipitation, resulting in an up-profile increase of both elements in soils. Because this predicted Na and K distribution pattern (high sodium and potassium content) is identical to that observed in soils developing in colder climates, the estimation method delivers very low temperature estimates. Therefore, the anomalously low temperature estimates obtained from Red Continental Strata paleosols do not indicate a cold Maastrichtian climate but rather one characterized by strong seasonality of precipitation (Retallack, 2001; Sheldon et al., 2002).

Table 3

Estimates of mean annual precipitation (MAP) and mean annual temperature (MAT) from different predictive methods (Eqs. 1 through 4 in text) applied to various paleosols of the Red Continental Strata, Densuş-Ciula Formation, and Pui beds (Vurpăr Western from calcareous paleosol illustrated in Fig. 11, Vurpăr Eastern from non-illustrated calcareous paleosol, Tuştea L and Q are 2Bt and Bw horizons, respectively, from calcareous profile illustrated in Fig. 13, Tuştea I is from nest horizon illustrated in Fig. 14, Pui B and D are from noncalcareous paleosol illustrated in Fig. 16)

Paleosol sample	MAP (1) (mm)	MAP (2) (mm)	MAP (3) (mm)	MAT (4) (Celsius)
Red Continental Strata				
Vurpăr Western (Bw)	756	853	714	11.5
Vurpăr Eastern (Bt)	747	844	708	11.7
Densuş-Ciula Formation				
Tuştea L (Bt)	1086	1115	794	12.4
Tuştea Q (Bw)	903	981	735	12.6
Tuştea I (Bw)	1036	1081	775	11.6
Pui beds				
Pui B (Bw)	921	996	793	8.7
Pui D (Bt)	958	1024	791	9.3
Average of Sânpetru Formation	670	766	664	8.7
Standard error of estimate	185	182	204	3.7

Palaeobotanical studies	Petrescu and Duşa (1982a)	Pop and Petrescu (1983)
Palaeoprecipitation estimates	1500 mm/year	1300–2200 mm/year
Palaeotemperature estimates	22 °C	22–24 °C

These values are compared to the mean of estimates from Sânpetru paleosols [derived from noncalcareous (category 4) and calcareous (category 5) paleosols in Therrien, 2004] and estimates from palaeobotanical studies. The standard error of estimate was calculated from the data presented in Sheldon et al. (2002: Table 1).

The molecular weathering ratios of paleosols of the Red Continental Strata demonstrate the extent of geochemical differentiation of the various pedogenic horizons (Fig. 11). Clay and iron content gradually increase up-profile, reflecting the increased weathering of parent material, creation of pedogenic clays, and rubification of the paleosol. The upper horizons are relatively impoverished in bases, which were released by the weathering of the parent material and evacuated from the profile. However, a distinct enrichment in carbonates is observed in the lower part of the profile. The intermediate leaching index throughout the profile reflects the well-drained conditions under which this

Table 4
Taphonomic, sedimentologic, and palaeopedologic comparison of the four Maastrichtian dinosaur-bearing formations of Romania

	Red Continental Strata	Densuş-Ciula Formation	Pui beds	Sânpetru Formation
Vertebrate remains	Disarticulated, occasionally associated?	Disarticulated, rarely articulated, occasionally associated	Disarticulated, rarely articulated	Disarticulated, rarely articulated, occasionally associated
Faunal assemblage	Dinosauria: *Zalmoxes robustus*, *Z. shqiperorum*, *Telmatosaurus transsylvanicus*, *Strutiosaurus transilvanicus*, *Magyarasaurus dacus*, at least one indeterminate theropod Chelonia: *Kallokibotion bajazidi* Crocodyliformes: large indeterminate crocodilian Dinosaur trackway: *Iguanodontichnus* group (attributed to *Zalmoxes*)	Dinosauria: *Zalmoxes robustus*, *Z. shqiperorum*, *Telmatosaurus transsylvanicus*, *Magyarasaurus dacus*, velociraptorine theropod, troodontid-like theropod Pterosauria: *Hatzegopteryx thambema* Chelonia: *Kallokibotion bajazidi* Crocodyliformes: *Allodaposuchus precedens* and *Doratodon* sp. Anura: *Eodiscoglossus* sp., *Hatzegobatrachus grigorescui*, and *Paralatonia transylvanica* Albanerpetontidae: *Albanerpeton* sp. and *Celtedens* sp. Lacertilia: scincomorph lizards (two unnamed taxa)	Dinosauria: *Zalmoxes robustus*, (*Z. shqiperorum*?), *Telmatosaurus transsylvanicus*, *Magyarasaurus dacus*, velociraptorine theropod, troodontid-like theropod Chelonia: *Kallokibotion bajazidi* Crocodyliformes: *Allodaposuchus precedens* Anura: *Eodiscoglossus* sp. Albanerpetontidae: *Albanerpeton* cf. *inexpectatum* Multituberculata: ?*Paracimexomys dacicus* = *Barbatodon transylvanicum* and indeterminate taxon Lacertilia: indeterminate anguimorph(?) lizards and three scincomorph lizards (the teiid *Paraglyphanodon* sp. and the paramacellodids	Dinosauria: *Zalmoxes robustus*, *Z. shqiperorum*, *Telmatosaurus transsylvanicus*, *Strutiosaurus transilvanicus*, *Magyarasaurus dacus*, *Euronychodon* sp., *Paronychodon* sp., *Richardoestesia* sp., *Bradycneme draculae* (tetanuran or maniraptoran), *Elopteryx nopcsai* (troodontid or pygostylian), *Heptasteornis andrewsi* (alvarezsaurid?), one velociraptorine (closely related to *Saurornitholestes*), one neoceratosaur (abelisaurid?), indeterminate enantiornithine Pterosauria: cf. *Ornithodesmus* sp. Chelonia: *Kallokibotion bajazidi* Crocodyliformes: *Allodaposuchus precedens* Anura?: discoglossid? Albanerpetontidae:

		Multituberculata: ?*Paracimexomys dacicus* = *Barbatodon transylvanicum*, *Hainina* sp., and indeterminate kogaiononidae fishes: *Lepisosteus* sp. and numerous others 2 dinosaur nests with eggs (3 clutches) (*Megaloolithus* sp. parataxon)	*Becklesius* sp. and *B*. aff. *hoffstetteri*) fishes: indeterminate acipenseriforms and characids 5 eggshell types: discretispherulitic, prolatospherulitic, prismatic, ratite, and geckonoid	indeterminate taxon Multituberculata: *Kogaionon ungureanui*, *Kogaionon* n. sp., indeterminate kogaiononidae, *Barbatodon* n. sp., and indeterminate taxon Lacertilia: 2 indeterminate scincomorphs 11 dinosaur nests with eggs (*Megaloolithus* cf. *siruguei* parataxon) + prismatic eggshells (theropod?) + geckonoid eggshells
Preservation environments	Paleosol, channel	Paleosol, splay deposit	Paleosol, channel	Floodplain depression (sandy lenses), channel, paleosol
Fluvial system	Meandering rivers	Braided streams	Meandering rivers	Braided streams (+ meandering rivers)
Palaeoenvironments	Moderately- to well-drained floodplains	Well-drained floodplains with local areas of impeded drainage	Moderately- to well-drained floodplains	Mosaic of wetlands and moderately-drained floodplains
Climate	Subhumid with alternating wet and dry periods (monsoonal)	Subhumid with alternating wet and dry periods (monsoonal)	Subhumid with alternating wet and dry periods (monsoonal)	Subhumid with alternating wet and dry periods (monsoonal)

Characteristics of the Sânpetru Formation were obtained from Grigorescu and Kessler (1980), Grigorescu (1983), Weishampel and Jianu (1996), Jianu and Weishampel (1997), Csiki and Grigorescu (1998), Grigorescu et al. (1999), Codrea et al. (2002b), Grigorescu and Csiki (2002), Smith et al. (2002), Weishampel et al. (2003), Naish and Dyke (2004), Therrien (2004), Van Itterbeeck et al. (2004), and P. Godefroit (personal communication, December 2004).

paleosol developed. Such geochemical trends, reflecting clear horizon differentiation, necessitate extended periods of subaerial exposure. Comparison with the Sânpetru paleosols (Therrien, 2004) reveals that the paleosols of the Red Continental Strata are very similar to category 5 (calcareous) paleosols, although slightly more mature. These paleosols formed on moderately- to well-drained floodplains.

5.1.3. Fossil remains

The typical fossil fauna found in the Red Continental Strata near Vurpăr is dominated by dinosaurs and consists of the euornithopods *Zalmoxes robustus* and rarer *Zalmoxes shqiperorum*, the hadrosaurid *Telmatosaurus transsylvanicus*, the nodosaurid *Strutiosaurus transilvanicus*, at least one (indeterminate) theropod, at least one turtle (the selmacryptodire *Kallokibotion bajadizi*), and large (indeterminate) crocodilians (Codrea et al., 2002a; Weishampel et al., 2003). Remains of the titanosaurid *Magyarasaurus dacus* and ornithopod trackways are also preserved south of the Mureş River in deposits ascribed to the same formation with a more prominent lacustrine presence (Table 4; Codrea et al., 2002a; Vremir and Codrea, 2002).

Fossil vertebrates are found usually as disarticulated remains in red and brown paleosols; e.g., theropod postcranial elements were found in the surficial red horizon of the studied paleosol (Fig. 11). Such attributes suggest preservation of attritional assemblages in paleosols, where bones are disarticulated, exposed to the elements, and possibly transported prior to their incorporation into paleosol profiles. Channels can also be concentration agents, as revealed by lag deposits preserving long bones and vertebrae of broad taxonomic diversity (Vremir and Codrea, 2002). Recently, associated ankylosaur material (*Strutiosaurus*, V. Codrea, personal communication, December, 2004) was discovered in the Western section by a team from the Babeş-Bolyai University (Cluj) in a thin (23 cm) lens of red, trough cross-stratified very fine sandstone to siltstone directly overlying channel deposits, suggesting that carcasses could also be stranded and preserved in infilling or crevasse splay channels. South of the Mureş River, dinosaur trackways (*Iguanodontichnus* group, attributed to *Zalmoxes*) were found near the top of a trough-to-tabular cross-stratified sandstone, interpreted as a riverbank environment (Vremir and Codrea, 2002).

5.2. Densuş-Ciula Formation, Tuştea

The Densuş-Ciula Formation is exposed in the northwestern Haţeg Basin, along the margin of the Poiana Ruscă Mountains (Fig. 3). While the coarse, nonfossiliferous, lower member is broadly exposed between the villages of Stei and Densuş, the finer members rich in red mudstones are only poorly exposed. Creeks dissecting the formation provide discontinuous exposures of the finer members generally limited to a few tens of meters in thickness. In the late 1980s, a fortuitous landslide in the hills west of the village of Tuştea exposed a 12 m-section of the middle member of the Densuş-Ciula Formation. This famous locality has yielded at least two dinosaur nests containing eggs as well as embryonic-to-hatchling and adult skeletal material (Grigorescu et al., 1990, 1994; Grigorescu and Csiki, 2002) and was included in this study because it preserved an exquisite sedimentary sequence. A stratigraphic section of the locality (45°36′ 26″ N 022°50′ 53″ E) was measured and corrected for the attitude of the strata (092°N, dip 14° to the south). Grigorescu (1993) argued that this locality is situated in the uppermost middle member of the Densuş-Ciula Formation, presumably near the K/T boundary, because the remainder of the formation is devoid of dinosaur remains. However, given the nonfossiliferous nature of the upper member of the Densuş-Ciula Formation, the assignment of the middle member to the latest Maastrichtian must be considered cautiously and requires reevaluation with a datation method independent of fossil preservation (e.g., Panaiotu and Panaiotu, 2002; Therrien, 2004).

5.2.1. Fluvial system

The deposits of the Densuş-Ciula Formation exposed at Tuştea are red, pedogenically-modified mudstones bisected by a nearly 6-m-thick conglomerate and sandstone channel sequence (Fig. 12). The channel deposits consist of a light green fining-upward sequence that becomes gradually brown toward the top. At the base of the channel sequence, a thick, poorly imbricated cobble-to-pebble conglomerate overlies an erosional contact with minimal (<15 cm) relief. The basal conglomerate is overlain by conglomeratic litharenite exhibiting an upward sedimentary structure sequence of large-scale trough cross-stratification, horizontal lamination, large-scale tabular cross-strat-

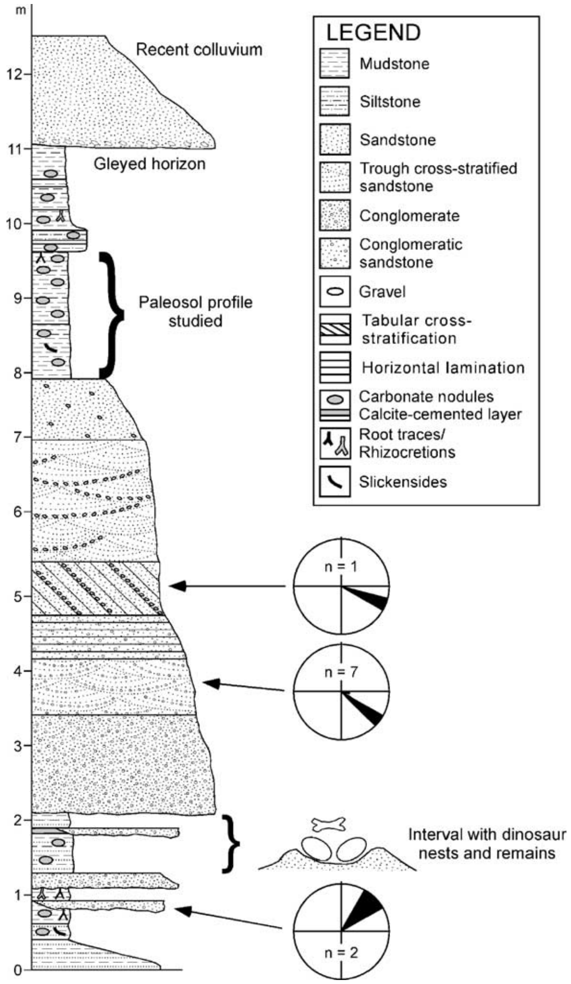

Fig. 12. Stratigraphic section of the Tuştea locality, Densuş-Ciula Formation (Haţeg Basin, Hunedoara county). Total thickness of the section is 12.58 m. The base of the section consists of interbedded sandstone and mudstone intervals, typical of splay deposits. A stratigraphic interval containing dinosaur nests, eggs, and fossil remains underlies a thick sandstone bed preserving a sequence of sedimentary structures typical of braided streams. The upper part of the section is dominated by thick, pedogenically-modified red mudstones rich in carbonate nodules, suggesting a well-drained floodplain environment. A gleyed interval occurs at the top of the section but its occurrence underneath recent colluvium and the presence of recent illuvial features suggest that it may not be a Maastrichtian paleosol horizon. The rose diagrams, reflecting the palaeocurrent direction measured in a few channel deposits, indicate that low-sinuosity rivers flowing primarily to the southeast and crevasse splays formed the deposits.

ification, medium-scale trough cross-stratification, and small-scale trough cross-stratification. The top of the channel deposits is structureless. Although the number of palaeocurrent directions measured in the channel sequence is limited, large trough and tabular cross-stratification indicate a unique direction of palaeoflow to the south-east (Fig. 12). These results contrast with the general northward palaeocurrents reported for the Densuş-Ciula Formation by Grigorescu (1983: Fig. 3, labeled as part of the "Sînpetru beds"). The sequence of sedimentary structures and variability in palaeocurrent orientation is very similar to the facies models developed for distal gravelly and sandy braided streams: a large channel filled by the migration of crescent-shaped dunes (trough cross-stratification) and straight crested dunes or sandbars (tabular cross-stratification; Cant and Walker, 1976, 1978; Cant, 1978; Miall, 1978; Bentham et al., 1993).

A thin, weakly-imbricated conglomeratic bed situated lower in the section preserved palaeocurrent orientation perpendicular to the channel sequence (Fig. 12). This characteristic, combined with the presence of pedogenically-modified sandy overbank deposits overlying this unit, suggests that the thin conglomeratic bed represents proximal crevasse splay deposits. Indeed, crevasse splays tend to breach natural levees at high angle to the main channel and deposit coarse material on the floodplain (see Mjøs et al., 1993).

The channel deposits of Tuştea are moderately to poorly sorted lithic wackes, composed primarily of very angular to subrounded polycrystalline and monocrystalline quartz, andesite, and metamorphic clasts (Table 1). The abundance of andesitic clasts (up to cobble size) in the Densuş-Ciula Formation has long been recognized as evidence of syndepositional volcanism; indeed, contemporaneous banatitic intrusions are known from the nearby Poiana Ruscă Mountains, located to the northwest of Tuştea (Nopcsa, 1905; Anastasiu, 1991; Weishampel et al., 1991; Grigorescu, 1992). Comparison of compositional modes reveals that the Densuş-Ciula Formation is compositionally distinct from the Sânpetru Formation: although the Tuştea sandstone contains a relatively similar quantity of quartz (both Qp and Qt) and is of similar low maturity (low Qt/F+L and Qp/F+L ratios) as the Sânpetru sandstones, it is far richer in lithic fragments, mainly andesitic clasts fragments (Fig. 10; Table 1). These results strongly suggest that the composition of the source area for the Densuş-Ciula Formation was different from the source area of the Sânpetru Formation. Indeed, the occurrence of andesitic intrusions in the Poiana Ruscă Mountains combined with the southeastward palaeocurrents of the large channel deposits at Tuştea (Fig. 12) argue for a source area somewhere in the Getic/Supragetic crystalline and sedimentary nappes situated northwest of the Densuş-Ciula Formation (see Figs. 1 and 3), contrary to the conclusions reached by Grigorescu (1983: Fig. 3), who suggested a source area to the south. In contrast, the source area of the Sânpetru Formation, which lacks volcanic fragments, was the large metamorphic complex situated south of the Haţeg Basin, as supported by palaeocurrent orientation in that formation (Grigorescu, 1983; Therrien, 2004).

If the Tuştea locality is representative of the middle member of the Densuş-Ciula Formation, it can be concluded that braided streams were involved in the deposition of this part of the formation. The significant quantity of overbank deposits is typical of braided streams flowing in symmetrical, extensional basins like the Haţeg Basin (Bentham et al., 1993; Mack and James, 1993). In the depositional context of the Densuş-Formation, where the coarse basal member has been interpreted as alluvial fan deposits (e.g., Anastasiu and Csobuka, 1989; Weishampel et al., 1991), several authors have interpreted the fossiliferous middle member in terms of a distal alluvial fan setting (Anastasiu and Csobuka, 1989; Anastasiu, 1991; Grigorescu et al., 1994; Grigorescu and Csiki, 2002). This palaeoenvironmental reconstruction does not contradict the results presented here, as deposition on distal alluvial fans (in the broad sense of the term, contra Blair and MacPherson, 1994) is often accomplished by braided streams and deposits of such depositional environments are difficult to differentiate from those of alluvial plains (see López-Gómez and Arche, 1997; Therrien, 2004).

5.2.2. Paleosols

The mudstones of the Densuş-Ciula Formation preserve cumulative and composite paleosol profiles (Figs. 12 and 13; Table 2). As was the case in Vurpăr,

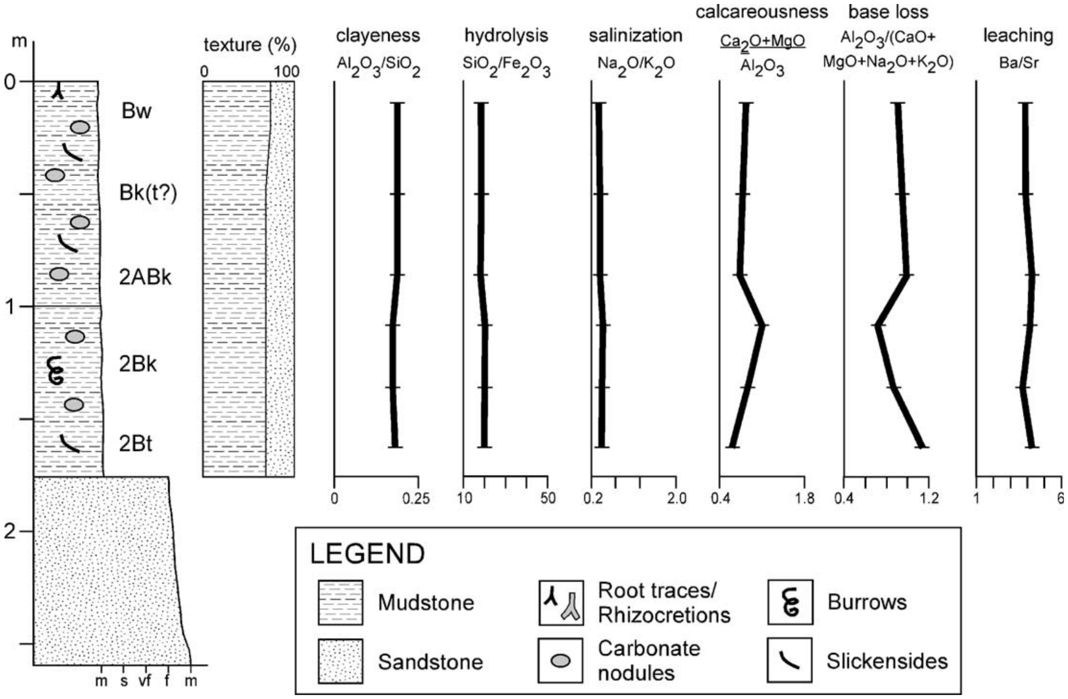

Fig. 13. Typical paleosol profile of the Densuş-Ciula Formation. This brown-to-red paleosol contains carbonate nodules, root traces, and slickensides. The various molecular weathering ratios reflect a distinct geochemical trend through the profile, indicating that the pedogenic horizons are well-differentiated. The textural index reveals that the profile consists predominantly of mudstone.

the paleosols of Tuştea formed in a climate characterized by alternating wet and dry periods. Slickensides are extremely abundant in the Tuştea paleosols, although pseudoanticlines were not observed. Preliminary results of clay mineralogy analysis presented in Grigorescu and Csiki (2002) and those conducted by the present author indicate that smectite is present in the studied paleosols. Carbonate nodules are omnipresent in the Tuştea overbank deposits, forming well-developed calcic (Bk) horizons (Fig. 12); however, plugged horizons (K) are not present. Microscopically, the carbonate nodules display fractures that were later filled by sparite or soil materials, as well as ferruginous intergrowths. All these pedogenic features suggest seasonal precipitation, possibly varying between 500 and 760 mm/year (Royer, 1999, 2000; Khadkikar et al., 2000). As explained earlier, pedogenic features, when considered by themselves, do not indicate the periodicity of the alternating wet and dry periods, but when considered in combination with a palaeoflora, suggestive of annual variation in precipitation, these alternations can be inferred to have occurred seasonally.

Coal layers have been reported in the Densuş-Ciula Formation (Weishampel et al., 1991; Grigorescu, 1992; Grigorescu et al., 1994; Grigorescu and Csiki, 2002), indicating that poorly-drained environments characterized the Densuş-Ciula landscape, at least locally. Although no coal layer is preserved at the Tuştea locality, the uppermost paleosols of the section become gradually grayer until they can be considered gleyed (Fig. 12). Such features could be interpreted as hydromorphic paleosols, indicative of prolonged saturation of the soil profile by groundwater. However, because these gleyed horizons are located near the top of the section underneath recent colluvium, are invaded by modern roots, and contain evidence of recent illuvial features (films of carbonate accumulation), they could be the result of recent pedogenic processes.

Estimates of palaeoprecipitation and palaeotemperatures derived from paleosol geochemistry are indicative of a subhumid climate. Curiously, the MAP estimates obtained from the chemical index of alteration without potash are superior to estimates derived from the molecular ratio of bases/alumina (the former range from 900 to 1090 mm/year, the latter vary between 735 and 794 mm/year) and estimates from contemporaneous paleosols of other Romanian formations (Table 3; Fig. 17). However, all of these estimates are compatible given the standard errors associated with these methods. The high estimates derived from the Tuştea paleosols appear to be influenced by the higher Al_2O_3 and lower Na_2O content of these paleosols, which could reflect differences in parent material composition (more volcanic clasts), texture (muddier=enriched in Al_2O_3), or degree of pedogenesis (more mature paleosol=enriched in Al_2O_3 and impoverished in Na_2O). The MAT estimates from Tuştea paleosols are less than the estimate of 22–24 °C derived from the fossil tropical flora of the region (Petrescu and Duşa, 1982a,b; Pop and Petrescu, 1983). Once again, this is due to the reduced weathering of feldspars in a climate characterized by seasonal precipitation (Sheldon et al., 2002).

The geochemical profiles for a segment of the overbank sequence overlying the channel deposits demonstrate the extent to which pedogenesis modified Tuştea floodplain deposits (Fig. 13). This sequence represents a composite paleosol profile, where the A horizon of a paleosol was overprinted with pedogenic features of a second paleosol that developed on top of it. The clay content (clayeness) and hydrolysis indices are, respectively, high and low throughout the profile, reflecting the advanced state of weathering of the parent material resulting in the high clay and iron content of the paleosols. The lower half of the overbank sequence displays distinct geochemical differentiation of the horizons. The presence of a carbonate- and base-impoverished horizon overlying a horizon enriched in these same elements is interpreted as evidence for the leaching of carbonates and bases from the surficial A horizon followed by their accumulation in an illuvial B horizon (Fig. 13). Such well-developed geochemical trends suggest that pedogenesis was uninterrupted by the addition of material to the profile, thus allowing clear differentiation of the horizons within the paleosol. In contrast, the upper half of the overbank sequence is poorly differentiated geochemically, suggesting that addition of material to the profile may have been more frequent, resulting in less extensive pedogenic modification. Finally, the intermediate-to-high leaching index throughout the profile confirms the well-drained nature of the floodplain on which these paleosols developed. Comparison with the Sânpetru paleosols (Therrien, 2004) indicates that the Densuş-Ciula paleosols present at Tuştea represent well-developed category 5 (calcareous) paleosols, possibly slightly more mature than their Sânpetru equivalents. These paleosols formed on well-drained floodplains where the watertable was very deep and fluctuations in its level did not affect the hydrologic conditions within the profile.

5.2.3. Fossil remains

The fossil vertebrate fauna known from the Tuştea locality consists of *Zalmoxes robustus*, *Zalmoxes shqiperorum*, *Telmatosaurus transsylvanicus*, a velociraptorine theropod, the eucrocodilian *Allodaposuchus precedens*, the selmacryptodire *Kallokibotion bajazidi*, indeterminate pterosaurs, frogs (?discoglossid), albanerpetontids (*Albanerpeton* sp.), and multituberculates (indeterminate Kogaiononidae; Csiki and Grigorescu, 1998, 2000; Grigorescu et al., 1999; Grigorescu and Csiki, 2002; Weishampel et al., 2003). Remains of *Magyarasaurus dacu*s, the giant azhdarchid pterosaur *Hatzegopteryx thambema*, troodontid-like theropods, the "mesosuchian" *Doratodon* sp., multituberculates (?*Paracimexomys* sp., *Hainina* sp., and indeterminate taxon), frogs (*Eodiscoglossus* sp., *Hatzegobatrachus grigorescui*, and *Paralatonia transylvanica*), albanerpetontids (*Celtedens* sp.), scincomorph lizards (two unnamed taxa), and fishes (*Lepisosteus* sp. and numerous other taxa) found at other localities within the middle member (e.g., Vălioara; see Fig. 3) complete the faunal assemblage of the Densuş-Ciula Formation (Table 4; Csiki and Grigorescu, 1998, 2000; Grigorescu et al., 1999; Buffetaut et al., 2002; Grigorescu and Csiki, 2002; Venczel and Csiki, 2003).

Grigorescu and Csiki (2002) described the taphonomy of the Tuştea locality. Disarticulated fossil remains tend to be found in calcareous paleosols and in bioturbated overbank deposits, although the faunal assemblages found in paleosols are taxonomically more diverse. The previous authors did not explain this difference in diversity, but I posit that it may be attributable to the fact that paleosols represent longer time intervals, thus resulting in time-averaged fossil assemblages. Grigorescu and Csiki (2002) inferred that the low degree of weathering and abrasion of the bones, combined with their occurrence within paleosols, indicate that the fossiliferous units in the Densuş-Ciula Formation represent attritional assemblages formed by limited hydraulic transport. The preponderance of small specimens and bone fragments (<10 cm) in the fossiliferous units was also interpreted as evidence that destructive processes, such as scavenging and trampling, were important (Grigorescu and Csiki, 2002), although simple mechanical breakage of the elements cannot be excluded.

The exceptional discovery of a fossiliferous horizon containing two dinosaur nests with 19 eggs, as well as hatchling and adult *Telmatosaurus* material at Tuştea (Grigorescu et al., 1990, 1994; Weishampel et al., 1993; Grigorescu and Csiki, 2002) offers the unique opportunity to study direct interaction between dinosaurs and their palaeoenvironments. The subspherical eggs were closely spaced and lying in nearly linear rows following the topographic relief of the surface (Grigorescu et al., 1994; Grigorescu and Csiki, 2002). Within one of the nests, the eggs are grouped in two clutches 50 cm apart. In each clutch, the eggs are vertically arranged in superposed levels containing 2 to 4 eggs. Recently, a third clutch preserving 5 eggs was recovered a few meters from the aforementioned nests (Grigorescu and Csiki, 2002). Most eggs are hatched, being represented by their lower halves only, but at least two eggs are complete and unhatched (Grigorescu et al., 1994). Although the presence of hatchling and adult *Telmatosaurus transsylvanicus* material suggested initially that the nests were built by hadrosaurids, this hypothesis was weakened when the eggs found in the nests were established to pertain to the megaloolithid ootaxonomic group, a category generally attributed to sauropods (Grigorescu et al., 1990).

The lower part of the Tuştea section consists of alternating thin conglomeratic beds and pedogenically-modified overbank deposits (Fig. 12). This sedimentary sequence indicates sporadic deposition by crevasse splays on the floodplain with periods of subaerial exposure separating each event. The nesting horizon is located within a sandy mudstone interval below the thick channel deposits (Figs. 12 and 14). Although the exact level at which the nests were found could not be identified with certainty at the time fieldwork was conducted, the fact that they are preserved with in situ eggs suggests that they occur either near the top of the calcareous interval or in the noncalcareous interval above the thin discontinuous conglomeratic layer found in mid-interval (2Bk or Bw horizon, respectively, in Fig. 14 and Table 2), a claim

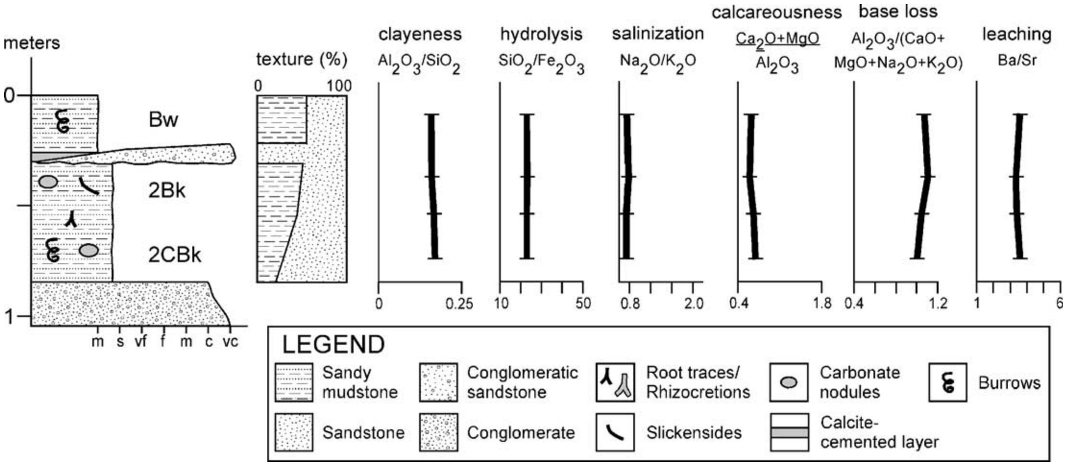

Fig. 14. Detailed stratigraphy of the nesting horizon at Tuştea. The nests occur either near the top of the calcareous interval (2Bk horizon) or in the noncalcareous interval (Bw horizon). The lower mudstone exhibits the pedogenic and geochemical signatures of a poorly developed calcareous paleosol (small carbonate nodules, weak geochemical differentiation of horizons). In contrast, the upper mudstone displays very limited pedogenic modification, indicative of a very immature paleosol. The textural index reveals that these paleosols are sandy, presumably reflecting a more proximal position on the floodplain.

supported by a schematic representation and description of this interval by Grigorescu et al. (1994) and Grigorescu and Csiki (2002), as well as photographs and description of the nest horizon (D.B. Weishampel, personal communication, May 2004). The presence of carbonate nodules, slickensides, root traces, and burrows and the lack of mottles in this stratigraphic interval indicate that these dinosaurs established their nests on well-drained parts of the floodplain. However, the less mature stage of development of the paleosol (carbonate nodules less abundant and generally smaller, also noted by Grigorescu et al., 1994, and poor geochemical differentiation of pedogenic horizons) and the sandier parent material compared to the other paleosols of the same locality (Figs. 13 and 14; Table 2) suggest that the nests were not built in the distal-most reaches of the floodplain, where addition of fine-grained material was infrequent, but rather closer to the channels where sediment accumulation occurred more frequently through crevasse splay deposition. Grigorescu and Csiki (2002) mentioned that the results of an undisclosed geochemical analysis indicated the presence of an early successional plant community in the region, an interpretation that lends support to the current palaeoenvironmental reconstruction of the nesting site on a floodplain subject to frequent flooding. Nevertheless, the dinosaur nests must have been buried rapidly in a relatively calm setting (such as by distal crevasse splay deposits) for the egg clutches to be preserved undisturbed.

The palaeoenvironmental conditions in which the dinosaur nesting site of Tuştea is preserved are not unique. Association of dinosaur nesting horizons with calcareous paleosols and crevasse splay deposits has also been observed in Late Cretaceous formations of North America (Lorenz and Gavin, 1984), Southern France (Cousin et al., 1994; Cojan et al., 2003), Mongolia (Mikhailov et al., 1994), India (Sahni et al., 1994; Mohabey, 1996; Sahni, 1997), and South Korea (Paik et al., 2004). Although they do not exhibit carbonate accumulation, the red paleosols in which the famous titanosaurid nests of the Anacleto Formation of Argentina and Patagonia are preserved contain slickensides (Chiappe et al., 2000; Dingus et al., 2000). These pedogenic similarities indicate that some dinosaurs established nests on well-drained floodplains, although some *Megaloolithus* eggs have been documented from mound-nests on tidal flats (López-Martinez et al., 2000) and poorly-drained habitats (Van Itterbeeck et al., 2004).

5.3. Pui beds

A red bed sequence is exposed near the village of Pui, located in the central part of the Haţeg Basin, approximately 15 km to the southeast of the Sânpetru

Formation outcrops found along the Sibişel Valley. Exposure of the light green conglomeratic sandstones and red mudstones of the Pui beds is extremely limited, being restricted to the width of the Bărbat River bed, which rarely exceeds 10 m. Unfortunately, lithostratigraphic correlation of the Pui beds to other formations within the Haţeg Basin is impossible due to the absence of Maastrichtian outcrops between the central and western part of the Haţeg Basin (Fig. 3). The Pui beds have been correlated historically to the basal portion of the Sânpetru Formation exposed along the Sibişel River on the basis of lithological similarities, namely the red colour of the beds (Nopcsa, 1905; Grigorescu et al., 1985). Unfortunately it is impossible to test this assertion because the dips of the two units are perpendicular to each other (see Fig. 3), preventing determination of the relative stratigraphic position of the Pui beds in relation to the Sânpetru section exposed along the Sibişel River.

A single, continuous stratigraphic section of the red deposits (45°30′28″N 023°05′41″E), approximately 100 m in thickness (not 200 m as previously estimated by Grigorescu et al., 1985), was measured when the river level was low (Fig. 15). Because the dip of these strata is weak (067°N, dip 14° to the south), correction for stratigraphic thickness would have been minimal (3%) and for palaeocurrent orientation unnecessary (Potter and Pettijohn, 1963). Consequently, no correction was made.

Recently, Van Itterbeeck et al. (2004) described the sedimentology and paleopedology of a short (18 m) stratigraphic interval of the Pui beds where fossil remains were discovered. Their results will be compared to those obtained in the current research.

5.3.1. Fluvial system

The Pui sedimentary sequence consists of stacked fining-upward sequences, each defined by a basal light green conglomeratic sandstone grading upward into brown and/or red mudstone (Fig. 15). The fining-upward sequences are often incomplete, either truncated by the overlying fining-upward sequence or by thin fine-to-coarse-grained sandstone layers interpreted as crevasse splays. Sandstone beds vary generally between 0.15 m and 1.50 m in thickness (rarely exceeding 2.00 m) while the fine-grained intervals range from 0.30 m to 2.00 m thick (usually less than 1.00 m). All sandstone beds are single-storied. Although it was often difficult to identify channel scours due to the limited exposure, it was occasionally possible to recognize the arcuate, concave-up erosional contact of a channel scour or to see the unit pinch-out laterally. Unfortunately, it was impossible to determine the width/depth ratios of channel scours.

Conglomerates, containing clasts up to cobble size, occur predominantly as lag deposits at the base of channel scours but also as thin (<30 cm thick), distinct beds in the section (too thin to appear in Fig. 15). Imbrication and large-scale trough cross-stratification are visible in the conglomeratic intervals, while small-scale trough cross-stratification is rarely recognizable in finer channel deposits. Due to the poor exposure of the Pui beds, trough cross-stratification is often the only recognizable sedimentary structure in channel deposits. The presence of horizontal laminations can be inferred from the horizontal orientation of light green reduction haloes, which appear to be restricted to the upper sandy portion of fining-upward sequences. Palaeocurrent direction was measured from imbrication and trough cross-stratification preserved in channel deposits (Fig. 15). Although few palaeocurrent measurements could be taken, rivers from the Maastrichtian Pui beds appeared to have flowed predominantly northward (northeast through northwest). However, intra- and interchannel palaeocurrent variability is clearly higher than that observed in channel deposits from the Densuş-Ciula Formation at Tuştea (Fig. 12) and the Sânpetru Formation along the Sibişel River (Therrien, 2004). Such high variability in palaeocurrent orientation, reminiscent of the condition observed in the Red Continental Strata (Fig. 8), suggests deposition in a high sinuosity fluvial system (e.g., Collinson, 1978; Jackson, 1978; Bridge, 1985). Therefore, the east-northeast paleoflow direction inferred by Van Itterbeeck et al. (2004) based on the trend of a single channel is not unusual or unexpected in this context.

The sandstones of the Pui beds are moderately to poorly sorted lithic arenites and wackes, composed of very angular to subrounded monocrystalline and polycrystalline quartz, feldspars, and metamorphic fragments (Table 1). Andesite clasts, although rare, are found in the Pui deposits, suggesting that volcanic rocks were present in the source area. In that aspect, Pui sandstones are similar to sandstones of the

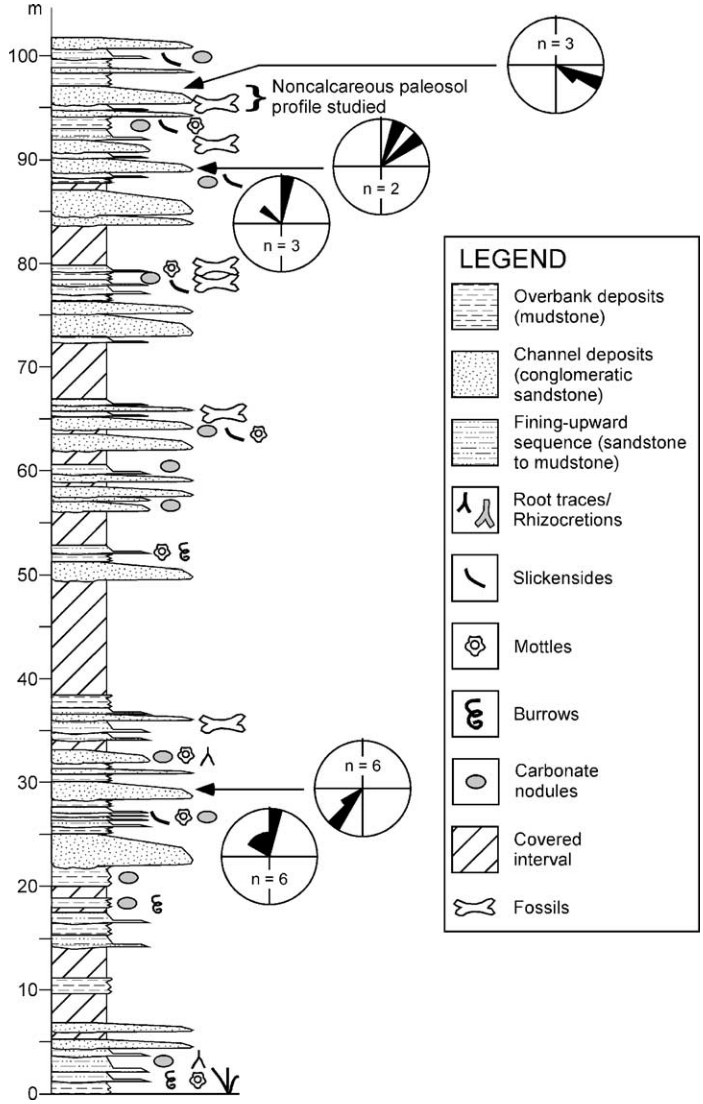

Fig. 15. Composite stratigraphic section of the Pui beds (Haţeg Basin, Hunedoara county). Total thickness of the section is 102.58 m. Pedogenic features characterizing the red paleosols and the stratigraphic location of fossil finds are indicated. The rose diagrams, reflecting the palaeocurrent direction measured in various channel deposits, indicate that high-sinuosity rivers flowing primarily northward formed the deposits.

Densuş-Ciula Formation and Red Continental Strata but different from those of the Sânpetru Formation, as no volcanic clasts have been reported from Sânpetru sandstones (Therrien, 2004). However, the compositional mode of the Pui sandstone studied differs markedly from those of the Red Continental Strata and Densuş-Ciula Formation, but is very similar to that of Sânpetru sandstones (Fig. 10; Table 1). The slightly richer quartz content of the Pui sandstones relative to Sânpetru sandstones could be due to the finer grain size of the sample, which results in a bias against lithic fragments requiring large grains for proper recognition (Ingersoll et al., 1984; Zuffa, 1985). Consequently, the source area for the Pui and Sânpetru deposits must have been similar. The compositional immaturity (low Qt/F+L and Qp/F+L ratios; Table 1) and angularity of grains, indicative of proximity to the source area, combined with the northward palaeocurrent direction of rivers, suggest that Pui sediment is derived primarily from the metamorphic Ţarcu-Retezat mountain range, although rivers were subject to occasional andesitic volcanic input.

The Pui stratigraphic section, dominated by thin fining-upward sequences, suggests that splay deposition predominated over floodplain accumulation. Had floodplain accumulation been higher, thick overbank sequences, similar to the Red Continental Strata and Densuş-Ciula Formation, would have been more abundant. The preponderance of thin fining-upward sequences may reflect proximal floodplain settings, i.e., in proximity to channels, where deposition by crevasse splay deposits is common; in contrast, the rarer mudstone sequences present in the Pui section might represent distal floodplain settings, where aggradation is accomplished by the deposition of fine material only. Furthermore, the absence of multistorey sandstones, i.e., superposed channel deposits produced by the repetitive migration of channels over the same area, indicates that aggradation rate could have been superior to avulsion rate. Although the limited exposure prevents a detailed study of the alluvial architecture of the Pui beds, the evidence described above suggests deposition in a high-sinuosity fluvial system possibly where the proximal part of the floodplain, which underwent aggradation through crevasse splay deposition, is predominantly represented over the muddier, distal floodplain environments.

5.3.2. Paleosols

The stacking of fining-upward sequences in the Pui stratigraphic sequence resulted in the formation of distinct, non-overlapping paleosol profiles in proximal floodplain settings. In contrast, the few thick pedogenically-modified overbank intervals present in the Pui beds, characteristic of distal floodplain settings, suggest the development of cumulative paleosol profiles through incorporation of a small quantity of material. At least two different types of paleosols are found in the Pui beds: brown-red calcareous paleosols and dark red noncalcareous paleosols.

5.3.2.1. Calcareous paleosols. Calcareous paleosols are by far the most common paleosols in the Pui beds and were also observed by Van Itterbeeck et al. (2004). As their name suggests, they are characterized by carbonate accumulation within the profile. Most accumulations occur as small to large carbonate nodules, although coalescence of nodules to form indurated horizons is common (Fig. 6A; also see Van Itterbeeck et al., 2004: Fig. 2). Bone fragments are occasionally found within indurated horizons. When an indurated horizon is present, carbonate nodules generally decrease in size and degree of interconnectedness up-profile. Calcareous paleosols also occasionally contain well-developed slickensides (although these were not reported in the stratigraphic interval studied by Van Itterbeeck et al., 2004), drab-haloed root traces, and burrows, which may be common to abundant. Distinct red mottles are occasionally present in calcareous paleosols.

The suite of pedogenic features found in the Pui calcareous paleosols is reminiscent of the paleosols of the Red Continental Strata and category 5 paleosols of the Sânpetru Formation (Therrien, 2004); Tuştea paleosols differ from all these paleosols in lacking mottles. However, some Pui calcareous paleosols have reached a greater degree of maturity, as exemplified by the coalescence of carbonate nodules and development of indurated K horizons. Cementation of an indurated horizon generally begins at the mean depth of rainfall penetration and expands up-profile as meteoric water accumulates on top of the impermeable layer, explaining why isolated carbonate nodules still occur occasionally outside of this horizon (Reeves, 1976; Goudie, 1983; Birkeland, 1985). These well-developed caliche (or calcrete) layers require a longer period of subaerial exposure to form than paleosols containing nodules; therefore, such paleosols formed on very stable floodplains characterized by infrequent depositional events.

Although the geochemistry of calcareous paleosols was not studied, the pedogenic features they preserve give insight into the palaeoclimatic conditions under which they formed. The red color of the groundmass and the occasional occurrence of mottles suggest that the paleosols developed on moderately- to well-drained floodplains, conclusions also reached by Van Itterbeeck et al. (2004). Calcic horizons, such as those observed in the Pui beds, develop in climates where evapotranspiration exceeds precipitation (Reeves, 1976; Goudie, 1983; Birkeland, 1985), generally where rainfall is less than 760 mm/year (Royer, 1999, 2000). Furthermore, the abundance and well-developed nature of slickensides in these paleosols strongly suggest that alternating wet and dry periods occurred during the formation of the Maastrichtian calcareous paleosols. Supporting this interpretation, Van Itterbeeck et al. (2004) reported that smectite was the dominant clay mineral in the calcareous paleosols of Pui.

5.3.2.2. Noncalcareous paleosols. Noncalcareous paleosols are uncommon in the Pui beds but, when they occur, are easily recognizable as they possess an upper dark red horizon (7.5R 3/6) and are devoid of any kind of carbonate accumulation. Van Itterbeeck et al. (2004) did not observe this pedotype in the stratigraphic interval they studied. The noncalcareous paleosol profile is generally brown at the base but gradually becomes dark red toward the top (Fig. 16; Table 2). Small to large purple mottles are occasionally present in the red horizon and represent zones of iron depletion. Generally, slickensides are abundant and very well developed in the red horizon but rare to absent in the underlying brown horizon. Sandy infills and elongate green haloes, interpreted as root traces, occur throughout the paleosol profile. Well-developed pedogenic features are also visible in thin section. The groundmass, generally weakly impregnated by iron oxides in the brown horizon, becomes increasingly more impregnated (up to moderately impregnated sensu Bullock et al., 1985) in the upper red horizon. Ferruginous accumulations, such as bridges and caps on clastic grains or hypocoatings along channels (Fig. 7A), are well-developed in the red horizon. Clay coatings on clastic grains and along channel walls are also present throughout the profile, although better developed in the upper red horizon.

Geochemical profiles of the noncalcareous paleosols exhibit clear horizon differentiation, unlike any other observed in contemporaneous Romanian paleosols (Fig. 16). The hydrolysis index reveals an important increase in iron oxide content of the upper part of the paleosol, mirroring accurately its gradual yet rapid shift to dark red colour. The clay content

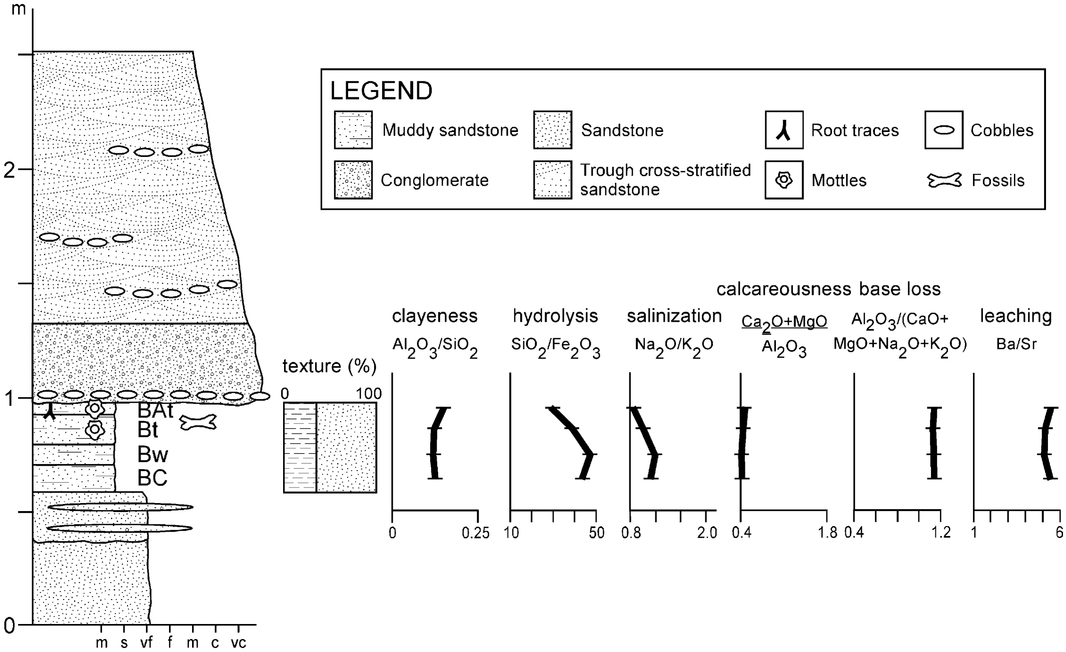

Fig. 16. Typical noncalcareous paleosol profile in the Pui beds. This brown-to-red paleosol contains root traces, occasional mottles, and may contain slickensides. The various molecular weathering ratios reflect a clear geochemical trend through the profile, indicating that the pedogenic horizons are very well differentiated. The extremely low and high indices of calcareousness and base loss, respectively, indicate that the profile was intensely leached. The textural index reveals that the profile is rich in sand-sized particles.

(clayeness) index indicates that the uppermost horizon of the profile is richer in clay, which is corroborated microscopically by the presence of illuviated clay. The calcareousness and base loss indices are, respectively, extremely low and extremely high throughout the profile, indicating that all horizons are impoverished in mobile elements released by weathering of the parent material. Finally, the leaching index, Ba/Sr, is the highest of all Romanian paleosols studied, reflecting the extensive leaching the paleosol profile underwent due to effective drainage.

Noncalcareous paleosols are interpreted as mature, intensely leached paleosols that developed on a moderately- to well-drained floodplain. The very sandy parent material suggests that this type of paleosol may have developed in proximal floodplain settings. In turn such sandy material, characterized by high soil porosity, led to improved percolation of meteoric water through the profile. With more efficient water circulation through the profile, weathering products and soluble elements were more efficiently leached from the paleosol, resulting in the lack of carbonate accumulation. Consequently, the presence of noncalcareous paleosols in the Pui beds, otherwise dominated by calcareous paleosols, does not reflect climatic changes but rather is the result of differences in parent material.

The presence of purple mottles in the red horizon of noncalcareous paleosols indicates that iron depletion was induced by alternating oxidizing and reducing conditions due to abundant precipitation (surface gley or pseudogley; e.g., PiPujol and Buurman, 1994, 1997). The extent of clay coatings observed in these paleosols suggests indeed that rainfall was abundant at least seasonally, an interpretation supported by the occurrence of slickensides in the red horizons.

The geochemical composition of the illuvial horizons of noncalcareous paleosols was used to estimate palaeoprecipitation and palaeotemperature. Because a single paleosol was geochemically analyzed, two horizons from the same profile were used to estimate MAP and MAT. As was the case previously, MAP estimates derived from paleosols are well below estimates based on the fossil tropical flora, varying between 791 and 1024 mm (Table 3; Fig. 17). However, these estimates are generally

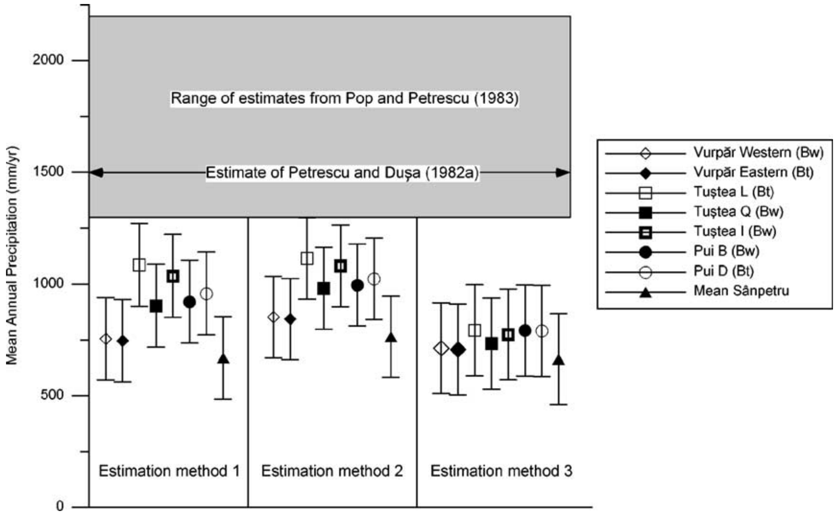

Fig. 17. Comparison of palaeoprecipitation estimates obtained from paleosol geochemistry and palaeobotanical studies [Vurpăr Western from calcareous paleosol illustrated in Fig. 11, Vurpăr Eastern from non-illustrated calcareous paleosol, Tuştea L and Q are 2Bt and Bw horizons, respectively, from calcareous profile illustrated in Fig. 13, Tuştea I is from nest horizon illustrated in Fig. 14, Pui B and D are from noncalcareous paleosol illustrated in Fig. 16, mean Sânpetru is derived from noncalcareous (category 4) and calcareous (category 5) paleosols in Therrien, 2004]. Although the palaeoprecipitation estimates derived from paleosols of the Red Continental Strata, Pui beds, and Densuş-Ciula and Sânpetru formations are compatible among themselves, the three estimation methods, based on various geochemical parameters, employed in this research (Eqs. (1–3) in text) consistently provide mean annual precipitation values inferior to those inferred from the Maastrichtian tropical palaeoflora of Romania. This incongruence of results presumably reflects the capacity of tropical plants to live in warm climates characterized by strong seasonality of precipitation.

higher than those derived from Sânpetru paleosols, although their standard errors of estimate overlap. Van Itterbeeck et al. (2004) inferred lower MAP values (100–500 mm) based on their study of the calcareous paleosols but did not recognize the presence of slickensides, which would have increased their rainfall estimates to 500–700 mm/year (see Khadkikar et al., 2000). The MAT estimates are low, ranging from 8.7 to 9.3 °C, again an artifact of limited weathering in climates with seasonal precipitation (see above). Consequently, the studied paleosols of the Pui beds indicate that the climate of Romania during part of the Maastrichtian was subhumid with a pronounced alternation of wet and dry periods, presumably on a seasonal periodicity.

5.3.3. Fossil remains

The fossil vertebrate fauna from the Pui beds, known from macro- and microfossil remains, consists of *Zalmoxes robustus* (+ *Zalmoxes shqiperorum*?), *Telmatosaurus transsylvanicus*, *Magyarasaurus dacus*, small theropods (one velociraptorine and one troodontid-like), crocodilians (probably *Allodaposuchus precedens*), the selmacryptodire *Kallokibotion bajazidi*, multituberculates (?*Paracimexomys dacicus* = *Barbatodon transylvanicum* and an indeterminate taxon), frogs (*Eodiscoglossus* sp.), albanerpetontids (*Albanerpeton* cf. *inexpectatum*), indeterminate anguimorph(?) lizards and three scincomorph lizards (the teiid *Paraglyphanodon* sp. and paramacellodids *Becklesius* sp. and *B*. aff. *hoffstetteri*), and fishes (indeterminate acipenseriforms and characids, Table 4; Grigorescu et al., 1985, 1999; Radulescu and Samson, 1986; Grigorescu and Hahn, 1987; Csiki and Grigorescu, 1998; Folie et al., 2002; Grigorescu and Csiki, 2002). Furthermore, eggshell fragments referable to five different morphotypes (discretispherulitic, prolatospherulitic, prismatic, ratite, and geckonoid) have been discovered in the Pui beds (Garcia et al., 2002).

Fossil remains occur generally as disarticulated elements in various facies of the Pui beds, although articulated remains have been discovered in fine-grained overbank deposits (Van Itterbeeck et al., 2004). The most diverse faunal assemblage known to date was found in a sandy lens (Grigorescu et al., 1985), presumably concentrated by hydraulic processes, but abundant microvertebrate remains (amphibians and lizards) are preserved also in greenish-gray silty mudstones. While red mudstones may preserve only sparse amphibian material, they tend to be hosts to a great diversity of eggshell fragments (Grigorescu et al., 1999) and dinosaur remains. Microvertebrate localities and isolated to articulated dinosaur elements have been discovered in calcareous paleosols (Van Itterbeeck et al., 2004), sometimes even in indurated caliche layers (Fig. 15).

In the course of this research, abundant disarticulated and disassociated skeletal remains were discovered in the noncalcareous paleosol described above (Fig. 16). Elements were small (<5 cm) and fragmentary, and were concentrated in the dark red horizon of the paleosol. Although a detailed taphonomic study of the site was not conducted, the state of preservation of the bones is consistent with an attritional assemblage formed by skeletal elements that were originally exposed at the surface for some time before being transported and/or incorporated into the surficial horizon of the paleosol profile through burial.

5.3.4. Are the Pui beds truly part of the Sânpetru Formation?

The current study reveals that the correlation of the Pui beds to the lower part of the Sânpetru Formation exposed along the Sibişel River on the basis of superficial similarities (conglomerates and sandstones interbedded with red mudstones; Nopcsa, 1905; Grigorescu et al., 1985, 1999; Grigorescu, 1992) is overly simplistic. Although the provenance of sediment appears to have been similar at the two localities (Fig. 10; Table 1), the fluvial systems and paleosols are different. The Sânpetru Formation consists of stacked fining-upward cycles, with a basal gray to green sandstone fining into dark gray, green, brown or red mudstone, interpreted to have been deposited on a poorly channelized braidplain where a mosaic of wetlands and drier floodplains developed (see Therrien, 2004). Although red paleosols are present in the Sânpetru Formation, they only characterize 34% of all overbank deposits (and only 33% of the lower 50 m of the section). Furthermore, red calcareous paleosols represent only 17% of all overbank deposits present in the Sânpetru section (25% of the lower 50 m of the section) and are never as well developed as those observed near Pui (see Therrien, 2004). In contrast, the Pui beds were deposited by meandering rivers and red-coloured paleosols characterize nearly 100% of all overbank deposits (red calcareous paleosols representing probably at least 80%). While these differences could reflect proximal-to-distal changes along the longitudinal axis of a fluvial system, this possibility is precluded by the parallel orientation of rivers in the two lithological units (inferred from palaeocurrent directions). Although it is possible that the Pui beds may interdigitate with the Sânpetru deposits, the lithological similarities used to correlate the Pui beds to the base of the Sânpetru Formation exposed along the Sibişel River (Grigorescu et al., 1985, 1999; Grigorescu, 1992) have been greatly exaggerated. Consequently, the sole claim that can be made about the Pui beds is that they represent distinctive sedimentary facies (possibly a new formation, tentatively named the Bărbat Formation because Pui Formation is already in use) deposited contemporaneously (based on similarity of fossil assemblages) with the Sânpetru Formation (see Mamulea, 1953) in response to the uplift of the Ţarcu-Retezat mountains.

6. Palaeoenvironmental conditions in the studied formations and comparison to the Sânpetru Formation

The palaeoenvironments in which dinosaurs are preserved in the Red Continental Strata (Vurpăr), the Densuş-Ciula Formation (Tuştea), and the Pui beds share numerous similarities (Table 4). Landscape reconstruction for each formation indicates that moderately- to well-drained floodplain settings were predominant, although regions of impeded drainage may have been present locally. Soils were saturated with water occasionally during the year, but never long enough to form hydromorphic (gleyed) horizons (usually requiring water saturation for 25%–50% of the year; Daniels et al., 1971). These brief periods of water saturation, related to abundant precipitation and/or watertable fluctuation, produced alternating reducing and oxidizing conditions in the soils and resulted in the formation of mottles. The abundance of slickensides and carbonate nodules with ferruginous intergrowths testify to the irregularity of palaeoprecipitation in the Maastrichtian climate of Romania, where wet and dry periods alternated. The pedogenic features do not indicate the periodicity of those alternations (i.e., seasonal, annual, decadal) but the palaeoflora reveals that these alternations were probably seasonal, similar to the monsoonal climate observed today in southeast Asia and India. Paleosols of the Pui beds are generally more mature, i.e., better developed caliche layers or more intensely leached profiles, than those found in the Red Continental Strata or Densuş-Ciula Formation. The mature Pui paleosols, which required more time to develop, indicate that sediment accumulation rates were lower and floodplains more stable (less frequent floods) than in the other two formations.

The Sânpetru Formation, as exposed along the Sibişel Valley, was reconstructed as a dynamic mosaic of wet and dry habitats where wetlands were predominant (Therrien, 2004). Although the Sânpetru setting differs significantly from that of the aforementioned formations, the diagnostic paleosols of dry, high floodplains or “interfluves” found in that formation are very similar to those of the Red Continental Strata, Densuş-Ciula Formation, and Pui beds. Category 5 paleosols of the Sânpetru Formation are brown to red calcareous paleosols exhibiting slickensides and horizons of carbonate nodules containing ferruginous intergrowths (Therrien, 2004). These paleosols tend to be thinner, sandier, and less mature (smaller and less abundant carbonate nodules) than those of the other formations, possibly reflecting the greater avulsion/accumulation rate of the Sânpetru fluvial system and greater proximity of developing paleosols to the rivers (more frequent floods).

Deeply-penetrating root traces and burrows were reported in the dry floodplain environments of the Sânpetru Formation (Therrien, 2004) but were not observed in the other contemporaneous formations. While the absence of such features might simply reflect a preservation bias or may be due to the limited exposures, it is also possible that their presence in the Sânpetru Formation is related to a watertable that remained close to the base of paleosol profiles (paleosol profiles in this formation generally are less than 1.00 m thick and are always underlain by channel deposits that could have acted as an aquifer; see Therrien, 2004). Indeed, deeply-penetrating roots and burrows are typical of plants and soil organisms attempting to reach a deep watertable during droughts (see Hasiotis and Honey, 2000; Retallack, 2001;

Therrien, 2004). Hydromorphic paleosols are predominant in the Sânpetru Formation, representing 63% and 100% of the recorded habitats in the lower and upper half of the formation, respectively, and gleyed horizons and/or mottles are found commonly in the better-drained paleosols (Therrien, 2004). The abundance of Sânpetru habitats characterized by impeded drainage or affected by alternating wet and dry conditions is evidence of the proximity of the watertable to the surface. In contrast, hydromorphic paleosols are rare, if not absent, in the three formations studied in this paper and evidence of wet soil conditions is often limited to mottling. Thus the absence of deep root traces and burrows combined with the paucity of hydromorphic horizons could indicate that the watertable was very deep in the palaeoenvironments of the Red Continental Strata, Densuş-Ciula Formation, and Pui beds, at a depth too great to be attained by surface organisms.

In terms of palaeoclimatic conditions, the paleosols of all studied Maastrichtian dinosaur-bearing formations of Romania formed under a subhumid climate characterized by alternating wet and dry periods (monsoonal), confirming earlier models of the Maastrichtian climate of the Tethyan region based on disparate evidence (e.g., Horrell, 1991; Bush, 1997; Voigt et al., 1999). The palaeoprecipitation and palaeotemperature estimates derived from paleosols vary among formations, but all values are compatible within their standard errors of estimate (Table 3; Fig. 17). Although several paleoprecipitation estimates fall close to or slightly above the threshold of 760 mm/year identified by Royer (1999) for the formation of calcic horizons, it must be noted that calcic horizons are known from climates where annual rainfall can attain or exceed 1000 mm (see Retallack, 1994: Fig. 3–2; Royer, 1999: Fig. 1). Consequently, the estimates presented above should not be rejected dogmatically. The most interesting conclusions obtained from the study of the Maastrichtian paleosols of Romania is that they provide consistently lower paleoprecipitation estimates than those derived from palaeobotanical studies: MAP values are below 1000 mm/year and MAT below 12.6 °C from paleosols, while the tropical palaeoflora suggests annual precipitation in excess of 1300 mm and mean annual temperatures between 22 °C and 24 °C (Table 3). As explained earlier, these differing estimates are the result of the strong seasonality of precipitation. Tropical plant species can live in warm climates with seasonal precipitation, such as monsoonal climates, if they are still able to obtain water during the dry seasons (Horrell, 1991). Because the watertable was located at too great a depth to be reached by surface organisms of the Red Continental Strata, Densuş-Ciula Formation, and Pui beds, the limited palaeoprecipitation of the dry periods must have been sufficient to support the metabolic needs of tropical plants. Indeed, Pop and Petrescu (1983) suggested that the amount of rainfall during the dry periods varied generally between 20 and 30 mm/month but was never less than 10 mm/month. Thus precipitation can be inferred to have been frequent during wet seasons but limited during the dry seasons.

Finally, the palaeoenvironmental reconstruction presented for each formation paves the way to an improved understanding of the palaeoecology of the Romanian dinosaurian fauna, giving insight into geographic distribution and habitat preferences of various taxa (Table 4). Indication that palaeoecological partitioning may have occurred among dinosaurian taxa of the Sânpetru Formation has been suggested initially by Grigorescu (1983), although he did not discuss the arguments supporting his claim: alluvial islands inhabited by crocodiles, swamps inhabited by ornithopods and turtles, moist floodplains inhabited by sauropods and ankylosaurs, and nearby drier uplands inhabited by theropods. However, comparison of the fossil assemblages and palaeohabitats known from the Red Continental Strata, Densuş-Ciula Formation, and Pui beds to the Sânpetru Formation reveals significant differences. Whereas the three rock units considered in this paper are dominated by stable, moderately- to well-drained floodplains (mature calcareous paleosols), the Sânpetru Formation represents an unstable, constantly shifting mosaic of habitats (immature paleosols) dominated by areas of impeded drainage. Moderately drained habitats are uncommon and calcareous paleosols developing on dry floodplains akin to the three formations studied in this paper are rare (18.5%; see Therrien, 2004). Furthermore, fossil assemblages of the Red Continental Strata, Densuş-Ciula Formation, and Pui beds generally are preserved in well-drained overbank deposits and paleosols that presumably represent attritional mortality assemblages or as lag deposits in channel facies. In contrast, fossil remains in the Sânpetru Formation occur predominantly as lenticular bonebeds (“fossiliferous pockets”) concentrated in topographic depressions on the floodplain by fluvial processes (Grigorescu, 1983) or as microvertebrate assemblages in poorly-drained paleosols (Codrea et al., 2002b; Smith et al., 2002; Van Itterbeeck et al., 2004). These palaeoenvironmental and taphonomical differences reflect underlying differences in fluvial system parameters and basin evolution to which dinosaurs had to adapt and that could bear on palaeoecological hypotheses. A review of the palaeoecology of the Romanian dinosaur-dominated fauna is in order, one in which the palaeoenvironmental and taphonomic conditions of each fossiliferous site have to be considered (e.g., Csiki, 1995).

7. Conclusions

Maastrichtian dinosaurs of Romania, which lived on a collapsing orogen in the Mediterranean Tethys Ocean, thrived in a subhumid climate characterized by a strong seasonality of precipitation, probably similar to the monsoonal climate of present-day southeastern Asia. They roamed moderately- to well-drained floodplains that surrounded braided streams and meandering rivers, although localized areas of impeded drainage and lakes were present. The dinosaurs shared their palaeoenvironments with pterosaurs, crocodilians, turtles, lizards, amphibians, and mammals. Predation and mortality due to natural causes (illness, old age, etc.) produced time-averaged attritional bone assemblages that were incorporated in paleosol profiles by sporadic sediment accumulation associated with crevasse splays and floods. Occasionally, short-lived flood events, such as crevasse splays, buried nesting horizons and preserved eggs and remains of hatchling and adult dinosaurs. These fossil assemblages represent brief time intervals and provide near instantaneous windows into the life of the Maastrichtian.

Even though palaeoprecipitation was below 1000 mm/year, tropical plants populated the floodplains of Romania during the Maastrichtian. Rainfall was abundant for part of the year, but limited during the remainder. Plants could survive on the reduced amount of precipitation or had access to groundwater and/or surface water during the dry periods.

The dinosaur-dominated fauna of Romania lived in a volcanically active region. Volcanic clasts and/or ash deposits of andesitic composition are found in the Red Continental Strata, the Densuş-Ciula Formation, and occasionally in the Pui beds. These volcanic fragments are most assuredly derived from the contemporaneous banatitic volcanism that developed in the Southern Carpathians and Apuseni Mountains in response to the subduction of oceanic crust under the Rhodope microcontinent.

The palaeoenvironments documented in the Red Continental Strata, Densuş-Ciula Formation, and Pui beds are markedly different from those recorded in the famous Sânpetru Formation. Whereas the three localities considered in this paper are dominated by stable, moderately- to well-drained floodplains (mature paleosols), the palaeoenvironments of the Sânpetru Formation are highly unstable (immature paleosols) and dominated by areas of impeded drainage, moderately-drained habitats being less common. Furthermore while fossil assemblages of the Red Continental Strata, Densuş-Ciula Formation, and Pui beds are preserved generally in well-drained overbank deposits and paleosols or as lag deposits in channel facies, they occur predominantly as lenticular bonebeds concentrated by fluvial processes or as microvertebrate remains in poorly-drained paleosols in the Sânpetru Formation. These palaeoenvironmental and taphonomical differences reflect underlying differences in fluvial system parameters and basin evolution that need to be considered in the context of future palaeoecological studies.

Acknowledgements

This paper was written as part of the author’s Ph.D. dissertation supervised by David Weishampel at the Johns Hopkins University. I wish to thank Maria Coralia Jianu, Adriana Pascaru, and Silvia Burnaz from the Muzeul Civilizaţiei Dacice şi Romane, Deva, as well as Bogdan Scarlat for their help and support, without which fieldwork would have been impossible. I also thank David Weishampel for innumerable enlightening discussions, his willingness to share information, and constant support throughout this research. Many thanks are also extended to David Fastovsky, Lawrence Hardie, and Stan Mertzman for their help at various phases of this project. Finally, I wish to thank Raymond Rogers, Kenneth Rose, Jimmy Van Itterbeeck, and In Sung Paik for their constructive comments, which improved this manuscript. This research was financially supported by a National Science and Engineering Research Council (NSERC, Canada) doctoral research grant, a Fonds Nature et Technologies (FCAR, Québec) postgraduate research grant, and the Bryan Patterson Award of the Society of Vertebrate Palaeontology (2001).

References

Allen, J.R.L., 1965. A review of the origin and characteristics of recent alluvial sediments. Sedimentology 5, 89–191.

Anastasiu, N., 1991. Pyroclastic flow deposits in the Densuş-Ciula Formation (Haţeg Basin-Romania). The Volcanic Tuffs from the Transylvanian, pp. 127–133.

Anastasiu, N., Csobuka, D., 1989. Non-marine uppermost Cretaceous deposits in the Stei-Densuş region (Haţeg Basin): sketch for a facial model [sic]. Revue Roumaine de Géologie, Géophysique et Géographie-Géologie 33, 43–53.

Antonescu, E., 1973. Asociaţii palinologice caracteristice unor formaţiuni Cretacice din Munţii Metaliferi. Dări de Seamă ale Şedinţelor LIX, 115–169 (+2 plates).

Antonescu, E., Lupu, D., Lupu, M., 1983. Corrélation palynologique du Crétacé terminal du Sud-Est des Monts Metaliferi et des Dépressions de Haţeg et de Rusca Montană. Anuarul Instituţului de Geologie şi Geofizică Stratigrafie şi Paleontologie 59, 71–77.

Atchley, S.C., Nordt, L.C., Dworkin, S.I., 2004. Eustatic control on alluvial sequence stratigraphy: a possible example from the Cretaceous–Tertiary transition of the Tornillo Basin, Big Bend National Park, West Texas, USA. Journal of Sedimentary Research 74, 391–404.

Baltes, N., 1966. Remarque sur la microflore de certains dépôts charboneux daniens du Bassin de Rusca Montană (Roumanie). Pollen et Spores 8, 214–221.

Bentham, P.A., Talling, P.J., Burbank, D.W., 1993. Braided stream and flood-plain deposition in a rapidly aggrading basin: the Escanilla Formation, Spanish Pyrenees. In: Best, J.L., Bristow, C.S. (Eds.), Braided Streams, Geological Society, Special Publication, vol. 75, pp. 177–194.

Berza, T., Constantinescu, E., Vlad, S.-N., 1998. Upper Cretaceous magmatic series and associated mineralisation in the Carpathian-Balkan orogen. Resource Geology 48, 291–306.

Birkeland, P.W., 1974. Pedology, weathering, and geomorphological research. Oxford University Press, New York. 285 pp.

Birkeland, P.W., 1985. Quaternary soils of the western United States. In: Boardman, J. (Ed.), Soils and Quaternary Landscape Evolution. John Wiley & Sons, New York, NY, pp. 303–324.

Blair, T.C., MacPherson, J.G., 1994. Alluvial fans and their natural distinction from rivers based on morphology, hydraulic processes, sedimentary processes, and facies assemblages. Journal of Sedimentary Research, A 64, 450–489.

Blodgett, R.H., 1988. Calcareous paleosols in the Triassic Dolores Formation, southwestern Colourado. In: Reinhardt, J., Sigleo, W.R. (Eds.), Paleosols and Weathering Through Geologic Time: Principles and Applications. Special Paper-Geological Society of America, vol. 216, pp. 103–121.

Blodgett, R.H., Crabaugh, J.P., McBride, E.F., 1993. The colour of red beds: a geologic perspective. In: Bigham, J.M., Ciolkosz, E.J. (Eds.), Soil Colour. SSSA Special Publication, vol. 31. Soil Science Society of America, pp. 127–159.

Brewer, R., 1964. Fabric and mineral analysis of soils. Wiley, New York, NY. 470 pp.

Bridge, J.S., 1985. Paleochannel patterns inferred from alluvial deposits: a critical evaluation. Journal of Sedimentary Petrology 57, 587–601.

Buffetaut, E., Grigorescu, D., Csiki, Z., 2002. A new giant pterosaur with a robust skull from the latest Cretaceous of Romania. Naturwissenschaften 89, 180–184.

Bullock, P., Fedoroff, N., Jongerius, A., Stoops, G., Tursina, T., 1985. Handbook for soil thin section description. Waine Research, Volverhampton. 152 pp.

Burchfiel, B.C., Bleahu, M., 1976. Geology of Romania. Special Paper-Geological Society of America 158, 1–82.

Bush, A.B.G., 1997. Numerical simulation of the Cretaceous Tethys circumglobal current. Science 275, 807–810.

Cant, D.J., 1978. Development of a facies model for sandy braided river sedimentation: comparison of the South Saskatchewan River and the Battery Point Formation. In: Miall, A.D. (Ed.), Fluvial Sedimentology. Memoir Canadian Society of Petroleum Geologists, vol. 5, pp. 627–639.

Cant, D.J., Walker, R.G., 1976. Development of a facies model for sandy braided-fluvial facies for the Devonian Battery Point Sandstone, Quebec. Canadian Journal of Earth Sciences 13, 102–119.

Cant, D.J., Walker, R.G., 1978. Fluvial processes and facies sequences in the sandy braided South Saskatchewan River, Canada. Sedimentology 25, 625–648.

Caudill, M.R., Driese, S.G., Mora, C.I., 1996. Preservation of a paleo-vertisol and an estimate of late Mississippian paleoprecipitation. Journal of Sedimentary Research 66, 58–70.

Chiappe, L.M., Dingus, L., Jackson, F., Grellet-Tinner, G., Aspinall, R., Clarke, J., Coria, R.A., Garrido, A., Loope, D., 2000. Sauropod eggs and embryos from the Upper Cretaceous of Patagonia. First Symposium of Dinosaur Eggs and Embryos Isona, Spain, pp. 23–29.

Codrea, V., Hosu, A., Filipescu, S., Vremir, M., Dica, P., Săsăran, E., Tanţău, I., 2001. Aspecte ale sedimentaţiei Cretacic Superioare din aria Alba-Iulia—Sebeş (Jud. Alba). Studii şi Cercetări (Geologie-Geografie) 6, 63–68.

Codrea, V., Săsăran, E., Dica, P., 2002a. Vurpăr (Vinţu de Jos, Alba district). The 7th European Workshop of Vertebrate Paleontology—Sibiu (Romania), pp. 60–62.

Codrea, V., Smith, T., Dica, P., Folie, A., Garcia, G., Godefroit, P., Van Itterbeeck, J., 2002b. Dinosaur egg nests, mammals and other vertebrates from a new Maastrichtian site of the Haţeg Basin (Romania). Comptes Rendus. Palévol 1, 173–180.

Cojan, I., Renard, M., Emmanuel, L., 2003. Palaeoenvironmental reconstruction of dinosaur nesting sites based on a geochemical approach to eggshells and associated palaeosols (Maastrichtian Provence Basin, France). Palaeogeography, Palaeoclimatology, Palaeoecology 191, 111–138.

Collinson, J.D., 1978. Vertical sequence and sand body shape in alluvial sequences. In: Miall, A.D. (Ed.), Fluvial Sedimentology, Memoir Canadian Society for Petroleum Geologists, vol. 5, pp. 577–586.

Courty, M.A., Fédoroff, N., 1985. Micromorphology of recent and buried soils in a semi-arid region of northwestern India. Geoderma 35, 287–332.

Cousin, R., Breton, G., Fournier, R., Watte, J.-P., 1994. Dinosaur egglaying and nesting in France. In: Carpenter, K., Hirsch, K.F., Horner, J.R. (Eds.), Dinosaur Eggs and Babies. Cambridge University Press, New York, NY, pp. 56–74.

Csiki, Z., 1995. Studiul paleontologic şi tafonomic al faunai Maastrichtian superioare din depozitele continentale ale Bazinului Haţeg (Formaţiunile de Densuş-Ciula şi de Sînpetru): implicaţii paleoecologice. M.S. thesis. University of Bucharest, Bucharest.

Csiki, Z., Grigorescu, D., 1998. Small theropods from the Late Cretaceous of the Haţeg Basin (Western Romania)—an unexpected diversity at the top of the food chain. Oryctos 1, 87–104.

Csiki, Z., Grigorescu, D., 2000. Teeth of multituberculate mammals from the Late Cretaceous of Romania. Acta Palaeontologica Polonica 45, 85–90.

Csontos, L., Vörös, A., 2004. Mesozoic plate tectonic reconstruction of the Carpathian region. Palaeogeography, Palaeoclimatology, Palaeoecology 210, 1–56.

Daniels, R.B., Gamble, E.E., Nelson, L.A., 1971. Relations between soil morphology and water-table levels on a dissected North Carolina coastal plain surface. Proceedings-Soil Science Society of America 35, 157–175.

Decker, J., Helmold, K.P., 1985. The effect of grain size on detrital modes: a test of the Gazzi–Dickinson point-counting method—discussion. Journal of Sedimentary Petrology 55, 618–620.

Dingus, L., Clarke, J., Scott, G.R., Swisher III, C.C., Chiappe, L.M., Coria, R.A., 2000. Stratigraphy and magnetostratigraphic/faunal constraints for the age of sauropod embryo-bearing rocks in the Neuquén Group (Late Cretaceous, Neuquén Province, Argentina). American Museum Novitates 3290, 1–11.

Dudal, R., Eswaran, H., 1988. Distribution, properties and classification of Vertisols. In: Wilding, L.P., Puentes, R. (Eds.), Vertisols: their Distribution, Properties, Classification and Management. Texas A&M University Printing Center, Texas, pp. 1–22.

Duşa, A., 1974. Aspecte ale formarii carbunilor din Bazinul Rusca Montană. Studia Universitatis Babeş-Bolyai. Geologia-Mineralogia 19, 36–43.

Feakes, C.R., Retallack, G.J., 1988. Recognition and chemical characterization of fossil soils developed on alluvium: a Late Ordovician example. In: Reinhardt, J., Sigleo, W.R. (Eds.), Paleosols and Weathering Through Geologic Time; Principles and Applications. Special Paper Geological Society of America, vol. 216, pp. 35–48.

Folie, A., Codrea, V., Dica, P., Garcia, G., Godefroit, P., Smith, T., Van Itterbeeck, J., 2002. Late Cretaceous amphibians and lacertilians from Pui (Haţeg Basin, Romania). 7th European Workshop on Vertebrate Paleontology—Sibiu (Romania), p. 11.

Garcia, G., Smith, T., Folie, A., Godefroit, P., Van Itterbeeck, J., Codrea, V., 2002. Parataxonomic classification of eggshells from Pui in the Haţeg Basin (Romania). 7th European Workshop on Vertebrate Paleontology—Sibiu (Romania), p. 14.

Garzanti, E., Vezzoli, G., 2003. A classification of metamorphic grains in sands based on their composition and grade. Journal of Sedimentary Research 73, 830–837.

Gile, L.H., Peterson, F.F., Grossman, R.B., 1966. Morphological and genetic sequences of carbonate accumulation in desert soils. Soil Science 101, 347–360.

Givulescu, R., 1966. Sur quelques plantes fossiles du Danien de Roumanie. Comptes Rendus des Séances de l'Académie des Sciences 262, 1933–1936.

Givulescu, R., 1968. Nouvelles plantes fossiles du Danien de Roumanie. Comptes Rendus des Séances de l'Académie des Sciences 267, 880–882.

Goudie, A.S., 1973. Duricrusts in tropical and subtropical landscapes. Oxford Clarendon Press, United Kingdom. 174 pp.

Goudie, A.S., 1983. Calcrete. In: Goudie, A.S., Pye, K. (Eds.), Chemical Sediments and Geomorphology—Precipitates and Residua in the Near-Surface Environment. Academic Press, Orlando, FL, pp. 93–131.

Grigorescu, D., 1983. A stratigraphic, taphonomic and palaeoecologic approach to a "forgotten land": the dinosaur-bearing deposits from the Haţeg Basin (Transylvania—Romania). Acta Palaeontologica Polonica 28, 103–121.

Grigorescu, D., 1992. Nonmarine cretaceous formations of Romania. In: Mateer, N., Pen-Ji, C. (Eds.), Aspects of Non-Marine Cretaceous Geology. China Ocean Press, Beijing, China, pp. 142–164.

Grigorescu, D., 1993. The latest Cretaceous dinosaur eggs and embryos from the Haţeg Basin—Romania. Revue de Paléobiologie, Special Volume 7, 95–99.

Grigorescu, D., Csiki, Z., 2002. Excursions field guide. The 7th European Workshop of Vertebrate Paleontology—Sibiu (Romania), pp. 47–69.

Grigorescu, D., Hahn, G., 1987. The first multituberculate teeth from the Upper Cretaceous of Europe (Romania). Geologica et Palaeontologica 21, 237–243.

Grigorescu, D., Kessler, E., 1980. A new specimen of *Elopteryx nopcsai* Andrews from the dinosaurian beds of Haţeg basin. Revue Roumaine de Géologie, Géophysique et Géographie. Série de Géologie 24, 171–175.

Grigorescu, D., Hartenberger, J.L., Radulescu, C., Samson, P., Sudre, J., 1985. Découverte de mammifères et dinosaures dans le Crétacé supérieur de Pui (Roumanie). Comptes Rendus de l'Académie des Sciences. Série 2 301, 1365–1368.

Grigorescu, D., Seclaman, M., Norman, D.B., Weishampel, D.B., 1990. Dinosaur eggs from Romania. Nature 346, 417.

Grigorescu, D., Weishampel, D.B., Norman, D.B., Seclamen, M., Rusu, M., Baltres, A., Teodorescu, V., 1994. Late Maastrichtian dinosaur eggs from the Haţeg Basin (Romania). In: Carpenter, K., Hirsch, K.F., Horner, J.R. (Eds.), Dinosaur Eggs and Babies. Cambridge University Press, New York, NY, pp. 75–87.

Grigorescu, D., Venczel, M., Csiki, Z., Limberea, R., 1999. New latest Cretaceous microvertebrate fossil assemblages from the Haţeg Basin (Romania). Geologie en Mijnbouw 78, 301–314.

Hasiotis, S.T., Honey, J.G., 2000. Paleohydrologic and stratigraphic significance of crayfish burrows in continental deposits: examples from several Paleocene Laramide basins in the Rocky Mountains. Journal of Sedimentary Research 70, 127–139.

Hofmann, B.A., 1990. Possible microbiological origin of reduction spots in red beds. In: Fliermans, C.B., Hazen, T.C. (Eds.), Proceedings of the First International Symposium on Microbiology of the Deep Subsurface. WSRC Inf. Serv. Sect. Publ. Group, United States, pp. 2.125–2.133.

Hofmann, B.A., Dearlove, J.P.L., Ivanovich, M., Lever, D.A., Green, D.C., Baertschi, P., Peters, T., 1987. Evidence of fossil and recent diffusive element migration in reduction haloes from Permian red-beds of northern Switzerland. In: Come, B., Chapman, N.A. (Eds.), Natural Analogues in Radioactive Waste Disposal, Radioactive Waste Management Series. Graham & Trotman, London, England, pp. 217–238.

Horrell, M.A., 1991. Phytogeography and paleoclimatic interpretation of the Maestrichtian. Palaeogeography, Palaeoclimatology, Palaeoecology 86, 87–138.

Iamandei, E., Iamandei, S., 1997. Xylotomical study of some fossil dicot trunks of Techereu in the metalliferous Carpathians. Acta Palaeontologica Romaniae 1, 107–112.

Ingersoll, R.V., Bullard, T.F., Ford, R.L., Grimm, J.P., Pickle, J.D., Sares, S.W., 1984. The effect of grain size on detrital modes: a test of the Gazzi–Dickinson point-counting method. Journal of Sedimentary Petrology 54, 103–116.

Jackson, R.G.I., 1978. Preliminary evaluation of lithofacies for meandering alluvial streams. In: Miall, A.D. (Ed.), Fluvial sedimentology. Memoir Canadian Society of Petroleum Geologists, vol. 5, pp. 543–576.

Jianu, C.M., 1992. Un fragment de dentar de hadrosaurian (Reptilia, Ornithischia) din Cretacicul superior din Bazinul Haţeg (Sânpetru, jud. Hunedoara). Sargetia 15, 385–396.

Jianu, C.M., 1994. A right dentary of *Rhabdodon priscus* Matheron, 1896 (Reptilia: Ornithischia) from the Maastrichtian of Haţeg Basin (Romania). Sargetia 16, 29–35.

Jianu, C.M., Weishampel, D.B., 1997. A new theropod dinosaur material from the Haţeg Basin (Late Cretaceous, western Romania)—a preliminary study. Sargetia 17, 11–27.

Johnsson, M.J., Stallard, R.F., Lundberg, R.F., 1991. Controls on the composition of fluvial sands from a tropical weathering environment: sands from the Orinoco river drainage basin, Venezuela and Columbia. Geological Society of America Bulletin 103, 1622–1647.

Khadkikar, A.S., Chamyal, L.S., Ramesh, R., 2000. The character and genesis of calcrete in Late Quaternary alluvial deposits, Gujurat, western India, and its bearing on the interpretation of ancient climates. Palaeogeography, Palaeoclimatology, Palaeoecology 162, 239–261.

Kraus, M.J., 1999. Paleosols in clastic sedimentary rocks: their geologic applications. Earth-Science Reviews 47, 41–70.

Kraus, M.J., Bown, T.M., 1986. Paleosols and time resolution in alluvial stratigraphy. In: Wright, V.P. (Ed.), Paleosols—their Recognition and Interpretation. Princeton University Press, Princeton, NJ, pp. 180–207.

Kräutner, H.G., Vâjdea, E., Romanescu, O., 1984. K–Ar dating of the banatitic magmatites from the southern Poiana Ruscă Mountains (Rusca Montană sedimentary basin). D.S. Institutului de Geologie Geofizică 70–71, 373–388.

López-Gómez, J., Arche, A., 1997. The Upper Permian Boniches Conglomerates Formation: evolution from alluvial fan to fluvial system environments and accompanying tectonic and climatic controls in the southeast Iberian Ranges, central Spain. Sedimentary Geology 114, 267–294.

López-Martinez, N., Moratalla, J.J., Sanz, J.L., 2000. Dinosaur nesting on tidal flats. Palaeogeography, Palaeoclimatology, Palaeoecology 160, 153–163.

López-Martinez, N., Canudo, J.I., Ardèvol, L., Suberbiola, X.P., Orue-Etxebarria, X., Cuenca-Bescós, G., Ruiz-Omeñaca, J.I., Murelaga, X., Feist, M., 2001. New dinosaur sites correlated with Upper Maastrichtian pelagic deposits in the Spanish Pyrenees: implications for the dinosaur extinction pattern in Europe. Cretaceous Research 22, 41–61.

Lorenz, J., Gavin, W., 1984. Geology of the two medicine formation and the sedimentology of a dinosaur nesting ground. In: McBane, J.D., Garrison, P.B. (Eds.), Montana Geological Society 1984 Field Conference, Northwestern Montana, Guidebook. Montana Geological Society, Billings, MT, pp. 175–186.

Mack, G.H., James, W.C., 1993. Control of basin symmetry on fluvial lithofacies, Camp Rice and Palomas Formations (Plio–Pleistocene), southern Rio Grande rift, USA. In: Marzo, M., Puigdefábregas, C. (Eds.), Alluvial Sedimentation, Special Publication, vol. 17. Blackwell Scientific Publications, Oxford, pp. 439–449.

Mamulea, M.A., 1953. Studii geologice in regiunea Sînpetru-Pui (Bazinul Haţegului). Anuarul Comitetului Geologic (Romania) 25, 211–274.

Mărgărit, G., Mărgărit, M., 1967. Asupra prezentei unor resturi de plante fosile în împrejurimile lacalitaţii Demsuş (Bazinul Haţeg). Studii şi Cercetari de Geologie, Geofizică, Geografie. Seria Geologie 12, 471–476.

Marriott, S.B., Wright, V.P., 1993. Palaeosols as indicators of geomorphic stability in two old red sandstone alluvial suites, South Wales. Journal of the Geological Society (London) 150, 1109–1120.

McBride, E.F., 1974. Significance of colour in red, green, purple, olive, brown, and gray beds of Difunta Group, northeastern Mexico. Journal of Sedimentary Petrology 44, 760–773.

McKeague, J.A., 1983. Clay skins and the argillic horizon. In: Bullock, P., Murphy, C.P. (Eds.), Soil Micromorphology. Soil Genesis, vol. 2. AB Academic, Berkhamsted, pp. 367–388.

Miall, A.D., 1978. Lithofacies types and vertical profile models in braided river deposits: a summary. In: Miall, A.D. (Ed.), Fluvial Sedimentology. Memoir Canadian Society of Petroleum Geologists vol. 5, pp. 597–604.

Mikhailov, K., Sabath, K., Kurzanov, S., 1994. Eggs and nests from the Cretaceous of Mongolia. In: Carpenter, K., Hirsch, K.F., Horner, J.R. (Eds.), Dinosaur Eggs and Babies. Cambridge University Press, New York, NY, pp. 88–115.

Mjøs, R., Walderhaug, O., Prestholm, E., 1993. Crevasse splay sandstone geometries in the Middle Jurassic Ravenscar Group of Yorkshire, UK. In: Marzo, M., Puigdefábregas, C. (Eds.), Alluvial Sedimentation. Special Publication Number, vol. 17. Blackwell Scientific Publications, Oxford, UK, pp. 167–184.

Mohabey, D.M., 1996. A new oospecies, *Megaloolithus matleyi*, from the Lameta Formation (Upper Cretaceous) of Chandrapur district, Maharashtra, India, and general remarks on the palaeoenvironment and nesting behaviour of dinosaurs. Cretaceous Research 17, 183–196.

Mykura, H., Hampton, B.P., 1984. On the mechanism of formation of reduction spots in the Carboniferous/Permian red beds of Warwickshire. Geological Magazine 121, 71–74.

Naish, D., Dyke, G.J., 2004. *Heptasteornis* was no ornithomimid, troodontid, dromaeosaurid or owl: the first alvarezsaurid (Dinosauria: Theropoda) from Europe. Neues Jahrbuch für Geologie und Paläontologie. Monatshefte 7, 385–401.

Nopcsa, F., 1897. Vorläufiger bericht über das Auftreten von oberer Kreide im Hatzeger Tal in Siebenbürgen. Verhandlungen der Kaiserlich-Königlichen Akademie der Wissenschaften, 273–274.

Nopcsa, F., 1899. Dinosaurierreste aus Siebenbürgen (Schädel von *Limnosaurus transsylvanicus* nov. gen. et spec.). Denkschriften der Königlichen Akademie der Wissenschaften Mathematisch. Naturwissenschaftliche Klasse 68, 555–591.

Nopcsa, F., 1900. Dinosaurierreste aus Siebenbürgen: I. Schadel von *Limnosaurus transylvanicus* nov. gen. et sp. Denkschriften der Kaiserlichen Akademie der Wissenschaften 68, 555–591.

Nopcsa, F., 1901. Synopsis und Abstammung der Dinosaurier. Földtani Közlöny 31, 247–279.

Nopcsa, F., 1902a. Dinosaurierreste aus Siebenbürgen: II. (Schädelreste von *Mochlodon*). Denkschriften der Königlichen Akademie der Wissenschaften. Mathematisch-Naturwissenschaftliche Klasse 72, 149–175.

Nopcsa, F., 1902b. Über das Vorkommen der Dinosaurier bei Szentpéterfalva. Zeitschrift der Deutschen Geologischen Gesellschaft 1902, 34–39.

Nopcsa, F., 1904. Dinosaurierreste aus Siebenbürgen: III. Weitere Schädelreste von *Mochlodon*. Denkschriften der Königlichen Akademie der Wissenschaften. Mathematisch-Naturwissenschaftliche Klasse 74, 229–263.

Nopcsa, F., 1905. Zur Geologie der Gegend zwishen Gyulafehérvár, Deva, Ruszkabánya und der Rumänischen Landesgrenze. Mittheilungen aus dem Jahrbuche der Königlich Ungarischen Geologischen Reichsanstalt 14, 91–279.

Nopcsa, F., 1915. Die Dinosaurier der Siebenbürgischen Landesteile Ungarns. Mitteilungen aus dem Jahrbuche der Königlich Ungarischen Geologischen Reichsanstalt, Budapest 23, 3–24.

Nopcsa, F., 1923a. *Kallokibotion*, a primitive amphichelydean tortoise from the Upper Cretaceous of Hungary. Palaeontologica Hungarica 1, 1–34.

Nopcsa, F., 1923b. On the geological importance of the primitive reptilian fauna in the uppermost Cretaceous of Hungary: with a description of a new tortoise (*Kallokibotium*). Quarterly Journal of the Geological Society of London 79, 100–116.

Nopcsa, F., 1928. Dinosaurierreste aus Siebenbürgen: IV. Die Wirbelsäule von *Rhabdodon* und Orthomerus. Palaeontologica Hungarica 1, 273–304.

Nopcsa, F., 1929. Dinosaurier aus Siebenbürgen. V. Geological Hungarica 4, 1–76.

Paik, I.S., Huh, M., Kim, H.J., 2004. Dinosaur egg-bearing deposits (Upper Cretaceous) of Boseong, Korea: occurrence, palaeoenvironments, taphonomy, and preservation. Palaeogeography, Palaeoclimatology, Palaeoecology 205, 155–168.

Panaiotu, C., Panaiotu, C., 2002. Paleomagnetic studies. 7th European Workshop on Vertebrate Paleontology—Sibiu (Romania), p. 61.

Panhuys-Sigler, M.V., Trewin, N.H., Still, J., 1996. Roscoelite associated with reduction spots in Devonian red beds, Gamrie Bay, Banffshire. Scottish Journal of Geology 32, 127–132.

Patrascu, S., Panaiotu, C., 1990. Paleomagnetism of some Upper Cretaceous deposits in the South Carpathians. Revue Roumaine de Géophysique 34, 67–77.

Petrescu, I., Duşa, A., 1980. Flora din Cretacicul Superior de la Rusca Montană—o raritate în patrimoniul paleobotanic naţional. Ocrotirea Naturii şi a Mediului Inconjurător 24, 147–155.

Petrescu, I., Duşa, A., 1982a. Paleoflora din Senonianul Bazinului Rusca Montană. D.S.. Institutului de Geologie şi Geofizică LXIX, 107–124.

Petrescu, I., Duşa, A., 1982b. The Upper Cretaceous fossil flora of Rusca Montană. In: Petrescu, I. (Ed.), Simpozionul de Paleobotanica–Palinologie. University Babeş-Bolyai, Cluj-Napoca, pp. 37–39.

Pimentel, N.L., Wright, V.P., Azevedo, T.M., 1996. Distinguishing early groundwater alteration effects from pedogenesis in ancient alluvial basins: examples from the Paleogene of southern Portugal. Sedimentary Geology 105, 1–10.

PiPujol, M.D., Buurman, P., 1994. The distinction between groundwater gley and surface-water gley phenomena in Tertiary paleosols of the Ebro Basin (NE Spain). Palaeogeography, Palaeoclimatology, Palaeoecology 110, 103–113.

PiPujol, M.D., Buurman, P., 1997. Dynamics of iron and calcium carbonate redistribution and paleohydrology in middle Eocene alluvial paleosols of the southeast Ebro Basin margin (Catalonia, northeast Spain). Palaeogeography, Palaeoclimatology, Palaeoecology 134, 87–107.

Pop, G., Petrescu, I., 1983. Consideraţii paleoclimatice asupra vegetaţiei din Cretacicul superior de la Rusca Montană. Studia Universitatis Babeş-Bolyai. Geologia-Geographia 18, 49–54.

Potter, P.E., Pettijohn, F.J., 1963. Paleocurrents and basin analysis. Springer, Berlin. 296 pp.

Radulescu, C., Samson, P.-M., 1986. Précisions sur les affinités des Multituberculés (Mammalia) du Crétacé supérieur de Roumanie. Comptes Rendus de l'Académie des Sciences 303, 1825–1830.

Radulescu, C., Samson, P.-M., 1996. The first multituberculate skull from the Late Cretaceous (Maastrichtian) of Europe (Haţeg Basin, Romania). Anuarul Institutului Geologic al României - Abstracts 69, Supplement to Number 1, unnumbered pages.

Reeves, C.C.J., 1976. Caliche: origin, classification, morphology, and uses. Estacado Books, Lubbock, Texas. 233 pp.

Retallack, G.J., 1994. The environmental factor approach to the interpretation of paleosols. In: Amundson, R., Harden, J., Singer, M. (Eds.), Factors of Soil Formation: A Fiftieth Anniversary Retrospective. Special Publications of the Soil Science Society of America, vol. 33. Soil Science Society of America, pp. 31 – 64.

Retallack, G.J., 1997. A colour guide to paleosols. John Wiley and Sons, New York, NY. 175 pp.

Retallack, G.J., 2001. Soils of the past: an introduction to paleopedology, 2nd edition. Blackwell Science, Oxford, UK. 404 pp.

Retallack, G.J., 2004. Late Oligocene bunch grassland and early Miocene sod grassland paleosols from central Oregon, USA. Palaeogeography, Palaeoclimatology, Palaeoecology 207, 203 – 237.

Royer, D.L., 1999. Depth to pedogenic carbonate horizon as a paleoprecipitation indicator? Geology 27, 1123 – 1126.

Royer, D.L., 2000. Depth to pedogenic carbonate horizon as paleoprecipitation indicator? Reply. Geology 28, 572 – 573.

Sahni, A., 1997. Paleoenvironments of Late Cretaceous dinosaur nesting sites of India. In: Wolberg, D.L., Stump, E., Rosenberg, G.D. (Eds.), DinoFest International Proceedings. Academy of Natural Sciences, Philadelphia, PA, pp. 291 – 300.

Sahni, A., Tandon, S.K., Jolly, A., Bajpai, S., Sood, A., Srinivasan, S., 1994. Upper Cretaceous dinosaur eggs and nesting sites from the Deccan volcano-sedimentary province of peninsular India. In: Carpenter, K., Hirsch, K.F., Horner, J.R. (Eds.), Dinosaur Eggs and Babies. Cambridge University Press, New York, NY, pp. 204 – 226.

Sanders, C.A.E., 1998. Tectonics and Erosion, Competitive Forces in a Compressive Orogen: A Fission Track Study of the Romanian Carpathians. Ph.D. dissertation. Vrije University, Amsterdam.

Sandulescu, M., Kräutner, H., Borcos, M., Nastaseanu, S., Patrulius, D., Stefanescu, M., Ghenea, C., Lupu, M., Savu, H., Bercia, I., Marinescu, F., 1978. Geological map of Romania 1:1,000,000, Instituţul de Geologie şi Geofizică, Bucharest.

Schmid, S.M., Berza, T., Diaconescu, V., Froitzheim, N., Fugenschuh, B., 1998. Orogen-parallel extension in the Southern Carpathians. Tectonophysics 297, 209 – 228.

Schwertmann, U., 1993. Relations between iron oxides, soil colour, and Soil Formation. In: Bigham, J.M., Ciolkosz, E.J. (Eds.), Soil Colour. SSSA Special Publication, vol. 31. Soil Science Society of America, pp. 51 – 69.

Sheldon, N.D., Retallack, G.J., 2004. Regional paleoprecipitation records from the late Eocene and Oligocene of North America. The Journal of Geology 112, 487 – 494.

Sheldon, N.D., Retallack, G.J., Tanaka, S., 2002. Geochemical climofunctions from North American soils and application to paleosols across the Eocene–Oligocene boundary in Oregon. The Journal of Geology 110, 687 – 696.

Smith, T., Codrea, V.A., Săsăran, E., Van Itterbeeck, J., Bultynck, P., Csiki, Z., Dica, P., Fărcaş, C., Folie, A., Garcia, G., Godefroit, P., 2002. A new exceptional vertebrate site from the Late Cretaceous of the Haţeg Basin (Romania). Studia Universitatis Babeş-Bolyai. Geologia Special Issue 1, 321 – 330.

Stampfli, G., Borel, G., Cavazza, W., Mosar, J., Ziegler, P.A., 2001. The paleotectonic atlas of the PeriTethyan domain. European Geophysical Society. CD-ROM.

Suttner, L.J., Dutta, P.K., 1986. Alluvial sandstone composition and paleoclimate: I. Framework mineralogy. Journal of Sedimentary Petrology 56, 329 – 345.

Therrien, F., 2004. Paleoenvironmental reconstruction of Late Cretaceous (Maastrichtian) dinosaur-bearing formations of Romania. Ph.D. dissertation. The Johns Hopkins University, Baltimore. 309 pp.

Therrien, F., Fastovsky, D.E., 2000. Paleoenvironments of early theropods in the Chinle Formation (Late Triassic), Petrified Forest National Park, Arizona. Palaios 15, 194 – 211.

Therrien, F., Jianu, C.M., Scarlat, B., Weishampel, D.B., King, J.W., 2002. Paleoenvironmental reconstruction of latest Cretaceous dinosaur-bearing formations of Romania: preliminary results. Sargetia 19, 33 – 59.

Thomas, R.G., Smith, D.G., Wood, J.M., Visser, J., Calverley-Range, E.A., Koster, E.H., 1987. Inclined heterolithic stratification—terminology, description, interpretation and significance. Sedimentary Geology 53, 123 – 179.

Tuszon, J., 1913. Addidamenta ad floram fossiliem Hungariae III. A Mágyar Allami Földtani Intézet, Evkönive. Budapest 8, 209 – 233.

Van Itterbeeck, J., Sasaran, E., Codrea, V., Sasaran, L., Bultynck, P., 2004. Sedimentology of the Upper Cretaceous mammal and dinosaur bearing sites along the Raûl Mare and Bărbat rivers. Haţeg Basin, Romania. Cretaceous Research 25, 517 – 530.

Van Itterbeeck, J., Markevich, V.S., Codrea, V., in press. Palynology of the Maastrichtian mammal and dinosaur bearing sites along the Raûl Mare and Bărbat rivers. Haţeg Basin, Romania. Geologica Carpathica.

Venczel, M., Csiki, Z., 2003. New frogs from the latest Cretaceous of Haţeg Basin, Romania. Acta Palaeontologica Polonica 48, 609 – 616.

Vepraskas, M.J., 1992. Redoximorphic features for identifying aquic conditions. Technical Bulletin-North Carolina Agricultural Research Service 301, 1 – 33.

Vepraskas, M.J., Wilding, L.P., Drees, L.R., 1994. Aquic conditions for soil taxonomy: concepts, soil morphology and micromorphology. In: Ringrose-Voase, A.J., Humphreys, G.S. (Eds.), Soil Micromorphology: Studies in Management and Genesis. Elsevier, Amsterdam, The Netherlands, pp. 117 – 131.

Voigt, S., Hay, W.W., Höfling, R., DeConto, R.M., 1999. Biogeographic distribution of late Early to Late Cretaceous rudist-reefs in the Mediterranean as climate indicators. In: Barrera, E., Johnson, C.C. (Eds.), Evolution of the Cretaceous Ocean–Climate System. Special Paper Geological Society of America, vol. 332, pp. 91 – 103.

von Eynatten, H., Gaupp, R., 1999. Provenance of Cretaceous synorogenic sandstones in the Eastern Alps: constraints from framework petrography, heavy mineral analysis, and mineral chemistry. Sedimentary Geology 124, 81 – 111.

Vremir, M., Codrea, V.A., 2002. The first Late Cretaceous (Maastrichtian) dinosaur footprints from Transylvania (Romania). Studia Universitatis Babeş-Bolyai. Geologia 47, 93 – 104.

Weishampel, D.B., Jianu, C.M., 1996. New theropod dinosaur material from the Haţeg Basin (Late Cretaceous, western Romania). Neues Jahrbuch für Geologie und Paläontologie. Abhandlungen 200, 387–404.

Weishampel, D.B., Grigorescu, D., Norman, D.B., 1991. The dinosaurs of Transylvania. National Geographic Research and Exploration 7, 196–215.

Weishampel, D.B., Norman, D.B., Grigorescu, D., 1993. *Telmatosaurus transsylvanicus* from the Late Cretaceous of Romania: the most basal hadrosaurid. Palaeontology 36, 361–385.

Weishampel, D.B., Jianu, C.M., Csiki, Z., Norman, D.B., 2003. Osteology and phylogeny of *Zalmoxes* (n.g.), an unusual ornithopod dinosaur from the latest Cretaceous of Romania. Journal of Systematic Palaeontology 1, 123–143.

Wilding, L.P., Tessier, D., 1988. Genesis of Vertisols: shrink-swell phenomena. In: Wilding, L.P., Puentes, R. (Eds.), Vertisols: Their Distribution, Properties, Classification and Management. Texas A&M University Printing Center, Texas, pp. 55–81.

Willingshofer, E., 2000. Extension in Collisional Orogenic Belts: the Late Cretaceous Evolution of the Alps and Carpathians. Ph.D. dissertation. Netherlands Research School of Sedimentary Geology (NSG). Amsterdam.

Willingshofer, E., Andriessen, P., Cloething, S., Neubauer, F., 2001. Detrital fission track thermochronology of Upper Cretaceous syn-orogenic sediments in the South Carpathians (Romania): inferences on the tectonic evolution of a collisional hinterland. Basin Research 13, 379–395.

Wright, V.P., Taylor, K.G., Beck, V.H., 2000. The paleohydrology of Lower Cretaceous wetlands, Isle of Wight, southern England. Journal of Sedimentary Research 70, 619–632.

Yang, S., Fang, X., Li, J., An, Z., Chen, S., Fukusawa, H., 2001. Transformation functions of soil colour and climate. Science in China, Series D: Earth Sciences 44, 218–226.

Zuffa, G.G., 1985. Optical analyses of arenites: influence of methodology on compositional results. In: Zuffa, G.G. (Ed.), Provenance of Arenites, NATO ASI Series. Series C: Mathematical and Physical Sciences. D. Reidel Publishing, Boston, MA, pp. 165–189.