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# Palaeoenvironmental reconstruction of the Late Cretaceous Sânpetru Formation (Haţeg Basin, Romania) using paleosols and implications for the "disappearance" of dinosaurs

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ABSTRACT

Paleosols of the Late Cretaceous Sânpetru Formation (Haţeg Basin, Romania) are the subject of macroscopic, microscopic, and geochemical investigation in order to reconstruct the palaeoenvironmental and palaeoclimatic conditions in which dinosaurs lived. Study of overbank deposits present in an 860-m-thick stratigraphic interval of the Sânpetru Formation exposed along the Sibişel Valley reveals the presence of one facies and five different pedotypes: 1) finely laminated gray-green mudstones and siltstones interpreted as pond deposits; 2) bioturbated gray-green mudstones lacking macroscopic pedogenic features, interpreted as very poorly-developed hydromorphic paleosols; 3) bioturbated gray-green mudstones containing carbonate concretions, interpreted as poorly-developed hydromorphic paleosols; 4) mottled gray-green mudstones containing carbonate concretions and limited illuvial clay accumulation, interpreted as moderately-developed paleosols characterized by a high but fluctuating watertable; 5) bioturbated brown-red mudstones lacking macroscopic pedogenic features other than the occasional mottles, interpreted as poorly-developed paleosols that formed on the higher and better-drained floodplains; and 6) bioturbated brown-red mudstones containing carbonate nodules, interpreted as moderately-developed calcareous paleosols that formed on distal floodplain settings. Although limited exposure prevents the documentation of lateral relationships of pedotypes, the presence of paleosol profiles that display characteristics of two different pedotypes suggests that they represent a lateral continuum on the landscape related to local differences in hydrology and relief (i.e., catena). The pedotype assemblage reveals that the Sânpetru landscape was a mosaic of wetlands, seasonal wetlands, and better-drained floodplain habitats, similar to the present-day Indogangetic Plains. Pedogenic features and paleosol geochemistry indicate that the Maastrichtian climate of Romania was subhumid (<1000 mm rain/year) and characterized by strongly seasonal precipitation.

The distribution of pedotypes through the Sânpetru Formation reveals small- and large-scale palaeoenvironmental changes associated with the shifting of a complex mosaic of wet and dry habitats in response to shifts in river position on the alluvial plain. However, a major palaeoenvironmental change occurs in the upper Sânpetru Formation, where the region was transformed into extensive wetlands. Such dramatic changes coincide with river competence increase, change in palaeocurrent directions, and dearth of macrovertebrate remains, which had been previously misinterpreted as evidence for the disappearance of dinosaurs at the Cretaceous-Tertiary boundary. These palaeoenvironmental changes, induced by tectonism, are responsible for the shift from preservation of macrofossils concentrated by hydraulic processes into conspicuous lenticular bonebeds in the lower Sânpetru Formation to preservation of microfossil, and more rarely macrofossil, remains in hydromorphic calcareous paleosols in the upper Sânpetru Formation. The consequences of palaeoenvironmental changes on vertebrate preservation mode must be considered in the search for fossils and interpretation of the fossil record.



## 1. Introduction

The early Maastrichtian Sânpetru Formation of the Haţeg Basin (Southern Carpathian Mountains, western-central Romania) is one of the best-exposed latest Cretaceous continental successions of Eastern Europe. It preserves one of the most diverse Late Cretaceous dinosaur-

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dominated faunas of Europe (for a review, see Grigorescu and Csiki, 2002; Therrien, 2005) and is one of the few non-North American, latest Cretaceous dinosaur-bearing formations for which a significant fossil record and stratigraphic section are known. Consequently, this formation provides a unique opportunity to investigate Maastrichtian continental palaeoenvironments outside of North America and has the potential to improve our understanding of the changes in palaeoenvironments and biodiversity at the end of the Cretaceous.

The fossils of the Sânpetru Formation have been the topic of extensive studies (for a review, see Grigorescu and Csiki, 2002; Therrien, 2005), but the palaeoenvironmental setting in which they are preserved and the cause of the apparent absence of dinosaur remains in the upper part of the formation (Weishampel et al., 1991; Grigorescu, 1992), have only been the topic of limited study (Nopcsa, 1905; Grigorescu, 1983; Weishampel et al., 1991; Therrien, 2006). Bojar et al. (2005) studied the paleoenvironmental setting of the Sânpetru Formation based on sedimentology, stable isotopes, clay mineralogy, and superficial macroscopic pedogenic features, but the small number of localities studied and lack of a strong stratigraphic control between localities restricted their interpretation to general trends within the formation. Here we present the first detailed study of the macro- and micromorphology, and geochemistry of paleosols of the Sânpetru Formation in order to reconstruct the latest Cretaceous continental palaeoenvironments and palaeoclimate of the northern Mediterranean Tethys region and to document the palaeoenvironmental changes associated with the apparent absence of dinosaurs in the upper Sânpetru Formation.

## 2. Geologic setting

The Sânpetru Formation is a 2500 m-thick continental succession found in the Haţeg Basin, an intramontane basin approximately 45 km long (E–W) by 15 km wide (N–S), situated in the Southern Carpathian Mountains of western-central Romania (Fig. 1A). The Sânpetru Formation was deposited in an extensional basin in response to the latest Cretaceous collapse of the Southern Carpathian orogen (Willingshofer et al., 2001; Therrien, 2006). Exposure of the Sânpetru Formation is limited due to vegetation cover and the strong dip of strata (between 45° and 80°). The best exposed and most extensively studied outcrops, which consist of discontinuous exposures on the faces of high hills located along the Sibişel River, represent an 860-m-thick stratigraphic interval from the uppermost reaches of the formation (Fig. 1B). Based upon the distribution of rock formations in the Haţeg Basin, the Sânpetru Formation may have been covered by as little as 500 m of Cenozoic deposits (Stilla, 1985).

The Sânpetru Formation consists of a repetitive succession of laterally-extensive, predominantly single-storied, sandstone (or conglomerate) sheets fining-upward into gray, green, brown, or red mudstone (Grigorescu, 1983; Bojar et al., 2005; Therrien, 2006). The fluvial deposits are characterized by rare shallow channel-shaped scours at the base of sandstone sheets, abundant horizontal laminations and high flow velocity sedimentary structures, low variability of palaeocurrent indicators, the absence of pointbar deposits, and the presence of facies assemblages associated with sheetfloods and braided streams (Therrien, 2006). This sedimentary succession is interpreted as having been deposited on a broad, poorly-channelized braidplain by frequently avulsing rivers that flowed northward in response to the latest Cretaceous collapse of the Southern Carpathian orogen (Grigorescu, 1983; Bojar et al., 2005; Therrien, 2006). Along the Sibişel Valley, the Sânpetru Formation is divided into a lower member that displays a mixture of gray-green and red mudstones, and an upper member that is characterized by the presence of coarser channel deposits, a change in palaeocurrent direction, the lack of red mudstones, and the apparent absence of dinosaur remains (Grigorescu, 1983, 1992; Weishampel et al., 1991; Bojar et al., 2005; Therrien, 2006). The absence of dinosaur remains in the last 200 m of the Sânpetru Formation had been previously interpreted as evidence of continuous deposition across the Cretaceous-Tertiary (K/T) boundary in the Haţeg Basin (Grigorescu 1992; also see Weishampel et al., 1991) before palynological (Van Itterbeeck et al., 2005) and magnetostratigraphic (Panaiotu and Panaiotu, 2002; Therrien, 2004) studies revealed that the Sânpetru Formation was deposited during the early Maastrichtian.

Maastrichtian palaeogeographic reconstructions of the Tethys Ocean reveal that the Haţeg region was situated in the tropical–subtropical belt, between 20° and 30° North latitude (Patrascu and Panaiotu, 1990; Panaiotu and Panaiotu, 2002). Long believed to have been a small island based on vertebrate fossil evidence (e.g., Nopcsa,

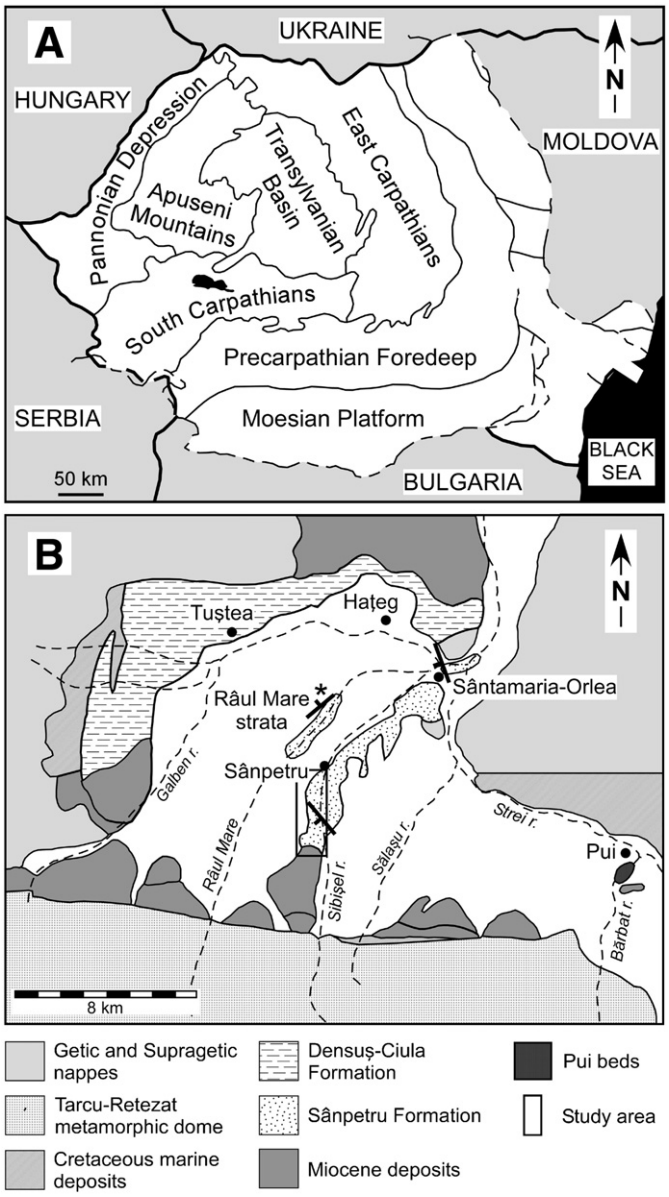


**Fig. 1.** Sânpetru Formation in the Haţeg Basin. A) Geographic position of the Haţeg Basin within the Southern Carpathians of western central Romania. B) Geologic map of the western half of the Haţeg Basin where three Maastrichtian continental formations (Sânpetru and Densuş-Ciula formations, and the Pui beds) are exposed. Deposits of the Sânpetru Formation are found along several rivers in the Haţeg Basin, but the best outcrops represent an 860 m-thick sequence exposed along the Sibişel River. The attitude of the strata (strike and dip) are reported for various rock exposures in the Haţeg Basin; all were measured by the lead author except for the one indicated by an asterisk "*," which was reported by Codrea et al. (2002b) and Smith et al. (2002). Strata attitude: exposure near Sântamaria-Orlea (136°N, 55° to the west), along the Sibişel River (142°N, 45° to the west), and Raûl Mare strata* (220–230°N, dip: 75–80° north). Modified from Weishampel et al. (1991).