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Uppermost Cretaceous megaloolithid eggs from the Haţeg Basin, Romania, associated with hadrosaur hatchlings: Search for explanation

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ABSTRACT

Four localities in the Upper Cretaceous (Maastrichtian) of the Haţeg Basin (in order of discovery, Tuştea, Toteşti-baraj, Nălaţ-Vad and Livezi) have yielded clutches of megaloolithid eggs. Egg morphology and size, eggshell thickness, external ornamentation and internal microstructure, pore density and geometry, as well as morphology of the clutches (where this could be observed) are all similar among the four localities, allowing the assignment of the eggs to *Megaloolithus* cf. *siruguei*. Most egg occurrences are related to paleosols of variable chemical composition and maturity, developed within different parts of the floodplain. The nesting horizon from Tuştea was partially reconstructed on a 160 m^2 surface, allowing a thorough analysis of the taphonomy of the eggs and clutches. It has also yielded hatchling remains at different ontogenetic developmental stages, and even, more rarely, embryo remains as well. The bones occur in the vicinity of or even within the clutches; in a single case, incompletely ossified embryonic skeletal remains, including a dentary tooth, were found inside an incomplete egg. Without exception, the neonate remains belong to the basal hadrosaurid *Telmatosaurus transsylvanicus*, one of the common dinosaur species in the faunal assemblage. No sauropod neonate remains were found in the nesting horizon from Tuştea; only a fragmentary pelvic girdle and caudal vertebrae of an adult titanosaurian were unearthed recently 20 cm above the nesting horizon. None of the other three megaloolithid localities in the Haţeg Basin provided neonatal remains of any dinosaur species.

Despite the general consensus that the *Megaloolithus* oogenus belongs exclusively to titanosaurian sauropods, the co-occurrence of megaloolithid eggs and hadrosaurid neonatal remains at Tuştea seems to contradict this view. Previous cladistic analyses of dinosauroid ootaxa might offer an explanation of this controversial issue. These analyses have revealed that Megaloolithidae appears to be the sister group of Spheroolithidae, usually regarded as a hadrosaurid egg family. Perhaps a significant amount of homoplasy is present in the evolution of dinosaurian eggs, whose structure depends on incubation environment as well as biology and physiology of the reproductive system itself, and that the oospecies of *Megaloolithus* might have been laid by different higher-level taxa, including both titanosaurian sauropods and (basal) hadrosaurids. Understanding the significance of this paraphyletic distribution requires further study.

1. Introduction

Unknown in the dinosaur-bearing deposits of the Haţeg Basin until 1988, dinosaur eggs and eggshells were discovered afterwards in numerous localities across the Maastrichtian of the Haţeg Basin. In spite of the large variety of eggshells, found mainly by screen-washing the sediments, including testudoid, crocodiloid, geckonoid, dinosauroid and ornithoid ratite morphotypes (e.g., Grigorescu et al., 1999; Garcia et al., 2002, 2003a; Grigorescu and Csiki, 2008; Garcia et al., 2009), only the megaloolithid morphotype is represented by incomplete eggs as well. Most of these eggs are either hatched or eroded (based on the preservation of only the lower halves), and often preserved within the original clutches.

Although diverse eggshell fragments have been recovered from several localities, only four Haţeg Basin sites have provided megaloolithid eggs and large egg fragments: Tuştea (Grigorescu et al., 1990) and Livezi (Grigorescu and Csiki, 2008) in the Densuş-Ciula Formation which is restricted to the northwestern part of the basin, and Toteşti-baraj (*Toteşti-dam*) (Codrea et al., 2002) and Nălaţ-Vad (Smith et al., 2002), both along the Râul Mare River in the Sânpetru Formation, in the central–western part of the basin (Fig. 1). The two sites from the Densuş-Ciula Formation are situated about 4 km to the northeast, while

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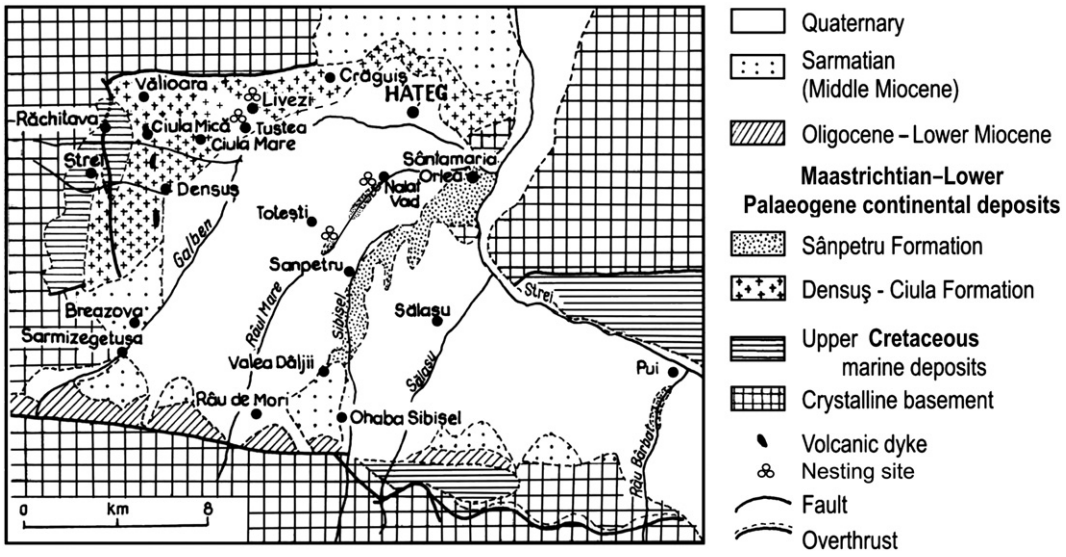

Fig. 1. Geological map of the central and western part of the Haţeg Basin showing the location of the four sites with megaloolithid eggs.

the sites from the Sânpetru Formation are 3 km apart, along a southwest–northeast transect. Each of the sites includes one to more than six horizons with egg clutches or concentrations of eggshells. The lack of marker beds and the probable presence of faults make the correlation between the different lithological sequences difficult.

Soon after the first discovery of megaloolithid egg clutches at Tuştea, a few isolated limb bones of neonate hadrosaurs were also found close to the eggs (Weishampel et al., 1991, 1993). Numerous hatchling remains were discovered subsequently in the surroundings or even inside the egg clutches from Tuştea, all identified as belonging to the hadrosaurid *Telmatosaurus transsylvanicus* (Weishampel et al., 1993; Grigorescu, 2006). This peculiar co-occurrence from Tuştea raises again the issue of concordance between dinosaur egg parataxonomy and dinosaurian taxonomy. Generally, megaloolithid eggs are assigned to titanosaurian sauropods (see Sander et al., 2008 and references therein), the most convincing evidence for this assignment coming from Auca Mahuevo, Argentina, where entire skeletons of titanosaurian embryos were found inside megaloolithid eggs (Chiappe et al., 1998). The co-occurrence of hadrosaurid embryonic bones with megaloolithid eggs was originally met with skepticism (Carpenter et al., 1994; Sander et al., 2008), since hadrosaurid embryonic and hatchling remains were reported to be associated with eggs and nests referred to Spheroolithidae (e.g., Horner and Currie, 1994; Horner, 1999). Unfortunately, none of the other three localities with megaloolithid eggs from the Haţeg Basin yielded remains of dinosaurian embryos or hatchlings, despite the rich microvertebrate assemblages (including frogs, lizards, dinosaurs and mammals) reported from Toteşti-baraj (Codrea et al., 2002) and Nălaţ-Vad (Smith et al., 2002).

In order to explain this unusual and rather paradoxical association of megaloolithid eggs and hadrosaurid hatchlings at Tuştea, this paper presents a first overview of the characters of individual eggs and clutches and of their depositional environments, including all four localities that yielded megaloolithid eggs in the Haţeg Basin.

Abbreviations: FGGUB, Faculty of Geology and Geophysics, University of Bucharest, Bucharest, Romania; IRSNB, Institut Royal des Sciences Naturelles de Belgique; UBB, Babeş-Bolyai University, Cluj-Napoca, Romania.

2. Geological setting

Localities with megaloolithid eggs are present in both Maastrichtian continental lithostratigraphic units of the Haţeg Basin: the Densuş-Ciula Formation and the Sânpetru Formation (Grigorescu, 1992; Fig. 1). The detailed chronostratigraphic position of the two units is still not completely clarified. Palaeomagnetic studies by Panaiotu and Panaiotu (2002, 2010-this issue) on the section of Sânpetru Formation outcropping along the Sibişel valley, south of Sânpetru village, revealed a succession that corresponds to the interval between Chron 32n 1n and the end of Chron 31n (70.8–68.4 M.y., terminal Campanian — Early to earliest Late Maastrichtian; Gradstein et al., 2004). On the other hand, palaeomagnetic measurements made on the reddish mudstones from Tuştea, as well as other sites within the middle member of the Densuş-Ciula Formation revealed the presence of a normal polarity zone which, in the chronostratigraphic context of the region, might correspond to Chron 30n (67.5–65.9 M.y., Late Maastrichtian; Gradstein et al., 2004). Based on the strike of the beds, Nălaţ-Vad appears to be slightly older than Toteşti-baraj (Smith et al., 2002), while Livezi is slightly younger than Tuştea.

The Ultoane Hill section near the Tuştea village (Fig. 2A) is dominated by a 6 m thick, cross-bedded, matrix-supported conglomerate bed that includes middle-sized volcanoclasts. The conglomerate bed is underlain by a thick bed of massive red silty micaceous and bioturbated mudstones, rich in carbonate nodules that sometimes unite into continuous levels; these levels are separated by dark red blocky mudstones showing vertical root traces and finger-like calcite-cemented burrows. The calcretes, spread within the currently outcropping 3 m thickness of the mudstone, mark distinct Bk horizons of moderately developed calcisols (Bojar et al., 2005; Therrien, 2005). A 20 cm thick, grey-greenish medium-to-coarse grained sandstone bed separates the egg-bearing mudstone unit from a second red mudstone unit showing comparable petrological–lithological features; most of this second mudstone body is currently covered by the sediment pile removed during the excavation of the nesting level. Vertebrate fossils are present throughout the red mudstones, while dinosaur eggs are restricted to a horizon within the upper mudstone body. The nesting horizon (N20°E/12°S) is located 0.5 to 0.8 m below the conglomerate–mudstone contact, depending on the unevenness of the scour surface from the base of the conglomerate bed, and is closely associated with a calcrete horizon. Several egg clusters, interpreted as nests (see below; Taphonomy), were discovered along this horizon, together with isolated to partly articulated remains of vertebrates, including neonate dinosaur remains.

At Livezi, sites rich in eggshell fragments were recognized within the outcropping sequence located along several dry gulches and created by torrents in this area of badlands (Fig. 2B; see Grigorescu and Csiki, 2008). As at Tuştea, the fossiliferous levels are located in