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Dinosaur Eggs and Babies in the UNESCO Global Geopark Network 'Haţeg Country' Dinosaur Geopark (Romania)

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Abstract

In 1898, when the first dinosaur eggs were discovered in Haţeg Country (which in 2005 became part of the UNESCO Global Geopark Network), not one dinosaur egg had ever been unearthed either in the vicinity or anywhere in Romania. Twenty years later, tens of sites bearing remnants of dinosaur eggs – of which at least eight are dinosaur incubation sites – had been mapped in Haţeg Country and across Southern Transylvania as a whole. The most famous is the site at Tuștea, situated in the north-western part of the Haţeg Basin, especially well known because of the so-called "Tuștea Puzzle" whereby spherical megaloolithid eggs, almost universally seen as those of titanosaurid sauropods, are associated with hadrosaurid neonates. Tuștea is the only site in Europe to feature the remains of dinosaur neonates alongside eggs and eggshells from the Upper Cretaceous. Research here and in other areas of the Haţeg Basin highlighted the climates and sedimentology of the areas where the eggs were laid roughly 68–70 million years ago, and revealed aspects of nest building and the behavior of dinosaur neonates after hatching. The site's scientific importance is strengthened by the great diversity of vertebrate fossil discoveries: frogs, lizards, snakes, saurischian and ornithischian dinosaurs, pterosaurs and mammals – 21 taxa in total, ranking Tuștea among the richest paleontological sites in Europe. After 24 years of continuous research primarily by professors and students from the University of Bucharest, the current owner of the land, making use of legislative inconsistencies governing the right to land ownership, forbade further investigation. During this time, the research site has degraded substantially and today requires urgent restorative and conservation measures lest it be lost forever.

Keywords: Dinosaur eggs, Megaloolithidae, Hatchlings, *Telmatosaurus*, Late Cretaceous, "Tuștea puzzle", Deadlocked research.

Article information

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Introduction

The Haţeg Country is a region of central Romania surrounded by mountains, which meant it was named as a 'country' in traditional Romanian geographical toponymy (Fig. 1). The region is well known for the charm of its vistas and for the particularly well-preserved vestiges of its lengthy history, ranging from the Roman colonization of Dacia in the 1st–4th centuries A.D. through Mediaeval times with numerous stone churches, up to the Habsburg-dominated period in the 18th and 19th centuries with the ruined mansions and castles of the nobility. Haţeg Country is one of the few regions that still preserves its folkloric uniqueness in our globalized age, evident in the traditional costumes worn for special holidays, in their songs and dance, and in their artisanal crafts.

For the past 125 years, Hațeg County has also become known for its dinosaurs. As was the case for other famous paleontological discoveries, history records a woman as having made the earliest finds: in this case, Ilona (the younger sister of Franz Nopcsa who would become a famous paleontologist) uncovered the first dinosaur remains in 1895 on the family estate, much as Mary Ann Mantell had discovered the first clue to the existence of dinosaurs in Sussex, England – classified as *Iguanodon* by her husband, Gideon Mantell; or like Mary Anning who discovered the world's first *Ichthyosaurus* in southern England at Lyme Regis in 1812, aged just 12.

Nearly 100 years later, the first dinosaur eggs were discovered in Hațeg County, in 1988. This was accidentally facilitated by the collapse of a rock wall in Oltoane Hill near the village of Tuștea in the summer of 1988. Geologists Marin Şeclăman and Nicolae Ghinescu investigated the collapse, and Marin phoned me immediately afterwards,

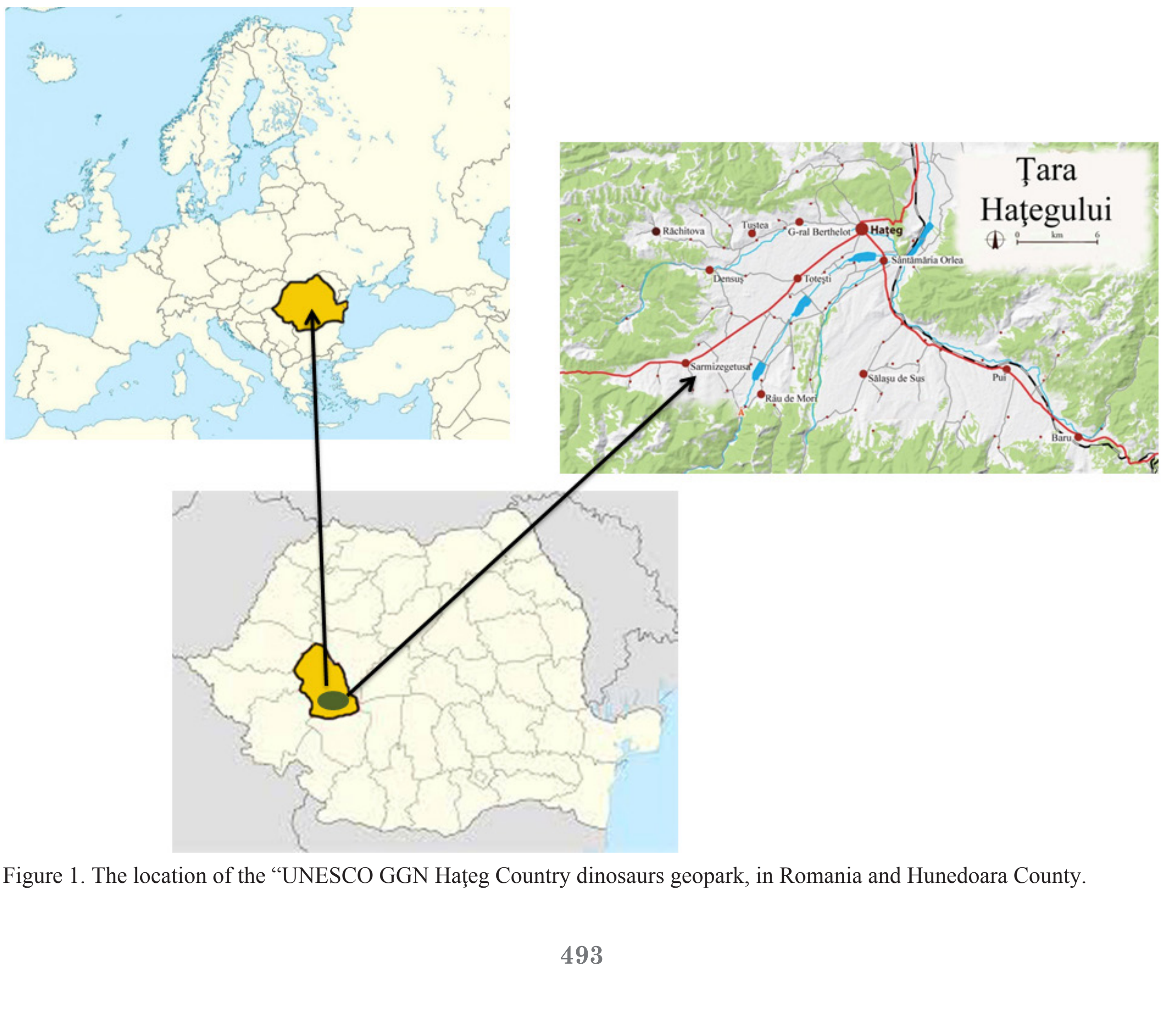

Figure 1. The location of the "UNESCO GGN Haţeg Country dinosaurs geopark, in Romania and Hunedoara County.

informing me of some "bizarre concretions" that had been uncovered, which I later identified as dinosaur eggs.

The vertical plane of the outcrop did not allow for initial research on the deposits, only for the collection of the exposed eggs, most of which had been fragmented. In order to expand our research, over the following years the outcrop was levelled by bulldozers, resulting in a horizontal platform on which paleontological research would be conducted for 24 years. The results of our research, in which an invaluable role was played by students from the Faculty of Geology and Geophysics at the University of Bucharest, were more than a match for our lengthy efforts: around 100 dinosaur eggs, with their position within the nest at the time of hatching nearly intact; numerous bones of newly-hatched dinosaur neonates – a discovery unique in Europe and very rare across the world – and the remains of over 20 vertebrate species. This assemblage represents one of the largest troves of vertebrate remains from the Transylvanian uppermost Cretaceous from a single locality, and very likely ranks among the richest in Europe (Csiki-Sava *et al.* 2015). The discoveries formed the basis for over 100 scientific works published in several countries, the site's notoriety further enhanced by the megaloolithid type of eggs, which had previously been attributed to the titanosaurid dinosaurs, but which in Tuștea are associated with the hatchling remains of hadrosaurids, thereby presenting a problem sometimes called the "Tuștea puzzle".

The Geological Setting of the Dinosaur Egg Deposits

The Haţeg Basin is a subsiding intramontane basin located in central-western Romania within the Southern Carpathians (Fig. 2). The Basin was shaped in the two phases of the Middle and Late Cretaceous Alpine orogenies (Săndulescu 1984; Bojar *et al*. 1998).

At the end of Cretaceous, the Hateg Basin (together with the Transylvanian Basin and the broader Western Carpathians) was part of a large island of about 80,000 km², one of an archipelago of islands that stretched over much of southern Europe at a latitude of roughly 27°N (Panaiotu & Panaiotu 2010).

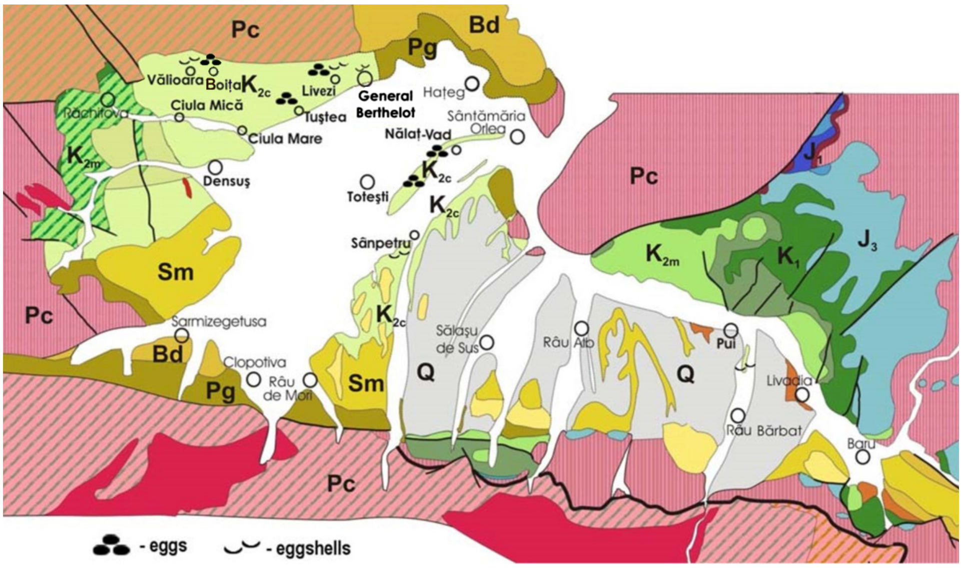

Figure 2. Geological map of the Hațeg Basin indicating the locations where dinosaur egg clutches and eggshells were found. Abbreviations: Bd – Badenian; J1 – Lower–Middle Jurassic; J3 – Upper Jurassic; K1 – Lower Cretaceous; K2m – marine Upper Cretaceous; K2c – continental Upper Cretaceous (the Densuș-Ciula and Sânpetru Formations); Pc – crystalline basement, mainly Precambrian; Pg – Paleogene; Q – Quaternary; Sm – Sarmatian.

The basal part of the newly formed basin is made up of molasse-type, primarily siliciclastic continental deposits that formed outcrops over large areas in the north-western part of the basin, and over smaller patches in its central and eastern parts. The deposits are dated to the Maastrichtian (71.6–66.5 Ma), based on palynological data (Antonescu *et al*. 1983; Van Itterbeeck *et al*. 2005) confirmed by radiometric dating (Bojar *et al*. 2011) and magnetostratigraphy (Panaiotu *et al*. 2011). These deposits are further divided into two formal lithostratigraphic units, considered to be largely synchronous: the Sânpetru Formation in the central part of the basin, and the Densuș-Ciula Formation, restricted to the northwest (Grigorescu 1992). The two formations are differentiated by the presence of volcanic source material, abundant in the lower and middle strata of the Densuș-Ciula Formation, yet rare and very fine-grained in the Sânpetru Formation.

The section around Oltoane Hill, near the village of Tuştea, is composed of a 6 m thick bed of greenish-gray, cross-bedded, matrix-supported conglomerates and coarse sandstone, underlain by a thick body of massive, red, silty, micaceous, bioturbated mudstone. On top of these conglomerates and sandstones lies a second level of reddish calcareous mudstone, covered in turn by more recent soils (Grigorescu *et al*. 1994; Grigorescu & Csiki 2002; Bojar *et al*. 2005). The conglomerate bed includes andesitic clasts, diverse metaclasts (quartzites, amphibolites) and red mudstone rip-up clasts from the underlying fossiliferous strata (Fig. 3). The main structures of the formation are planar and trough cross bedding, characteristic of channel deposits.

The dinosaur eggs were discovered in the lower part of the Tuştea section, which consists of alternating horizons of reddish silty mudstone with pedogenic features such as well-developed ver-

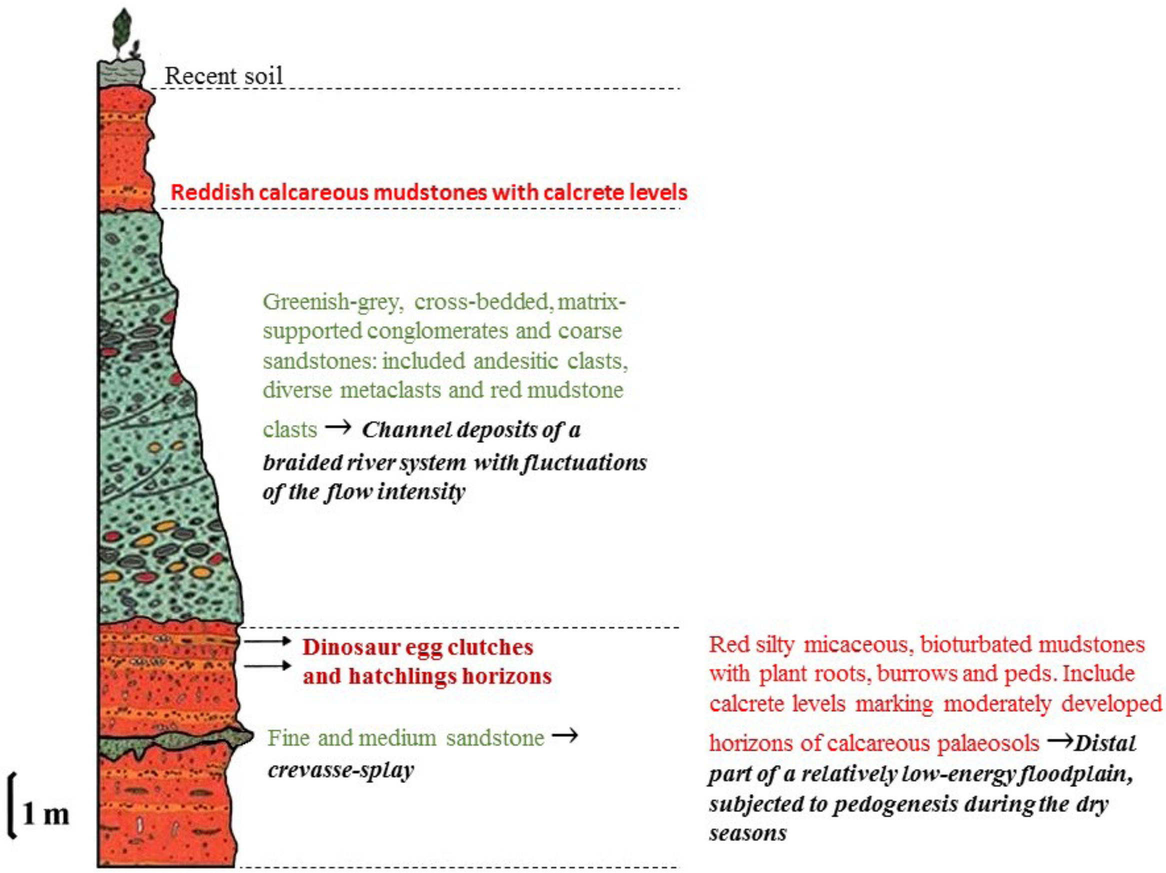

Figure 3. Lithostratigraphic column of the Oltoane hill (Tuștea) fossiliferous section indicating the depositional environments.

tical roots and burrows, blocky structures (peds) and slickensides. Successive levels of carbonate nodules (calcretes) are spread throughout the reddish mudstone sequence, marking distinct Bk horizons of moderately developed calcareous paleosols (Bojar *et al*. 2005; Therrien 2005). The red mudstone is divided by a layer of light greenish sandstone, ranging in thickness from 10 to 20 cm, interpreted as crevasse-spay deposits in a river depositional system. The fossiliferous level was found above the sandstone level, on an uneven surface about 1 m below the base of the conglomerate (Grigorescu *et al*. 1994); a second level, 0.4 m above the first, was revealed by subsequent excavations on the horizontal platform (Bojar *et al*. 2005; Botfalvay *et al*. 2017).

Two further localities with dinosaur eggs were discovered in the central part of the basin along the banks of the Râul Mare at Totesti (Codrea *et al*. 2002) and Nălaț (Smith *et al*. 2002). The lithology of the two sites is similar, but differs from Tuştea, in being dominated by mica-rich silty mudstone, with coarser-grained intercalations represented by yellowish pebbly sandstone and gray fine-grained sandstone. The silty mudstone is usually blackish or dark gray to dark reddish-brown in color; it contains levels of pedogenetic calcrete associated with wedge-shaped peds bounded by slickensides, interpreted as vertisols with variably developed carbonate (Bk) horizons (Van Itterbeeck *et al*. 2004). Both sections have a nearly vertical dip (75-80° N), unlike at Tuştea where the beds are almost horizontal (dipping 12° S). Egg clutches were recovered from at least six horizons at Toteşti (Codrea *et al*. 2002), and from more than seven horizons at Nălaț. Most of these occur in silty and clayey floodplain deposits of dominantly blackish color; more rarely, egg remains were recovered from light gray sandy crevasse splay deposits.

Dinosaur eggs were later discovered in the northern part of the basin, at Livezi (Grigorescu & Csiki, 2008) and Boița (Csiki *et al.* 2018); isolated dinosaur eggshells were also found in several microvertebrate sites around Vălioara and General Berthelot (Vasile 2008; Vasile *et al*. 2011). At Livezi, sites rich in eggshell fragments were recognized along several dry gulches created by torrents in this area of badlands. As at Tuştea, the fossiliferous levels are in calcrete-rich red mudstone interbedded with up to 2 m thick matrix-supported conglomerates and rare dark gray silty mudstone. However, contrary to the Tuştea section, at Livezi the conglomerates are devoid of volcaniclastic sediments. The egg remains are usually represented by eggshell fragments, often greatly eroded, and found concentrated on the slopes of the gulches; though, occasionally, partial eggs and eggshell fragments were apparently also recovered *in situ*. Poor field exposure makes it difficult to trace the eggshell-bearing horizons laterally, or to undertake more complete excavations.

The most recent finds of dinosaur eggs, not yet studied in detail, were in gulches and hill escarpments at Boița on the Hateg Basin's northernmost boundary (Csiki *et al*. 2018). The lithology here closely resembles the Tuştea outcrop: reddish silty mudstone affected by pedogenesis, with channel conglomerates and gray-yellowish siltstone representing crevasse splay deposits.

Material and Methods

Our research was divided into field work and laboratory analysis. The former encompasses all activities relating to the eggs' discovery and topographic registration, their removal from the surrounding rock faces and their careful packaging in plaster jackets, followed by their transport to the laboratory. The duration of our field research varied very much between the various sites mentioned above, depending on the topography of the terrain and the tectonic character of the fossiliferous deposits, which also affected our capacity to undertake in-depth analysis in the field.

At Tuștea, field research continued for 24 years. In the initial stages (1988–1996), inquiries focused on the vertical outcrops on Oltoane Hill. The latter stages were carried out after the outcrop was levelled and a horizontal platform created, from 1997–2012. Throughout, research efforts were headed by Professor Dan Grigorescu, who was later joined by some of his younger colleagues at the University of Bucharest, Zoltan Csiki and Ștefan Vasile. Each year, over the course of 10–14 days, we were joined by teams of students from the University of Bucharest (8–12 students each year), followed a few years later by students from the University of Petroșani, led by Professors Grigore Buia and Dumitru Popescu. Numerous dissertations drawing on the studies conducted at this site were penned during this period by the students who took part in the fieldwork.

For the other sites, field research was undertaken in shorter stints, over the course of only a few days: 2000–2005 for the two sites on the Râul Mare basin (Totești and Nălaț) – an effort spearheaded by researchers from the 'Babeș-Bolyai' University of Cluj-Napoca and the Natural History Museum in Brussels, Belgium – and 2005–2011 for the Livezi site and 2015–2018 the Boiţa site respectively, the latter two for periods of up to one week with students from the University of Bucharest. The shorter durations of these fieldwork initiatives, especially compared to the Tuștea site, were because of topographic and tectonic constraints. The Râul Mare valley sites lie on the often-flooded banks of the river, rendering the retrieval of egg samples difficult, while the near-vertical exposure further severely restricts field research. At the Livezi and Boița sites, short field seasons were because the egg-bearing deposits lie across steep gulches and hill escarpments which, in order to be adequately surveyed, require further extensive levelling similar to that carried out at the Tuștea site.

At Tuștea, the levelled plateau, roughly 180 m^2 in area, was produced initially by an electrically driven jackhammer, alongside pickaxes and shovels. Once the first occurrences of eggs within a cluster were identified, the students proceeded – in some cases for as long as two or three consecutive summers – to study that cluster, using chisels and brushes, to dislodge the fossils from the surrounding deposits. Once the extent of an egg cluster was demarcated and the rock residue removed from the surface, the cluster was wrapped in plaster jackets internally reinforced with gauze strips, then removed across wooden traverses towards the all-terrain vehicle to take them to our base and, from there to Bucharest. Some of the sediments excavated from within and around the egg clusters were screen washed and sifted to recover microvertebrates, including neonate dinosaur bones, and then studied under a Zeiss STEMI 200-C binocular microscope.

Once in the lab, the eggs were further prepared for study by cleaning, consolidating fractures, and repairing the shells. Most egg clusters were stored in their plaster jackets and entrusted to several museums to be presented to the public; in a handful of cases, the eggs were detached from their protective sleeves so that individual eggs could be measured and studied in detail.

Eggshell thickness was measured on samples of 100 or more by a Vernier caliper and the data summarized. Tangential and radial thin sections of the eggshells were cut for histological study under polarizing light microscopy (PLM; AMPLIVAL and Olympus Bx41 transmitted light stereomicroscopes) and scanning electron microscopy (SEM; Geol 5600 LV). Several thin sections were also examined under cathodoluminescence (CL) to detect diagenetic changes. Pore geometry and pore distribution in the eggshells were studied in serial tangential thin sections. Eleven better preserved eggs were scanned to discover whether there were any embryos within the eggshells, using a Siemens Somatom HIQ CTS (computerized axial tomography, CAT).

Eggs and Eggshells

So far, 185 eggs and large egg fragments have been discovered in the five localities, of which 112 (60%) come from Tuştea. Despite the number of sites that provided dinosaur eggs, the lithological differences between the encasing deposits, and the large number of dinosaur taxa recorded in the Haţeg basin (about 18), almost all the eggs show the same characters, a fact that indicates they belong to the same dinosaur type.

It should be mentioned that two different egg morphotypes were noted at the Râul Mare sites, Totești and Nălaţ, by Grellet-Tinner *et al*. (2012), ten years before Smith *et al*. (2002) mentioned concentrations of eggshells ("eggshell coquinas") at Totești, of the ornithoid basic type, but in both cases, the taxonomic assignment was not presented.

The common eggs in the five localities have a sub-spherical shape, 14–16 cm in diameter with a 10–15% difference between the longest and shortest diameters (Fig. 4A). The extreme limits of eggshell thickness are 1.5–3.3 mm, with the average around 2.3–2.4 mm at Tuştea (Fig. 4B), Totești and Nălaţ, and slightly thicker at Livezi (2.9–3.0 mm. average) (Fig. 4C), and thinner (around 2.0 mm) at Boiţa. The differences in eggshell thickness are not relevant from a systematic point of view; these might be related to primary causes such as the dinosaurs' calcium secretion physiology or to the varying shell thickness across different parts of the egg, or to secondary causes such as diagene-

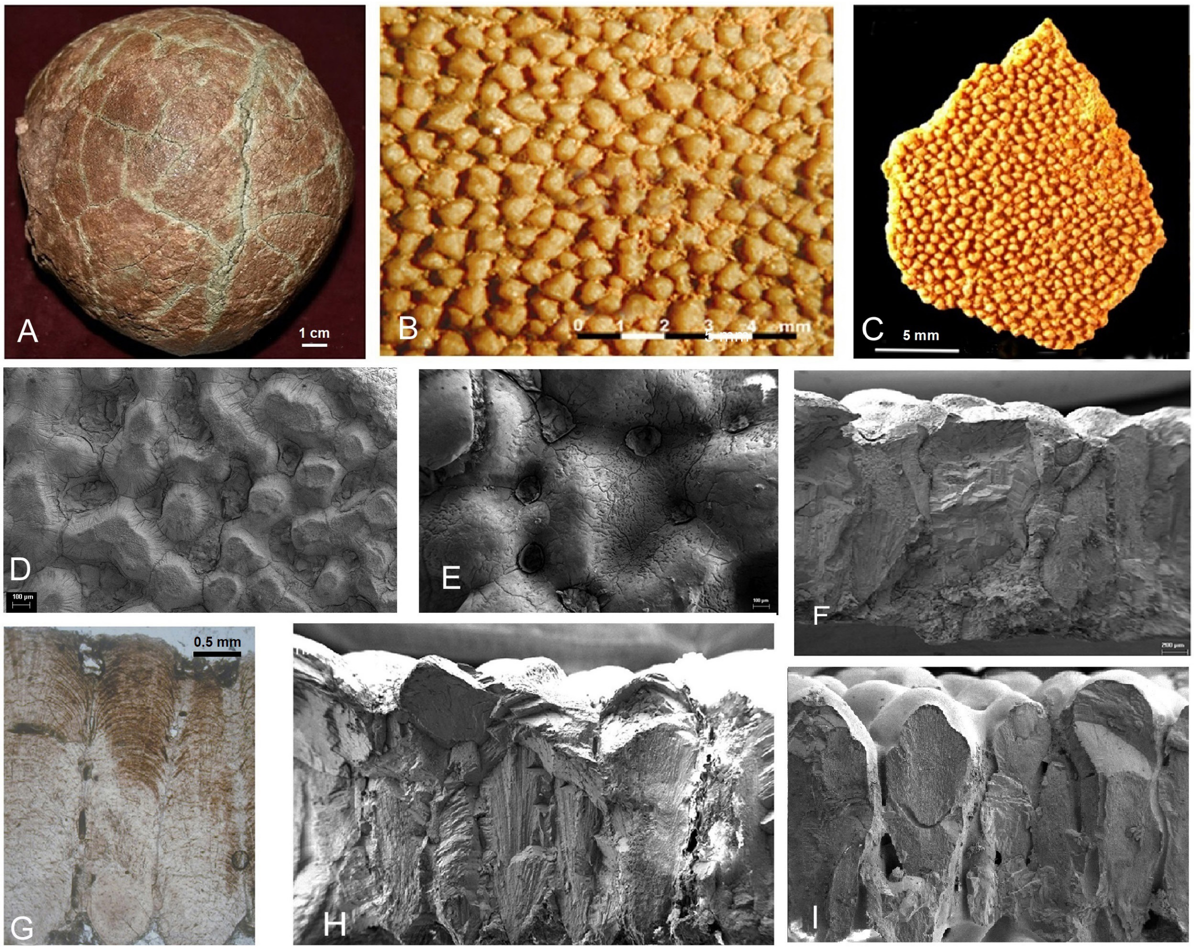

Figure 4. Characteristics of the *Megaoolithus siruguei* dinosaur eggs from the Haţeg Basin. A) Dinosaur egg from Tuştea. B, C) Upper surface of the eggshells showing the closely packed rounded nodes in Tuştea (B) and Livezi (C) eggshells. D) SEM image at the base of the eggshell, presenting the conical base of the shell units. E) SEM image at the upper surface of the eggshell, showing the pore openings. F) SEM radial ultrastructure presenting twisted and Y-shaped pores filed with carbonate material. G) Radial thin eggshell section in non-polarized light microscopy. H) SEM radial ultrastructure showing the spherulitic shell units. I) Recrystallization of the shell units during diagenesis. (D- H: Tuştea eggshells, I - eggshell from Livezi).

sis. The outer surface of the eggshell is covered by closely-packed rounded nodes with diameters varying from 0.3–1.1 mm and an average of 0.6 mm; the nodes rise 0.4–0.7 mm above the eggshell's surface. Some nodes coalesce into well separated chains, randomly located across the different egg regions. The inner surfaces of the eggshells show a complicated hieroglyph pattern created by the randomly coalesced bases of the crystalline units (Grigorescu *et al*. 2010) (Fig. 4D).

The microstructural data that follows is mostly based on the Tuștea egg samples which were studied in greater detail; comparisons with eggs and eggshells from the other locations show close similarities that confirm the eggs all belong to the same structural morphotype. The microstructure of the eggshells matches the dinosauroid-discretispherulitic morphotype of Mikhailov *et al*. (1996). In radial section, the shell comprises elongated fan-shaped units of variable width, on average 2.45 times taller than wide, separated by well-defined, non-parallel margins. Shell growth lines are strongly arched upwards and steeply curved close to the unit margins, crossing continuously between adjacent bundles (Fig. 4G, H). Unlike the Tuştea eggshells, which have not been altered by diagenesis, the Livezi eggshells are completely recrystallized and this obliterates the primary features (Fig. 4I).

The pore pattern is irregular, consisting of a complicated network of sinuous and branching tubes with connections among them and variable diameters along the pore length, ranging from 0.13–0.38 mm. The pore openings are situated in interstitial spaces around the nodes (Fig. 4E). In radial section, the pore canals have variable shapes: straight, twisted, bottle-necked, Y-shaped, or networked by sinuous branches (Fig. 4F). In transverse section, the pore openings are subcircular, ranging from 30–85 μm in diameter and varying along the pore length from 0.13–0.38 mm. Because of their complex pathways, the lengths of some pore canals are considerably greater than the thickness of the shell, estimated at a maximum of 4.6 mm, that is, twice the mean shell thickness (2.30 mm).

Serial thin sections spaced by 0.2 mm increments through the eggshell thickness of the Tuştea eggs reveals details of pore geometry and distribution (Baltres in Grigorescu *et al*. 1994). The pore density of the Tuştea eggshells is about 100 pores/cm^2, less than half that of eggshells associated with *Megaloolithus siruguei* from Southern France, which show 250 pores/cm^2 (Garcia & Vianey-Liaud 2001).

Calculated values for shell water vapor conductance, based on an average pore length of 3.45 mm (using the minimal and maximal figures, shown above), yielded values of 2.782 mg/day/mmHg for minimal pore length, and 1.391 mg/day/mmHg for the maximal pore length, with an estimated average value of about 2080 mg H_2O day^{-1}Torr^{-1} (Grigorescu *et al*. 1994; Grigorescu 2017). These values are significantly higher than those reported for the Argentinian *Megaloolithus patagonicus* (341 mg H_2O day^{-1}Torr^{-1}), yet only about half of those calculated for the *M. siruguei* eggshells from Pinyes, Spain: 3979 mg H_2O day^{-1}Torr^{-1} (Jackson *et al*. 2008).

The morphological, microstructural and ultrastructural characters of the Haţeg dinosaur eggs correspond to the parataxonomic Megaloolithidae oofamily, well represented by Upper Cretaceous eggs in France, Spain, India, Argentina and other countries, with more than 20 megaloolithid oospecies described in the literature. Among these, *Megaloolithus siruguei* from Begude in Southern France is the closest to the Hateg oospecies, presenting an identical external eggshell ornamentation, a similar "reticulate" pattern of pore canals and comparable eggshell thickness (Vianey-Liaud *et al*. 1994). Quantitative differences (Grigorescu *et al*. 2010; Grigorescu 2016) are the smaller size of the Haţeg eggs (an average 16 cm in diameter versus roughly 20 cm in southern France), the shape and diameter of pore canals, and the different height-length ratio of the crystalline units were also shown across other localities in France and Spain where *M. siruguei* was discovered; these represent character variation within a particular species. The differences in pore density – about 100 pores/cm² for *M. siruguei* from Haţeg compared to about 250 pores/cm² for the French specimens (Garcia & Vianey-Liaud 2001) may indicate different incubation conditions or differences in the females' reproductive physiology.

Taphonomic and Paleoenvironmental Conditions of the incubation.

Although around 185 dinosaur eggs have been discovered from the five localities in the Haţeg Basin, a detailed study of taphonomic conditions was possible only at Tuştea on the cleared surface. At all other sites, as noted above, the steep slopes in the gulches or the almost vertical dip of the fossiliferous strata limited observations.

Figure 5. Egg clutches in plaster jackets preserving the original position of the eggs in the nests A, B) clutches from Tuştea, C) clutches from Totești. D) clutch from Livezi, E) clutch from Boița.(From Csiki et al. 2018)

More than 100 megaloolithid eggs, in various stages of fragmentation, were collected from Tuştea between 1988 and 2009. Most of these were found in the lower nesting level, named because a second level was recognized above it (Botfalvay *et al*. 2017). Most eggs are preserved as complete lower halves, and near-complete eggs are much less common. The eggs had been affected variously by diagenetic processes that include compaction (producing flattening and cracks), pedogenetic processes (leading to carbonate coatings on the eggs and calcareous nodules in the infilling matrix) and tectonic movements (producing slickensides in the encasing mudstone and sometimes within the eggs). The eggs were found in clusters of two to 14 eggs, randomly distributed on the surface (Fig. 5). Within the clusters, the eggs display two arrangements, either tightly grouped in linear rows, or randomly dispersed, sometimes 30–40 cm apart. The spaces between neighboring eggs might indicate places where the mothers replaced eggs during incubation or where erosion occurred during or after incubation. The disposition of eggs within the clusters looks similar to the original nest setting, with some displacement of eggs, pre-burial erosion, weathering and by post-burial geological processes. The fact that eggshell fragments are found around the eggs but not more generally between the clusters suggests that the nests and eggs were not disturbed much after deposition (Cousin 2002; Chiappe *et al*. 2004).

As with the megaloolithid nesting sites in southern France and northern Spain (Cousin 2002; Vila *et al*. 2010a), visible traces of nest construction are missing; this has generally been interpreted as evidence of floods over the area of incubation that obliterated digging marks. Nevertheless, some conclusions about nest construction are possible from the relative positions of the eggs within the clutches; they often lie at slightly different levels, and sometimes slightly overlap. In clutches with randomly distributed eggs, the outer ones are usually at a slightly higher elevation than the central ones, suggesting that the mothers made use of the unevenness of the surface, laying the eggs into small depressions, either elongated or bowl-shaped, likely with some adjustments made by digging (Vila *et al*. 2010b). In clutches with a moderate number of eggs (at most 6–7), the vertical dip of the substratum does not exceed an egg half diameter.

Eggshell ornamentation and porosity, as well as isotopic analysis and computed tomography (CT) data show that the eggs were superficially buried by excavated sediments and plant material (Grigorescu 2016). This would have protected the nests and eggs from removal by floods or damage by severe weather. With a few exceptions (Cousin *et al*. 1989; López-Martinez *et al*. 2000), the megaloolithid sites in France and Spain present similar conditions: eggs are either linearly or randomly arranged in clutches, they are more or less tightly grouped, buried and covered by the surrounding sediments and vegetation, and they lack nest-building traces.

Most of the Tuştea eggs appear to have hatched; these eggs are complete below, and above show a large 'hatching window' (Cousin *et al*. 1994). Further strong evidence of hatching is that most of the eggshell fragments are inside the eggs and not spread in the surrounding sediments (Mueller-Towe *et al.* 2002). After hatching, CT scans suggest that the complete lower parts of the eggs collapsed under the weight of sediment and broke into large fragments; the concave-up orientation of the these eggshell fragments might be because the hatchlings pushed the upper half of the egg upwards during hatching, immediately after which the fragments fell back, overturned, inside the egg (Cousin, 2002). This scenario is supported at Tuştea by the rarity of eggshells around the hatched eggs. Less-damaged eggs were also uncovered, albeit much less frequently: these were crushed on top, but complete and interpreted as unhatched rather than fertilized eggs (Grigorescu 2016). A third category of eggs at Tuştea is unhatched fertilized eggs that were damaged during incubation, either by erosion, by egg-eaters or by the mother herself, as shown by CT scans (Fig. 6).

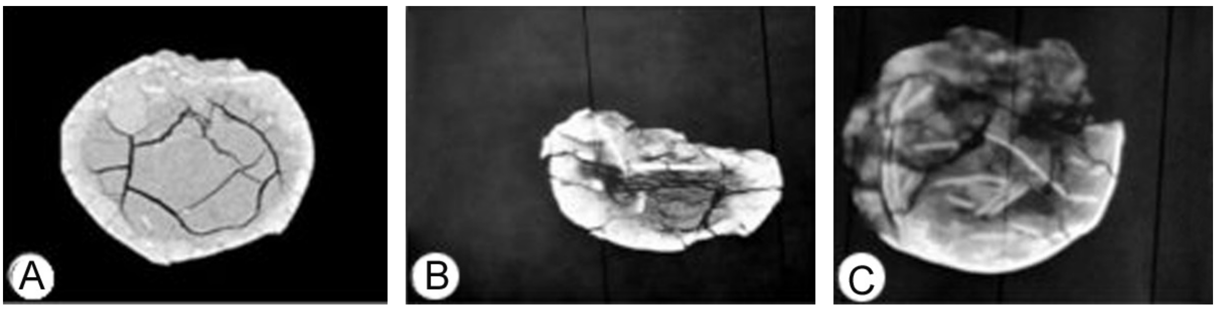

Figure 6. Computed tomographic scans of *Megaloolithis siruguei* eggs from Tuștea, interpreted as: A) unhatched, infertile egg; the two large fragments of the egg cup convergently pushed down suggest the shell's implosion following the putrefaction of the organic matter within the egg. B) Presumed fertilized egg, unhatched due to erosion during incubation. C) Unhatched egg due to a sudden strong pressure during incubation, suggested by the large concave shell fragments downward. (From Grigorescu, 2016).

More than 40 eggs, including almost complete specimens, were collected at Toteşti (Codrea *et al*. 2002). They were grouped in small clutches, usually containing five to eight and exceptionally 14 mainly compressed and probably hatched eggs. As at Tuştea, the clutches appear to represent original nests, slightly altered either during incubation or by diagenetic processes (Fig. 5C). Contrary to the Tuştea specimens, at Nălaț several clutches include eggs with both their lower and upper halves preserved, although crushed and flattened. Dispersed eggshell fragments occur around the nests, but generally few and isolated; in some instances, however, eggshell fragments were found in larger numbers (about 100) closely associated with the nest, suggesting these might be the remains of destroyed eggs (Smith *et al*. 2002).

The Livezi site produced the fewest large egg fragments, but many concentrations of eggshells (Grigorescu & Csiki 2008). The large egg fragments were strongly crushed, and the eggshell concentrations probably comprised large, crushed and dismantled egg fragments. In addition, megaloolithid eggshells were frequently encountered as loose elements on the slopes of gulches, having been reworked from the original eggshell-bearing layers.

Two nesting levels with identical megaloolithid eggs were recognized at the Tuştea site, at least three at Livezi, and at least five at Totești and Nălaț (Grigorescu *et al*. 2010). These suggest that members of the same egg-laying taxon returned to the same nesting area on several occasions, a pattern of multi-year repeated usage of the same nesting area termed "nest site fidelity" .

The Late Cretaceous paleoenvironment in the Hațeg basin, as well as across Transylvania, experienced a subtropical climate, with a mean annual temperature of ~14°C (Bojar *et al*. 2010) and with alternating wet and dry seasons, according to our sedimentological, geochemical and paleopedological investigations. Under these conditions, the incubation of the Tuştea eggs most probably took place on calcic soils, developed during a dry period and located on the distal part of a relatively low-energy floodplain, sparsely vegetated with low-growing plants (Bojar *et al*. 2005, 2010b; Therrien 2005), following fine sediment deposition in a previous humid season. The sediments were subjected to pedogenesis, which continued after the burial of the egg remains, as shown by the calcic nodules sometimes attached to the hatched eggs. The pedogenic processes took place under oxidizing, alkaline conditions, as indicated by the red color and micritic carbonate texture seen in the Tuştea paleosol sequences (Khadkikar *et al*. 2000; Bojar *et al*. 2005; Retallack 2008).

Identical floodplain conditions are also interpreted for the Livezi and Boiţa localities where the dinosaur eggs occur in the same type of red mudstone rich in calcrete-nodules lithofacies; however, additional sedimentological and geochemical data are needed for these sites.
The incubation environment at the Toteşti and Nălaţ sites was rather different from that at Tuştea and likely at Livezi and Boiţa, based on lithofacial similarities. The widespread occurrence of dark gray, fine-grained sediments with calcrete, interpreted as hydromorphic paleosols (vertisols), reflects the presence of a seasonally fluctuating but generally high groundwater table (Van Itterbeeck *et al*. 2004). Paleosol features suggest that nesting at these sites took place under more humid paleoenvironmental conditions than at Tuştea, within a poorly drained floodplain.

Successful incubation in hot climates can occur only if evaporative water loss from the embryo is limited through the eggshell pores. The Tuştea *Megaloolithus siruguei* eggshells are highly porous, so two possible strategies can be considered, either incubation in a high humidity environment, possibly waterlogged, or incubation in covered conditions, under sediments and, probably, vegetation. The eggshell ornamentation and porosity, combined with sedimentological and taphonomic data, supports the second proposition, that the eggs were superficially buried in substrate and covered by excavated sediments and plant material (Bojar *et al*. 2005; Therrien 2005; Bojar *et al*. 2010). As noted, this mode of incubation would also have reduced the risk that the eggs would be removed by floods or damaged by weathering.

The unexpected babies and the "Tuștea puzzle"
In summer 1990, around the time when *Nature* published a brief article announcing the discovery of the dinosaur eggs (Grigorescu *et al*. 1990), we found three fragments of small bones close to the egg site. We identified them as the proximal part of a femur and the fragments of a tibia that had been broken in two (Fig. 7A, B). The small dimensions of the bone remains – a mere few centimeters – led me to believe that they came from dinosaur embryos. This was a great stroke of fortune, coming on the heels of our luck two years prior when the collapsing rock face of Oltoane Hill uncovered the troves of dinosaur eggs.

Surprisingly, however, it turned out that these tiny bones did not belong to the dinosaurs we had assumed had laid the eggs, as noted by David Weishampel of John Hopkins University of Baltimore, with whom I was in the field at the time of our discovery, collaborating on a project funded by the National Science Foundation. The megaloothid eggs indicated that they had been laid by titanosaurid dinosaurs such as *Magyarosaurus dacus*, already known as a key element of the Hațeg assemblage. This identification of the egg-producer was underpinned by long accepted discoveries in southern France, where megaloothid eggs had been discovered in 1869 associated with tiny bones that were later identified as sauropod (Buffetaut & Le Loeuf 1994). This association between megaloolithid eggs and titanosaurid sauropod dinosaurs was later confirmed across many Late Cretaceous sites in southern France, northern Spain, India and Argentina. Yet, despite these discoveries comprising many thousands of eggs from many locations, nobody had confirmed the link by, for example, the discovery of megaloolithid eggs with sauropod embryos in the egg or even in the nest. Nonetheless, it is no surprise that we argued in our 1990 article that the eggs at Tuștea could well belong to the only sauropod in the Hațeg Basin, *Magyarosaurus*.

Eight years later, *Nature* published the first definitive proof that the megaloolithid eggs from Auca Mahuevo in Argentina contained embryos of a sauropod dinosaur (Chiappe *et al.* 1998). This discovery did not however exclude the possibility that dinosaurs other than sauropods could have laid some megaloolithid eggs, especially given that such eggs are diverse in shape, with over 20 oospecies recognized worldwide, including eight in the Late Cretaceous of southern France (Vianey-Liaud 1994), in contrast to the much smaller number of sauropod species (Csiki *et al.* 2015). Further, given that the diversity of ornithopod dinosaurs, rhabdodontids and hadrosaurids, is much greater in these latest Cretaceous sites than sauropods, they are also considered as potential megaloolithid egg-layers (Cousin 2002). A similar situation is found in northern Spain, where ornithopod dinosaurs are thought to have laid certain types of megaloolithid egg (cf. Bravo & Gaete 2015).

To test the possibility that the Tuștea eggs might contain dinosaur embryos, a dozen of more-or-less complete eggs were scanned by computerized axial tomography, using a Siemens Somatom HIQ CTS at the MedLife Health Centre in Bucharest. A further four eggs were analyzed using the µCT X-ray synchrotron at the European Synchrotron Radiation Facility in Grenoble, France. Unfortunately, none of the scanned eggs showed clear embryonic remains.

Despite the rarity of these early finds, several dozen bones of dinosaur hatchlings, including four partial skeletons with articulated bones, were found in subsequent years (Fig. 7D–F). All the remains were found in the two nesting horizons, situated either very close to the egg clutches, or

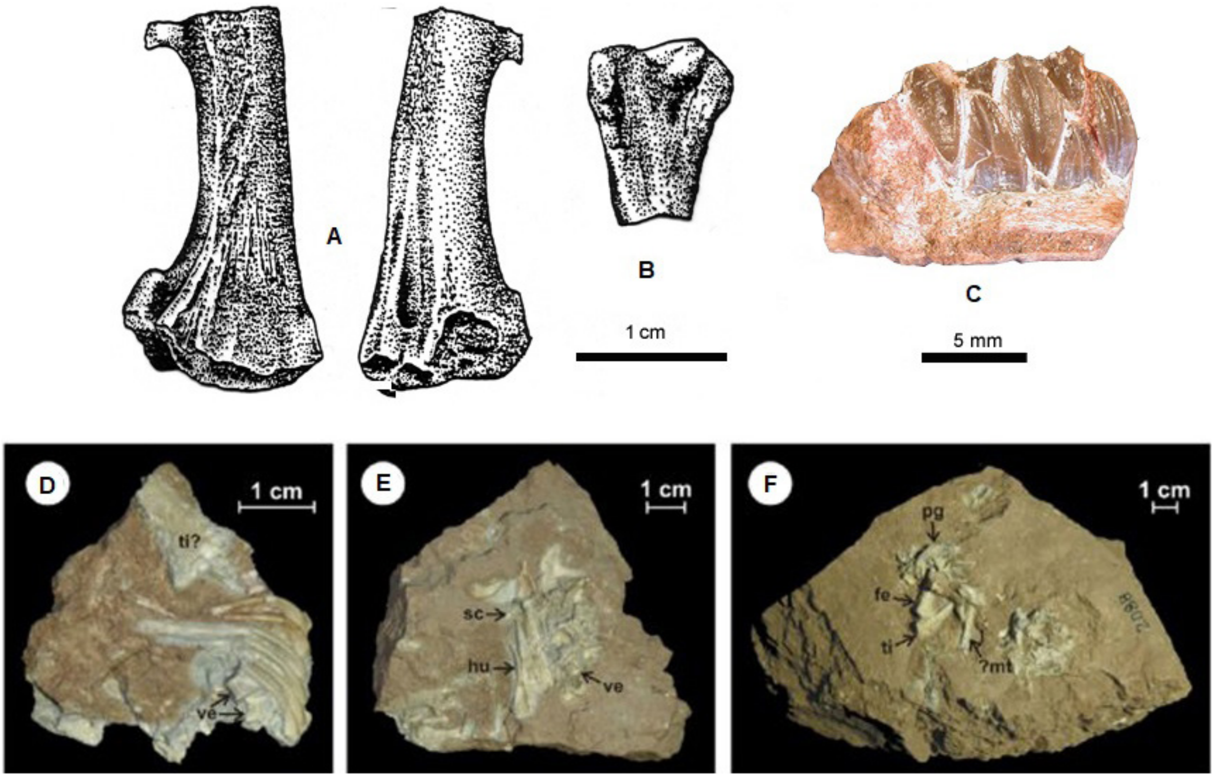

Figure 7. Hatchlings of the hadrosauroid *Telmatosaurus transsylvanicus.* Nopcsa. A, B) First discovered remains: A) right distal femur in lateral and cranial views (FGGUB R.248). B) left proximal tibia in lateral view (FGGUB R.249). C) left dentary fragment with teeth rows in medial view (FGGUB R.1850). D–F) Articulated hatchling remains: D) fragments of a ribcage and tibia (FGGUB. R.1852). E) scapula, humerus and dorsal vertebrae (FGGUB. R.2087). F) incomplete pelvic girdle, femur, tibia, fibula, metatarsal and indeterminate remains (FGGUB R.2088). fe –femur; hu – humerus; mt – metatarsals; pg - pelvic girdle; sc – scapula; ti – tibia; ve - vertebrae.

even inside them at times. Numerous microscopic, isolated remains have also been recovered by screen-washing the egg-encasing mudstone. The larger remains were collected as small bone clusters and, very rarely, as isolated bones. The most frequent bones are vertebral centra and limb bones, especially the more robust hindlimb elements (femora, tibiae). Teeth and skull elements have rarely been collected, among them one dentary fragment (14.4 mm long) that preserves remains of a dental battery specific to hadrosaurids (Fig. 7C). Different stages of ontogenetic development were recognized, based on differences in bone texture and osteological development. Bones with a fibrous, porous outer surface, lacking a dense outer cortical cover or articular ends, were interpreted as near-term embryos or early hatchlings, differentiated from the more advanced hatchlings whose limb bones are covered by a cortical layer and show a well-developed articular morphology (Grigorescu 1993, 2010, Grigorescu & Csiki 2006). All this osteological material can be assigned to the primitive hadrosaurid *Telmatosaurus transsylvanicus*, with the first bones from Tuștea (see Fig. 10) being used to illustrate the fundamental position of this taxon in the evolution of later hadrosaurids (Weishampel *et al.* 2003).

It should be also mentioned that, in the entire mudstone sequence below the conglomerate bed at Tuştea, the only hatchling remains are those of *Telmatosaurus*. Titanosaurid sauropods, the widely assumed originators of megaloolithid eggs, are not present in the nesting horizon except one individual reported approximately 20 cm above the upper nesting horizon (Grigorescu 2016; Botfalvay *et al*. 2017).

The discovery of hatchlings was the object of numerous presentations (Grigorescu 1993, Grigorescu *et al.* 1994) as our research progressed over the first three 'Dinosaur Eggs and Babies' international symposia held in Spain (Isona 1999), France (Montpellier 2003) and Argentina (Plaza Huincul 2006) respectively. The phrase I coined as the title of my presentation in Montpellier, "The Tuştea Puzzle," highlights the unexpected association of megaloolithid eggs and hadrosaurids, and this became the headline of our discoveries. A series of authors explored this hypothesis, supporting its possibility (e.g., Chiappe *et al.* 2005, Bravo & Gaete 2015), but it required further research.

In the following discussions, we consider the idea of convergence (homoplasy), whereby unrelated organisms acquire similar structures because of shared functions. Convergences in the structure and physiology of the female reproductive apparatus between sauropods and hadrosaurs might explain homoplasy between Megaloolithidae and Spheroolithidae eggs. It should be mentioned that, despite the great diversity of hadrosaurs and the rarity of sauropods in the Late Cretaceous in Europe, they are not associated with specific egg microstructures. The sphaeroolithid type of eggs, linked to the North American hadrosaurs, was only recently recognized in Europe as *Spherooolithus europaeus* (Sellés *et al*. 2014), and this ootaxon is closely similar to *Megaloolithus siruguei* from Tuştea.

A cladistic analysis by Garcia *et al*. (2006) of 19 oospecies laid by turtles, crocodiles, birds, and sauropod, hadrosaur and theropod dinosaurs revealed that Megaloolithidae, once assigned exclusively to sauropods, appears to cluster as the sister group of Spheroolithidae, considered as characteristic of hadrosaurs. The more recent cladistic analysis of Bravo & Gaete (2015), based on megaloolithid oospecies from northern Spain, southern France and Argentina, supports the paraphyly of the oogenus *Megaloolithus*.

An in-depth taphonomic study of the Tuștea sites (Botfalvay *et al*., 2017) identified three possible scenarios that might explain the association between the megaloolithid eggs and *Telmatosaurus* hatchlings:

Scenario 1: The *Telmatosaurus* hatchlings were transported post-mortem into a titanosaur nesting site by rivers, so the association of megaloothid eggs and hadrosaur bones is a taphonomic accident (Weishampel and Jianu 2011)

Scenario 2: Both the titanosaurian sauropods and the hadrosaur *Telmatosaurus* laid their eggs close to each other and at about the same time; the *Telmatosaurus* hatchlings occasionally visited the titanosaur nesting ground, where they were buried alongside the titanosaurid eggs during flooding events.

Scenario 3: The co-occurrence of *Telmatosaurus* hatchlings and *Megaloolithus* eggs represent a genuine hadrosaur nesting ground with megaloolithid eggs, where the perinatal hadrosauroid individuals remained close to their nests after hatching and were buried in situ together with the remnants of their nests.

The third scenario is supported by the following considerations: (1) the hatchling remains appear closely associated with the egg clusters, sometimes even occurring inside the nests; (2) the hatchling remains were discovered exclusively in the egg-bearing horizons, and are absent from other parts of the section; (3) the freshness of the bones suggests they could not have been transported far. Further, this scenario would suggest some altriciality of *Telmatosaurus* hatchlings, as already suggested for other hadrosaurids (e.g., Horner and Weishampel 1988; Horner *et al*. 2001).

The Tuştea nesting site is not only important for its dinosaur eggs and hatchlings, but also for its rich vertebrate assemblage. Until now, 21 taxa have been recognized (Botfalvay 2017), including dinosaurs (dominated by rhabdodontid and hadrosauroid ornithopods), turtles, pterosaurs, and numerous microvertebrates discovered through screen-washing – frogs, albanerpetontids, lizards (including geckoid eggshells), snakes (including the new madtsoiid species *Nidophis insularis*, found within a megaloolithid egg clutch), crocodyliforms, theropods and mammals.

Geoconservation and Conflict

After over 20 years of paleontological and geological research in the Hațeg Basin, renewing the important work of Franz Nopcsa 100 years earlier, we realized how important it was that the international standing of the locations should benefit the inhabitants of Hațeg County. I had a moral duty to some of them, particularly to Doenel Vulc of Sânpetru Village, who had guided me during the period of my initial research. The solution, as well as evidence that heritage values of a region can positively affect the lives of its inhabitants, came with the launch of the concept of the Geopark by UNESCO in 1998 (Grigorescu 2020). The first step was to present the mayors of the region's villages – alongside the moral leaders of the various communities, local teachers, professors, priests and doctors – with my ideas for a future project to establish a geopark in the Hațeg Country, predicated both on the region's well-known historical, cultural and folkloric traditions and on the dinosaur fossils found there, and associated local legends and myths. Through these representatives, I hoped my ideas would permeate to everyone in the region. In addition, alongside the renowned biologist Dan Manoleli and his team of students and researchers from the University of Bucharest, and my former student-now-faculty colleague, Alexandru Andrășanu, I initiated an interdisciplinary research project into the geology and biology of the Hațeg Country, to develop the necessary scientific documentation required by UNESCO to accredit the region as a new geopark. The project was joined by professors and researchers from the University of Petroșani (which neighbors the Hațeg region), the Agricultural University of Timișoara and the University of Architecture in Bucharest, who conducted extensive research and offered courses for the general population on topics of interest for regional development, such as modern agricultural and zootechnic practices, IT use and processing, tourism guidance and social assistance.

In the period after 2002, students from the above-mentioned universities returned to the region to undertake further research for their undergraduate and Masters' theses by tackling topics relevant to the region, and to order to foster an open relationship of frank communication between academics and the local communities. This resulted in concrete outcomes such as exhibitions and a series of jointly organized cultural and scientific events. Pupils from the local elementary, secondary and high schools were primary target groups for our educational endeavors, with a series of activities to enhance their scientific and cultural knowledge of the region, organized in conjunction with their school teachers and headmasters, even offering some fundamental training in dinosaur research and paleontology – an initiative greatly appreciated by the pupils.

This friendly environment led to the creation of the "Hațeg Country Intercommunal Association" in 2005, comprising the mayors and notables of the regions' 13 communes, representatives of the University of Bucharest which had spearheaded the project, and of the University of Petroșani. The Hunedoara County Council, as the representative authority for the region, in partnership with the University of Bucharest, forwarded the National Ministry of the Environment the necessary documentation for the creation of the "Hațeg Country Dinosaur Geopark", as a national protected area of significant natural and cultural heritage, the first in Romania to attain the status of 'geopark', with the aim of furthering the social and economic development of the region. Shortly after obtaining national recognition in November 2004, the documentation was also validated by UNESCO, with the "Hațeg Country" becoming the 18th geopark in Europe and the first in Eastern Europe.

Subsequent years were dedicated to the implementation of the Geopark concept, since the “Hațeg Country” could not benefit from any established national parks or other models within Romania. This created unique challenges when compared to other countries that already have such established entities and concepts. In the spirit of the underlying concept of the ‘geopark’, a series of touristic trails were either created or improved upon, incorporating notable sites of both natural and cultural heritage into individual routes. Moreover, several information offices were established, and a series of small exhibitions of the region’s folkloric and artisanal traditions to encourage the manufacture of local woven goods, were organized in the region’s villages.

Figure 8. The Research Centre of the Romanian Academy within the Hațeg Country Geopark has a great potential for supporting sustainable regional development based on natural and cultural heritage.

Scientific research, constituting the basis for the geopark’s creation, was also encouraged. Alongside paleontological and biological research, scientific social and economic inquiries also increased. The universities already engaged in the project were joined by the Romanian Academy which rebuilt one of the old manors of the Nopcsa family through a co-financed European program into a center for research on local geological and biological diversity, featuring an extensive library and analytical laboratories alongside well-equipped spaces to house researchers (Fig. 8). Those years saw a true cohesive spirit fostered between the academic establishment and local and regional administrations, with substantial budgets of partner institutions allotted annually to support the developments.

Paleontological research gained momentum, as the abundant fossiliferous sites attracted more and more foreign researchers from Europe and the United States each year. A major contributor to paleontological research was the county's largest construction firm, Hidroconstrucția Râul Mare-Retezat LLC, which had been responsible for clearing and leveling the primary archeological site near Tuștea.

Unfortunately, it was not merely researchers who were fascinated by the Hațeg region: the interest of fossil poachers was also similarly piqued. The theft of dinosaur eggs, eventually recovered by Italian carabinieri and returned to the Romanian authorities in 2011, was a highly-publicized case; and while it had a happy ending, it is likely that many other eggs illicitly extracted from the Hațeg Country's fossiliferous deposits, as well as other fossils and objects of great heritage value, have been lost forever. The inconsistencies and inefficiencies of existing legislation in this regard, often proven in many cases of theft of heritage items from archeological sites, continue to provide a great stimulus to smuggling activities.

As with any grand project, the road to the creation of a geopark, although aiming for the lofty goal of regional development and the prosperity of its inhabitants, is not without disillusionment and, at times, failure. In the case of the Hațeg Country Dinosaur Geopark, it is unfortunate that the above-mentioned cohesion of academic, administrative and local actors has frayed significantly over the years. However, the causes and effects of this reality are manifold, and we cannot analyze them further here.

Nevertheless, one significant failure was the interruption of research at Tuștea in 2012, when the owner of the land housing the dinosaur egg nests forbade further research. This was devastating after having allowed it for over 20 years, on the basis of an agreement with the local mayorship, and moreover, after allowing for the levelling of Oltoane Hill in order to further our investigations. Our appeals to national and regional forums that we might continue our research were stalled in the legislative tangle that cannot differentiate between the right to private property and the national interest. And, over the course of these last eight years,

Figure 9. Tuștea, a glorious past and an uncertain future. Images taken during fieldwork vs. the current aspect of the site.

the effects of this legislative tangle can be seen in the thick vegetation that has spread over the entire surface of the Tuștea site: nothing of what shined so brightly and enthused researchers before, can now be seen through the undergrowth (Fig. 9).

Conclusions

The Tuştea dinosaur incubation site, which provides scholars with an interesting and intriguing association of megaloolithid eggs and hadrosauroid hatchlings, represents a very important paleontological site, the only documented one from the European Upper Cretaceous where dinosaur eggs and hatchling remains are preserved together. The site's scientific importance is increased by the presence of more than 20 different vertebrate taxa – including frogs, lizards, snakes, saurischian and ornithischian dinosaurs, pterosaurs and mammals – over a very limited area, which exemplifies the exceptional fossiliferous potential of the site, which should be further exploited.

The interruption of research following an unbroken 24-year period, arising from unclear legislation governing sites of significant scientific/heritage relevance and importance at the national and international level, has led to natural deterioration of the site, which only worsens as the years go by. Furthermore, it also favors the smuggling of valuable heritage objects, such as the fossils discovered at Tuștea. The continuation and support of initiatives to resume research, including actions at the international level, are urgent.

Conflict of Interest: The author declares that he has no competing interest.

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