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First approach for a taphonomic key for fossil eggs and eggshells accumulations using optic microscopy: the case of Blasi-2B (Upper Cretaceous, Spain)

C. Núñez-Lahuerta[1, 2, 3], M. Moreno-Azanza[1, 2, 3] & M. Pérez-Pueyo[3]

[1] Departamento de Ciências da Terra, Faculdade de Ciências e Tecnologia, FCT, Universidade Nova de Lisboa, 2829-516 Caparica, Portugal.
[2] Museu da Lourinhã, R/João Luís de Moura 95, 2530-158 Lourinhã, Portugal.
[3] Grupo Aragosaurus-IUCA Departamento de Ciencias de la Tierra, Facultad de Ciencias, Universidad de Zaragoza. Pedro Cerbuna 12, 5009 Zaragoza, Spain.

Corresponding author:
C. Núñez-Lahuerta
carmennunezlahuerta@gmail.com

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Abstract

Taphonomic analysis are crucial for interpreting fossil accumulations. Taphonomic studies of eggshell remains have been faced by several authors, but a general methodology is lacking. The goal of this work is to elaborate a key for the taphonomic descriptions based on previously described and new characters that can be applied to every type of site (including nests, clutches, eggs or eggshell fragments). Eleven variables observable with optic microscopy have been selected, based on the size, the shape, the state of conservation and the presence of different types of marks. The key has been applied to the Upper Maastrichtian eggshell remains of Blasi-2B, revealing an attritional origin of the accumulation. More characters will be added to the key in the future (including different techniques). The application of this key will shed light on the relationships between facies and egg assemblages, leading to the understanding of the paleobiology of the nesting taxa.

Keywords: Taphonomy, Upper Maastrichtian, *Pseudogeckoolithus*, Theropoda, egghells.

1. Introduction

Several works have faced the taphonomic analysis of eggshell accumulations during the biostratinomic phase, mostly focusing in the relationships between eggshell fragments and sediment, both in nest or transported eggshell accumulations (Bravo *et al.,* 2003; Hayward *et al*., 1997, 2011). Two main aspects analysed in eggshell taphonomic studies are the size of the eggshell fragments (Tokaryk & Storer, 1991) and the orientation of the concavity of the eggshell (Hayward *et al*., 2011; Oser & Jackson, 2014 and references therein). The taphonomic analysis of eggshells is mandatory when interpreting the accumulations, as it can shed light both on the sedimentological characteristics of the site and on the paleobiology of the nesting taxa.

The main goal of this work is to establish a taphonomic key that could be systematically followed for the analysis of different sites, using independent characters both new and gathered from the literature. We aim to observe variations not only in the taxonomical composition of the oological assemblages, but in the state of conservation of the eggshells along studied sequences, and the possible relationships of state of conservation of ootaxa and particular facies.

To test our taphonomic key, we selected an allochthonous eggshell assemblage, aiming to find a wide range of values for each measured variable. The analysed eggshells were recovered from the Upper Cretaceous site of Blasi-2B, located near to Arén, in the Spanish Pyrenees. Blasi-2B site occurs in a grey marls level at the base of the Tremp Formation (Grey Garumnian unit, López-Martínez *et al*., 2001); which has been interpreted as transitional deposits, lagoonal and coastal environments. According to biostratigraphy and magnetostratigraphy the age of the site is late Maastrichtian, upper part of the magnetochron C30n (López-Martínez *et al*., 2001; Canudo *et al.,* 2016). The sites of Blasi are widely known for their palaeontological richness (Canudo *et al.,* 2016; Moreno-Azanza *et al.,* 2014).

2. Material and methodology

A deep bibliographical review has been performed in order to assess which variables could be included in the key. For this first approach only characters than can be studied with the help of optical microscopy have been considered. As the biomineral structure is different, the physical properties of the eggshell vary depending on the ootaxa (Zhao, 1994). For this reason, each ootaxon was coded separately, when sample size allowed it. For this analysis, the selected eggshells have been separated into four categories with a binocular microscope. No complete eggs have been found in the Blasi-2B site, eggshells were recovered by washing and sieving five tons of sediment, and the systematic analysis of the eggshells is currently ongoing. Three-hundred eggshell fragments have been selected for the taphonomic analysis. Eggshells were photographed with a digital photographic camera attached to a binocular microscope (Olympus SZ51) and processed with ImageJ (Rasband, 2012). For measuring eggshell fragment dimensions, sieve mesh size was used. Each eggshell fragment has been codified separately, resulting in a 11 by 300 data matrix.

3. Results

In order to establish a key of taphonomic characters of fossil eggshell accumulations, eleven variables have been selected: completeness of the eggs, size of the fragments, roundness of the fragments, edge roundness (after Oser & Jackson, 2014), mammillary preservation, inner surface abrasion, outer surface abrasion (Fig. 1A), and presence of corrosion/ dissolution, bioerosion, toolmarks, and crusts.

Completeness of the eggs has been divided in four categories: 0 nests and clutches, 1 complete eggs, 2 half eggs, and 3 eggshell fragments. The size of the fragments has been divided in four categories: 0 fragments bigger than 2cm, 1 fragments bigger than 1cm, 2 fragments bigger than 5mm and 3 for fragments smaller than 5mm. Roundness of the fragments has been divided in two categories, 0 rounded fragments and 1 for fragments with one of the axes twice as long as the other, as expressed in Fig. 1A. The roundness of the fragments is related to distance of transport from the source area (Selley, 2000), similar roundness percentages in the morphotypes could point to a similar distance from the area in which the eggs were laid. The edge roundness reflects the transport of the eggshell, and it has been categorised according to the work of Oser & Jackson (2014). Four categories have been established for that parameter, from 0 (fresh fracture) to 3 (complete rounding of the edge) as showed in Fig. 1A. Mammillary preservation has been divided in two categories. 0 intact mammillae, and 1 total or partially reabsorbed or eroded mammillae. The mammillary reabsorption is related with the embryo development (Tuan *et al*., 1991). It must be considered that the differentiation between the mammillary reabsorption and inner surface abrasion can be tricky (Bravo *et al.,* 2003). The presence of abrasion has been divided into two different variables, corresponding to the inner and outer surfaces. Three categories have been established for both variables, 0 intact surfaces, 1 partially abraded surfaces, and 2 completely abraded surfaces. Finally, absence or presence of the other variables has been categorised as 0 absence and 1 presence, respectively, like in the case of corrosion/dissolution, bioerosion (Gamez *et al.,* 2009), toolmarks, and mineral crusts.

An example of application of the taphonomic key: the Blasi 2B eggshell assemblage

We applied the taphonomic key to 300 eggshell fragments from Blasi-2B (Fig. 1B), which have been classified into four ootaxonomic groups: Type I (Prismatoolithidae indet., BL2_TAP-1 to 11, N=11), Type II (thick *Pseudogeckoolithus*, medium thickness 285µm, BL2_TAP-12 to 20, N=9), Type III (thin *Pseudogeckoolithus*, 141µm, BL2_TAP-21 to 31, N=11), and Type IV (indeterminate fragments, BL2_TAP-32 to 300, N=269). Discussion of this assignations can be found in Perez-Pueyo *et al.* (this volume).

All eggshell fragments have a size <5mm. Only 9 fragments show corrosion or dissolution effects (one from Type I, and eight in Type IV). All the morphotypes show a predominance of rounded shape (Fig. 1B), although Type I eggshells present more elongated fragments, probably due to a more compact ultrastructure that difficult breakage. The state of conservation of the eggshells varies, even within each category. In general Type IV show the higher levels of alteration, and Type III the lower (Fig. 1B). Type IV eggshells are the most abundant and degraded in the assemblage. Nevertheless, is important to note that the high degree of abrasion affects hinders the identification, and is possible that this category represents a ootaxa "grab-bag" that needs to be disentangled with further examination of the fragments. The data points to a high level of transport of all the remains Except Type III eggshells, which could point to a closer distance of the original nest to the accumulation site. The taphonomic analysis of the eggshell fragments points to an attritional origin of the BL-2B assemblage, with all eggshell types being allochthonous, with Type III being the less transported.

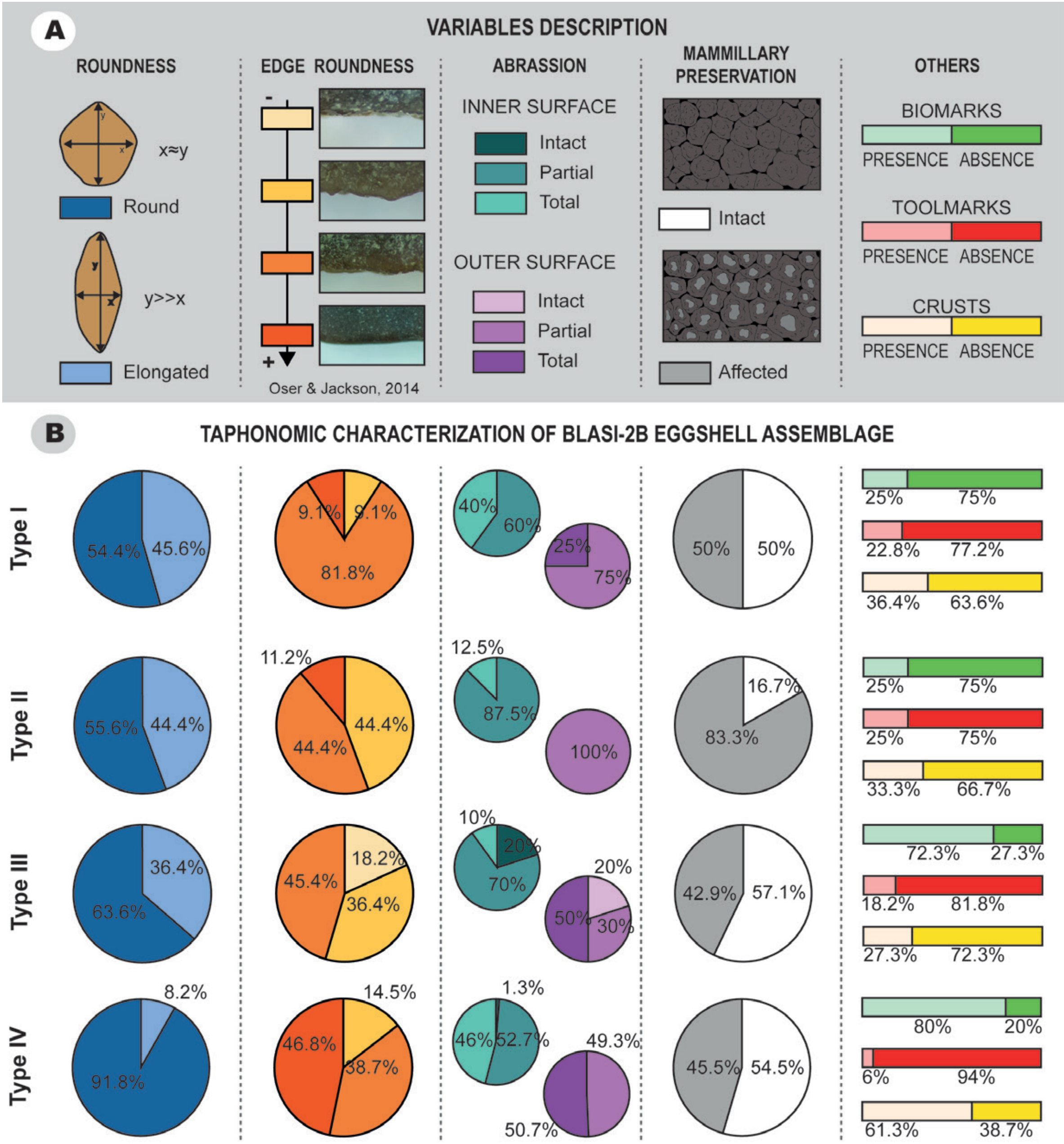

Fig. 1. -A-Description of the variables included in the proposed taphonomic key; B-Taphonomic characterization of Blasi-2B eggshell assemblage, based on the analysis of 300 eggshell fragments. Type I: Prismatoolithidae indet. Type II: Thick *Pseudogeckoolithus* eggshells. Type III: Thin *Pseudogeckoolithis* eggshells. Type IV: others

4. Discussion, limitations of the study and future work

Optical microscopy is adequate to study of characters at the scale of the tenths of millimetres but fails to address other microscopic features of the eggshell. Different variables will be included to the key in the future (including electronic microscopy, thin sections and cathodoluminescence techniques), which will allow the identification of other processes, including fossildiagenetic processes such as recrystallization. Also, the analysis of the bioerosions will allow a deeper understanding of the taphonomic history of the eggshells. Once a more complete key is built, the application of this new methodology in different sites along eggshell-rich formations will shed light on the relationships between the facies and egg assemblages, ultimately leading to a better understanding of the paleobiology of the nesting taxa.

5. Conclusions

A taphonomic key with eleven variables has been designed and tested using an Upper Cretaceous accumulation of eggshell fragments, evidencing the allochthonous origin of this accumulation, formed by attrition in a transitional environment. This taphonomic key will be systematically applied to assemblages in different facies within a sequence to explore the relations between oodiversity and palaeoenvironment.

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