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A new form of Elongatoolithidae, *Undulatoolithus pengi* oogen. et oosp. nov. from Pingxiang, Jiangxi, China

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Abstract

A new oogenus and oospecies of the Elongatoolithidae, *Undulatoolithus pengi* oogen. et oosp. nov., is described on the basis of specimens from the Upper Cretaceous Zhoutian Formation of the Pingxiang Basin, Jiangxi Province, China. The eggs are slightly asymmetrical, paired, and lay radially-oriented in a circular configuration within the clutch, and most suggestive of *Macroolithus* of the Elongatoolithidae by medium-sized eggs with average polar axis and equatorial diameter of 19.36 and 8.35 cm, and the ornamentation pattern of nodes and ridges on the outer surface. The new oogenus differs from *Macroolithus* in its prominent ridges 0.67 mm in height, about half of the entire eggshell thickness, gradational boundary between the cone layer and the overlying columnar layer, cone layer-to-columnar layer thickness ratio of 1/8 or 1/4. This discovery adds new data on the morphology and diversification of Late Cretaceous elongatoolithid ootaxa.

Key words: Elongatoolithidae, Dinosaur eggs, Zhoutian Formation, Upper Cretaceous, Pingxiang, China

Introduction

Elongatoolithids are elongate, asymmetrical eggs with prominent ornamentation of nodes and ridges on the outer surface, and have an eggshell microstructure referable to the ornithoid-ratite morphology. Eggs within a clutch are paired, and arranged in a circular configuration with the central part about 10 cm in diameter. The Elongatoolithidae is represented by seven oogenera, *Elongatoolithus*, *Macroolithus*, *Nanhsiungoolithus* (Zhao 1975), *Heishanoolithus* (Zhao & Zhao 1999), *Paraelongatoolithus* (Wang et al. 2010), *Trachoolithus* (Mikhailov 1994, 1997), and *Ellipsoolithus* (Mohabey 1998), all of which are known from the Cretaceous of Asia.

Since 2002, dinosaur egg clutches, single eggs, a large number of eggshell fragments and dinosaur bones have been found in the Upper Cretaceous in the Pingxiang Basin, Jiangxi Province, China (Fig. 1). The strata yielding dinosaur bones and egg fossils in the basin are composed of red sandstone, and silty-mudstone with interbedded gypsum layers. According the composition of lithology combination, the stratum which yields dinosaur egg fossils in the Pingxiang Basin can be compared with the Upper Cretaceous Zhoutian Formation (Department of Geology and Mineral Resources of Jiangxi Province 1997; Liu 2003). In this paper, we describe the first clutch of elongatoolithid eggs found in 2002 from the Pingxiang Basin.

Systematic paleontology

Elongatoolithidae Zhao, 1975

Diagnosis: Elongate, asymmetrical eggs; paired eggs arranged in a circular clutch; the polar axis length from 10.0 cm–21.0 cm, and equatorial diameter from 5 cm–9 cm, prominent nodes or ridges ornamentation on the outer surface; eggshell composed of the cone layer and the columnar layer, eggshell thickness ranges from 0.30 mm–2.00 mm.

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Type oogenus: *Elongatoolithus*, *Macroolithus*, *Nanhsiungoolithus* (Zhao 1975), *Heishanoolithus* (Zhao & Zhao, 1999), *Paraelongatoolithus* (Wang et al. 2010), *Trachoolithus* (Mikhailov 1994, 1997), and *Ellipsoolithus* (Mohabey 1998).

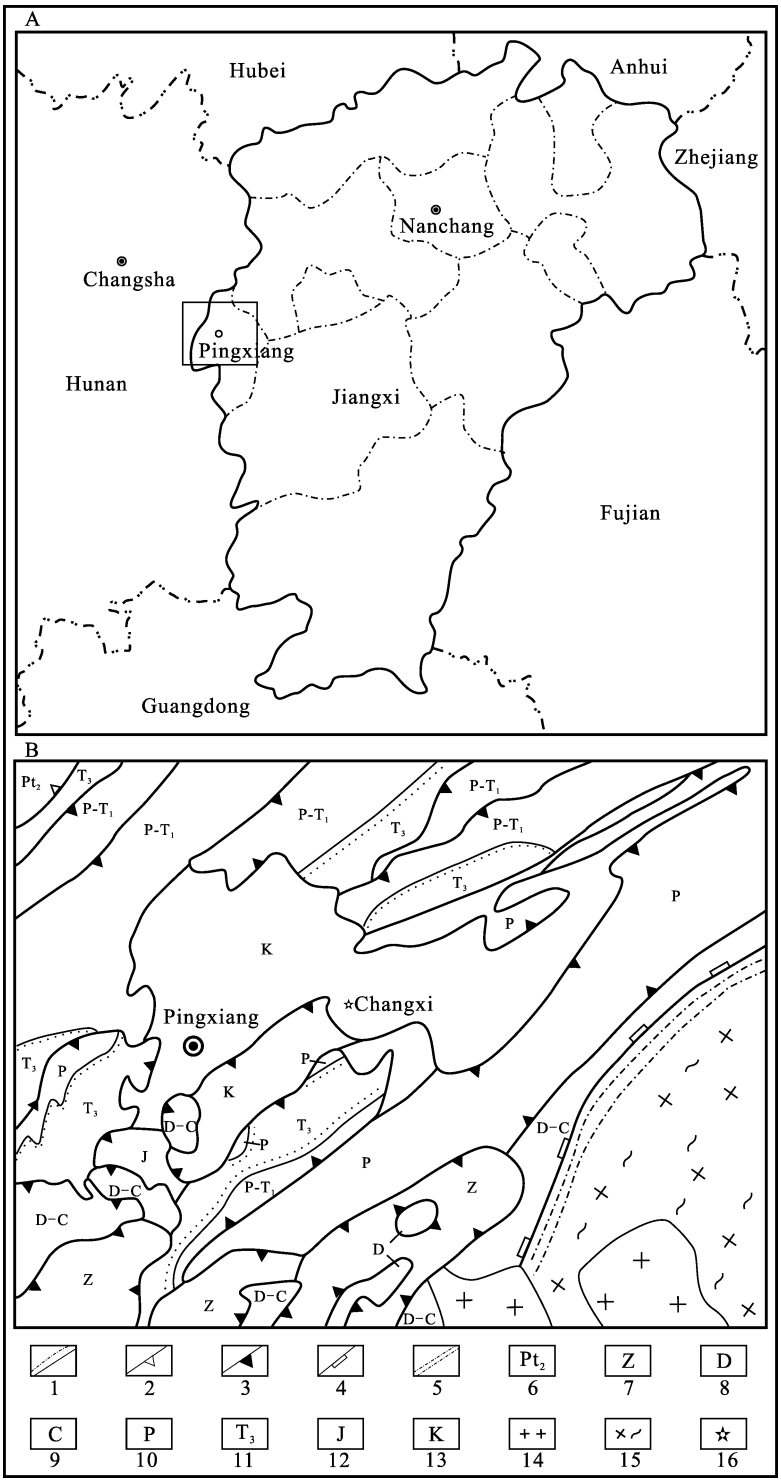

FIGURE 1. **A**, Sketch map of Jiangxi Province, China; **B**, Geological sketch map of Pingxiang area (modified from Liu, 2003) 1. Unconformity boundaries; 2. Nappe fault; 3. Gliding fault; 4. Shear-detachment fault; 5. Mylonite; 6. Middle Proterozoic; 7. Sinian; 8. Devonian; 9. Carboniferous; 10. Permian; 11. Upper Triassic; 12. Jurassic; 13. Cretaceous; 14. Mesozoic granites; 15. Early Paleozoic gneissic granite; 16. Locality of dinosaur egg.

***Undulatoolithus* oogen. nov.**

Etymology: From '*undulatus*', Latin for 'wavy', in reference to the undulating appearance of the eggshell ornamentation in radial section.
Diagnosis: As for the type and only oospecies.

***Undulatoolithus pengi* oogen. et oosp. nov.**

Holotype: A clutch with 5 more or less well preserved eggs and 3 broken eggs (PXMV-0016) (Fig. 2), housed in the Pingxiang Museum, Jiangxi Province.

Locality and horizon: Changxi (Fig. 1), Pingxiang City; Zhoutian Formation, Upper Cretaceous.

Etymology: The oospecific epithet honors the late Peng Anbao, chief curator of the Pingxiang Museum, who collected and protected the dinosaur eggs from the Pingxiang Basin.

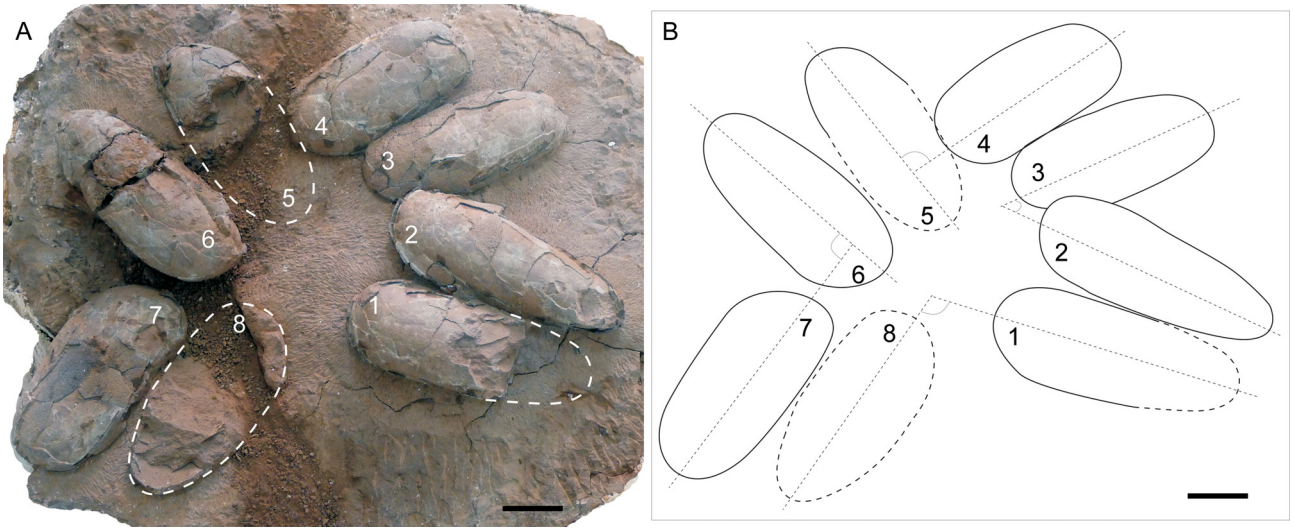

FIGURE 2. **A**. Holotype of *Undulatoolithus pengi* oogen. et oosp. nov. (PXMV-0016). **B**. Line drawings showing the angle between pairs. Scale bar: 5 cm

Diagnosis: Elongated egg type with a polar axis length of about 19.36 cm and equatorial diameter of 8.35 cm, giving a shape index is 43.1. The outer surface of the eggshell is sculptured with nodes and longitudinally aligned ridges, and the ridges is 0.67 mm in height, about half of the entire eggshell thickness. The eggshell thickness is 0.78mm (excluding ornamentation) or 1.46 mm (including ornamentation). Cone layer is thin, 1/8 or 1/4 of eggshell thickness. There is gradational boundary between cone layer and columnar layer.

Description: All the eggs are paired, and arranged in a circular configuration with the central part about 10 cm in diameter (Fig. 2A). The angle between pairs is 45.5–107 degrees (Fig. 2B). The eggs are slightly asymmetrical and elongate, with average polar axis length and equatorial diameter of 19.36 cm and 8.35 cm, respectively (Table 1). They are positioned with the blunt pole toward the centre of the nest and the narrow pole directing outwards.

The outer surface of the eggshell is sculptured, with the ornamentation pattern consisting of distinct nodes and short ridges that look like nodes coalesced. Both poles are always ornamented with irregularly shaped nodes (Fig. 3A). These ridges are parallel to one another or bifurcate in the equatorial part (Fig. 3B, C), and from 2.00 mm to 5.81 mm long. The flat interspaces between the ridges are 0.23-0.71 mm wide.

The eggshell thickness ranges from 0.78 mm (measured from the level of the cone apices to the valley between ridges) to 1.46 mm (measured including the ridges). The ridges have a height of 0.67 mm, about half of the total eggshell thickness (Fig. 4A, B).

The eggshell consists of the cone layer and the columnar layer. The contact between the cone layer and the overlying columnar layer is gradational (Fig. 4A, B). The cones are conical and closely packed (Fig. 4A, C, D). As part of cones eroded, so the cone layer is not complete and thinner than the actual thickness, especially they are little organic cores can be seen in the eggshell radial section (Fig. 4A, C). The thickness of the cone layer is

approaching 0.15 mm, and the thickness of the columnar layer is 0.62mm (excluding ornamentation) or 1.29 mm (including ornamentation), respectively. Thickness ratio of the two layers is 1/8 or 1/4.

The growth (accretion) lines undulate along with the outer sculptured surface, especially in the upper part of the columnar layer (Fig. 4A, B). Oval to elliptical pores penetrating the columnar layer are visible in tangential sections (Fig. 4D), with the pore diameter ranging from 0.14-0.18 mm.

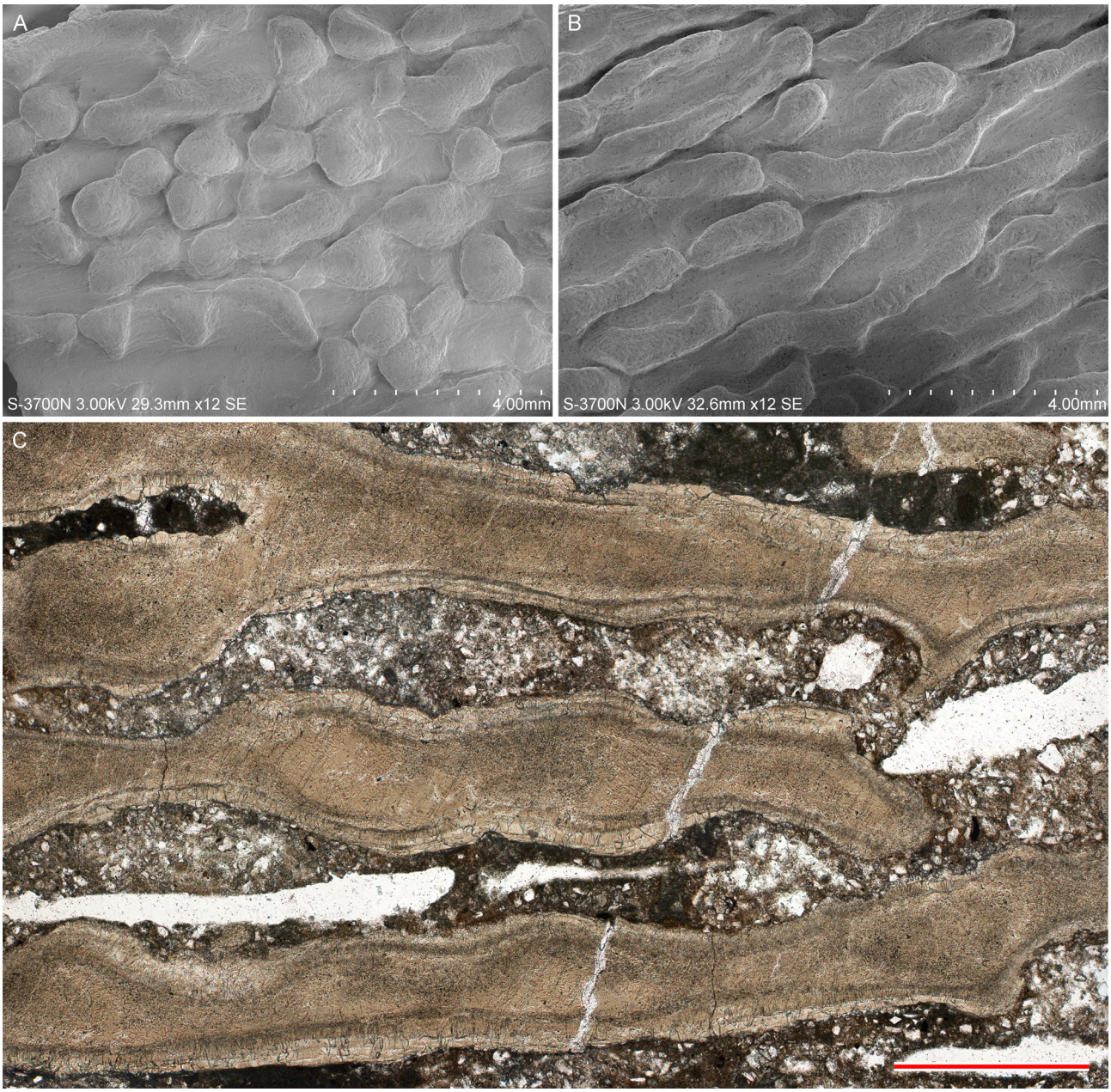

FIGURE 3. Outer surface of *Undulatoolithus pengi* oogen. et oosp. nov., showing variation in ornamentation of eggshell. **A**, Ornamentation consisting of bulbous, irregular- to regular-shaped nodes on both poles of egg (SEM); **B**, Ornamentation consisting of sinuous ridges in the middle part of egg (SEM); **C**, Tangential thin section, showing ridges. Scale bar: 1 mm

Discussion

The new clutch of eggs (PXMV-0016) described above can be referred to Elongatoolithidae based on the following features: slightly asymmetrical elongated eggs of medium size (up to 20 cm long in polar axis), the pattern of egg arrangement within the clutch, the ornamentation pattern of nodes and ridges on the outer surface, and the growth lines undulate along with the outer sculptured surface in radial sections of the eggshell.

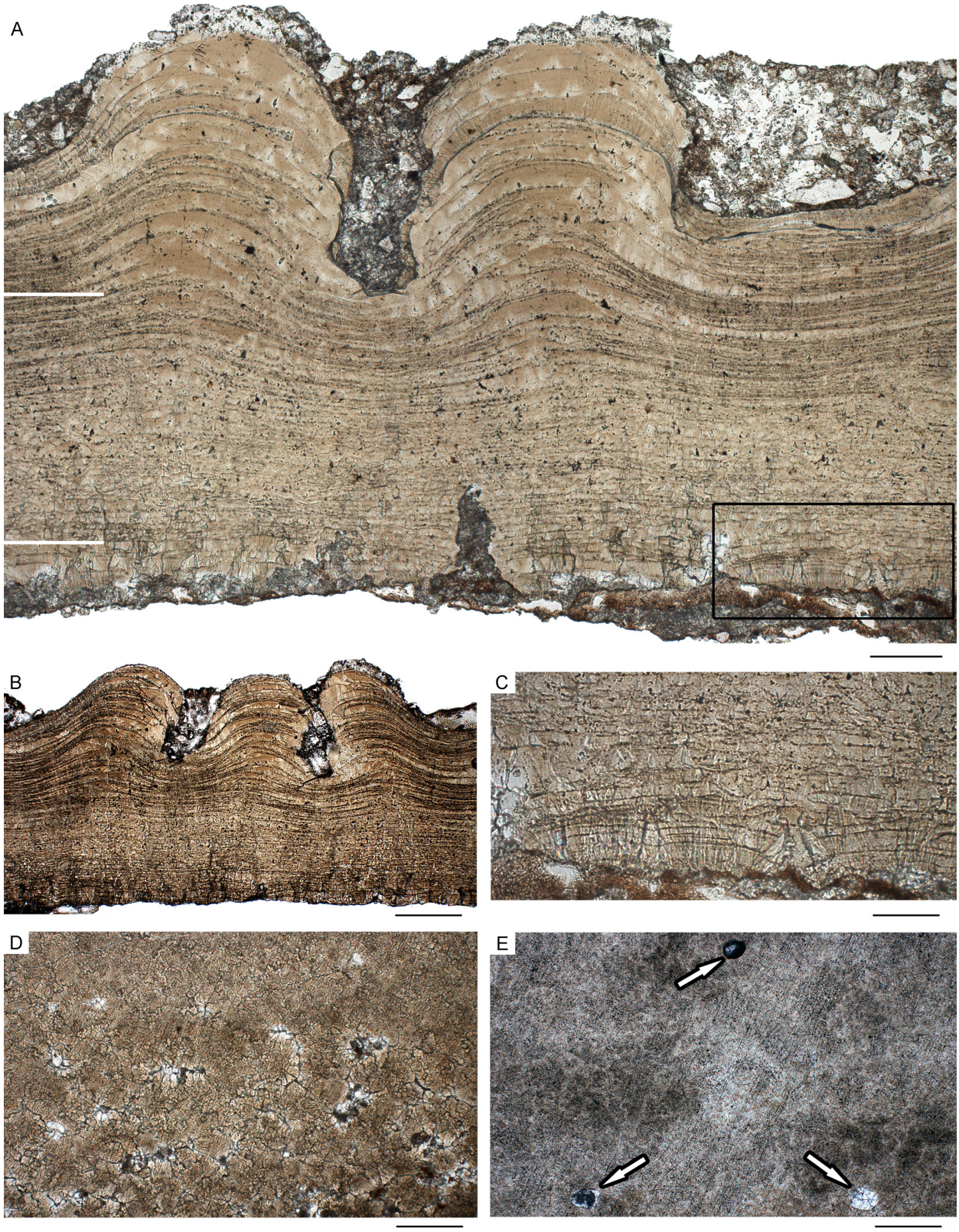

FIGURE 4. Eggshell microstructure of *Undulatoolithus pengi* oogen. et oosp. nov. Scale bar: 400 μm. **A-C**, Radial thin sections through eggshell, **A**, showing the cone layer and the columnar layer, gradational boundary between the two layers and undulating appearance of ornamentation (short white lines showing the boundary of the cone layer and the columnar layer, and the ornamentation); **B**, showing the undulated ornamentation; **C**, enlargement of in A, showing the closely packed and conical cones; **D**, Tangential section through eggshell near level of the boundary between the cone layer and the columnar layer, showing the interval between cones and pores; **E**, Tangential section through eggshell within columnar layer, showing the oval or elliptical pores (arrows).

TABLE 1. Measurements of *Undulatoolithus pengi* oogen. et oosp. nov.

No. of Eggs	polar axis length (cm)	equatorial diameter (cm)	shape index
1	?	7.8	?
2	21.5	8.7	40.5
3	19.1	8.3	43.5
4	18.5	8.4	45.4
6	20.0	8.5	42.5
7	17.7	8.4	47.5

TABLE 2. Comparison of oogenera of the Elongatoolithidae (modified from Wang *et al*. 2010)

Taxa	Polar axis length (cm)	Equatorial diameter (cm)	Thickness of eggshell?including ornamentation (mm)	Ratio of the cone layer to the columnar layer	Height of ornamentation (mm)	Ratio of the ornamentation height to entire shell thickness	References
Undulatoolithus oogen. nov.	19.36	8.35	1.46	1 : 8	0.67	1 : 2	This paper
Elongatoolithus	11.0–15.1	5.8–7.7	0.67–1.12	1 : 5	0.10 [1]	1 : 7	Young, 1954, 1965; Zhao, 1975
Macroolithus	16.5–20.8	6.7–9.4	1.39–1.93	1 : 3	0.17 [2]	1 : 10	Zhao, 1975
Nanhsiungoolithus	13.94	6.84	0.60–1.30	?	?	?	Zhao, 1975
Heishanoolithus	?	?	1.20–1.30	1 : 7	0.20 [3]	1 : 6	Zhao and Zhao, 1999
Paraelongaoolithus	17.00	7.20	0.70–0.85	1 : 2	0.20?0.25	1 : 3–1 : 5	Wang et al., 2010
Trachoolithus	?	?	0.30–0.90	1 : 4–1 : 3	0.60	2 : 3	Mikhailov, 1994
Ellipsoolithus	9.80–11.0	6.50–8.00	1.20–1.64	1 : 4	?	?	Mohabey, 1998

Height of ornamentation measured from eggshell radial section of holotype oospecies of oogenus: 1, *Elongatoolithus elongatus*; 2, *Macroolithus rugustus*; 3, *Heishanoolithus changii*.

The Elondatoolithidae includes seven oogenera, *Elongatoolithus*, *Macroolithus*, *Nanhsiungoolithus*, *Heishanoolithus*, *Paraelongatoolithus*, *Trachoolithus*, and *Ellipsoolithus*, all of which are known from the Cretaceous of Asia. The new clutch of eggs (PXMV-0016) is similar to *Macroolithus* in medium-sized eggs with average polar axis and equatorial diameter of 19.36 and 8.35 cm, and the ornamentation pattern of nodes and ridges on the outer surface. Nevertheless, the new clutch of eggs differs from *Macroolithus* in prominent high ridges (up to 0.67 mm), about half of the entire eggshell thickness; gradational boundary between the cone layer and the overlying columnar layer; cone layer-to-columnar layer thickness ratio of 1/8 or 1/4 (Table 2). Accordingly, the clutch of eggs (PXMV-0016) is regarded as a new ootaxon of Elongatoolithidae: *Undulatoolithus pengi*. Dinosaur eggs are abundant and widely distributed in China (Wang et al. 2012). Especially, elongatoolithids are diverse and widely distributed. This discovery adds new data on the morphology and diversification of Late Cretaceous elongatoolithid ootaxa.

Elongatoolithid eggs were first found in the Gobi Desert of Mongolia by the Central Asiatic Expedition of the American Museum of Natural History in the 1920s, and referred to *Protoceratops* eggs (Straelen 1925). However, the well-preserved remnants of an oviraptorid embryo have been found within an elongatoolithid egg (Norell et al. 1994), and associated adult skeletal remains found together with elongatoolithid eggs have been assigned to oviraptorids (Norell et al. 1994; Dong & Currie 1996; Sato et al. 2005). This confirms that the elongatoolithid eggs can only be the oviraptorids, rather than protoceratopsids. Although the clutch of *Undulatoolithus pengi* lacks associated skeletal remains, the arrangement, elongate asymmetrical shape and eggshell microstructure characteristic of the individual egg all suggest that the clutch belonged to an oviraptorosaur egg type.

Acknowledgments

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