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An egg clutch of the Stalicoolithidae discovered in Wuning, Jiangxi, China

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Abstract Here we describe an incomplete dinosaur clutch with three broken eggs and seven prints discovered in Wuning County, Jiangxi Province, that can be referred to *Coralloolithus shizuiwanensis* based on the following features: the eggs are nearly spheroid and arranged tightly and irregularly in the clutch, the eggshell thickness ranges 2.76–2.97 mm, the horizontal accretion lines are almost evenly distributed throughout the eggshell, and the secondary eggshell units are distributed in the medial and outer zones of the columnar layer. This egg clutch of *Coralloolithus shizuiwanensis* represents the first discovery of dinosaur eggs in Wuning County, and shows the age of the strata containing the dinosaur eggs in this area should be Late Cretaceous.

Key words Wuning County, Jiangxi Province; Late Cretaceous; dinosaur eggs; Stalicoolithidae

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1 Introduction

In October 2022, a clutch of dinosaur eggs was found at a construction site in the Duxi Village, Luoping Town, Wuning County, Jiangxi Province (Fig. 1). The lithology of the outcrop is mainly polymict conglomerate (conglomerate and fine sandstone) and the dip direction and dip angle of the stratum are 320° and 8° respectively. The Jiangxi Geology and Mineral Exploration and Development Bureau (2017) attributed the strata to the Paleogene Moxia Formation of the Wuning Group as piedmont pluvial facies. The Moxia Formation was named by the Department of Geology and Mineral Resources of the Jiangxi Province (1997) according to the Moxia-Wangbu stratotype section in Wuning County. The lower and upper parts of the Moxia Formation are composed of purplish-red thick layered polymict conglomerate and

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pebbly sandstone. The middle part (Wangbu limestone member) is composed of grey, purplish medium-thick layered cryptocrystalline limestone and pebbly cryptocrystalline limestone. The determination of its age mainly relies on the paleontological assemblage in the Wangbu limestone member, while there is little evidence that can be used to infer the geological age of the lower and upper parts of the Moxia Formation. In recent years, with the further study of the red beds in southern Jiangxi, the lithology assemblage has been found to be more in line with the characteristics of the Upper Cretaceous Lianhe Formation, Guifeng Group (Jiangxi Geology and Mineral Exploration and Development Bureau, 2017). This paper describes the dinosaur eggs found in Wuning and provides paleontological evidence for the geological age of the strata.

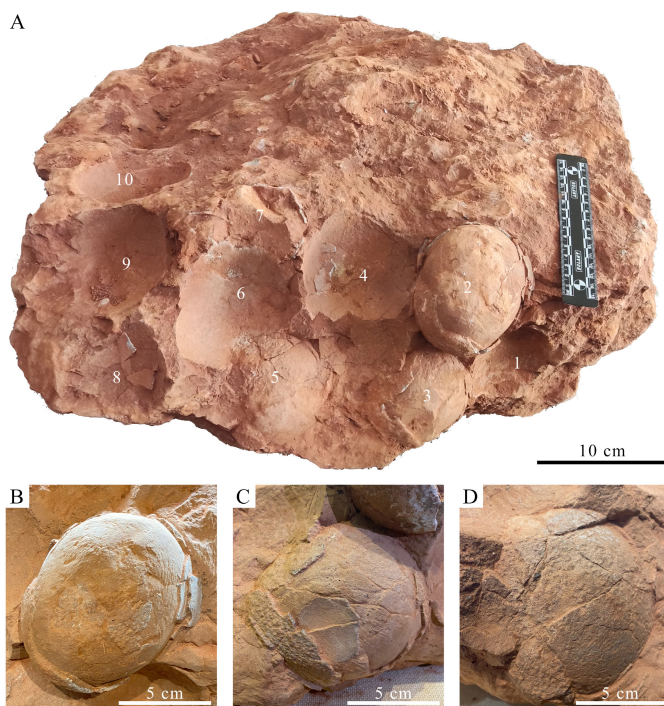


Fig. 1 The incomplete clutch of *Coralloidoolithus shizuiwanensis* (WNCM-V1) from Wuning, Jiangxi
A. three broken eggs (No. 2, 3, 5) and seven prints with a few eggshell remnants, eggs were arranged tightly and irregularly; B–D. magnification figures of the egg No. 2 (B), No. 3 (C) and No. 5 (D)

2 Materials and methods

The eggshells selected for microscopic sections were cleaned by ultrasonic and embedded in resin. Then they were cut and grinded by using EXAKT 300CP slicer and EXAKT 400CS grinder to slices approximately 30 μm thick. The eggshell slices were observed and photographed under a polarizing microscope. The eggshell experiments were performed in the Key Laboratory of Vertebrate Evolution and Human Origins, Chinese Academy of Sciences.

3 Systematic paleontology

Stalicolithidae Wang et al., 2012

***Coralloidoolithus* Wang et al., 2012**

***Coralloidoolithus shizuiwanensis* (Fang et al., 1998) Wang et al., 2012**

New referred specimens WNCM-V1, an incomplete clutch, with eggshell radial and tangential sections S221008-1①–②, S221008-2①–④, housed at Wuning County Museum.

Locality and horizon Duxi Village, Luoping Town, Wuning County, Jiangxi Province; Upper Cretaceous.

Diagnosis The eggs are nearly spheroid and arranged tightly and irregularly in the clutch. The thickness of the eggshell ranges from 2.76–2.97 mm. The eggshell can be divided into a cone layer and columnar layer. The thickness of the cone layer ranges from 0.22–0.32 mm, which is about 1/10 of the eggshell thickness. There are around 23–26 cones per a square millimeter. The columnar layer can be divided into inner, medial and outer zones. Secondary eggshell units are distributed in the medial and outer zones. A relatively large number of secondary shell units are distributed in the columnar layer, and most of the secondary eggshell units in the outer zone are closely arranged. Horizontal accretion lines are evenly distributed throughout the eggshell. The pores are irregular and worm-like.

Description An incomplete clutch consisting of three broken eggs and seven prints with a few eggshell remnants. The eggs were arranged tightly and irregularly in the clutch (Fig. 1). Egg No. 2 is nearly spheroid in shape, 106 mm × 86 mm. The outer surfaces are rough and covered with sediment.

In the radial section (Fig. 2), the thickness of the eggshell ranges from 2.76–2.97 mm, but it may not reach its original thickness due to weathering. The eggshell microstructure shows closely arranged eggshell units. The boundary between the cone layer and columnar layer is not clear. The eggshell units show radial extinction through the nucleation centers to the outer surface under cross-polarized light. The pore canals are irregular and worm-like.

The cone layer is thin and ranges from 0.22–0.32 mm in thickness, about 1/10 of the eggshell thickness. In the radial section, the gaps between the cones are significant (Fig. 2), but some cones are incomplete due to weathering. The accretion lines are concentric arcs around the nucleation centers (Fig. 3A). In the tangential section, the cones show a radial microstructure surrounding the nucleation centers (Fig. 4A), and the density of the cones is 23–26 per a square millimeter. The pores are irregular in shape and vary in size (Fig. 4A).

The columnar layer is thick, ranges 2.38–2.72 mm in thickness, and can be divided into three zones. The boundary between the inner zone and the medial zone is not obvious. The accretion lines are dark in color and evenly distributed in the columnar layer. The inner zone ranges from 0.78–0.92 mm thick, which is about 1/3 of the eggshell thickness. In the radial section, the gaps between eggshell units tend to be closed (Figs. 2, 3B). In the tangential section, the pores are nearly round (Fig. 4B).

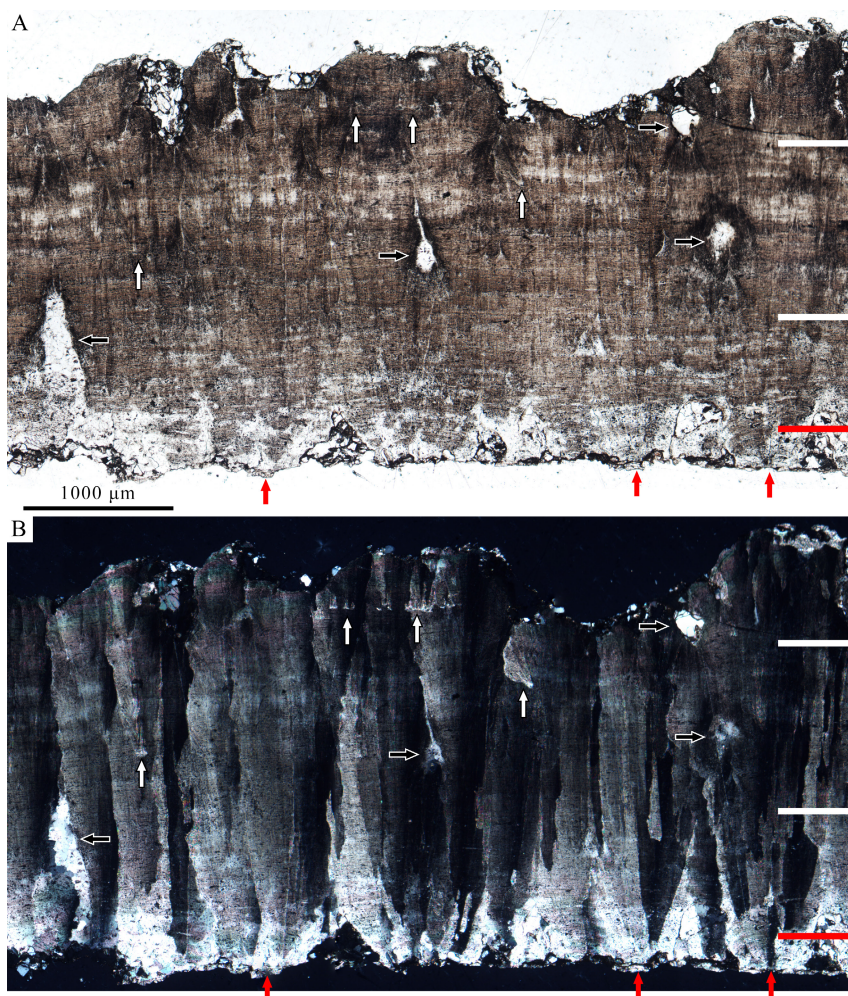


Fig. 2 Microstructure of the *Coralloidoolithus shizuiwanensis* in radial section (S221008-1②) under ordinary light (A) and cross-polarized light (B)

White lines show the boundaries between the inner, medial and outer zones

A. the boundary between the cone layer and columnar layer (red line) is not clear, accretion lines distribute through the shell, pore canals (black arrows) are irregular and worm-like, and the secondary eggshell units (white arrows) grow in the medial zone and the outer zone; B. the eggshell units show radial extinction through the nucleation centers (red arrows) to the outer surface, and secondary eggshell units (white arrows) show independent radial extinction

The medial zone ranges from 1.15–1.30 mm thick, which is about 2/5 of the eggshell thickness. In the radial section, the eggshell units are tightly arranged with no obvious gaps (Figs. 2, 3C–F). The upper part of this zone is distributed with multiple discontinuous light-colored stripes (Fig. 2). This zone distributes secondary eggshell units with two different shapes: conical (Fig. 3C, D) and fan-shape (Fig. 3E, F). In the tangential section, the pores are either nearly round, sickle-shape or nearly closed (Fig. 4C).

The outer zone distributes closely arranged secondary eggshell units, and its outer surface greatly undulates due to weathering (Fig. 2). In the radial section, the secondary eggshell units

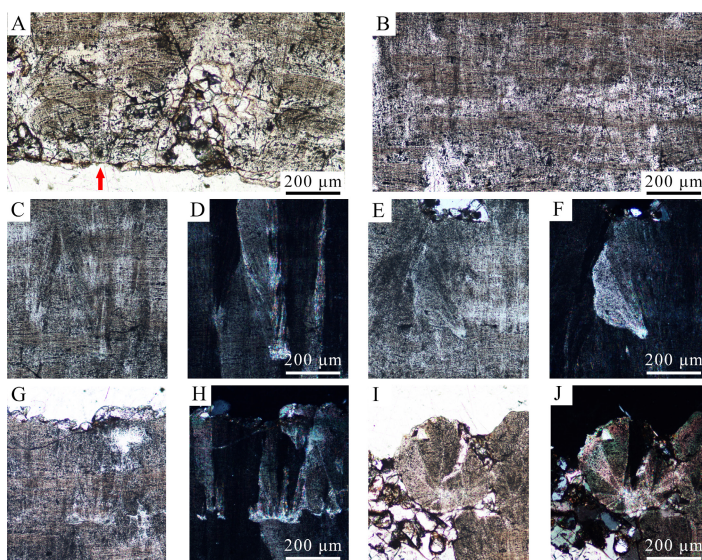


Fig. 3 Microstructure of the *Coralloidoolithus shizuiwanensis* in radial section

A. the accretion lines are concentric arcs around the nucleation centers (red arrow); B. the inner zone, light-colored stripes intersperse in accretion lines; C–F. the medial zone, accretion lines inside the light-colored stripes are blurred, conical (C, D) and fan-shaped (E, F) secondary eggshell units distributed; G–J. the outer zone, some secondary eggshell units are columnar-shaped and show narrow extinction under cross-polarized light (G, H), while the others are circular in shape and show petal-like extinction under cross-polarized light (I, J). A, C–H. S221008-1②; B, I, J. S221008-1①

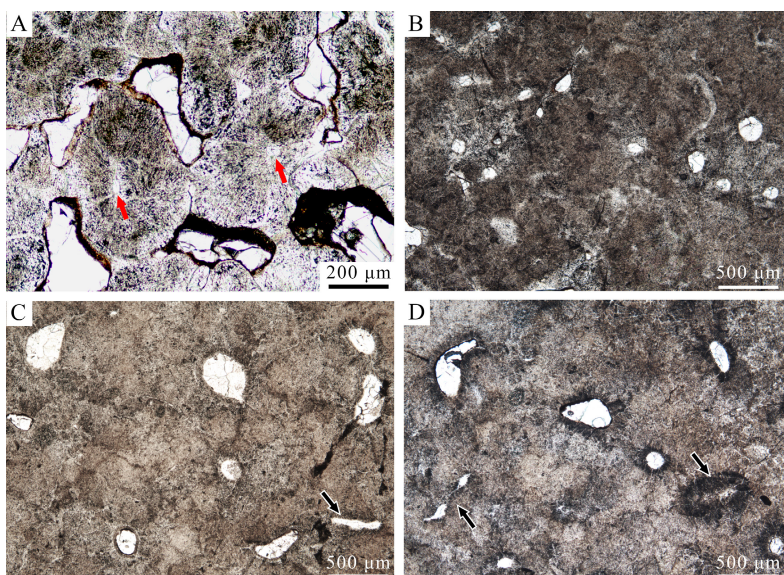


Fig. 4 Microstructure of the *Coralloidoolithus shizuiwanensis* in tangential section

A. section through the cone layer, red arrows point to radial microstructure surrounding the nucleation centers, pores are irregular in shape and vary in size; B. the inner zone, pores turn into more regular, most are nearly round; C. the medial zone, pores are nearly round, sickle-shape or nearly closed (black arrow); D. lower part in the outer zone, more pores are closed or nearly closed (black arrows)

A, B. S221008-2①; C. S221008-2②; D. S221008-2③

show independent extinction under cross-polarized light (Fig. 3G, H). The secondary eggshell units surrounding the pore openings are large and circular, have radial microstructures that are similar to those of the cones, and show fan-shaped extinction under cross-polarized light (Fig. 3I, J). In the tangential section, a greater number of the pores are closed or nearly closed (Fig. 4D).

4 Comparison and discussion

The eggs found in Wuning are nearly spheroid with rough surfaces. In regard to the eggshell microstructure, the eggshell can be divided into a cone layer and columnar layer, the eggshell units are tightly arranged and highly fused in the columnar layer, the cones are round, and the pores are irregular and worm-like, which can be compared with the oofamily *Stalicoolithidae* (Wang et al., 2012; Zhao et al., 2015) and *Paraspheroolithus* (Yang, 1965; Zhao and Jiang, 1974; Zhao et al., 2015). These eggs are distinct from the oogenus *Paraspheroolithus*, with a greater eggshell thickness and secondary eggshell units in the columnar layer (Zhao, 1979; Zhao et al., 2015).

Three oogenera, including four oospecies (*Stalicoolithus shifengensis*, *Coralloolithus shizuiwanensis*, *Shixingoolithus erbeni* and *Sh. qianshanensis*), are established in the *Stalicoolithidae* (Zhao et al., 1991; Wang et al., 2012; He et al., 2022). Comparing the eggshell microstructures, the outer zone of the eggshell distributing numerous secondary eggshell units, and the cone layer thickness (0.22–0.32 mm) and cones density (23–26/mm²) of these eggs are close to that of *Stalicoolithus shifengensis* (0.20–0.25 mm, 23–26/mm², respectively, Wang et al., 2012); but the eggshell thickness (3.50–4.00 mm) of *S. shifengensis* (Wang et al., 2012, Zhu et al., 2019) is significantly thicker than that of these eggs, which leads to a significant difference in the thickness ratio of the cone layer to the total eggshell. The accretion lines are slim or invisible in the medial zone of *S. shifengensis*, forming a bright-colored strip, unlike the evenly distributed accretion lines of equal thickness seen in the eggs from Wuning. Comparing these eggs with those of the oogenus *Shixingoolithus* is limited to the cone layer and the inner and medial zones of the columnar layer, due to the fact that all the outermost parts of the eggshell are weathered in both the holotype and referred materials of *Shixingoolithus erbeni* (Zhao et al., 1991, 2015; Fang et al., 1998, 2009a, b) and *Sh. qianshanensis* (He et al., 2022). The thickness ratio of the cone layer to total eggshell (1/10) of the eggs from Wuning is smaller than in *Sh. erbeni* (1/4, Zhao et al., 1991) and *Sh. qianshanensis* (1/7, He et al., 2022), and the secondary eggshell units are much more developed in these eggs than in the oogenus *Shixingoolithus*. The columnar layer of *Shixingoolithus* distributes significantly fewer secondary eggshell units than those of *Stalicoolithus* and *Coralloolithus*. Considering that the secondary eggshell units are easily weathered, it is uncertain whether there is an outer zone composed of secondary eggshell units present in *Shixingoolithus*.

Compared to *Coralloolithus shizuiwanensis*, which was discovered in Xixia and Xichuan of Henan Province (Fang et al., 1998; Zhao and Zhao, 1998; Wang et al., 2012; Zhao

et al., 2015), in Tiantai of Zhejiang Province (Fang et al., 2000, 2003; Wang et al., 2012; Barta et al., 2013; Zhao et al., 2015), and in Shanggao of Jiangxi Province (Fang et al., 2022), the eggs in Wuning have a similar cone density, thickness ratio of cone layer to total eggshell, and closely arranged secondary eggshell units. Therefore, these eggs can be assigned to *Coralloidoolithus shizuiwanensis*. The newly discovered eggs have a slightly greater thickness, which expands the thickness range of *C. shizuiwanensis*. The horizontal accretion lines are almost evenly distributed throughout the eggshells of the Wuning specimens, while the horizontal accretion lines are poorly developed in the medial and outer zones, which are filled with dark materials in the eggshells from Shanggao (Fang et al., 2022). This may represent differences in the preservation conditions of the specimens. Therefore, when classifying and comparing dinosaur eggs, it is necessary to fully consider the eggshell formation mechanism and the possible impact of later diagenesis.

5 Conclusion

These dinosaur eggs discovered from Wuning County, Jiangxi Province, could be referred to the Stalicolithidae based on their shape and size, pore shape, cone shape, and the presence of secondary eggshell units in the columnar layer, and to *Coralloidoolithus shizuiwanensis* based on the ratio of cone layer to total eggshell thickness, evenly distributed accretion lines, and the closely arranged secondary eggshell units in the outer zone.

This clutch of *Coralloidoolithus shizuiwanensis* represents the first discovery of dinosaur eggs in Wuning County, which enriches the palaeogeographical distribution of the oogenus *Coralloidoolithus*, and provides paleontological evidence for the comparison of the strata of the basin containing dinosaur eggs in Jiangxi Province. Also, it confirms the age of the strata containing the dinosaur eggs in this area to be Late Cretaceous. However, further works are required to clarify whether the strata are referred to the Late Cretaceous Lianhe Formation or the age of the Moxia Formation should be revised from Paleogene to Late Cretaceous.

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江西武宁石笋蛋类恐龙蛋蛋窝的发现

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摘要: 记述了江西省武宁县发现的一恐龙蛋不完整蛋窝。基于以下特征将这一新发现归入石嘴湾珊瑚蛋(*Corallooolithus shizuiwanensis*): 恐龙蛋化石近球形, 在蛋窝中紧密不规则分布, 蛋壳厚度2.76–2.97 mm; 水平生长线均匀分布于整个蛋壳, 柱状层中段和外段发育大量次生壳单元。这一蛋窝代表了武宁县恐龙蛋化石的首次发现, 也说明该区域产恐龙蛋地层时代应该为晚白垩世。

关键词: 江西武宁, 晚白垩世, 恐龙蛋, 石笋蛋类

中图法分类号: Q915.2 **文献标识码:** A **文章编号:** 2096-9889(2023)04-0317-09

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