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Discovery of Stalicoolithidae in Shanggao County, Jiangxi Province, China

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Abstract　Here we describe a partially-preserved dinosaur clutch with twelve nearly complete eggs discovered in Shanggao County, Jiangxi Province that can be assigned to *Coralloidoolithus shizuiwanensis*. These dinosaur eggs are nearly spheroid in shape, with an average polar axis of 11.8 cm and an average equatorial diameter of 9.8 cm. The eggshell has a maximum thickness of about 2.5 mm and is composed of a thin cone layer and a multilevel columnar layer, the latter of which can be divided into inner, medial and outer zones. There are dense horizontal growth lines in the inner zone, lamellar and speckled dark materials in the medial zone, and the secondary eggshell units are distributed in the medial and outer zones. According to this discovery, we revise the main taxonomic characteristic of *Coralloidoolithus* in the Stalicoolithidae to be the loose and dark materials in the medial zone of the columnar layer. This discovery not only extends the paleogeographic distribution of *Coralloidoolithus shizuiwanensis*, but also provides comparative evidence of the Late Cretaceous strata in the Shanggao red basin.

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

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1 Introduction

Dinosaur eggs have been collected from the Jiangxi Province since the 1960s, with the first report describing specimens found in Ganzhou and Taihe (Young, 1965). Most of the red bed basins in Jiangxi Province are rich with dinosaur eggs, especially those in the northern cities of Pingxiang (Wang et al., 2012, 2013; Zou et al., 2013; Zhu et al., 2019) and Shangrao (Liu, 1999) as well as those in the southern cities of Ganzhou (Young, 1965; Cheng et al., 2008; Tanaka et al., 2014; He et al., 2017), Xinfeng (Xie, 2001), and Yudu (Yu et al., 2020), but

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there have been no previous reports on eggs from the Shanggao area in northwestern Jiangxi. Here, we report an incomplete dinosaur egg clutch found in Yeshi town, Shanggao County in 2016. The egg clutch was broken up and twelve nearly complete dinosaur eggs were taken out separately (Fig. 1). These eggs are properly protected and housed at the Shanggao Museum, and were numbered as SGMV–002 (distinguished from No. 1 to No. 12).

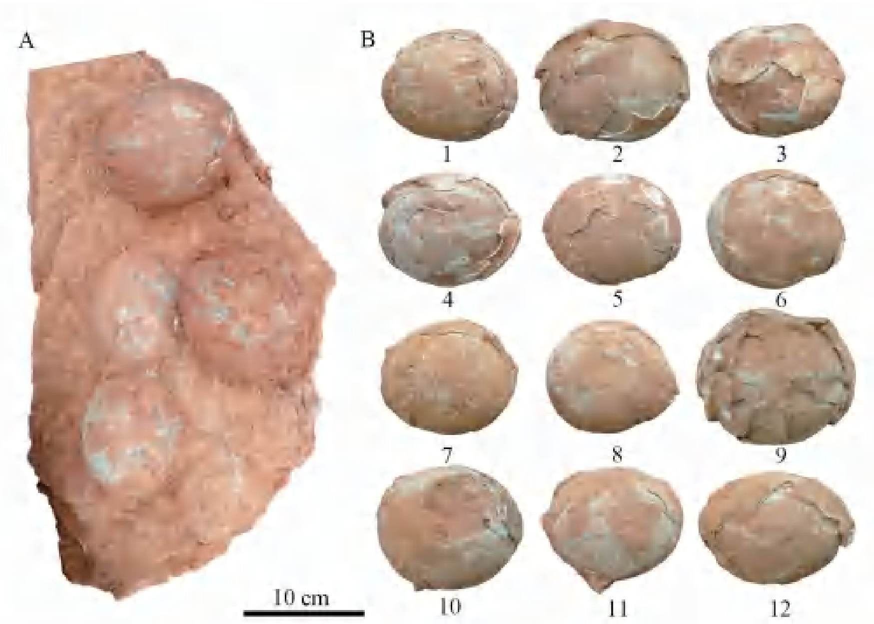

Fig. 1 The incomplete egg clutch showing a disordered stack of eggs (A) and twelve *Coralloidoolithus shizuiwanensis* eggs (B) found in Shanggao County (SGMV-002)

Shanggao County is located in the south of the Jinjiang Basin, which lies in a small Cretaceous red bed basin in northwestern Jiangxi Province (Wang et al., 2011). This region was generally assigned to the lower part of the Upper Cretaceous but without enough paleontological support (Bureau of Geology and Mineral Resources of Jiangxi Province, 1984; Department of Geology and Mineral Resources of Jiangxi Province, 1997).

2 Materials and methods

After measuring and photographing all of the eggs, we collected the eggshell samples from egg No. 2 (Fig. 1B) for hard tissue sections. Eggshell microstructure experiments were carried out in the Key Laboratory of Vertebrate Evolution and Human Origins of the Chinese Academy of Sciences, IVPP. All sections were shaped to a final thickness of about 30 μm using a EXAKT 300 CP macro slicer and EXAKT 400 CS automatic grinding machine. The microstructure of the eggshells was observed using an optical microscope under ordinary light, cross-polarized light, and fluorescence.

3 Systematics paleontology

Stalicoolithidae Wang et al., 2012

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

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

New referred specimens SGMV-002, twelve dinosaur eggs housed at Shanggao Museum; 160722-1①, 160722-1②, 160722-1④, 160722-2①–④, sections of eggshells housed at Institute of Vertebrate Paleontology and Paleoanthropology, Chinese Academy of Sciences (IVPP). In order to facilitate communication and follow-up research, the section numbers used in the study are listed.

Locality and horizon Yeshi Township, Shanggao County, Jiangxi Province; Upper Cretaceous.

Revised diagnosis The eggs are nearly spheroid in shape with a rough surface and are stacked disorderly. The eggshell is composed of parallel eggshell units. The eggshell can be divided into the cone layer and the columnar layer. The cone layer is thin and comprises only about one tenth of the eggshell's thickness. The boundary between the cone layer and the columnar layer is not distinct. The columnar layer can be divided into inner, medial, and outer zones. The inner zone has dense horizontal growth lines and makes up about one third of the thickness of the eggshell. The medial zone has lamellar and speckled dark materials and comprises about one third of the thickness of the eggshell. The secondary eggshell units are distribute in the medial zone, and the outer zone is composed of a large number of secondary eggshell units. The pores are irregular and wormlike in the radial section. The aperture of the pore tends to shrink in the medial zone of the columnar layer and expands in the outer zone.

Description Although the clutch was destroyed, it can be seen that the eggs were arranged irregularly in the clutch (Fig. 1A). The eggs are nearly spheroid in shape (Fig. 1B) with a certain degree of flattening. The average polar axis is 11.8 cm, and the average equatorial diameter is 9.8 cm (Table 1). Eggs are less affected by weathering, preserving some of the most external features show as a bumpy and rough outer surface.

The thickness of the eggshell reaches up to 2.5 mm. The eggshell units are closely arranged (Fig. 2A) and show columnar extinction independently in radial section (Fig. 2B, C). The eggshell can be divided into the cone layer and the columnar layer (Fig. 2A, B).

The cone layer is thin, and the thickness ranges from 0.15–0.25 mm, which is about one tenth of the eggshell's thickness (Fig. 3A, B). The cones are tightly arranged with discrete cone gaps (Fig. 3D). The cone consists of a nucleation center and the surrounding wedges. In tangential section, the cones are round or oval with a nucleation center and the surrounding

Table 1 Measurements of eggs from Shanggao (cm)

	1	2	3	4	5	6	7	8	9	10	11	12	Average
Polar axis	12.0	12.1	11.8	11.9	12.0	11.7	11.8	11.7	12.0	10.9 (residual)	11.5	11.2	11.8
Equatorial diameter	9.7	9.4	10.1	10.2	9.8	10	10.2	10.0	8.9	9.6	9.6	9.5	9.8

wedges form a flower-like shape (Fig. 3D). The cones show cross extinction in cross-polarized light (Fig. 3E). The nucleation center area has a brighter fluorescence than the wedges (Fig. 3C). The nucleation centers and wedges are not visible, and the cone boundaries are clearer at the higher level of the cone layer (Fig. 3F).

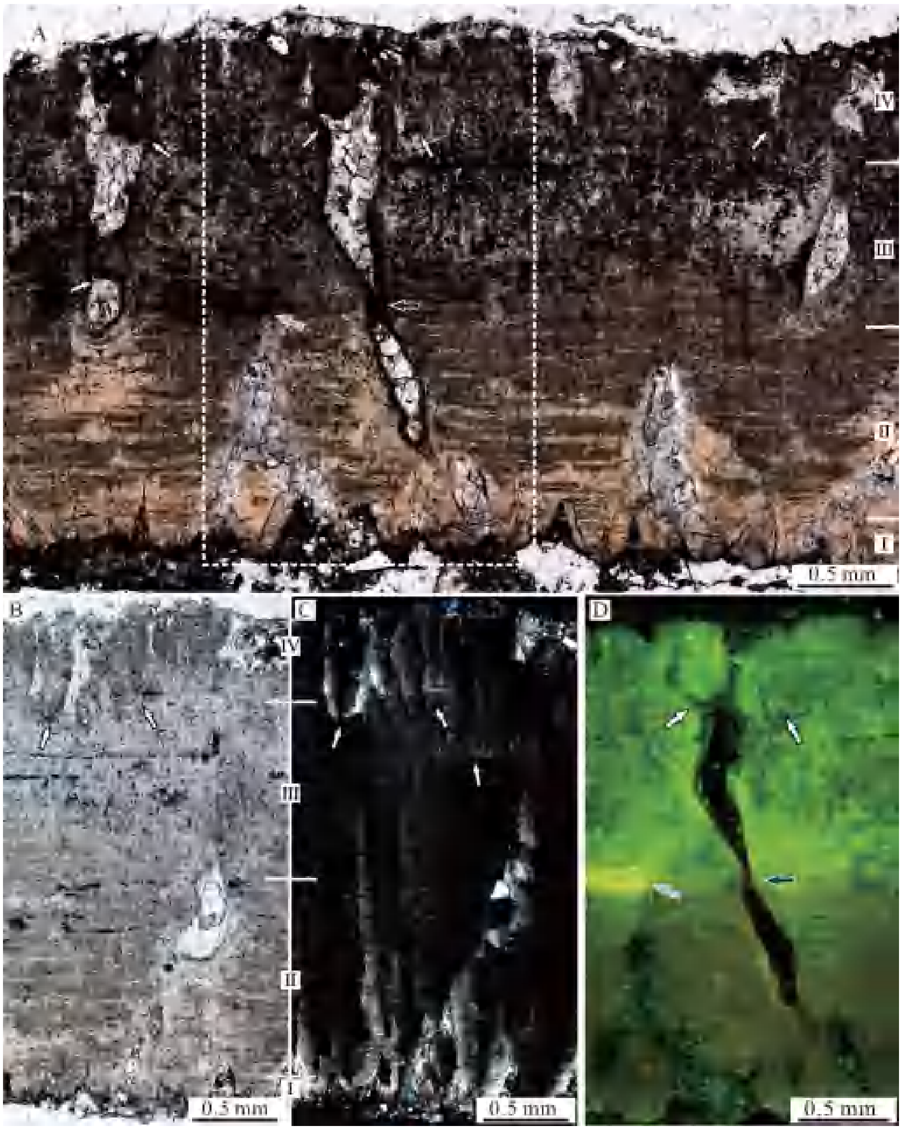

Fig. 2 Radial section of the *Coralloidoolithus shizuiwanensis* egg under ordinary light (A, B), cross-polarized light (C) and fluorescence (D)

A, D. 160722-1④; B, C. 160722-1①

I. the cone layer; II. the inner zone; III. the medial zone; IV. the outer zone

A. a wide horizon of *Coralloidoolithus shizuiwanensis* in radial section, pore canals are irregular and tend to shrink in the medial (black arrow), dark materials appears (gray arrow) and secondary eggshell units distribute in the medial and outer zones (white arrows); B. a large number of secondary eggshell units (white arrows) comprise the outer zone; C. eggshell units and secondary eggshell units (white arrows) show columnar extinction; D. the region of the white line in Fig. 2A, shows pore canal (black arrow) and secondary eggshell units (white arrows), dark material has the bright fluorescence (gray arrow)

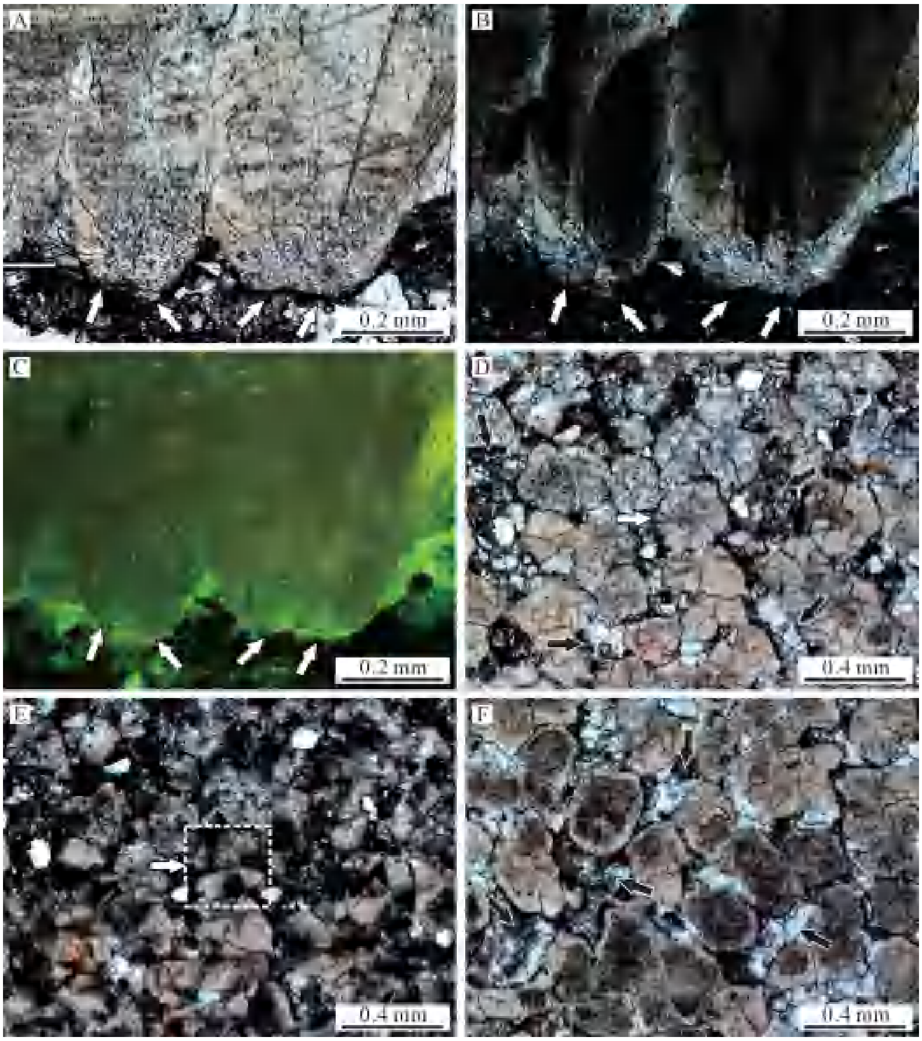

Fig. 3 Characteristics of the cone layer of the *Coralloidoolithus shizuiwanensis* egg
A–C. radial section under ordinary light (A), cross-polarized light (B) and fluorescence (C) respectively; D–F. tangential section under ordinary (D, F) and cross-polarized (E) light
A–C. 160722-1②; D–F. 160722-2①
Every cone has a nucleation center in different modes (white arrows) (A–C), nucleation centers have bright fluorescence, while the surrounding wedges have darker fluorescence relatively (C); nucleation center is flower-like (the position corresponds to the white line in A of radial section) (D) and shows cross extinction (white arrows) (E), cone gaps are scattered between the cones (black arrows) (D, F) and cone outlines are clearer at a higher level of the cone layer (F)

The columnar layer is thick and can be divided into inner, medial, and outer zones (Fig. 2A–C). The pores are developed and wormlike in shape (Fig. 2A). The average thickness of the inner zone is about 0.9 mm, about one third of the eggshell's thickness, and it is mainly characterized by the continuous development of dense horizontal growth lines (Fig. 2A, B). The fluorescence of the inner zone is not obvious (Fig. 2D). The pores are fusiform in radial section (Fig. 2A) and irregular in tangential section (Fig. 4A).

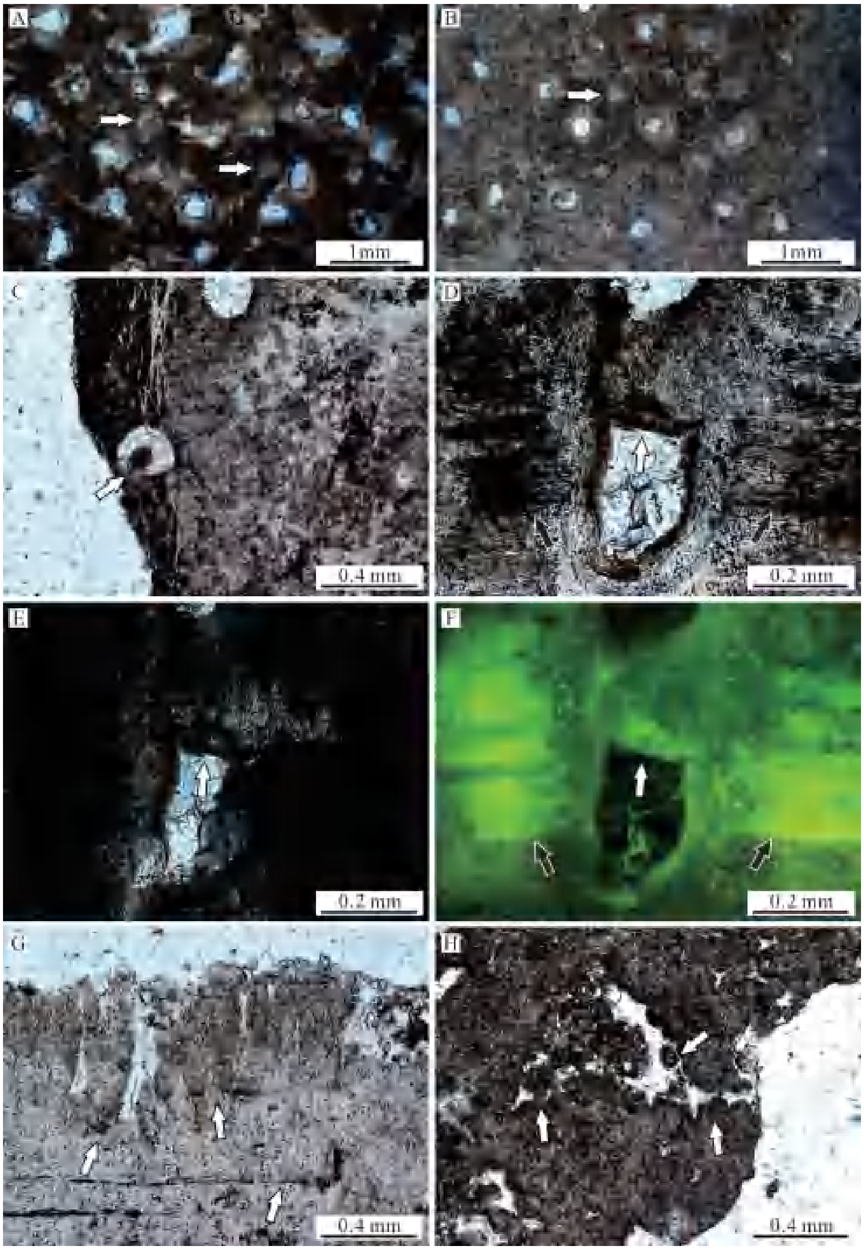

Fig. 4 Characteristics of the columnar layer of the *Coralloidoolithus shizuiwanensis* egg
A–C. tangential section through the inner zone (160722-2②) (A), and through the medial zone (160722-2③) (B, C) under ordinary light; D–F. radial section through the medial zone (160722-1④) under ordinary light (D), cross–polarized light (E) and fluorescence (F); G, H. radial section through the outer zone (160722-1②) (G), and tangential section through the outer zone (160722-2④) (H) under ordinary light
The density and diameter of pores in the medial zone are smaller than that in the inner zone, and some pores closure (white arrows) (A, B); secondary eggshell units grow in pore canals (white arrows) (C–F), some layered dark materials with bright fluorescence are distributed (black arrows) in the medial zone (D, F); close-up of the outer zone of Fig. 2B, secondary eggshell units are abundant (white arrows) (G); secondary eggshell units grow around the inner wall of the pores (white arrows) (H)

The average thickness of the medial zone is about 0.8 mm, which is about a one third of the eggshell's thickness. The growth lines become blurred in the medial zone, replaced by some lamellar and speckled dark materials instead (Fig. 2A, B). These dark materials have a bright fluorescent effect (Fig. 2D), which may reflect the locations of organic residues. Secondary eggshell units may occur in the medial zone (Fig. 4C–F), but this is not the primary zone of their growth. Pores in tangential section are relatively regular and nearly round (Fig. 4B). The density and the aperture of the poles decrease in the medial zone. The aperture of some pores can reach 0.1–0.2 mm, and some pores are closed (Fig. 4B). There is a gradual process in the eggshell structure between the inner and medial zone. The growth lines gradually weaken and the dark spots increase, but the inner and medial zone can be clearly distinguished under fluorescence (Fig. 2D).

The average thickness of the outer zone is about 0.6 mm, which is about one forth of the eggshell's thickness. A large number of the secondary eggshell units grow in the pores filling them in, and a portion of them clearly show a trend of growing around the inner wall of the pores (Figs. 2A, B; 4G, H). The columnar extinctions under the cross–polarized light of the secondary eggshell units are consistent overall (Fig. 2C).

4 Discussion and conclusion

According to Wang et al. (2012) and Zhao et al. (2015), the Stalicoolithidae have a spherical or nearly spherical macromorphology with a rough surface, and the eggs are randomly arranged in the clutch. The eggshell is thick, reaching up to 4 mm. In radial section, the columnar layer can be divided into inner, medial, and outer zones. The growth lines are well developed in the inner zone, a large number of secondary eggshell units are developed in the outer zone, and the diameter and density of the pore canals are reduced in the medial zone. Therefore, it is concluded that the eggs from Shanggao are from a member of the Stalicoolithidae.

There are three genera and three species (*Stalicoolithus shifengensis*, *Shixingoolithus erbeni*, and *Coralloidoolithus shizuiwanensis*) in the Stalicoolithidae (Zhao et al., 2015), and there are some distinguishing features for each species. In terms of the structure of the eggshell unit, the medial zone of *Stalicoolithus* is a bright part with a compact arrangement of calcite crystals with a few dark materials and makes up about one forth of the eggshell's thickness (Wang et al., 2012:fig. 4A). This is also true for *Shixingoolithus* (Zhao et al., 2015:fig. 72A, B). In contrast, the medial zone of *Coralloidoolithus* is relatively loose, contains a large number of intermittent lamellar and speckled dark materials, and is one third of the eggshell's thickness (Fig. 2; Wang et al., 2012:fig. 5A). Furthermore, when comparing the structure of the secondary eggshell units in type specimens, the secondary eggshell units of *Stalicoolithus* are dense and vimineous, which is the most obvious in the microscopic section of the three generaand the secondary eggshell units of *Coralloidoolithus* are relatively short and fat, although no outer zone have been found in type specimen of *Shixingoolithus*, but studies of Stalicoolithidae suggest that it should have an outer zone in its columnar layer. However, in the extensive observation, we found the morphological diversity of the secondary eggshell units, which needs to be further studied. The specimen of Shanggao has a loose medial zone in the vast majority of the columnar layer with a large number of dark materials, therefore it belongs to the *Coralloidoolithus shizuiwanensis*.

It is worth mentioning that *Stalicoolithus* is generally thick, can measure up to 3.0–4.0 mm or more in thickness, while *Coralloidoolithus* is relatively thin, with a complete thickness of about 2.5–3.0 mm. As the outer layer of the holotype of *Shixingoolithus* is missing (Zhao et al., 2015:fig. 72A, B), the retained part of eggshell is rather equivalent to *Stalicoolithus* without the outer zone, and the relationship between them is open to debate. Combined with previous cases, it can be seen that there are a large number of transitional characteristics and characteristics that are difficult to quantify such as the transformation of calcite mineralization

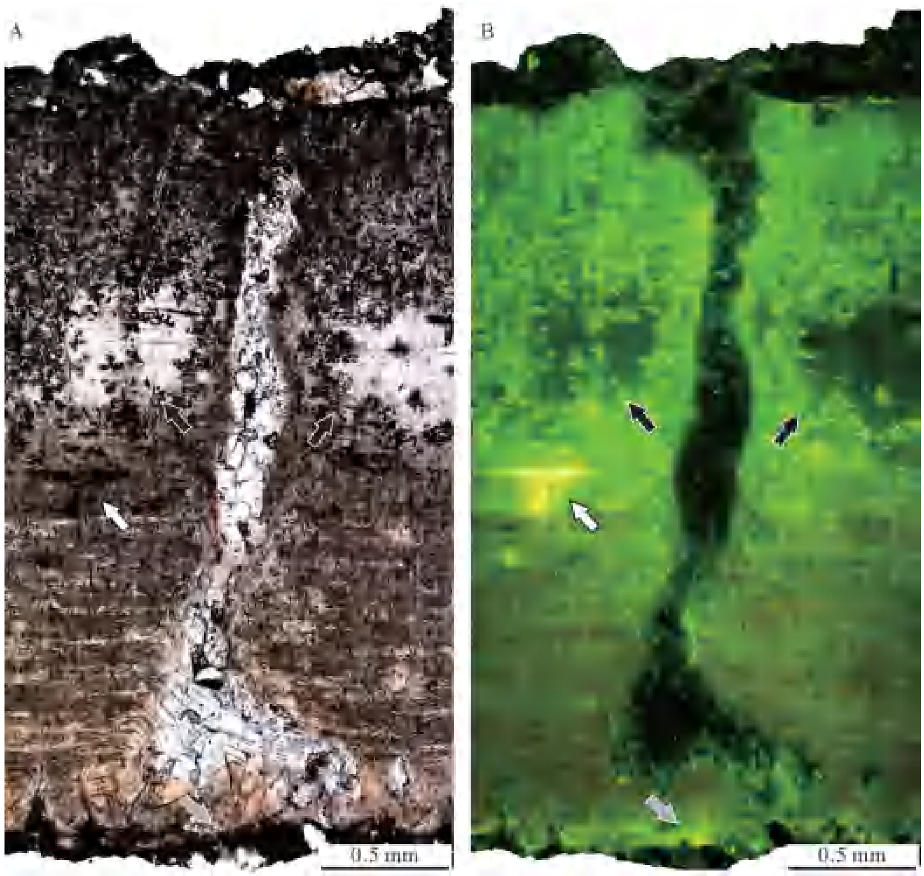

Fig. 5 Radial section of the *Coralloidoolithus shizuiwanensis* egg (160722-1④) under ordinary light (A) and fluorescent (B)

A nucleation center of the cones with a bright fluorescence (gray arrows), dark material with bright fluorescence appears in the middle zone (white arrows) and some areas of the medial zone have transparent crystals of calcite (black arrows) in the columnar and the characteristics of secondary eggshell units between different genera, which adds uncertainty to the evolutionary relationship in Stalicoolithidae.

The discovery of this specimen further enriches the variation range of some characteristics of *Coralloidoolithus*. Compared with the type specimen of *Coralloidoolithus*, it has some different characteristics, such as the nearly spherical macromorphology and relatively dense and translucent crystal arrangement in the local area of the medial zone of the columnar layer. The part with a bright fluorescence inside the fossil eggshell structure may be residual organic material (Dravis and Yurewicz, 1985; Magathan, 1986; Russo et al., 1997, 2006; Jackson et al., 2010). In contrast, the secondary calcite formed during the burial period as the large transparent calcite that fill in the pore canals and has no fluorescence. In the eggshell of the Shanggao specimen, the locations of the dark materials and bright fluorescence are consistent (Fig. 5A, B). In addition, the fluorescence of the translucent crystals, which is not common in *Coralloidoolithus* in the local part of the medial zone, is not obvious (Fig. 5A, B), and growth lines can be seen under the fluorescence light (Fig. 5B). The existence of this structure may reflect the local differences in the growth of calcite microcrystals under the control of organic matter in the process of biomineralization or as the result of changes in the structure of the eggshell later during burial, which may also reveal the internal relationship between different growth patterns in the Stalicoolithidae.

The Cretaceous stratigraphic classification of Jiangxi Province is mostly based on the strata in the southern Jiangxi Province. Due to the lack of accurate paleontological evidence, we reference the geological work in northern Jiangxi and open digital mapping data to conclude that the Shanggao location bearing the dinosaur eggs belongs to the Upper Cretaceous. Other localities include the Lower Cretaceous of Sangping (Sangping Formation), Henan Province (Fang et al., 1998, 2007), the Upper Cretaceous of Xichuan (Majiacun Formation), Henan Province, and the Upper Cretaceous of Tiantai (Chichengshan Formation), Zhejiang Province (Wang et al., 2012; Zhao et al., 2015). Unfortunately, we only know definitively that the exact age of the Chichengshan Formation of Tiantai basin is 91–94 Ma (Turonian) (He et al., 2013) and there is still a lot of work to do in geochronology and paleontology in this region.

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江西上高石笋蛋类恐龙蛋的发现

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摘要：记述了江西省上高县发现的一窝不完整蛋窝的恐龙蛋。根据恐龙蛋宏观形态和蛋壳显微结构特征将其归入石嘴湾珊瑚蛋(*Coralloidoolithus shizuiwanensis*)。该窝恐龙蛋为近圆形球体，平均长径11.8 cm, 平均赤道直径9.8 cm, 蛋壳厚度可达2.5 mm; 蛋壳由锥体层与柱状层组成，锥体层较薄，柱状层可分为内层、中间层和外层，内层发育致密的水平生长纹，中间层结构松散，含有大量暗色物质，中间层和外层发育次生壳单元。依据新标本的观察，明确珊瑚蛋属在石笋蛋科中以柱状层中间层结构松散为主要分类特征。上高新标本的发现，丰富了石嘴湾珊瑚蛋的古地理分布，同时也为上高地区晚白垩世含恐龙蛋红层的对比提供了新的证据。

关键词：江西上高，晚白垩世，恐龙蛋，石笋蛋类

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References

Bureau of Geology and Mineral Resources of Jiangxi Province, 1984. Regional Geology of Jiangxi Province. Beijing: Geological Publishing House. 1–307

Cheng Y N, Ji Q, Wu X C et al., 2008. Oviraptorosaurian eggs (Dinosauria) with embryonic skeletons discovered for the first time in China. Acta Geol Sin–Engl, 82(6): 1089–1094

Department of Geology and Mineral Resources of Jiangxi Province, 1997. Stratigraphy (Lithostratic) of Jiangxi Province. Wuhan: China University of Geosciences Press. 1–286

Dravis J J, Yurewicz D A, 1985. Enhanced carbonate petrography using fluorescence microscopy. J Sediment Petrol, 55(6): 795–804

Fang X S, Lu L W, Cheng Z W et al., 1998. Cretaceous Egg Fossils of Xixia, Henan. Beijing: Geological Publishing House. 7–40

Fang X S, Zhang Z J, Pang Q Q et al., 2007. Cretaceous strata and egg fossils in Xixia, Henan Province. Acta Geol Sin, 28(2): 123–142

He F L, Huang X J, Li X Y, 2017. Occurrence rule and buried characteristics of dinosaur fossils in the Ganzhou Basin, Jiangxi Province. East China Geol, 38(4): 250–254

He H Y, Wang X L, Wang Q et al., 2013. SIMS zircon U–Pb dating of the Late Cretaceous dinosaur egg–bearing red deposits in the Tiantai Basin, southeastern China. J Asian Earth Sci, 62: 654–661

Jackson F D, Horner J R, Varricchio D J, 2010. A study of a *Troodon* egg containing embryonic remains using epifluorescence microscopy and other techniques. Cretaceous Res, 31(2): 255–262

Liu Y G, 1999. Classification and stratification of dinosaur eggs in Jiangxi Province. Jiangxi Geol, 13(1): 3–7

Magathan E R, 1986. New wave carbonate research: what paleontologist can learn from it. Palaios, 1(1): 104–106

Russo F, Neri C, Mastandrea A et al., 1997. The mud mound nature of the Cassian Platform margins of the Dolomites. A case history: the Cipit bounders from Punta Grohman (Sasso Piatto Massif, Northern Italy). Facies, 36: 25–36

Russo F, Gautret P, Mastandrea A et al., 2006. Syndepositional cements associated with nannofossils in the Marmolada Massif: evidences of microbially mediated primary marine cements? (Middle Triassic, Dolomites, Italy). Sediment Geol, 185: 267–275

Tanaka K, Shao Z F, Fan S H et al., 2014. Intact theropod dinosaur eggs with embryonic remains from the Late Cretaceous of southern China. Geol Bull China, 33(7): 941–948

Wang Q, Wang X L, Zhao Z K et al., 2012. A new oofamily of dinosaur egg from the Upper Cretaceous of Tiantai Basin, Zhejiang Province, and its mechanism of eggshell formation. Chinese Sci Bull, 57: 3740–3747

Wang Q, Zhao Z K, Wang X L et al., 2013. A new form of Elongatoolithidae, *Undulatoolithus pengi* oogen. et oosp. nov. from Pingxiang, Jiangxi, China. Zootaxa, 3746(1): 194

Wang X P, Zhou J T, Fan A, 2011. The metallogenic model of the Qibaoshan lead and zinc iron cobalt deposit in Shanggao County, Jiangxi Province. J East China Inst Tech, 34(3): 248–256

Xie Z D, 2001. Characteristics of fossil dinosaur egg horizon in Datang Basin of Xinfeng and biostratigraphic classification. Jiangxi Geol, 15(3): 176–180

Young C C, 1965. Fossil eggs from Nanhsiung, Kwangtung and Kanchou, Kiangsi. Vert PalAsiat, 9(2): 19–37, 49–67

Yu C T, Fan X J, Zhong L Y, 2020. Distribution of dinosaur egg fossils and occurrence stratigraphic characteristics of Yudu Basin, southern Jiangxi. East China Geol, 41(4): 94–100

Zhao Z K, Wang Q, Zhang S K, 2015. Dinosaur eggs. Palaeovertebrata Sinica. Vol II, Amphibians, Reptilians, and Avians, Fascicle 7. Beijing: Science Press. 80–89

Zhu X F, Fang K Y, Wang Q et al., 2019. The first Similifaveoloolithidae (*Wormoolithus luxiensis* oogen. et oosp. nov.) from the Upper Cretaceous of Jiangxi Province, China. Hist Biol, 33(7): 1–10

Zou S L, Wang Q, Wang X L, 2013. A new oospecies of parafaveoloolithids from the Pingxiang Basin, Jiangxi Province of China. Vert PalAsiat, 51(2): 102–106