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A New Ootype of Dinosaur Egg (Faveoloolithidae: *Duovallumoolithus shangdanensis* oogen. et oosp. nov.) from the Late Cretaceous in the Shangdan Basin, Shaanxi Province, China

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Abstract: A new ootype collected from the Upper Cretaceous Lijiacun Formation in the Shangdan Basin, Shaanxi Province is described in this paper. Based on general external shape, size, eggshell thickness and honeycomb-like eggshell microstructure, eggs are referable to the oofamily Faveoloolithidae. Compared with other members of Faveoloolithidae, specimens described in this paper show special characteristics: adjacent pores are usually separated by two eggshell units between which often develop interspaces; columnar eggshell units are relatively closely arranged in radial view. According to these characteristics, we erect a new oogenus and a new oospecies: *Duovallumoolithus shangdanensis* oogen. et oosp. nov. The new discovery expands the diversity of Faveoloolithidae.

Key words: dinosaur egg, Faveoloolithidae, Late Cretaceous, Shangdan Basin, Shaanxi Province, China

1 Introduction

Several dinosaur eggs were unearthed during road construction at Renjiacun, Yangyuhe town, Shangluo city in March 2017 (Hao Ziguo et al., 2017). Upon the discovery of the eggs, both Shaanxi Nature Museum and Bureau of Land and Resources of Shangluo arrived at the site and conducted excavation work immediately. Eleven eggs were yielded at two sites which adjoined each other by less than one meter (Fig. 1). Four single complete eggs are preserved in Shaanxi Nature Museum; and two clutches containing seven eggs in the Bureau of Land and Resources of Shangluo City, three eggs for one clutch and four eggs for the other.

Little is reported about dinosaur eggs in Shaanxi province (Hao Ziguo et al., 2016). As early as 1987, dinosaur eggs were discovered in Lijiacun and Shanyang in the city of Shangluo (Xue Xiangxi et al., 1996). They were initially identified as *Spheroolithus* and the red beds containing dinosaur eggs in the Shangdan Basin was named Lijiacun Formation. Based on these discovered dinosaur eggs, the geologic age was confirmed as the Late Cretaceous. At that time, Xue Xiangxi et al. (1996) did not describe the characters of those dinosaur eggs in detail. In addition, the new excavation site, Renjiacun is 3 km away from the outcrop of the Lijiacun Formation.

This paper gives a systematic paleontological description of the newly discovered dinosaur eggs and identified its specific ootype. The study on these specimens will also provide new paleontological evidence for the classification and comparison of the dinosaur egg-bearing red beds.

2 Geological Settings

The Shangdan Basin is one of the largest basins in the eastern part of Qinling Mountains (Fig. 2). The basin is about 55 km long and only about 5 km wide, with a total area of about 200 km^2. The Shangdan Basin trends mainly along the southern Shangdan fault, which plays a controlling role of the basin's boundary and evolution (Xue Xiangxi et

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Fig. 1. The excavation site of dinosaur eggs layer in the Shangdan Basin.

al., 1996). The Paleozoic forms the main basement strata of the Shangdan Basin. Based on the sections of Lijiacun and Renzhi, Xue Xiangxi et al. (1996) divided the Mesozoic strata of Shangdan Basin into Lower Cretaceous Donghe Group (Fengjiashan Formation) and Upper Cretaceous Lijiacun Formation from bottom to top. Furthermore, the Lijiacun Formation can be subdivided into two members, both of which are confirmed to host dinosaur eggs.

After the discovery of the eggs at Renjiacun, we compared the new site with the Lijiacun Formation described by Xue Xiangxi et al. (1996). The dinosaur egg-bearing red beds at Renjiacun are composed of conglomerates and silty mudstones, and the gravels are mainly granite. The upper member of Lijiacun Formation is composed of reddish-brown mudstone, greyish-green sandstone with imbedded sandy mudstone, or grayish sandstone, glutenite interbedded with reddish-brown mudstone. While the lower member of Lijiacun Formation is mainly composed of sandy mudstone imbedded with hick sand conglomerate. Therefore, the Renjiacun site that containing dinosaur eggs should be the Upper Cretaceous Lijiacun Formation.

3 Samples and Methods

3.1 Research materials

Eggs collected in Shaanxi Nature Museum (GSW-087-2, GSW-087-3, GSW-087-4, GSW-087-5) (Fig. 3) and eggs collected in Bureau of Land and Resources of Shangluo City (SLGTJ-RJC-1, SLGTJ-RJC-2) (Fig. 4). After the eggs collected by Shaanxi Nature Museum have been prepared, the morphology data of eggs were measured, and eggshell thin sections of the scattered eggshells were prepared for microstructural study.

3.2 The preparation of eggshell thin sections

One piece of eggshell was selected after ultrasonic cleaning. It was split into two pieces and embedded in resin. One was prepared into two radial sections (D170323-1-1, D170323-1-2), the other was prepared into three tangential sections (D170323-2-1, D170323-2-2, D170323-2-3). Then they were observed, measured and photographed under a polarizing microscope. The preparation and microstructural study of eggshell thin sections were completed at Key Laboratory of Vertebrate Evolution and Human Origin of Chinese Academy of Sciences, Institute of Vertebrate Paleontology and Paleoanthropology, Chinese Academy of Sciences.

3.3 Systematic paleontology

Faveoloolithidae Zhao, 1976

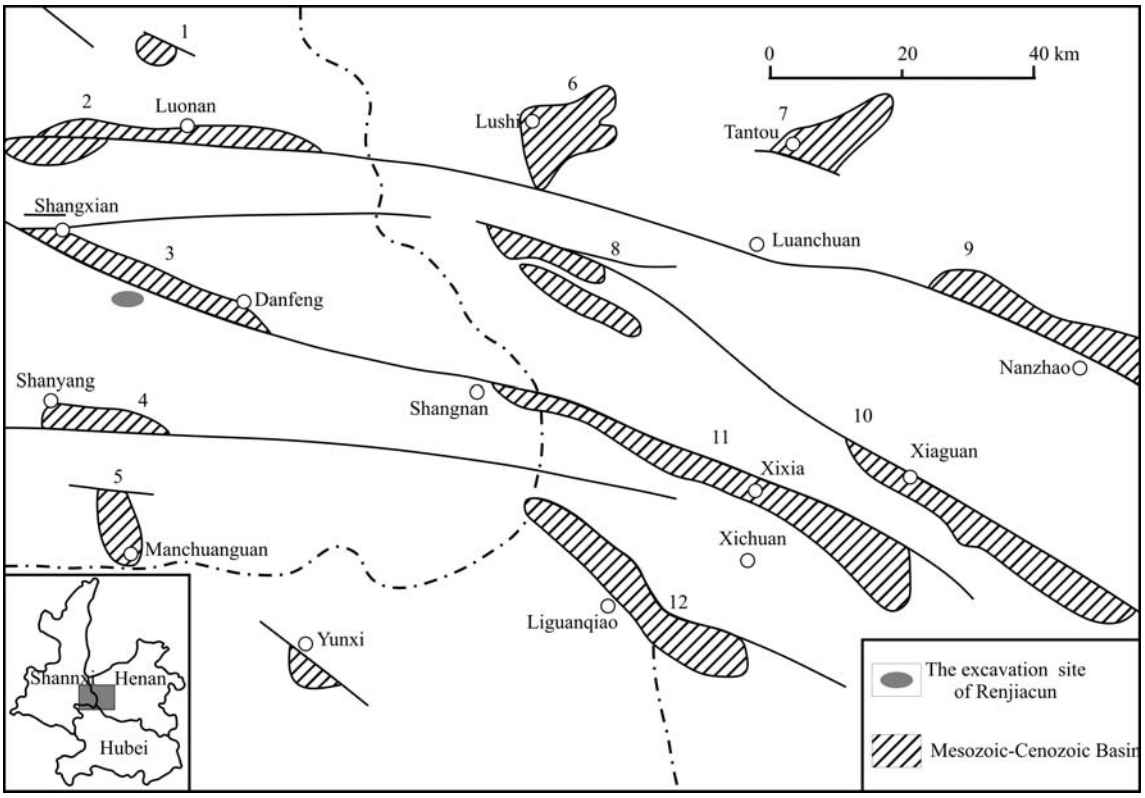

Fig. 2. The Mesozoic-Cenozoic basins in the eastern part of Qinling Mountains and the excavation site of Renjiacun (modified from Xue Xiangxi et al., 1996)

1, Shimen Basin; 2, Luonan Basin; 3, Shangdan Basin; 4, Shanyang Basin; 5, Manchuanguan Basin; 6, Lushi Basin; 7, Tantou Basin; 8, Wulichuan Basin; 9, Mashiping Basin; 10, Xiaguan Basin; 11, Xixia Basin; 12, Liguanqiao Basin.

***Duovallumoolithus* oogen. nov.**

Etymology: 'duo', Latin for double. 'vallum', Latin for wall. Implying that every two adjacent pores are separated by two eggshell units.

Diagnosis: see oospecies diagnosis below.

***Duovallumoolithus shangdanensis* oogen. et oosp. nov.**

Etymology: "shangdan" is the Chinese pinyin of the Shangdan Basin.

Holotype: four single dinosaur eggs (GSW-087-2, GSW-087-3, GSW-087-4, GSW-087-5), collected in Shaanxi Nature Museum (Fig. 3), eggshell thin sections (D170323-1-1, D170323-1-2, D170323-2-1, D170323-2-2, D170323-2-3) collected in Institute of Vertebrate Paleontology and Paleoanthropology, Chinese Academy of Sciences.

Paratype: two clutches containing seven eggs (SLGTJ-RJC-1, SLGTJ-RJC-2) collected in Bureau of Land and Resources of Shangluo (Fig. 4).

Other specimens: several eggshell fragments collected in Shaanxi Nature Museum.

Locality and horizon: Renjiacun, Yangyuhe town, Shangluo, Shaanxi Province, Lijiacun Formation, Late Cretaceous.

Diagnosis: The eggs are subsphaeroidal in shape and have a smooth outer surface. The eggshell is composed of one singlelayer of eggshell units which are columnar in shape and closely arranged, honeycomb-like structure can be observed through out the eggshell. Every two adjacent pores are separated by two eggshell units and interspaces are often observed between the two eggshell units.

Description: The eggs are subsphaeroidal in shape (Fig. 2) and have a smooth outer surface, the polar axis varies between 165–192 mm and the equatorial diameter varies between 143–168 mm, averaging 181 mm and 154 mm respectively. Shape index is 85.08 on average (Table 1). The eggshell is relatively thick with an average thickness of 1.80 mm. The eggshell is composed of one single layer of eggshell units which are closely arranged and shows columnar distinction under polarized light (Fig. 5a, b), and no secondary eggshell unit is observed, while interspaces can be observed in radial view (Fig. 5b). The eggshell pores are honeycomb-like in tangential views and are irregular both in size and shape, most of which are nearly round, oval, or irregular (Fig. 5c–f), the pore diameter varies between 0.12 to 0.44 mm. Instead of separated by a single eggshell unit like in other faveoloolithids, adjacent pores are usually separated by 2 eggshell units, between

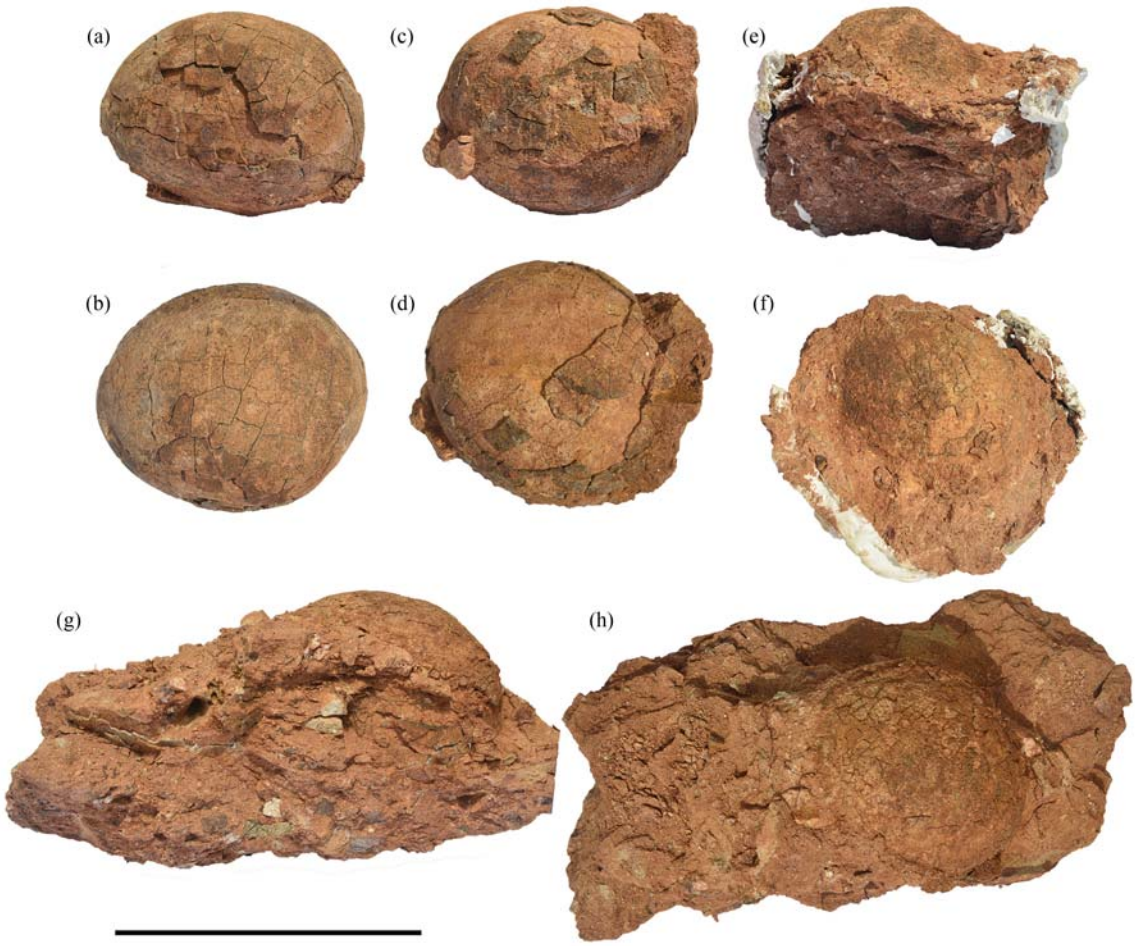

Fig. 3. Holotype collected in Shaanxi Nature Museum.
(a, b), lateral and upper views of GSW-087-2; (c, d), lateral and upper views of GSW-087-3; (e, f), lateral and upper views of GSW-087-4; (g, h), lateral and upper views of GSW-087-5. Scale bar equals 20 cm

Table 1 Morphology data of dinosaur eggs collected in Shaanxi Nature Museum

No.	polar axis (mm)	Equatorial iameter (mm)	shape index
GSW-087-2	175	168	96.0
GSW-087-3	192	156	81.3
GSW-087-4	165	148	89.7
GSW-087-5	192	143	74.5

which usually develops interspace, this is in accord with the observation in radial section (Fig. 5e, f). Eggshell is not fused near the outer surface, and pores change very little from the inner surface to the outer surface.

4 Comparison and Discussion

The specimen described in this paper can be assigned to Faveoloolithidae based on the honeycomb-like eggshell structure observed in tangential section. Faveoloolithids includes *Faveoloolithus* (Zhao Zikui and Ding Shangren, 1976; Zhang Shukang, 2010; Wang Qiang et al., 2011; Zhao Zikui et al., 2015), *Parafaveoloolithus* (Zhang Shukang, 2010; Zhao Zikui et al., 2015), and *Hemifaveoloolithus* (Wang Qiang et al., 2011; Zhao Zikui et al., 2015) of Faveoloolithidae and *Youngoolithus* (Zhao Zikui, 1979; Zhang Shukang, 2010; Zhao Zikui et al., 2015) of Youngoolithidae. Differ from the olive-like shape of *Youngoolithus xiaguanensis*, the eggs described in this paper are subsphaeroidal in shape and their eggshell is only composed of one single layer of eggshell units, which differ from *Youngoolithus xiaguanensis*'s (Zhao Zikui and Ding Shangren, 1976; Zhang Shukang, 2010). The eggshell unit described in this paper is arranged relatively close, and pore density is low, the characteristics that eggshell units near outer surface are not fused is different from *Parafaveoloolithus macroporus* and *P. microporus* whose eggshell units is arranged loosely (Zhang Shukang, 2010). In addition, the single-layer arranged eggshell units is also different from *P. tiansicunensis* (Zhang Shukang, 2010), *P. pingxiangensis* (Zou Songlin et al., 2013) and *P. wannanensis* (Hu Yuanchao et al., in press) which developed secondary eggshell unit and superimposed by double-layer or multi-layer eggshell units in some place. The most unique features of the specimens described in

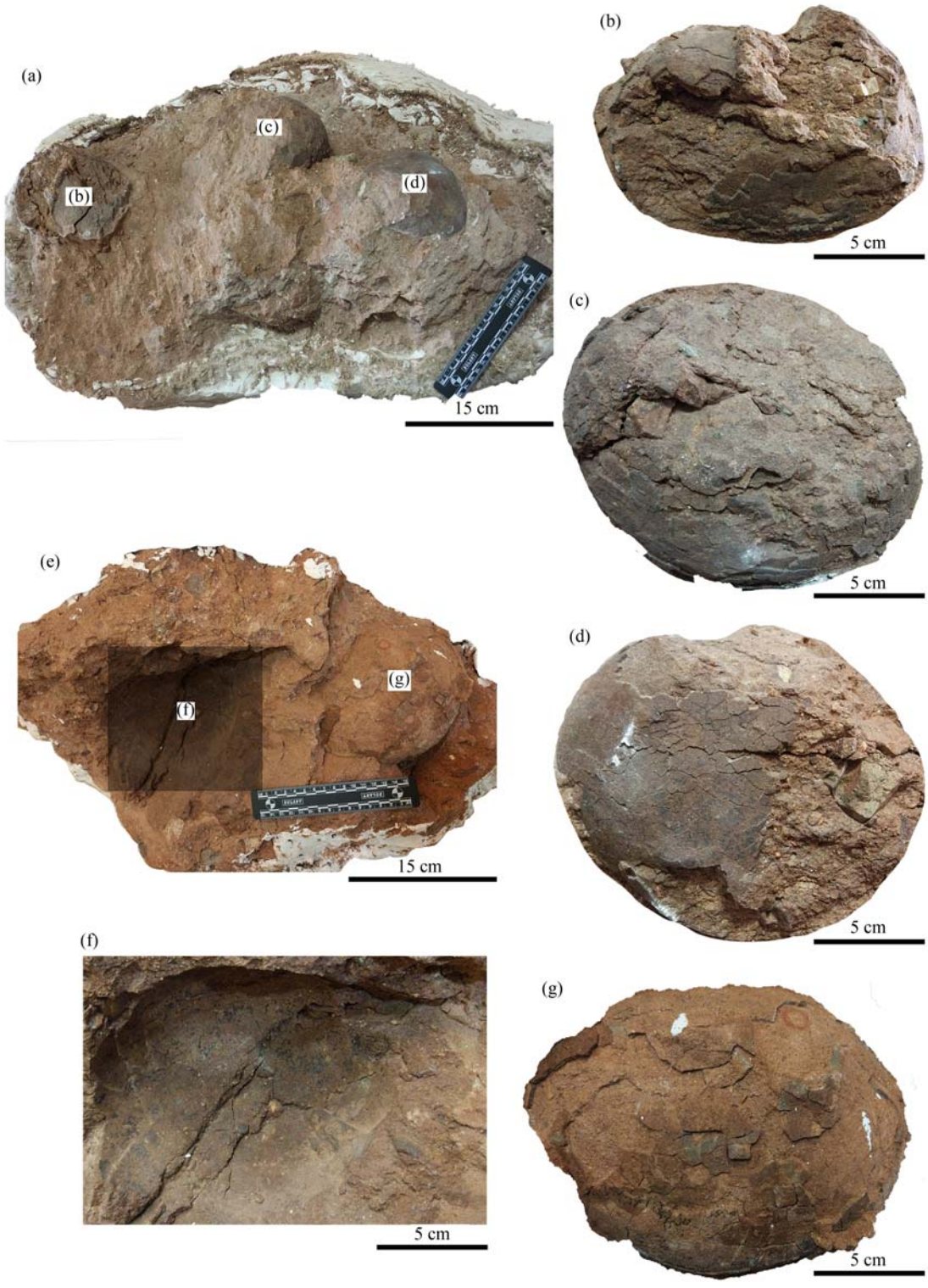

Fig. 4. Two partial clutches housed in Bureau of Land and Resources of Shangluo.
(a), SLGTJ-RJC-1; (b), the left egg shows in a; (c), the upper egg shows in a; (d), the right egg shows in a; (e), SLGTJ-RJC-2; (f), an egg print in shaded area in e; (g), the egg shows in e.

this paper is that adjacent pores are usually separated by two eggshell units between which often develops interspaces. According to these comparisons and these features, we erect a new oogenus and a new oospecies *Duovallumoolithus shangdanensis*.

Faveoloolithids are widely distributed in China. They are considered to be the relatively primitive ootypes (Zhao Zikui, 1994) which has not yet been found in dinosaur egg

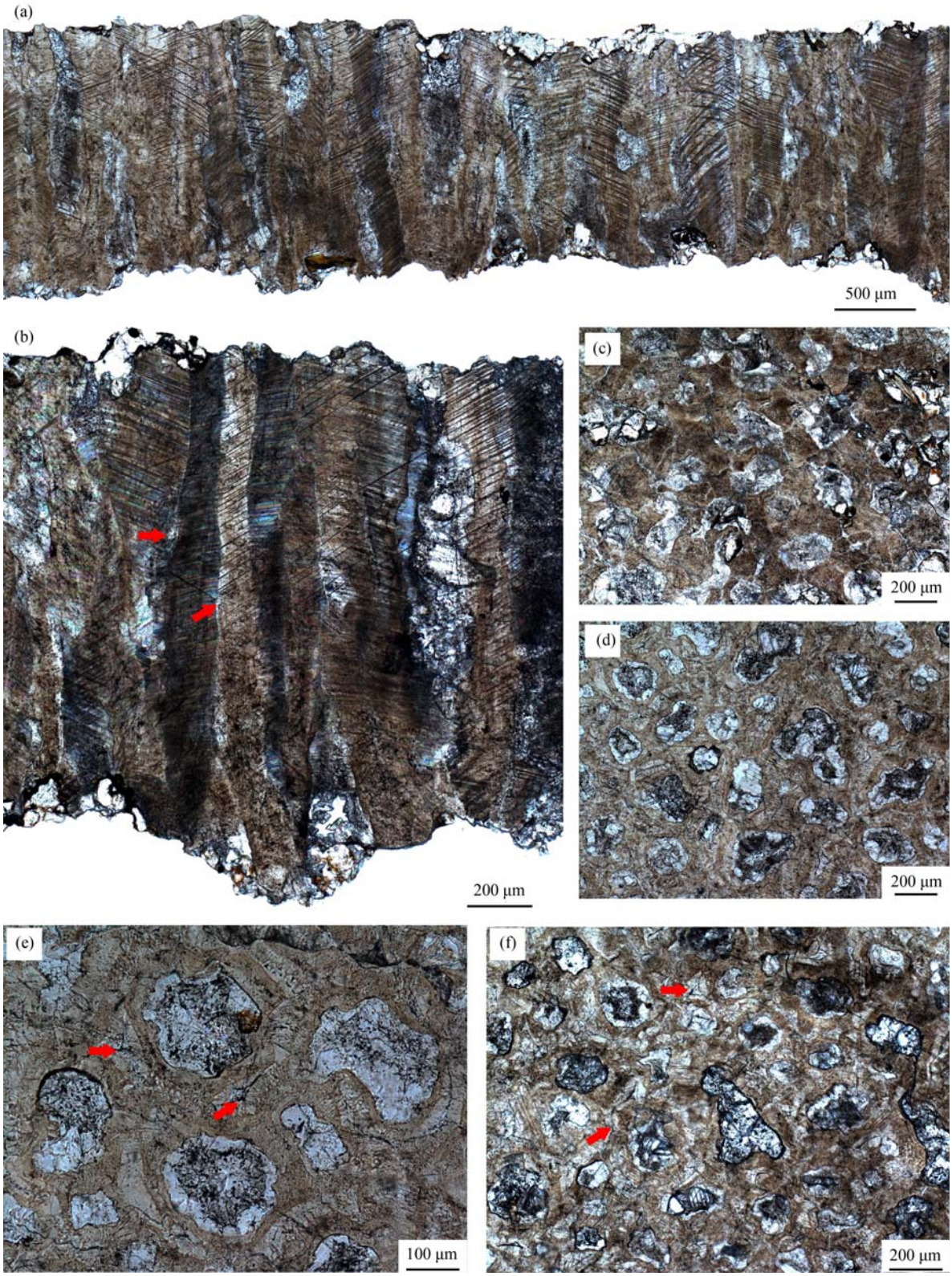

Fig. 5. Eggshell microstructure of *Duovallumoolithus shangdanensis* oogen. et oosp. nov.

(a), Radial section of eggshell showing the columnar eggshell units compactly arranged to each other; (b), Radial section of eggshell showing the columnar extinction eggshell units, while red arrows indicate the interspaces between the eggshell units; (c), Tangential section near the inner surface of eggshell showing the honeycomb-like pores and the closely arranged columnar eggshell units; (d), Tangential section through the middle part of eggshell showing the closely arranged columnar eggshell units and round, oval or irregular pores with different sizes; (e), Magnification of one segment of D showing the microstructure of columnar eggshell units, red arrows indicate the interspaces; (f), Tangential section near the outer surface of eggshell showing round, oval or irregular pores with different sizes and the structure of columnar eggshell units, red arrows indicate the interspaces. (b in cross polarized light, a, c, d, e and f in normal light).

fossil groups at middle-late stage of Late Cretaceous (Wang Xiaolin et al., 2012). Xue Xiangxi et al. (1996) considered that the Lijiacun Formation in Shangdan Basin can be compared with Shanyang Formation in Shanyang Basin, the age of the Shangdan Basin containing *Duovallumoolithus shangdanensis* oogen. et oosp. nov. described in this paper should be late Early Cretaceous to early Late Cretaceous, and there are some differences between it and the middle-late stage of Late Cretaceous strata in Shanyang Basin. As a result, the age of Lijiacun Formation in Shangdan Basin should be late Early Cretaceous to early Late Cretaceous.

Numerous Mesozoic-Cenozoic basins exist in the eastern part of Qinling Mountains, most of which have yielded dinosaur eggs. The study of these eggs will provide more paleontological information for the division and correlation of the strata in the dinosaur egg-bearing basins as well as their formation and evolution.

5 Conclusion

Based on the unique feature that every two adjacent pores are separated by two eggshell units and interspaces are often observed between the two eggshell units, this study confirmed a new oogenus and oospecies of Faveoloolithidae.

The Lijiacun Formation in the Shangdan Basin should be late Early Cretaceous to early Late Cretaceous in age.

This study presents the first detailed systematic description of the dinosaur egg in Shaanxi province, and provides more paleontological information for division and correlation of the strata in the dinosaur egg-bearing basins as well as their formation and evolution.

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