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New ootype prismatoolithids from the Late Cretaceous, Laiyang Basin and its significance

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Abstract Here we discribe a new ootypes of prismatoolithids found from the Late Cretaceous Jiangjunding Formation in the Laiyang Basin, Shandong Province. On the basis of characters such as elongate ovoids, smooth eggshell surface, relatively thinner eggshell thickness, prismatic eggshell units, slender pores in radial section of eggshell and little pores with round or irregular shapes in tangeital section of eggshell, we erect one new oogenus and one new oospecies: *Laiyangoolithus lixiangensis* oogen. et oosp. nov. The discovery of *L. lixiangensis* not only enriches the diversity and composition of the Laiyang Dinosaur Egg Fauna, but the paleogeographic distribution of primatoolithids as well. In addition, it provides more paleontological materials for the study of the diversity and paleogeographic distribution of troodontids in China.

Key words Laiyang, Shandong; Late Cretaceous; Jiangjunding Formation; dinosaur eggs, Prismatoolithidae

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1 Introduction

Laiyang is an important locality in China that is rich in both dinosaur bones and dinosaur eggs (Wang et al., 2010). The well-developed terrestrial strata around Laiyang are composed of the Lower Cretaceous Laiyang Group, Qingshan Group and the Upper Cretaceous Wangshi Group. The Wangshi Group is divided from bottom to top into the Xingezhuang, Jiangjunding, Jingangkou and Changwangpu formations (Hu et al., 2001). The Jiangjunding and Jingangkou formations contain rich concentrations of hadrosauroid bones, coexisting with an abundance of other vertebrate bones and dinosaur eggs. The dinosaurs and dinosaur eggs in the Wangshi Group form the Laiyang Hadrosauroid Fauna and Dinosaur Egg Fauna (Wang et al., 2010; Zhang et al., 2017).

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The Laiyang Dinosaur Egg Fauna was first found in 1950. Teachers and students from University of Shandong collected some dinosaurs and dinosaur eggs from the Upper Cretaceous strata around Laiyang, which were reported by Chow (1951). After that, Young C. C. led a field expedition to Laiyang in 1951 (Wang et al., 2010; Zhang et al., 2017). The team carried out massive excavations at Jingangkou (Wangshi Group) and Doushan (Qingshan Group), digging out an abundance of dinosaurs and dinosaur eggs. Young (1954) studied the dinosaur eggs and divided them into two categories: short eggs (*Oolithes spheroides*) and long eggs (*Oolithes elongates*), and proposed the preliminary classification of dinosaur eggs. Chow (1954) described the microstructure of dinosaur eggshells. These early studies helped to lay the methodological and nomenclatural foundation for subsequent research on dinosaur eggs (Zhang et al., 2017).

In the 1970s, Zhao Zikui further studied the microstructure of dinosaur eggs found in Laiyang Basin, and erected the two oofamilies, the Elongatoolithidae and Spheroolithidae (Zhao and Jiang, 1974; Zhao, 1979). According to the macrostructure of eggs and eggshell microstructure characteristics, he established the classification and nomenclature of dinosaur eggs that are widely used in the world today (Zhao and Jiang, 1974; Zhao, 1979). Liu and Zhao (2004) erected *Dictyoolithus jiangi* of the dinosaur eggs found from Laiyang, and Wang et al. (2013a) revised it as *Prodictyoolithus jiangi*. Zhao et al. (2015) verified the types of dinosaur eggs in China, and revised *Spheroolithus jiangjundingensis* found from Laiyang into *S. spheroids* and *S. jiangjundingensis*. Up to now, the Laiyang Dinosaur Egg Fauna has been composed of four oofamilies, five oogenera, and eleven oospecies (Zhao et al., 2013).

Since 2008, the IVPP-Laiyang expedition team has carried out a series of field investigations in Laiyang. These investigations have revealed sets of valleys and more than ten dinosaur bone and egg sites have been found in the valleys (Zhang et al., 2017). Among these fossils, a single elongated egg is the most noteworthy. This specimen was identified as a new type of turtle egg and named *Emydoolithus laiyangensis* (Wang et al., 2013b). Other specimens, especially some that have been collected in the past years, include new types of dinosaur eggs that have remained undescribed but can likely be assigned to the Elongatoolithidae, Ovaloolithidae or Prismatoolithidae based on preliminary observations (Zhao et al., 2013). Here, we will give a detailed report of the prismatoolithid dinosaur eggs found in 2012.

2 Systematic paleontology

Prismatoolithidae Hirsch, 1994

***Laiyangoolithus lixiangensis* oogen. et oosp. nov.**

Etymology The oogeneric name derives from 'laiyang'- Chinese phonetic alphabet of the locality Laiyang, the oospecific name 'lixiang'- Chinese phonetic alphabet from the hometown of the "Laiyang-pear".

Locality and horizon Jiangjunding village of Laiyang, Upper Cretaceous, Jiangjunding Formation.

Holotype An incomplete egg fossil (IVPP V 25232) (Fig. 1), dinosaur eggshell sections (120517-09, 120517-10, 120517-11).

Diagnosis Long-oval egg, the outer surface of eggshell smooth and no ornamentation. Thinner eggshell with average thickness is 0.43 mm. The eggshell units are prismatic and tightly arranged. The boundary between the cone layer and the columnar layer is not clear. Thickness of the cone layer is 0.14 mm, about 1/3 of the eggshell thickness. Cones are sturdy. Apertures between cones are clear. Growth lines are obvious in the cone layer. The edge of the eggshell units is composed of dense calcite. The number of pore is very small, and can be seen as round or irregular shapes in tangential section of eggshell.

3 Description and comparisons

An incomplete elongated ovoid egg (Fig. 1), the preserved polar axis about is 5.04 cm, and the equatorial diameter is 5.20 cm. The outer surface of the eggshell is smooth with no

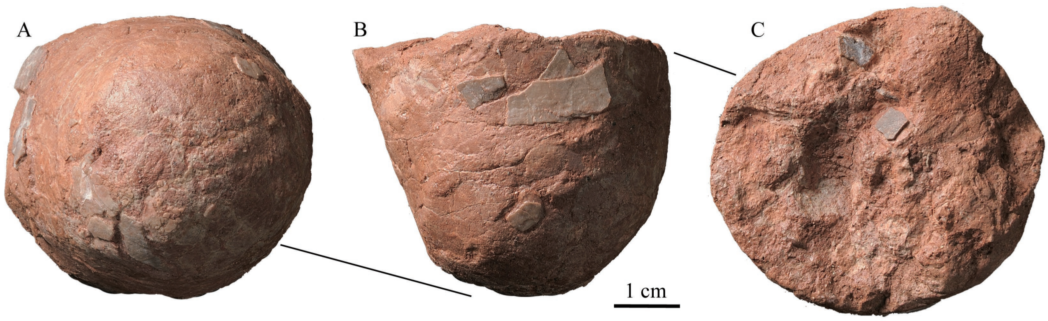

Fig. 1 Holotype of *Laiyangoolithus lixiangensis* oogen. et oosp. nov. (IVPP V 25232)
A. view in tip end of the incomplete egg, only a little eggshell preserved, show smooth surface of eggshells; B. the lateral view of the egg, showing smooth eggshell surface; C. view of the broken surface of the egg

ornamentation (Fig. 1B).

In radial section, eggshell units are prismatic and tightly arranged (Fig. 2). The eggshell is comparatively thinner, with an average thickness of about 0.43 mm. There is no clear boundary between the cone layer and the columnar layer, but they can be distinguished from each other (Fig. 2A). The thickness of the cone layer is 0.14 mm, about 1/3 of the eggshell thickness. There are growth lines in the cone layer that gradually become less obvious from the cone layer to the columnar layer (Fig. 2A). The cones are sturdy, with clear apertures between the cones (Fig. 2A). In tangential section cross the cone layer and near the boundary between the cone layer and the columnar layer, there are clear space between the eggshell units (Fig. 3A, B). In tangential section cross the middle part of the columnar layer and near the outer surface of the eggshell, the eggshell units are also well-defined, and the edge of the eggshell units is composed of dense calcite (Fig. 3C, D). The pores are slender in radial section (Fig. 2A), and unevenly distributed with round or irregular shapes in tangential section (Fig. 3).

According to the following characteristics, the elongated ovoids of the egg, smooth surface of the eggshell, and prismatic eggshell units, the egg can be classidied into the

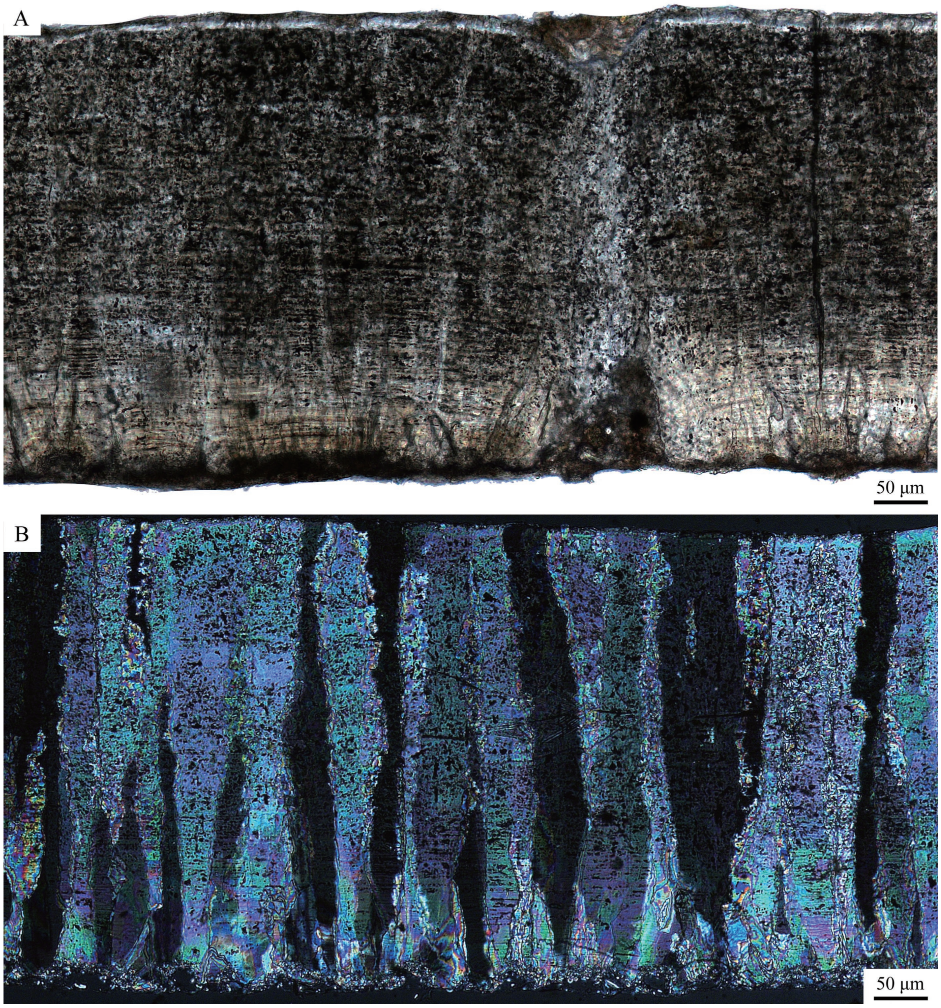

Fig. 2 Eggshell microstructure of *Laiyangoolithus lixiangensis* oogen. et oosp. nov. (IVPP V 25232)
A. radial section of eggshell in normal light, showing the prismatic eggshell units, and no clear boundary between the cone layer and the columnar layer, cones space more clear, with growth line in the cone layer; B. radial section of eggshell in cross polarized light, showing columnar extinction of eggshell units

Prismatoolithidae. At present, there are three oogenera and eleven oospecies of the Prismatoolithidae in the world. Only *Preprismatoolithus coloradensis* was found from America in the Late Jurassic (Hirsch, 1994; Zelenitsky and Hills, 1996). Others are found in the Late Cretaceous. In China, there are *Prismatoolithus gebiensis* at Bayan Mandahu (Zhao and Li, 1993), *Pri. hukouensis* in Nanxiong Basin (Zhao, 2000), *Pri. tiantaiensis* in the Tiantai Basin (Wang et al., 2011), *Pri. heyuanensis*? in the Heyuan Basin (Lü et al., 2006). In Mongolia, there are three oospeicies of *Protoceratopsidovum*, *Pro. sincerum*, *Pro. minimum* and *Pro. fluxuosum* (Mikhailov, 1994). In France, there are *Pri. tenuous* and *Pri. matellensis* (Vianey-Liaud and Crochet, 1993). Also, *Pri. levis* was found from the Two Medicine Formation in America (Hirsch and Quinn, 1990) and the Oldman Formation in Canada (Zelenitsky and

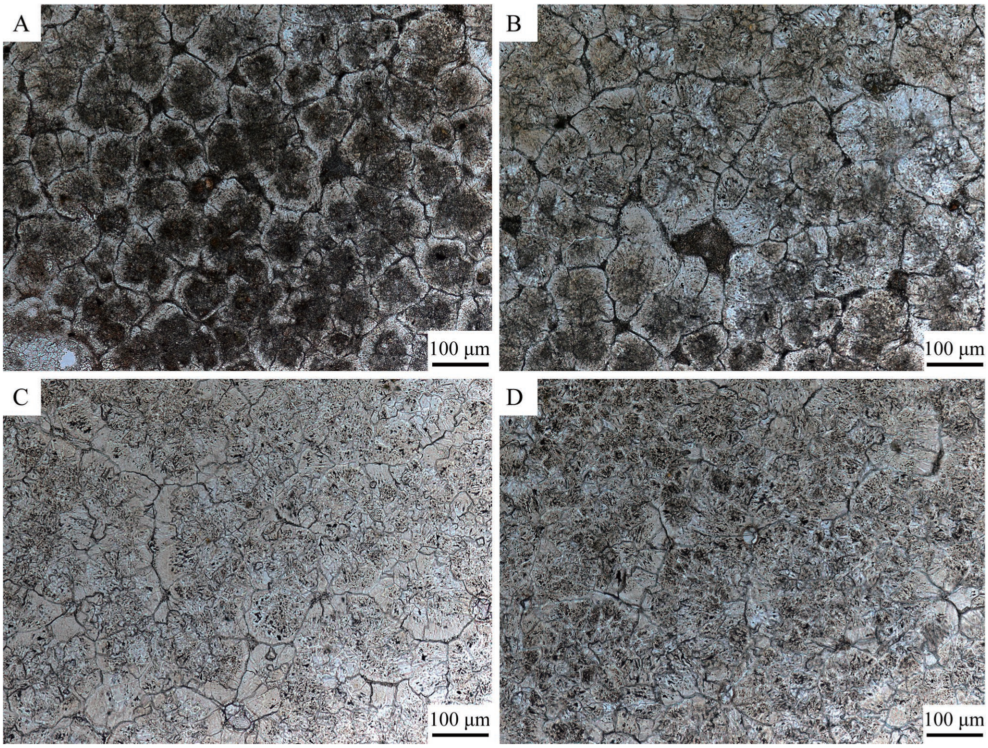

Fig. 3 Eggshell microstructure of *Laiyangoolithus lixiangensis* oogen. et oosp. nov. (IVPP V 25232)
A. tangential section cross the cone layer, showing cones with more clear space between each other; B. tangential section cross the cone layer near the boundary of the cone layer and the columnar layer, showing eggshell units with clear space of cones, and round or irregular pores; C–D. tangentail section cross the middle part of columnar layer (C) and cross nearly outer surface of the eggshell (D), showing eggshell units with clear space, with edge of the eggshell units composed of dense calcite, and unevenly distributed round or irregular pores

Hills, 1996; Zelenitsky et al., 2002).

The eggshell units are sturdy and differ from the slender eggshell units of other prismatoolithids eggs. The edge of the eggshell units is composed of dense calcite, with obvious space between eggshell units. The thinner eggshell thickness with the thickness of the cone layer about 1/3 of the eggshell thickness obviously distinguishes it from other ootypes of prismatoolithids eggs. Based on the differences of the above characteristics, we erect a new oogenus and oospecies *Laiyangoolithus lixiangensis* oogen. et oosp. nov.

Prismatoolithids is one of the few dinosaur egg types that can link dinosaurs with their dinosaur eggs. According to the discovery of embryos from dinosaur eggs in North America, it was linked to the troodontids (Horner and Weishampel, 1988, 1996). As mentioned earlier, prismatoolithids eggs in China that have been described were mainly found in the Late Cretaceous strata (Table 1). In addition, prismatoolithid eggs are also reported in Xixia, Henan Province (Wang et al., 2008). The troodontids are widely distributed in China, and have been distributed from the Middle-Late Jurassic to Late Cretaceous. The main types include 17

Table 1 Troodontids and Prismatoolithids in China

Geological time	Localities	Taxa	References
Middle-Late Jurassic	Jianchang	*Anchiornis huxleyi*	Xu et al., 2008
		Xiaotingia zhengi	Xu et al., 2011b
		Eosinopteryx brevipenna	Godefroit et al., 2013a
		Aurornis xui	Godefroit et al., 2013b
		Serikornis sungei	Lefèvre et al., 2017
		Caihong juji	Hu et al., 2018
Early Cretaceous	Fengning	*Jinjengopteryx elegans*	Ji et al., 2005
	Beipiao	*Sinovenator changii*	Xu et al., 2002
		Mei long	Xu and Norell, 2004
		Sinusonasus magnodens	Xu and Wang, 2004
		Liaoningvenator curriei	Shen et al., 2017b
		Daliansaurus liaoningensis	Shen et al., 2017a
	Yixian	*Jianianhualong tengi*	Xu et al., 2017
	Ordos	*Sinornithoides youngi*	Russell and Dong, 1993
Late Cretaceous	Bayan Mandahu	*Linhevenator tani*	Xu et al., 2011a
		Philovenator curriei	Xu et al., 2012
		*Prismatoolithus gebiensis**	Zhao and Li, 1993
	Xixia	*Xixiasaurus henanensis*	Lü et al., 2010
		*Prismatoolithus gebiensis**	Wang et al., 2008
	Tiantai	*Prismatoolithus tiantaiensis**	Wang et al., 2011
	Nanxiong	*Prismatoolithus hukouensis**	Zhao, 2000
	Heyuan	*Prismatoolithus heyuanensis**	Lü et al., 2006
	Laiyang	*Laiyangoolithus lixiangensis**	this paper

* prismtaoolithids dinosaur eggs; the other taxa are troodontids.

genera and 17 species (Table 1).

Therefore, the discovery of *Laiyangoolithus lixiangensis* not only enriches the diversity of the Laiyang Dinosaur Egg Fauna, but also enriches the palaeogeographic distribution of primatoolithids. In addition, it provides more paleontological materials for the study of the diversity and palaeogeographic distribution of troodontids in China.

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山东莱阳晚白垩世棱柱形蛋新属种及其意义

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摘要：记述了发现于莱阳上白垩统将军顶的半枚蛋化石，据其保存较尖的一端，蛋壳外表面光滑无纹饰，蛋壳较薄，紧密排列的棱柱状壳单元，壳单元边缘由致密的方解石组成，以及气孔较少，气孔呈圆形或椭圆形等特征，将其归入棱柱形蛋科，建立新蛋属新蛋种：梨乡莱阳蛋(*Laiyangoolithus lixiangensis* oogen. et oosp. nov.)。梨乡莱阳蛋的发现不仅丰富了莱阳恐龙蛋化石群组成，同时也增加了棱柱形蛋类的古地理分布，并为研究伤齿龙类的多样性和古地理分布提供了新的证据。

关键词：山东莱阳，晚白垩世，将军顶组，恐龙蛋，棱柱形蛋

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