中国晚白垩世陆相红层与恐龙蛋化石群序列及其地层学意义①

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摘 要：中国的恐龙蛋化石埋藏丰富，分布广泛。迄今为止，已报道有14个省(区)发现恐龙蛋化石。尤其在浙江天台盆地、山东莱阳盆地、广东南雄盆地以及河南西峡和淅川盆地等晚白垩世陆相红层中发现大量的恐龙蛋化石，同时也发现大量共生的恐龙等脊椎动物化石。中国恐龙蛋化石具有数量大、种类多、保存好、分布广、时代跨度大等特点，因此恐龙蛋可以作为中国白垩纪陆相地层划分与对比的重要化石之一。本文在建立天台盆地赖家组和赤城山组的岩石地层、年代地层和恐龙蛋生物地层层序框架的基础上，重点对比讨论了我国几个主要含恐龙蛋沉积盆地的恐龙蛋类群组合序列及其对应的地层关系。同时，对我国周边相邻地区如蒙古、韩国和印度以及其他各个大陆发现的恐龙蛋化石进行了初步对比讨论。

天台恐龙蛋化石群与我国其他几个主要的恐龙蛋化石群之间存在一定的差距。相比较而言，天台恐龙蛋化石群和南雄恐龙蛋化石群组合特征鲜明，前者主要以网形蛋类和蜂窝蛋类为主，后者以长形蛋类为优势类群，结合天台盆地陆相红层中多个凝灰岩夹层获得的98~91 Ma和南雄盆地67 Ma的同位素年龄，据此，天台恐龙蛋化石群代表了晚白垩世早期的恐龙蛋组合，而南雄恐龙蛋化石群则代表了晚白垩世晚期的恐龙蛋组合。

天台恐龙蛋化石群与莱阳恐龙蛋化石群明显不同，莱阳盆地的主要蛋化石类型——圆形蛋类和椭圆形蛋类在天台盆地至今没有被发现。但莱阳恐龙蛋化石群与南雄恐龙蛋化石群比较相似，如莱阳盆地金刚口组以椭圆形蛋类为主，含有少量的长形蛋类，而南雄盆地以长形蛋类为主，含有少量的椭圆形蛋类，其中金刚口椭圆形蛋、薄皮椭圆形蛋、长形长形蛋和安氏长形蛋等2属4种蛋化石在两个盆地均有发现。此外，在莱阳盆地王氏群中下部的将军顶组还发现了相对原始的网形蛋类。综合以上分析，莱阳恐龙蛋化石群大致介于晚白垩世早期的天台恐龙蛋化石群和晚白垩世晚期的南雄恐龙蛋化石群之间，更接近于南雄恐龙蛋化石群，时代应为晚白垩世中-晚期。

天台恐龙蛋化石群与西峡恐龙蛋化石群非常相似，在科一级分类单元中，至少有巨型长形蛋类、蜂窝蛋类和棱柱形蛋类等6个蛋科在两个盆地中均有发现，尤其是巨型长形蛋科仅在天台和西峡两个盆地中有化石记录，其中西峡巨型长形蛋这一蛋种同时产于西峡盆地走马岗组、赵营组和天台盆地的赤城山组。西峡盆地发现的其他一些蛋化石也可以归入到天台盆地新建立的一些蛋化石类型中。据此推断，走马岗组和赵营组与赤城山组的层位可能大致相当。虽然我们对西峡盆地已报道的部分恐龙蛋化石进行了初步厘定，但鉴于西峡盆地大量恐龙蛋化石的形态学和分类学尚存在较多的问题，两盆地的详细对比还有待于进一步的研究。

天台恐龙蛋化石群与淅川盆地的恐龙蛋化石组合差别很大，相应的淅川盆地的恐龙蛋类群与相邻的西峡盆地的差别也较大，此外，在淅川盆地高沟组发现有树枝蛋类，这一类蛋化石在天台盆地未发现，据此推测淅川盆地的时代应晚于天台盆地和西峡盆地。相比较而言，淅川盆地的蛋化石组合与莱阳和南雄恐龙蛋化石群有一定的相似性，都含有长形蛋类、圆形蛋类和椭圆形蛋类等，因而，淅川盆地的马家村组和寺沟组的层位被认为可能与莱阳盆地的金刚口组和南雄盆地的坪岭组相当。

综上分析，我们可以初步建立我国晚白垩世恐龙蛋化石群的组合序列及其对应的地层层序和时代框架，从下至上至少包含了4个恐龙蛋化石群：1)天台恐龙蛋化石群，赋存层位为天台群中上部的赖家组和赤城山组，时代约为晚白垩世早期（塞诺曼期-土伦期）；2)西峡恐龙蛋化石群，赋存层位为走马岗组、赵营组和六爷庙组，晚白垩世早中期（土伦期-桑顿期）；3)莱阳恐龙蛋化石群，赋存层位为王氏群中上部的将军顶组和金刚口组，晚白垩世中晚期（科尼亚克期-坎潘期）；4)南雄恐龙蛋化石群，赋存层位为南雄群园圃组和坪岭组，晚白垩世晚期（坎潘

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① 国家自然科学基金(No.40772017, 41172018)，青年基金(No.40825005)，国家基础科(973)项目(1012CB821900)，中国科学院古脊椎动物与古人类研究所新脊椎动物进化系统学重点实验室项目(2011LESV004)资助；国家自然科学基金(No.91114201)和国家重点基础研究发展计划(2012CB821906)资助出版。

文稿接受日期: 2011-09-08；修改稿收到日期: 2012-01-11, 2012-03-15。

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期—马斯特里赫特期)。此外，随着研究工作的继续和深入，有望建立起包括早白垩世恐龙蛋化石群在内的白垩纪恐龙蛋化石群的组合特征序列，为进一步划分与对比我国白垩纪地层提供更多的基础资料。

关 键 词：生物地层学，恐龙蛋，陆相红层，晚白垩世，天台盆地，中国

中图法分类号：P 534.53　　文献标识码：A　　文章编号：0253-4959 (2012) 02-0400-17

DINOSAUR EGG FAUNAS OF THE UPPER CRETACEOUS TERRESTRIAL RED BEDS OF CHINA AND THEIR STRATIGRAPHICAL SIGNIFICANCE

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Abstract Dinosaur eggs are abundant and widely distributed in China. They play an important role in the division and correlation of Cretaceous terrestrial strata. By studying the lithostratigraphy, chronostratigraphy and dinosaur egg biostratigraphy of the Tiantai Basin, this paper presents preliminary comparisons among the dinosaur egg faunas and strata of the major Chinese basins in which dinosaur eggs have been found. These comparisons show that the dinosaur egg fauna of the Tiantai Basin is the oldest, and is successively followed by younger faunas from the Xixia, Laiyang and Nanxiong basins. Compared against the overall stratigraphic framework of the Upper Cretaceous terrestrial red beds of China, the strata of these four basins are early, early-middle, middle-late and late Late Cretaceous in age, respectively.

Key words biostratigraphy, Dinosaur eggs, terrestrial red beds, Late Cretaceous, Tiantai Basin, China

1 Introduction

Dinosaur eggs are abundant and widely distributed in China. To date, numerous dinosaur egg localities have been reported from 14 provinces /autonomous regions throughout China (Fig. 1). In particular, large numbers of dinosaur eggs have been reported from the Tiantai Basin of Zhejiang Province, the Laiyang Basin of Shandong Province, the Nanxiong Basin of Guangdong Province and the Xixia and Xichuan basins of Henan Province, attracting widespread interest from geologists and paleontologists from around the world. Although research on the dinosaur eggs and other vertebrate fossils from each of these basins is relatively well-known, the overall stratigraphic framework and the relative ages of the deposits in various basins remain uncertain. One major reason for this is the lack of precise and reliable isotopic ages for several key rock units.

As a whole, the record of dinosaur eggs in China has the following characteristics: 1) Great abundance, this is exemplified by Xixia Basin in Henan Province and Heyuan Basin in Guangdong Province, each having yielded more than 10 000 dinosaur eggs; 2) Great variety, the dinosaur oospecies known from China outnumber the total from the rest of the world; 3) Excellent preservation, many dinosaur eggs preserved completely, and most oospecies are known from nests rather than only from isolated eggs or eggshell fragments; 4) Wide distribution, dinosaur eggs occur all over eastern China, as well as in the Junggar Basin in the northwest and in the Songliao Basin in the northeast China, and 5) Large stratigraphic coverage, dinosaur eggs have been found from the Shahai to Pingling local stratigraphic formations in China, spanning from middle-late Early Cretaceous to late Late Cretaceous in age.

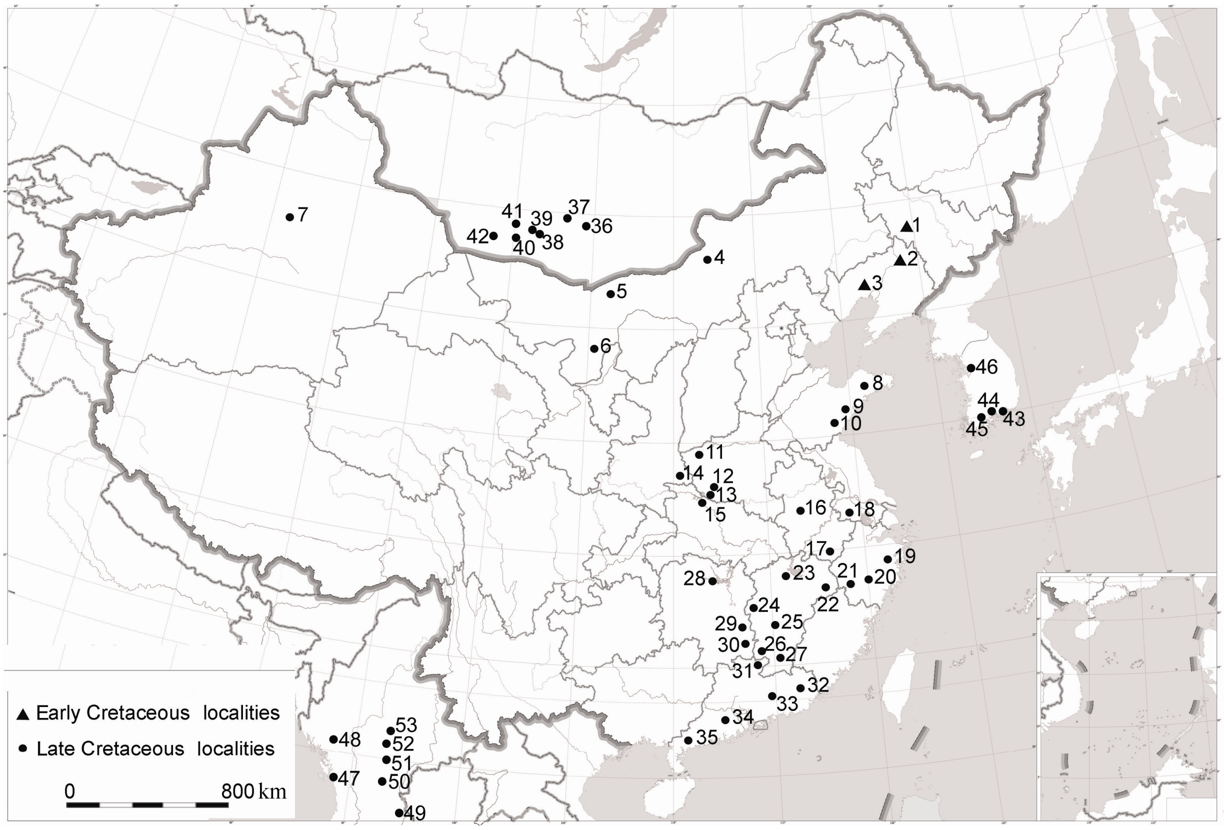

Fig. 1 Dinosaur egg localities in China and neighboring countries

1. Gongzhuling, Jilin Province; 2-3. Changtu and Heishan, Liaoning Province; 4-6. Erenhot, Urat Rear Banner and Alxa Left Banner, Inner Mongolian Autonomous Region; 7. Zhungaer(Junggar), Xinjiang Uygur Autonomous Region; 8-10. Laiyang, Jiaozhou and Zhucheng, Shandong Province; 11-13. Lingbao, Xixia and Xichuan, Henan Province; 14. Shanyang, Shaanxi Province; 15. Yunxian, Hubei Province; 16-17. Guichi and Xiuning, Anhui Province; 18. Yixing, Jiangsu Province; 19-21. Tiantai, Lishui and Quzhou, Zhejiang Province; 22-27. Xinjiang, Gao'an, Pingxiang, Taihe, Ganzhou and Xinfeng, Jiangxi Province; 28-30. Taoyuan, Zhuzhou and Chaling. Hunan Province; 31-35. Nanxiong, Meixian, Heyuan, Guangzhou and Maoming, Guangdong Province; 36-42. Bayn Dzak, Toogreeg, Khulsan, Nemegt, Altan Ula IV, Tsagan Khushu and Khermeen Tsak in Mongolia (Sabath, 1991); 43-46. Hadong, Boseong, Goseong and Whaseong in South Korea (Lee, 2003); 47-53. Bombay, Ahmadabad, Madras, Hyderabad, Asifabad, Nagpur and Jabalpur in India (Mohabey, 1998)

Owing to these features of the record, dinosaur eggs can play an important role in the division and correlation of terrestrial strata in China. In this paper, we present preliminary comparisons among the dinosaur egg faunas and stratigraphic sequences of major Chinese basins in which dinosaur eggs occur, based on the lithostratigraphy, chronostratigraphy and dinosaur egg biostratigraphy of the Tiantai Basin in Zhejiang Province.

2 Major dinosaur egg faunas of China

2.1 Tiantai Basin

The Tiantai Basin is located in the eastern part of Zhejiang Province (Fig. 2) and has an area of about 230 km^2. The Cretaceous strata of the basin are divided into the Moshishan Group and the Tiantai Group, in ascending order. According to new ^{40}Ar-^{39}Ar geochronology and paleomagnetic data, the Moshishan Group is late Early Cretaceous in age (Wang F et al., 2010). The Tiantai Group consists of the Lower Cretaceous Tangshang Formation, composed of ignimbrite, and the Upper Cretaceous Laijia and Chichengshan formations. Dinosaur eggs are present in the upper beds of the Laijia Formation, but more numerous in the first member of the Chichengshan Formation (Fig. 3). A total of nine laminated tuff beds were found interspersed with the red beds of both formations. SIMS U-Pb zircon dating of the Laijia and Chichengshan formations indicated an age of 98~91 Ma (to be published in another paper), corresponding to the early Late Cretaceous (Cenomanian–Turonian).

Detailed studies of stratigraphic sections, and surveys of dinosaur egg localities to accurately locate the dinosaur egg horizons, began in 2007 and are still ongoing. The dinosaur egg fauna of the Tiantai Basin includes seven oofamilies, 12 oogenera and 15 oospecies, according to our own revisions of the work of previous researchers (Wang Q., 2010; Wang et al., 2010b, 2010c, 2011; Zhang, 2010).

Dinosaur eggs were previously reported from the Tiantai Basin by Fang et al. (2000, 2003), Jin et al. (2007) and Qian et al. (2008). However, these papers contain some taxonomic inaccuracies, awaiting later revisions. For example, the nominal oospecies *Macroelongatoolithus zhangi* is a synonym of *M. xixiaensis*, and the genus *Macroelongatoolithus* is distinct from Elongatoolithidae and belongs in a new oofamily alongside the new oogenus *Megafusoolithus* (Wang et al., 2010c). "*Elongatoolithus chichengshanensis*" Fang, 2003, "*E. laijiaensis*" Fang, 2003 and "*E. tiantaiensis*" Fang et al., 2000 are not elongatoolithids either (Wang et al, 2010b).

The Tiantai dinosaur egg fauna are composed of relatively primitive faveoloolithids and dictyoolithids, as well as macroelongatoolithids (Fig. 4). Within China, macroelongatoolithids are otherwise known only from the Xixia Basin of Henan Province. The Laijia Formation has yielded eggs referable to one oofamily, two oogenera, and three oospecies, among which faveoloothids are the dominant group, but a distinctive new mosaicoolithid is also known. Dinosaur eggs are abundant and diverse in the first member of the Chichengshan Formation. Eggs from this member are referable to six oofamilies, nine oogenera and nine oospecies, including two oogenera and oospecies of macroelongatoolithid. Faveoloolithids and dictyoolithids are the prevalent groups in the lower part of the second member of the Chichengshan Formation (Fig. 3).

2.2 Laiyang Basin

The Laiyang Basin,which has also been called the Jiaolai or Laizhu Basin in the east of Shandong Province (Fig. 5) was the site of the first substantive discoveries of, and sustained research on dinosaur and dinosaur egg fossils in China (Wang X. et al., 2010). It has yielded many dinosaurs, such as the famous hadrosaur *Tsintaosaurus* (Young, 1958) as well as *Tanius* (Wiman, 1929; Young, 1958; Zhen, 1976) and *Shantungosaurus* (Hu, 1973; Hu et al., 2001). Since 2008, we have extensively investigated the distribution of dinosaur bones and eggs in the Laiyang Basin, and found dinosaur bones and eggs at many different localities and stratigraphic levels (Wang X. et al., 2010). In particular, we excavated two sites containing dinosaur bones and eggs in the Laiyang Basin in 2010 and 2011(Fig. 5).

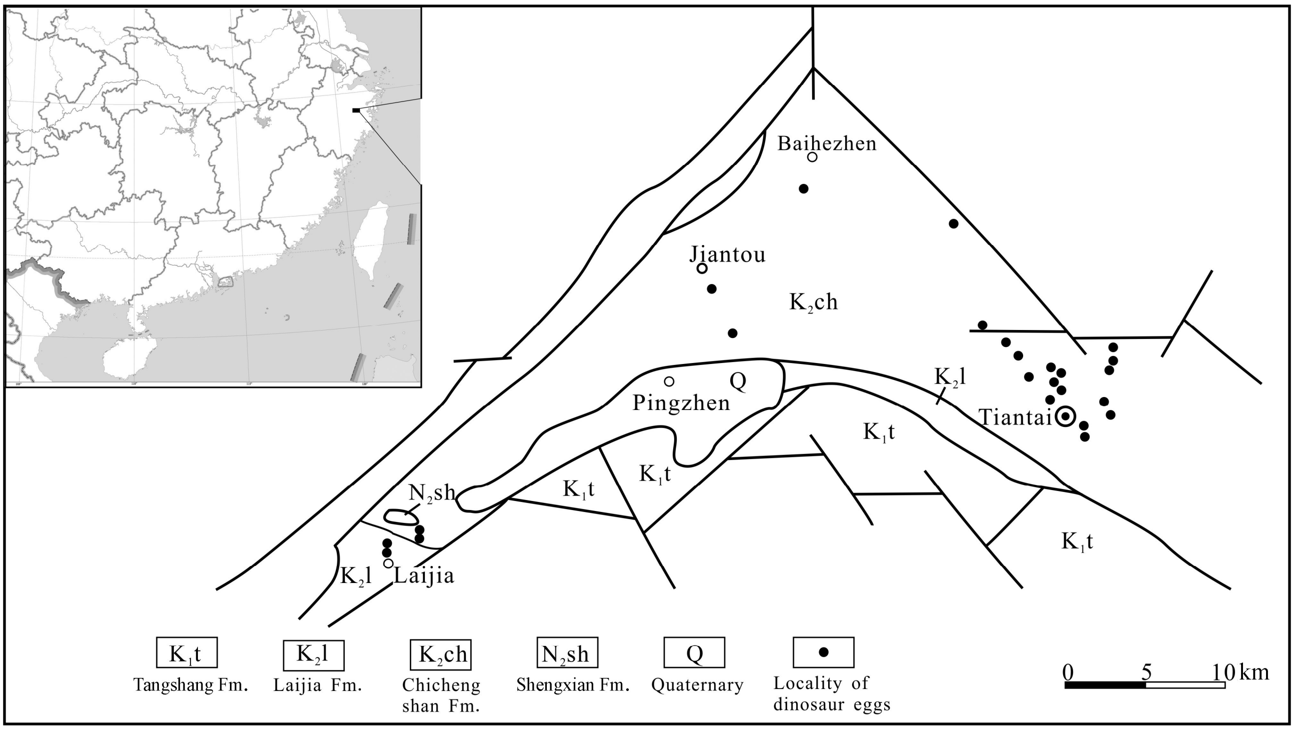

Fig. 2　Localities of dinosaur eggs of the Tiantai Basin, Zhejiang Province

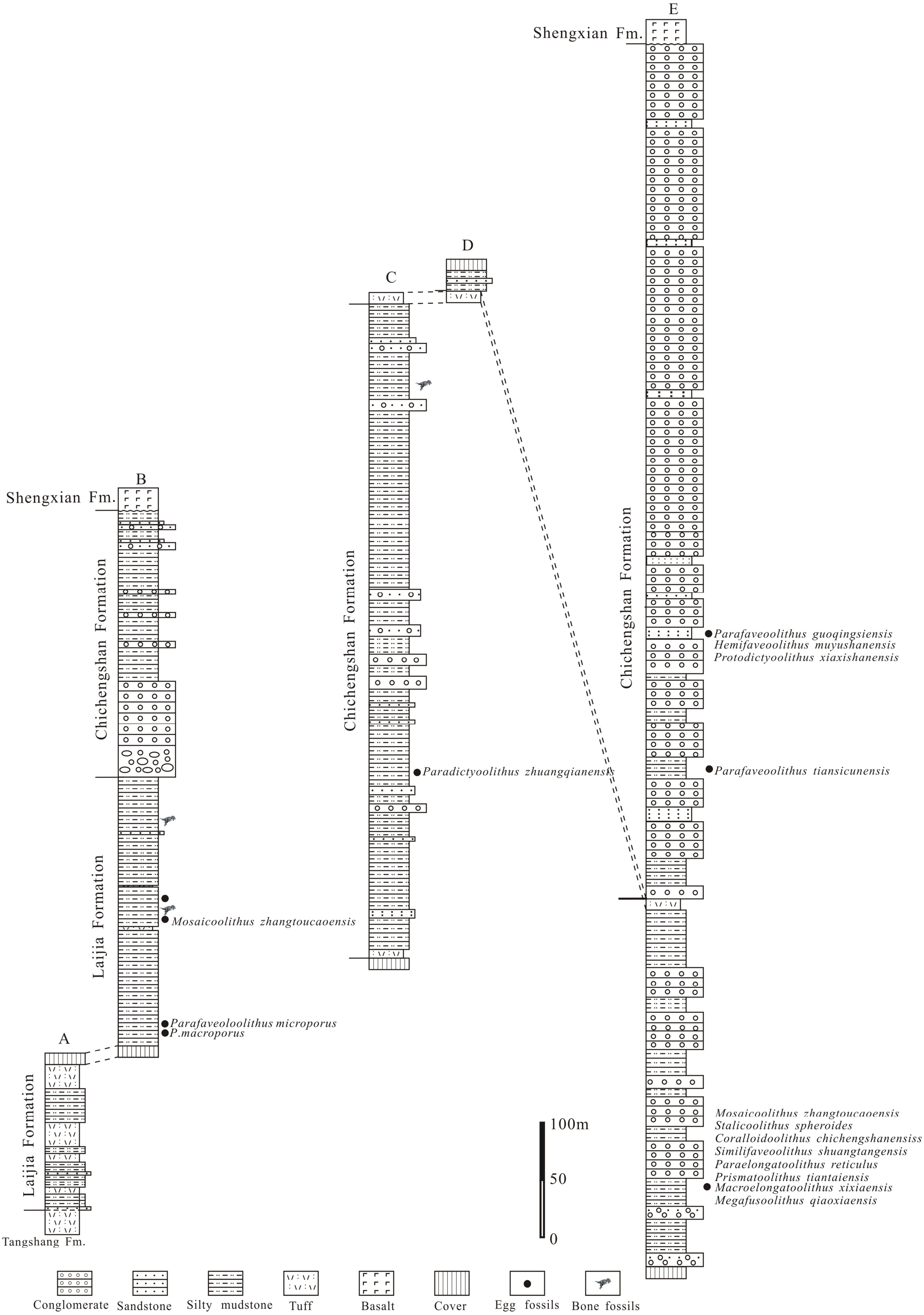

Fig. 3 Strata and dinosaur egg fauna of the Tiantai Basin (modified from Wang Q, 2010, PhD thesis)

A. Jincun Section; B. Laijia-fangshan Section; C. Tunqiao Section; D. Jiantou Section; E. Ganjuchang-Guoqingsi Section

The strata of the basin comprise red sandstones, siltstones, and mudstones. The strata were initially named "Wangshi Series" by Tan (1923), a term subsequently amended to "Wangshi Formation" and then "Wangshi Group" (Wang, 1930; Zhao, 1979, 1994; Bureau of Geology and Mineral Resources of Shandong Province, 1991). There are currently different views about the boundaries and correct geological age of these strata, and about how they should be subdivided and correlated with other units. Hu et al. (2001) divided the strata, from bottom to top, into the Xingezhuang Formation, Jiangjunding Formation, Jingangkou Formation and Changwangpu Formation, the last of which was thought to occur only in Zhucheng and to be absent in Laiyang. Based on fossil vertebrates, especially hadrosaurids and basal neoceratopsians, and on fossil invertebrates and pollen, Hu et al. (2001) believed the Xingezhuang Formation was Cenomanian-Turonian in age, the Jiangjunding Formation Coniacian−Santonian, the Jingangkou Formation Campanian, and the Changwangpu Formation Maastrichtian. Yan & Chen (2005) obtained an isotopic age of 73 Ma for the Jingangkou Formation (which they called the Hongtuya Formation) based on a basalt sample from Daxizhuang Town, Jiaozhou City.

Up to now, four oofamilies, five oogenera and 11 oospecies of dinosaur eggs have been reported from the Laiyang Basin. All the dinosaur eggs were found in the Jiangjunding and Jingangkou formations, belonging to the middle part of the Wangshi Group (Chow, 1951, 1954; Young, 1954, 1959, 1965; Zhao & Jiang, 1974; Zhao, 1975, 1979, 1994; Liu & Zhao, 2004). Spheroolithids are the dominant group in the Jiangjunding Formation, although elongatoolithids and dictyoolithids are also present. Ovaloolithids are the main group in the Jingangkou Formation, which has also yielded some spheroolithids and elongatoolithids (Fig. 6).

2.3 Nanxiong and Ganzhou basins

The Nanxiong Basin lies in the northwestern part of Guangdong Province (Fig. 7) and contains widely distributed Late Cretaceous−Paleocene continental red beds, namely the Nanxiong Group, which has been divided into the Yuanpu Formation and the overlying Pingling Formation (Zhao et al., 1991). The strata of the basin are composed of lacustrine red conglomerate, pebbly sandstone, siltstone and mudstone (Fig. 8). Alternatively, the strata have been divided into the Zhutian and Zhenshui formations by Zhang et al. (2006). Based on K-Ar isotopic dating of the Yuanpu Formation at 67 Ma (Zhao et al., 1991), as well as paleom Nanxiong Basin are thought to be late Late Cretaceous agnetic and biostratigraphic research, the strata of the in age, equivalent to the Campanian−Maastrichtian, The contact between the Pingling Formation and the Upper Shanghu Formation is regarded to represent the K\T boundary (Zhao et al., 1991). Accordingly, the Nanxiong Basin is thought to be the best locality in China for the study of non-marine K-T boundary and the great end-Cretaceous extinction (Zhao et al., 1991, 1993, 1998, 2002, 2009; Zhao & Yan, 2000; Ling et al., 2005).

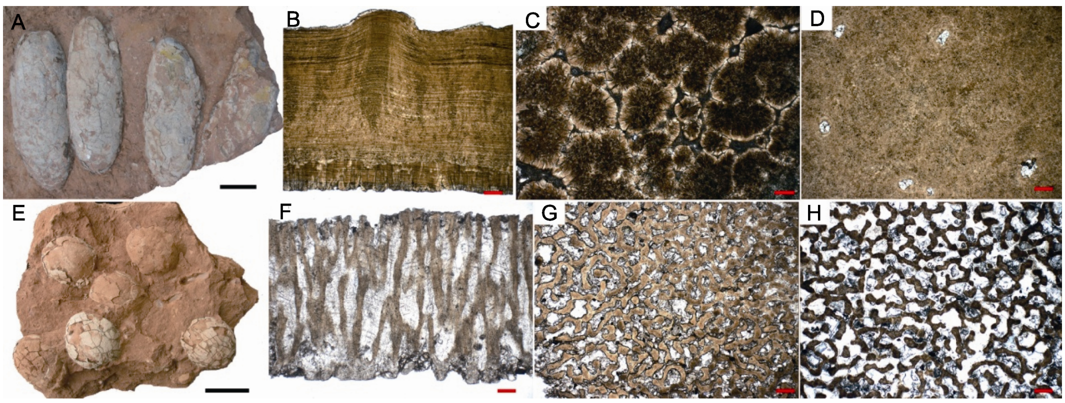

Fig. 4 Representative oospecies of the Tiantai dinosaur egg fauna

A-D. *Macroelongatoolithus xixiaensis* A TTM15; B. Radial section of eggshell; C-D. Tangential section of eggshell; E-H. *Protodictyoolithus xiaxishanensis* E TTM16 (Holotype); F. Radial section of eggshell; G-H. Tangential sections of eggshell. Scale: A, E=10 cm; B, D, F, G, H=400 μm; C=200 μm

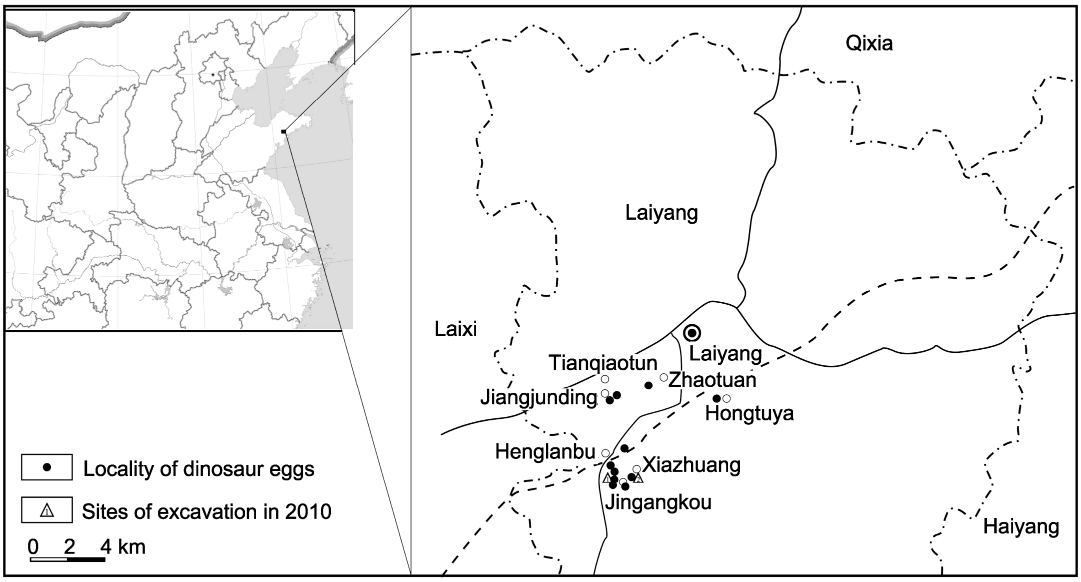

Fig. 5 Localities of dinosaur eggs of the Laiyang Basin, Shandong Province

Dinosaur eggs from Nanxiong belong to five oofamilies, eight oogenera and 11 oospecies, in addition to some indeterminate specimens (Fig. 8) (Young, 1965; Zhao, 1975, 1994, 2000; Zhao et al., 1991, 2009). The strata are rich in elongatoolithids. Apart from elongatoolithids, only ovaloolithids have been discovered in the lower part of the Yuanpu Formation, whereas the upper part of the Pingling Formation has yielded prismatoolithids, ovaloolithids, megaloolithids and stalicoolithids (Fig. 8).

The Ganzhou Basin, borders with the Nanxiong Basin, and is located in the southwest of Jiangxi Province (Fig. 1). Many dinosaur eggs are also found in this basin (Young, 1965), with elongatoolithids as the majority, and the dinosaur egg assemblage is very similar to that found in the Nanxiong Basin.

2.4 Xixia Basin

The Xixia Basin in Henan Province contains one of the richest samples of dinosaur eggs known from China (Fig. 9). The strata are composed of lacustrine red conglomerates, sandstones and mudstones. Dif-ferent schemes for dividing the strata have been proposed (Cheng et al., 1995; Zhou et al., 1997; Zhu, 1997; Fang et al., 1998, 2007). Cheng et al. (1995) and Fang et al. (1998, 2007) divided the strata into the Zoumagang, Zhaoying and Liuyemiao formations, in ascending order (Fig. 9). In contrast, Zhou et al. (1997) and Zhu (1997) used stratigraphic units established in the Xichuan Basin that borders the Xixia Basin to the south. From bottom to top, these are the Gaogou, Majiacun and Sigou formations.

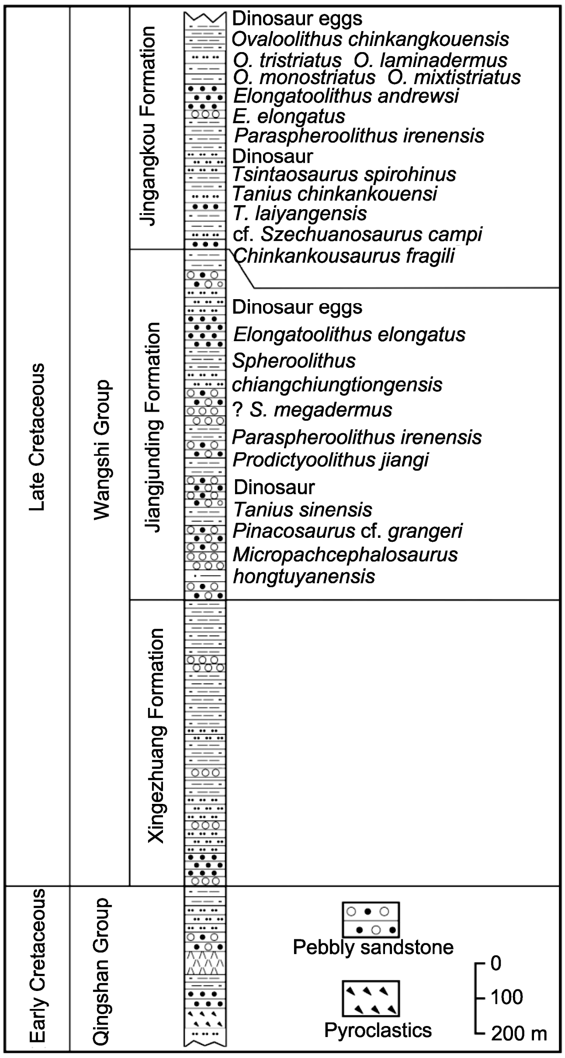

Fig. 6 Strata, dinosaur egg fauna, and dinosaur bone fossils of the Laiyang Basin, Shandong Province
(strata according to Hu et al., 2001; legend as in Fig. 3 except as noted)

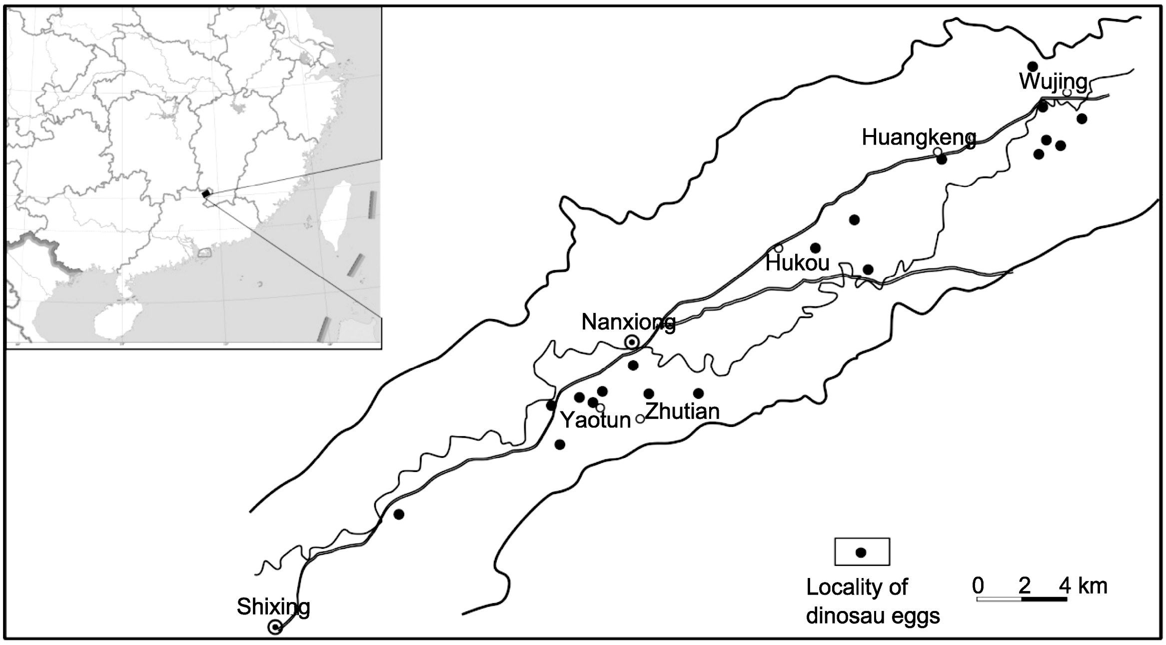

Fig. 7 Localities of dinosaur eggs of the Nanxiong Basin, Guangdong Province (modified from Young, 1965)

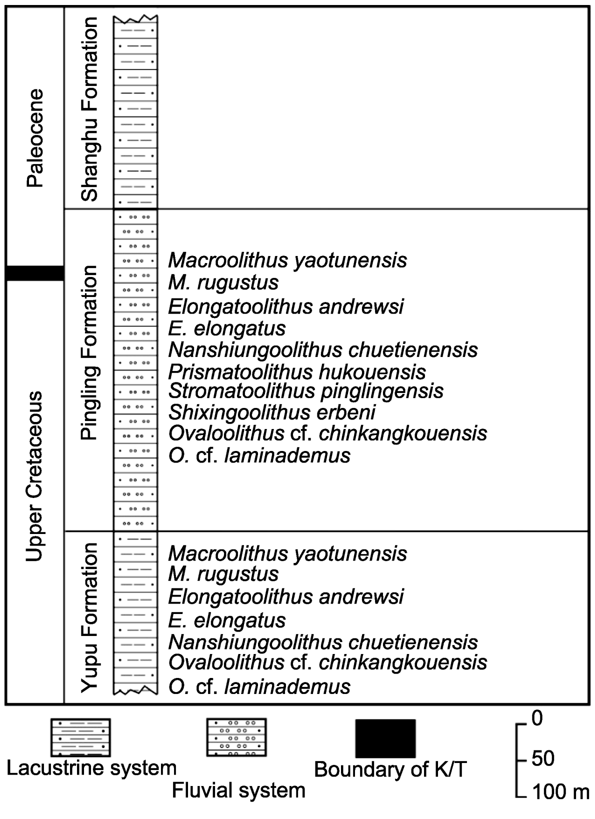

Fig. 8 Strata, dinosaur egg fauna of the Nanxiong Basin, Guangdong Province (strata modified from Zhao et al., 2009)

Wang D. et al. (2008) comprehensive analysis of fossils found in the Xixia Basin, including dinosaur eggs and skeletal fossils, bivalves, gastropods, ostracods, charophytes and pollen, concluded that the Gaogou Formation (corresponding to the Zoumagang Formation) is early- middle Late Cretaceous (Turonian-Coniacian), whereas the Majiacun Formation (corresponding to the Zhaoying Formation) is middle Late Cretaceous (Coniacian–Santonian) and the Sigou Formation (corresponding to the Liuyemiao Formation) is late Late Cretaceous (Campanian). Li et al. (2009) reported an occurrence of the spinicaudatan *Tylestheria xixiaensis* in the Majiacun Formation of the Xixia Basin, and suggested that the fossil-bearing strata could be correlated with the First Member of the Nenjiang Formation and were of Turonian age.

Dinosaur eggs representing seven oofamilies, eight oogenera and 15 oospecies have been reported from the Xixia Basin (Fig. 10) (Zhao, 1994; Wang & Zhou, 1995; Fang et al., 1998, 2007; Wang D. et al., 2008; Zhang, 2010). Some aspects of the classifications of this oofauna are obviously incorrect, so we conducted a preliminary revision and obtained the above statistic. Within the Xixia Basin, the Zoumagang and Zhaoying formations are rich in dinosaur eggs. Only one oospecies (*Dictyoolithus hongpoensis*) has been found in the uppermost strata, the Liuyemiao Formation (Fig. 10).

2.5 Other Upper Cretaceous basins

Apart from the above four major basins, many other Chinese basins also have yielded dinosaur eggs (Fig. 1). One is the Xichuan Basin, which lies to the south of the Xixia Basin (Fig. 1) and is northwest-trending and small in area. South of the Xichuan Basin is the Yunxian Basin

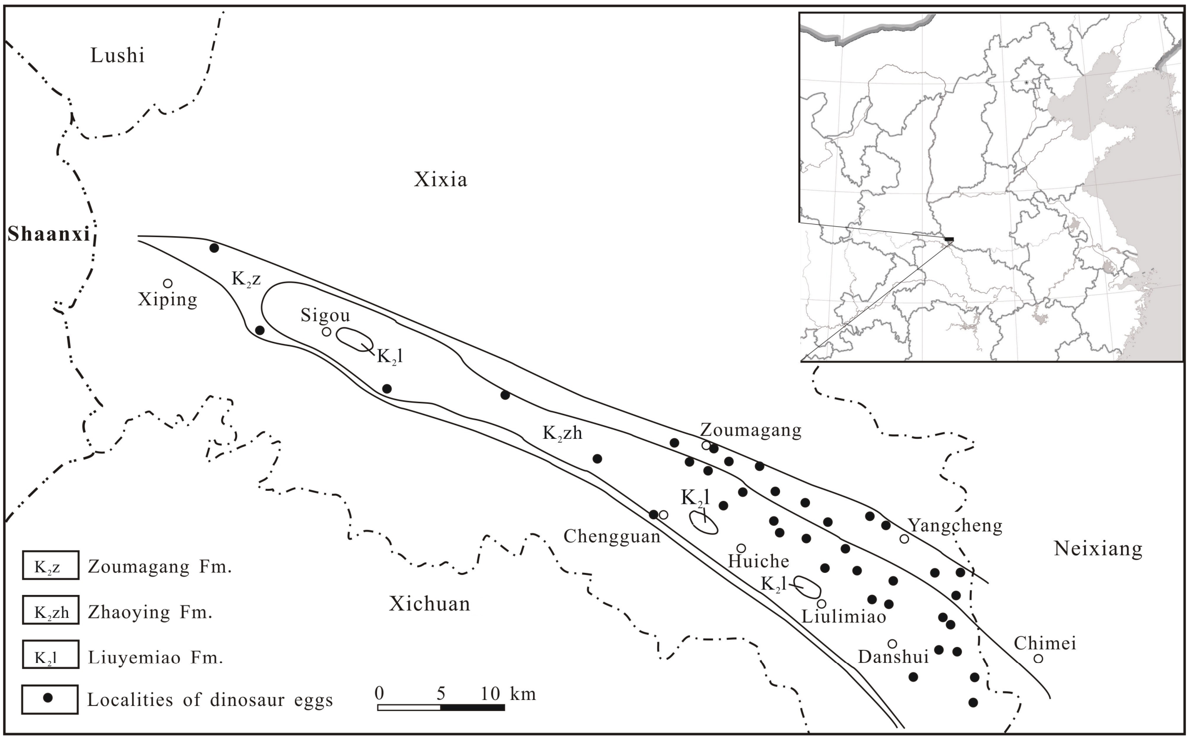

Fig. 9 Localities of dinosaur eggs of the Xixia Basin, Henan Province (modified from Fang et al., 2007)

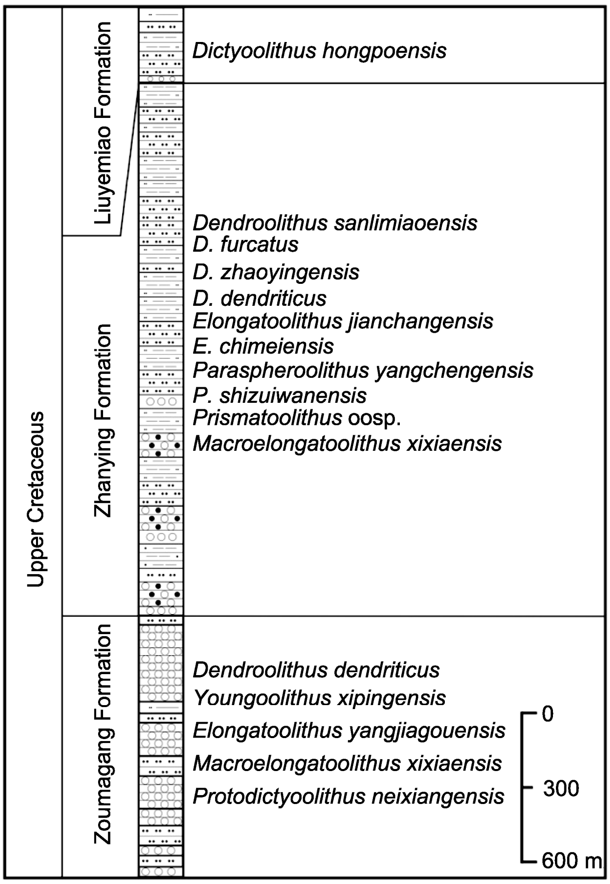

Fig. 10 Strata and dinosaur egg fauna of the Xixia Basin (strata modified from Fang et al., 2007; dinosaur egg classification revised in some respects; legend as in Figs. 3, 6)

of northern Hubei Province, which also contains a large area of Upper Cretaceous exposure that has yielded a number of dinosaur eggs. The sedimentary of the Xichuan Basin and Yunxian Basin are composed of red siltstone and mudstone. In 1974, the Twelfth Teams of Henan Geology made the initial findings of dinosaur eggs in nests in Xichuan, and divided the strata into the Gaogou, Majiacun and Sigou formations.

Dinosaur eggs from the basin that have so far been identified belong to four oofamilies (elongatoolithids, spheroolithids, ovaloolithids and dendroolithids), six oogenera and six oospecies (Zhao & Zhao, 1998). The comparison shows that there is no prevalent group of dinosaur eggs, but elongatoolithids occur in relatively larger numbers.

The Heyuan Basin is located in the northeastern part of Guangdong Province (Fig. 1), and has yielded more than 10 000 dinosaur eggs. The sequence of strata in this basin is divided into the Geling, Xiantang and Dongyuan formations (Fang et al., 2005). Large quantities of dinosaur eggs occur in the Dongyuan Formation, but only a relatively small number of them have been classified, including spheroolithids, dendroolithids, elongatoolithids and prismatoolithids (Fang et al., 2005; Lü et al., 2006).

2.6 Lower Cretaceous basins

Although there are only a small number of Lower Cretaceous dinosaur egg localities in China (Fig. 1), dinosaur egg assemblages from these basins can be important in large-scale comparisons among different strata that contain dinosaur eggs. One of these localities is in Heishan County, Liaoning Province. The strata at this locality belong to the famous Lower Cretaceous Yixian Formation, as well as to the Jiufotang, Shahai and Sunjiawan formations. To date, dinosaur eggs have been found in the upper Lower Cretaceous Shahai Formation (Zhao & Zhao, 1999), making this rock unit the oldest in China to contain dinosaur eggs. Dinosaur eggs also occur at two localities within the Lower Cretaceous Quantou Formation of Changtu County, Liaoning Province and Gongzhuling City, Jilin Province (Li et al, 1998; Wang Q. et al., 2006).

3 Dinosaur egg assemblages in other countries

Worldwide, more than 100 localities have produced dinosaur eggs. Countries in which such localities occur include, among others, Mongolia, India and Korea in Asia; France, Spain and Portugal in Europe; Canada and the United States in North America; Argentina, Uruguay, Brazil and Peru in South America; and Tanzania in Africa. The dinosaur egg assemblages of some of these countries, such as Mongolia and the United States, are particularly important in their abundance and great variety.

3.1 Mongolia

Dinosaur eggs were first discovered in Mongolia by the Central Asiatic Expeditions of the American Museum of Natural History in the 1920s. Subsequently, the Mongolian Paleontological Expeditions of the USSR Academy of Sciences (1946-1949), the Joint Soviet-Mongolian Paleontological and Geological Expeditions (since 1969), and the Polish-Mongolian Paleontological Expeditions (1963-1971) have expanded the number of known Cretaceous egg-bearing localities in the Gobi area of Mongolia (Mikhailov et al., 1994). Important discoveries have been reported by Sochava (1969, 1971, 1972), Kurzanov and Mikhailov (1989)，Sabath (1991), Mikhailov (1991, 1994, 1995, 1996) and Mikhailov et al. (1994, 1996). At present, the known dinosaur egg assemblage of Mongolia as a whole includes six oofamilies, eight oogenera and 17 oospecies (Mikhailov, 1991, 1994, 1996; Mikahilov et al., 1994, 1996). Five oofamilies, six oogenera and four oospecies of dinosaur eggs are common to both China and Mongolia (Mikhailov, 1995). The richest egg-bearing localities in Mongolia comprise deposits of the Djadokhta and Barun-Goyot formations (Santonian−Campanian), as well as the Nemegt Formation (Maastrichtian) (Mikhailov, 1995). However, based on comparisons between the vertebrates in each formation and those in North American non-marine units, Jerzykiewicz (2000) inferred ages for the Upper Cretaceous formations of Mongolia, as mid-Campanian for the Djadokhta Formation, mid-late Campanian for the Barun-Goyot Formation, and late Campanian for the Nemegt Formation.

3.2 Korea and India

Dinosaur egg assemblages in Korea and India are also important on the Asian regional scale. In Korea, dinosaur eggs were first found in the Hasandong Formation in Hadong, south Gyeongsang Province, in 1972 (Lee et al., 2001). More dinosaur eggs and eggshell fragments were reported from other Korean localities by Yun & Yang (1997), Lee et al. (2000), Huh & Zelenitsky (2002) and Lee (2003). Collectively, the dinosaur egg assemblages of Korea include five oofamilies. Most of the assemblages are comparable in oofauna content to those found in the Upper Cretaceous of China, but some geological ages of egg-bearing deposits of Korea can’t directly compare with China’s. For example, the age of the Hasandong Formation in Hadong was found to be 117±18 Ma, based on ^{238}U-^{206}Pb isochron age ion microprobe dating of a dinosaur tooth (Lee & Lee, 2006), the egg-bearing deposits of the Seonso Conglomerate, Boseong, are Upper Cretaceous (Paik et al., 2004).

In India, dinosaur eggshell fragments, complete eggs, clutches and nests have been found since the 1980s. Indian dinosaur egg localities are currently restricted to Upper Cretaceous rocks (Jain, 1989), and a large number of dinosaur nesting sites have been documented from the Maastrichtian Lameta Formation. Most the dinosaur egg assemblages of India are composed of megaloolithids only (Sahni et al., 1994; Mohabey, 1998), but others contain elongatoolithids and/or forms that must be left incertae sedis (Mohabey, 1998). None of the Indian dinosaur egg assemblages are comparable with their Chinese contemporaries, because there is only one megaloolithid oospecies found in the Nanxiong Basin..

3.3 North America

Dinosaur eggs, eggshell fragments and nests in North America have been found from many localities in Canada and USA. The geological age of egg-bearing deposits in North America range from Late Jurassic to Late Cretaceous, for instance the Oldman Formation (upper Campanian) of southern Alberta in Canada (Zelenitsky & Hills, 1996, 1997; Zelenitsky et al., 1996) and the Morrison Formation (Upper Jurassic) of east-central Utah (Hirsch et al., 1989), the North Horn Formation (Upper Cretaceous) of central Utah (Jensen, 1970), the Two Medicine Formation (Upper Cretaceous) of Montana (Hirsch & Quinn, 1990), the Aguja Formation (late Campanian) of Texas (Welsh & Sankey, 2007), and the Fruitland Formation (Campanian) of New Mexico (Tanaka et al., 2011), etc in America.

Many dinosaur egg ootypes have been reported from North America. The majority of these were found in the Upper Cretaceous Oldman Formation (Campanian) of southern Alberta in Canada and the Two Medicine Formation (Campanian) of Montana in USA, which have collectively yielded an important North American dinosaur egg assemblage. A primary comparison of dinosaur egg assemblages between China and North America shows that macroelongatoolithids, elongatoolithids, prismatoolithids, spheroolithids and ovaloolithids occur in both regions, although the North American ovaloolithid record is limited to eggshell fragments (Zelenitsky, 2000). Faveoloolithids, dendroolithids and dictyoolithids occur in China but not in North America.

3.4 South America

Dinosaur eggshells in South America have been reported from the Bauru Formation of Brazil, the Asencion and Mercedes formations in Uruguay, the Vilquechico Formation of Peru, and the Allen, Rio Colorado and Anacleto formations of Argentina (Calvo et al., 1997; Grellet-Tinner et al., 2004). However, dinosaur eggs are most abundant in the Argentine strata. The deposits that bear dinosaur eggs or eggshell fragments are the Campanian-Maastrichtian Allen Formation of Rio Negro Province (Calvo et al., 1997), the lower Companian Anacleto Formation of Neuquen Province (Grellet-Tinner et al., 2004) and the Coniacian-Santonian Rio Colorado Formation of Neuquen Province (Calvo et al., 1997). The dinosaur egg assemblages of Argentina are composed of megaloolithids (Calvo et al., 1997; Chiappe et al., 1998; Grellet-Tinner et al., 2004). Accordingly, there is no dinosaur egg comparable to those found in China, but some dinosaur eggs found in Argentina are particularly important because they contain embryonic remains that allow the confident association of the megaloolithid eggs with sauropod dinosaurs (Chiappe et al., 1998).

3.5 Europe

In the Upper Cretaceous of Europe, dinosaur egg fragments have been discovered in the Aixen-Provence Basin and the Languedoc region of southern France (Vianey-Liaud & Crochet, 1993; Cousin et al., 1994; Vianey-Liaud, et al., 1994), the Hateg Basin of western Romania (Grigorescu et al., 1994), and the Tremp Basin in the southern Pyrenees of Spain (Vianey-Liaud & Lopez-Martinez, 1997). In France, the first dinosaur eggs were found in 1859, and all of the known clutches and eggs came from continental Maastrichtian deposits in the south of the country (Cousin et al., 1994; Vila et al., 2011). The dinosaur egg assemblages of France contain megaloolithids including one oogenus and four oospecies (Vianey-Liaud, et al., 1994), and prismatoolithids, including one oogenus and two oospecies (Vianey-Liaud & Crochet, 1993). Prismatoolithids are of little biostratigraphic value, because they range globally from the Upper Jurassic (Morrison Formation in America) to the Upper Cretaceous. The dinosaur egg assemblages of Spain share four oospecies with those of southern France, and correlations between the Spanish and French eggshell successions permit recognition of three main biostratigraphic zones characterized by different eggshell assemblages (Vianey-Liaud & Lopez-Martinez, 1997). Accordingly, dinosaur egg assemblages within Europe are similar to each other, but not closely comparable to Chinese assemblages.

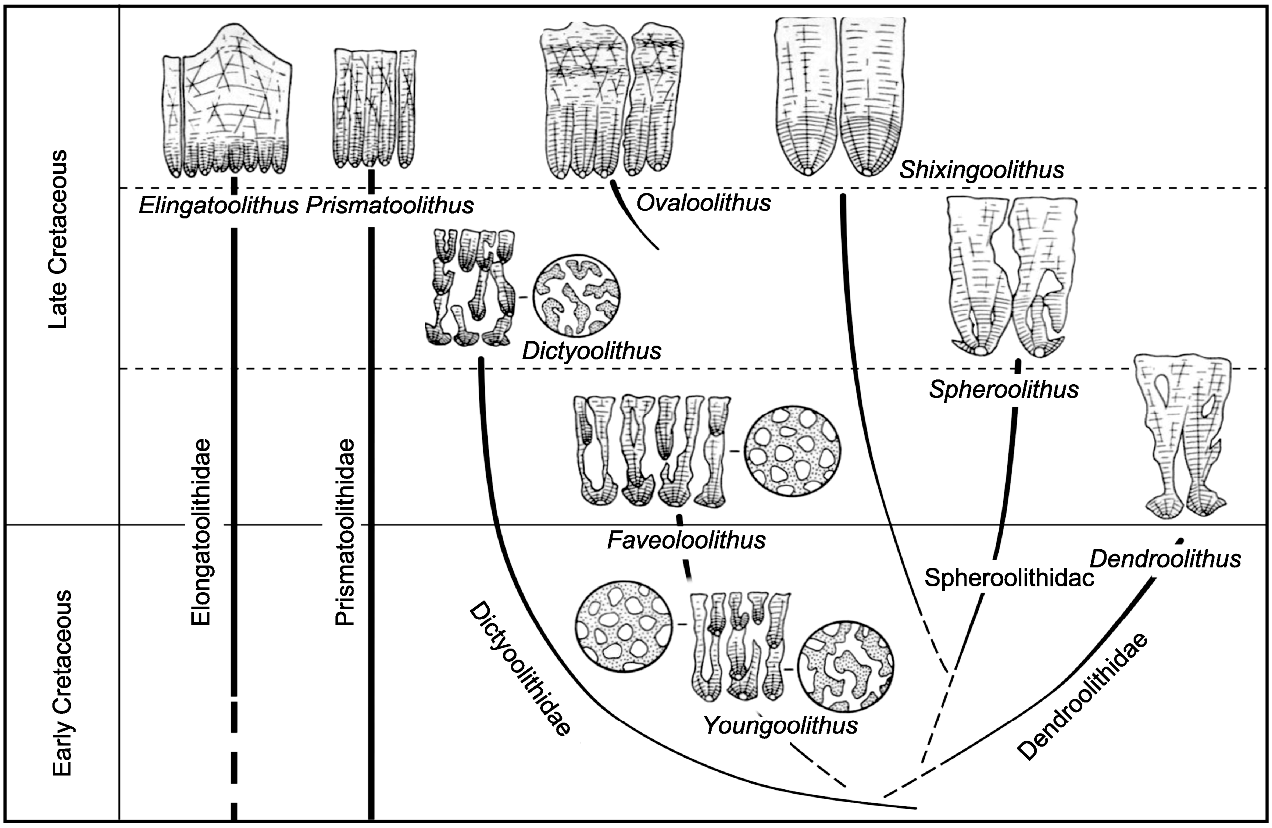

Fig. 11 Evolution and interrelationships of the major groups of dinosaur eggs (modified from Zhao, 1993)

3.6 African

Records of dinosaur eggs from Africa are very limited. In 2002, pieces of well-preserved eggshell were found from the Cretaceous deposits in Tanzania. This is the first dinosaur eggshell from the Cretaceous of Africa to be studied (Gottfried et al., 2004). The eggshell specimens were place in the Oofamily Megaloolithidae. Because of its limitations, the African dinosaur egg assemblage is not comparable to China's.

4 Biostratigraphy of different dinosaur egg faunas in China

Zhao (1993) proposed that dictyoolithids, faveoloolithids and dendroolithids are relatively primitive ootaxa, whereas elongatoolithids and prisma-toolithids are relatively advanced (Fig. 11). In particular, there are some microstructural similarities between elongatoolithid eggs and those of avians.

The dinosaur egg fauna of the Tiantai Basin differs in some respects from those of other basins. The dinosaur egg faunas of the Tiantai and Nanxiong basins are particularly distinct from one another, the former fauna consisting mainly of faveoloolithids and dictyoolithids and the latter mainly of elongatoolithids. Based on the geological ages of the Tiantai Basin (98~91 Ma) and the Nanxiong Basin (67.37~67.04 Ma) (Zhao et al., 1991), the dinosaur egg fauna of the Tiantai Basin is early Late Cretaceous in age, whereas the fauna of the Nanxiong Basin is late Late Cretaceous.

There are also significant differences between the dinosaur egg faunas of the Tiantai Basin and the Laiyang Basin. Spheroolithids and ovaloolithids are not found in the Tiantai Basin, but are abundant in the Laiyang Basin. Furthermore, the Laiyang dinosaur egg fauna is more similar to that of the Nanxiong Basin. Ovaloolithidae and Elongatoolithidae are major oofamilies in these basins, but there are no dictyoolithids in the Nanxiong Basin. For example, *Ovaloolithus jingangkouensis*, *O. laminadermus*, *Elongatoolithus elongatus* and *E. andrewsi* are found in both basins, and the dictyoolithid *Prodictyoolithus jiangi* is present in the Jiangjunding Formation of the Laiyang Basin. Based on a preliminary analysis of the above information, we think that the Laiyang dinosaur egg fauna is nearly the same age as that of the Nanxiong Basin, and represents a middle-late Late Cretaceous dinosaur egg fauna.

The Tiantai dinosaur egg fauna is similar to that of the Xixia Basin. Six oofamilies, including Macroelongatoolithidae, Faveoloolithidae, Prismatoolithidae and others, are shared by the two basins (Tab. 1). In particular, the record of Macroelongatoolithidae in China is restricted to these two basins: *Macroelongatoolithus xixiaensis* is found in the Zoumagang and Zhaoying formations of the Xixia Basin, and in the Chichengshan Formation of the Tiantai Basin. Furthermore, some ootaxa found in the Xixia Basin can be classified into ootaxa that have been newly established on the basis of Tiantai Basin specimens. For example, *Paraspheroolithus shizuiwanensis* and *Ovaloolithus sangpingensis* belong to the stalicoolithids, and *Youngoolithus xipingensis* belongs to the parafaveoloolithids (Zhang, 2010). Based on these comparisons, the Chichengshan Formation may correspond to the Zoumagang and Zhaoying formations. However, known systematic work on dinosaur eggs from the Xixia Basin was somewhat preliminary, and a detailed comparison is needed to resolve the remaining morphological and taxonomic problems.

There are big differences between the dinosaur egg faunas of the Tiantai Basin and Xichuan basins, and the dinosaur egg assemblage of the Xichuan Basin is also different from that of the neighboring Xixia Basin. One possible reason may be that only a small number of dinosaur eggs have been found in the Xichuan Basin. But, there are some similarities among the dinosaur egg assemblages of the Xichuan, Laiyang and Nanxiong basins, which all include elongatoolithids, spheroolithids, ovaloolithids etc. For example, *Nanshiungoolithus chuetienensis* Zhao, 1975 was established in the Nanxiong Basin and *Ovaloolithus jingangkouensis* Zhao, 1979 and *Paraspheroolithus irenensis* Zhao, 1979 were first recorded in the Laiyang Basin, but all three were eventually found in the Zoumagang and/or Sigou formations of the Xichuan Basin. Zhao and Zhao (1998) thought that the Zoumagang and Sigou formations of the Xichuan Basin could be correlated with the Jingangkou Formation of the Laiyang Basin and the Pingling Formation of the Nangxiong Basin, respectively. Moreover, a dendroolithid oospecies has been found in the Xichuan Basin, but this family is absent from the Tiantai Basin. These comparisons suggest that the Xichuan Basin may be younger than the Tiantai and Xixia basins.

5 Sequence of Late Cretaceous dinosaur egg faunas

Comparisons between the dinosaur eggs of the Tiantai Basin and those from other basins indicate that the Tiantai Basin is similar in its fauna to the Xixia Basin, but different from the Laiyang Basin, which itself is more similar to the Nanxiong Basin. Based on biostratigraphic and isotopic dating, China's Late Cretaceous dinosaur eggs can be divided in a preliminary sense into four faunas. The Tiantai dinosaur egg fauna represents early Late Cretaceous dinosaur egg taxa and the Nanxiong dinosaur egg fauna represents the late Late Cretaceous, whereas the Xixia dinosaur egg fauna and the Laiyang dinosaur egg fauna are intermediate and represent early-middle and middle-late Late Cretaceous dinosaur egg fauna respectively (Fig. 12).

Tab. 1 Comparison of dinosaur egg assemblages from different basins in China

Dinosaur egg family	Tiantai Basin	Laiyang Basin	Nanxiong Basin	Xixia Basin	Xichuan Basin
Macroelongatoolithidae	●	—	—	●	—
Elongatoolithidae	●	●	●	●	●
Prismatoolithidae	●	—	●	●	—
Stromatoolithidae	●	—	●	●	—
Spheroolithidae	—	●	—	—	●
Ovaloolithidae	—	●	●	—	●
Dictyoolithidae	●	●	—	●	—
Faveoloolithidae	●	—	—	●	—
Similifaveoloolithidae	●				
Dendroolithidae	—	—	—	? ●	●

● present, - absent, ? presence doubtful

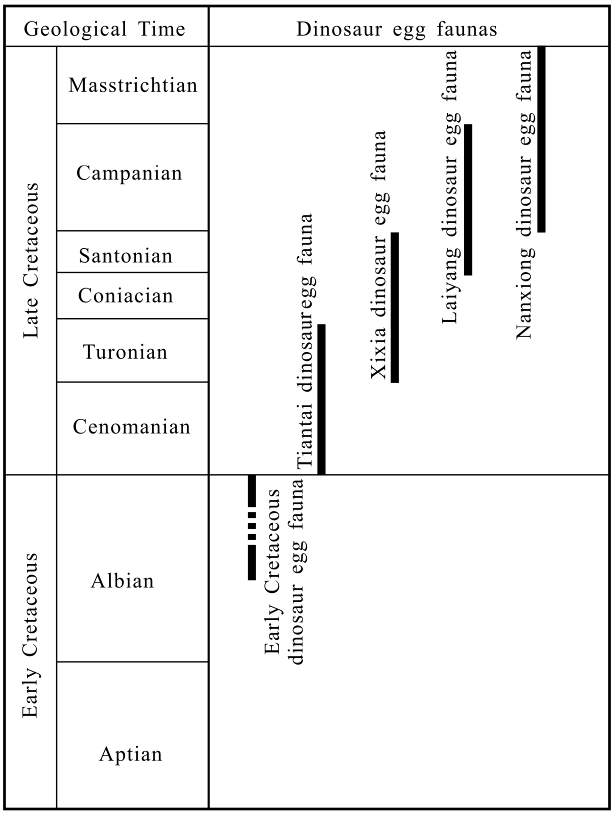

Fig. 12 Major Late Cretaceous dinosaur egg faunas of China (modified from Wang et al., 2010)

In conclusion, comparisons among the dinosaur egg faunas of the Upper Cretaceous basins in China reveal four successive dinosaur egg assemblages of different geological ages, while the strata of the corresponding basins collectively provide a framework for interpreting the Upper Cretaceous continental red. beds of China. With further research, it should be possible to establish a successive Cretaceous dinosaur egg assemblage including Early and Late Cretaceous dinosaur egg faunas in China.

Acknowledgments We thank Li Yan, Gao Wei, Shou Hua-quan, Xiang Long, Zhang Jie, Liu Xin-zheng, Zhang Shu-kang (Institute of Vertebrate Paleontology and Paleoanthropology, Chinese Academy of Sciences), Zhang Jian, Wang Gui-feng (Tiantai Museum, Zhejiang Province) and Wang Jian-hua (Laiyang Museum, Shandong Province) for help in field work. We thank Drs. Zhou Zhong-he and Corwin S. Sullivan (Institute of Vertebrate Paleontology and Paleoanthropology, Chinese Academy of Sciences) for improving the manuscript.

This study was supported by the National Natural Science Foundation of China (No. 40772017, 41172018), the National Science Fund for Distinguished Young Scholars (No. 40825005), National Key Basic Research Program of China (973 Program) (2012CB821900) and Key Laboratory of Evolutionary Systematics of Vertebrates, IVPP, CAS (2011LESV004).

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