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Oviraptorosaurian Eggs (Dinosauria) with Embryonic Skeletons Discovered for the First Time in China

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Abstract: Two elongatoolithid dinosaur eggs from the Upper Cretaceous of Ganzhou, Jiangxi Province and the embryonic skeletons they bear are described. They represent the first oviraptorosaurian eggs with embryonic skeletons in China and provide the first example that an oospecies can be correlated to certain dinosaur taxon/taxa. The two eggs are the same as the pair of the eggs inside a female oviraptorosaurian pelvis from the same horizon of the same area in both macro- and micro-structures of the egg shells, and can be referred to the oospecies, *Macroolithus yaotunensis* Zhao, 1975. The morphology of the preserved part of the embryonic skeletons indicates that they may have been laid by an oviraptorid, *Heyuannia huangi* from Guangdong Province or a closely related oviraptorosaurian, which may have been lived in the Ganzhou area too in the Late Cretaceous. The embryonic skeletons of the two eggs are not in the same developing stage. In one of the eggs, the postzygapophysis of the preserved vertebrae are well ossified, indicating that it was just hatched.

Key words: oviraptorosaurian, Elongatoolithidae, *Macroolithus*, embryonic skeleton, Upper Cretaceous, Jiangxi

1 Introduction

Dinosaur eggs are abundant in the Upper Cretaceous deposits of many places around the world (Carpenter et al., 1994), but eggs with embryonic skeletons from those red-beds are rare (Norell et al., 1994). In recent years, China has been proven to be the richest place for the Upper Cretaceous dinosaur eggs in the world because a number of great discoveries for dinosaur eggs have been made in Upper Cretaceous red-beds of Henan, Hubei, Zhejiang, Jiangxi and Guangdong provinces (Young, 1965; Zhao, 1975, 1994; Fang et al., 1998, 2003; Lü et al., 2006). Among these findings, the most famous is the one made in Xixia, Henan Province in the 1990s; thousands of dinosaur eggs belonging to a variety of egg taxa were collected from the 70 to 80 million year old rocks. Since the early 1990s, many of Chinese dinosaur eggs were illegally sold to abroad, one of which was revealed by a British buyer to contain a segnosaur embryonic skeleton (Cohen et al., 1995; Carpenter, 1999; Kundrát et al., 2007). However, none of the dinosaur eggs stored in Chinese museums and research institutions has been proven to have embryonic skeletons inside.

Most recently, a rich dinosaur egg locality was discovered in the Upper Cretaceous red-beds of Jiangxi Province. The site is in the Ganzhou Basin, the southern part of the province. From the basin a famous oviraptorid pelvic girdle with a pair of eggs was documented (Sato et al., 2005). Here we report two dinosaur eggs from the red-beds of the same area, which contain embryonic skeletons although the eggs were heavily damaged and the embryonic skeletons were largely eroded. The shell morphology and shape of the eggs indicate that they are referable to Elongatoolithidae and the anatomic features of the preserved portion of the embryonic skeleton suggest that the eggs most probably belong to an oviraptorosaurian. Oviraptorosaurian eggs are very common in the Upper Cretaceous red-beds in Mongolia and China (such as Iren Dabasu in Inner Mongolia Autonomous Region and Nanxiong Basin in Guangdong Province). Oviraptorosaurian eggs with embryo have been known only in Mongolia before (Norell et al., 1994; Carpenter, 1999). These two eggs reported here represent the first discovery of oviraptorosaurian eggs with embryonic

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skeletons in China and are possibly correlated to specific oviraptorosaurians.

2 Systematic Paleontology

Elongatoolithidae Zhao, 1975

Macroolithus Zhao, 1975

Macroolithus yaotunensis Zhao, 1975

Referred specimens: NMNS (National Museum of Natural Science)-0015726-F02-embryo-01, a nearly complete half (longitudinal) of an elongate egg, with partial embryonic skeleton. CM (Chimei Museum, Taiwan)-41, a nearly complete half (longitudinal) of an elongate egg, with elements of embryonic skeleton.

Locality and horizon: Two specimens were excavated from the Upper Cretaceous Nanxiong Formation of the Hongcheng area near Ganzhou city, southern Jiangxi Province, China.

Description and comparison:

NMNS-0015726-F02-embryo-01 is oblong in outline, with one half flattened during fossilization. It is about 173.5 mm long and 76.3 mm wide (Fig. 1). The shell was deformed, with shell fragments overlapping each other. The shell is missing in the flattened half (Fig. 2a). The preserved skeleton appears to be undisturbed. The shell is about 1.6 mm thick at the middle portion and the thickness does not change much at the end portion which has shell fragments attached. The outer surface of the shell is heavily ornamented (Fig. 2), with a series of ridges and nods. The ridges are longitudinally elongate and dominate the midsection. The nods are concentrated around the end (Fig. 2b). In the egg shape and the pattern of the surfacial ornamentation, the NMNS-0015726-F02-embryo-01 resembles elongatoolithid eggs. This is further supported by the microscopic morphology (Fig. 2c), which shows an abrupt boundary between the squamatic and mammillary layers seen in thin section (Zhao, 1975; Mikhailov, 1997).

CM-41 is slightly shorter but wider than NMNS-0015726-F02-embryo-01, about 169.00 mm in length and 83.8 mm in width. The shell is 1.8 mm thick at the midsection, 1.3 mm thick close to the end and 1.5 mm thick around the end. These measurements are not consistent at one region. As in NMNS-0015726-F02-embryo-01, the external ornamentations of the shell include elongate ridges and round nods. The longitudinally oriented ridges occur mainly in the midsection and the round nods around the ends (Fig. 3c, d). CM-41 is also similar to elongatoolithid eggs in both shape and the pattern of ornamentation. The macrostructural features are comparable to those seen in NMNS-0015726-F02-embryo-01 (Fig. 2d).

It is clear that the embryonic skeleton is better ossified in NMNS-0015726-F02-embryo-01 than it is in CM-41. In the former, the preserved part indicates that the embryonic skeleton appears to maintain its original posture. Much of the skeleton is missing and the preserved part consists mainly of vertebrae and elements of the hindlimbs. The neural arch and centrum in all preserved vertebrae are separate and disarticulated from one another (Fig. 1b, c). There are some neural arches and centra near the right femur and tibia, which are relatively smaller in size than those medial to the limb bones and most probably belong to the cervical series. In these vertebrae, the postzygapophysis is well ossified (Fig. 1c). This indicates that the embryonic skeleton may have been a hatchling because the zygapophyses of the cervical vertebrae are cartilaginous until hatching in living chickens and skua (Schinz and Zangerl, 1937). A midsection of the femur is preserved in both hindlimbs (Fig. 1a, b), showing that the femoral shaft is nearly round in cross section. The walls of the femoral shaft are very thin, even thinner than the shell. The left tibia is more complete than the right but its proximal end was broken away and its distal end is covered by bone fragments. The proximal portion is more expanded than the distal portion and the shaft is laterally compressed. Among the elements of the hindlimbs, the left pes is best preserved. Its 3rd and 4th metatarsals are nearly complete and its 2nd is missing only the dorsal half of the distal end so that its length can be accurately measured (Fig. 1b). Metatarsal IV is 22.5 mm in length, metatarsal III is the longest, about 32 mm long and metatarsal II is the second longest, about 29.6 mm in length. The 1st and 5th metatarsals are not preserved in both hindlimbs. The anatomical structures of the preserved three metatarsals are adequately evident. In the proximal portion, the three metatarsals are closely packed; the 3rd is obviously mediolaterally compressed, much narrower in dorsal view than metatarsals II and IV and than its distal portion (Fig. 1b). This pattern is comparable to that seen in an oviraptorid *Heyuannia huangi* from the Upper Cretaceous of Heyuan, Guangdong Province (see Fig. 6 in Lü, 2005). The 3rd and 4th metatarsals each has a phalange associated. The phalanges are well ossified. They are proximally simple but their distal end is morphologically complicated, with a trochanter-like tip to articulate the further distal phalange. The dorsal surface near the distal end is grooved and both medial and lateral sides of the distal end are pitted for the attachment of digital ligaments.

The preserved part of the embryonic skeleton in CM-41 is mainly represented by elements of the hindlimbs, few of which are complete. Among those elements, the distal portion of the two femurs is nearly complete (Fig. 3a, e). It is expanded and very concave in ventral view. The shaft of the preserved portion is thinner than in NMNS-0015726-F02-embryo-01, indicating an earlier developing stage. The

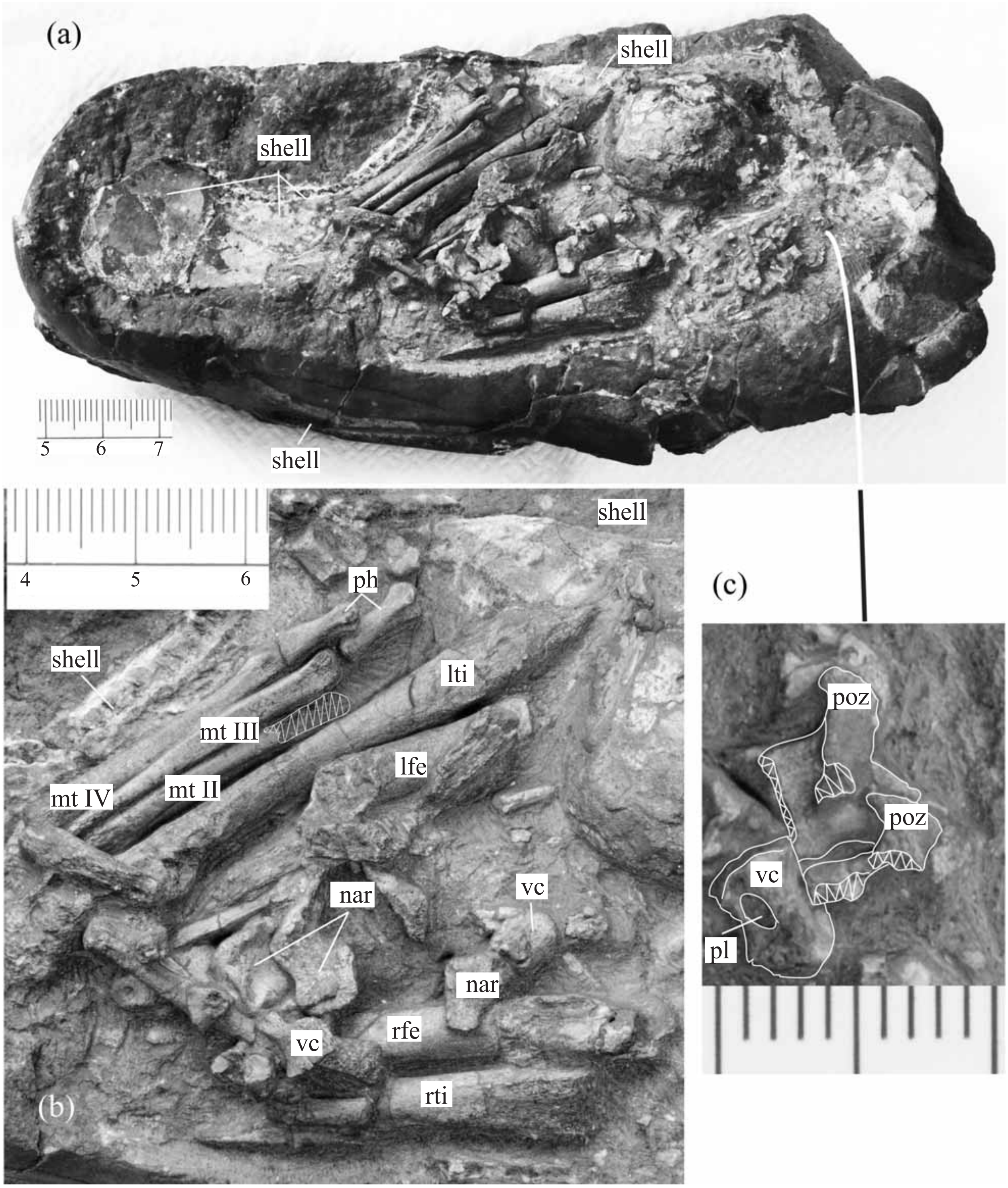

Fig. 1. One oviraptorosaurian egg with embryonic skeleton (NMNS-0015726-F02-embryo-01).
(a) Showing the embryonic skeleton; (b) a close-up view of the hind-limbs; (c) a close-up view of a centrum and an incomplete neural arch, showing the well ossified postzygapophysis. lfe – left femur; lti – left tibia; mtII-IV – metatarsals 2-4; nar – neural arch; ph – phalange; rfe – right femur; lfe – left femur; pl – pleurocoel; poz – postzygapophysis; vc – centrum of vertebra.

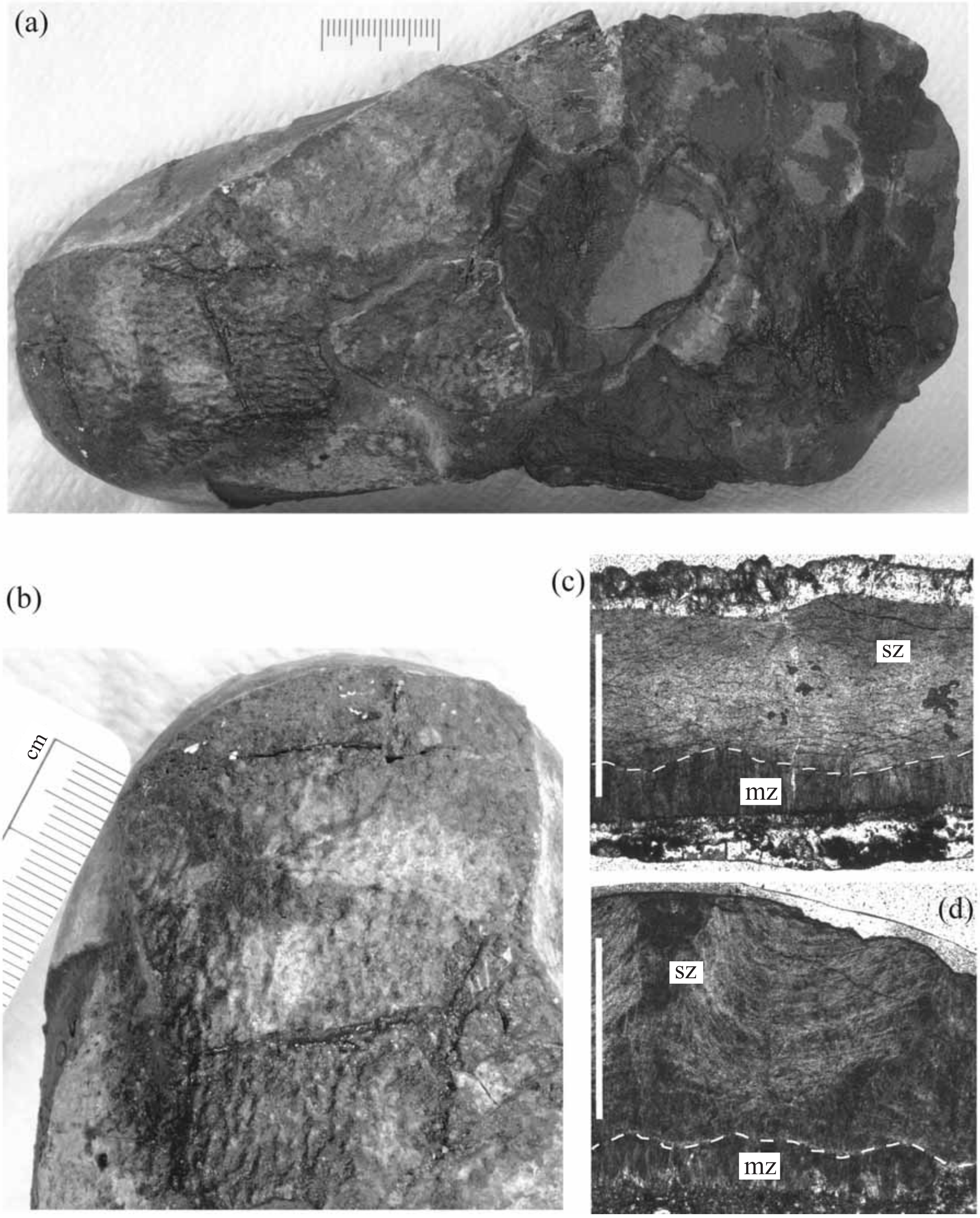

Fig. 2. Macro- and micro-structures of the oviraptorosaurian eggs described in the text.
(a) NMNS-0015726-F02-embryo-01, showing the ornamentation of the eggshell; (b) a close-up view of the ornamentation, showing the ridges dominating the midsection and node dominating the end area; (c) and (d) thin sections, showing the thick squamatic zone and thin mammlillary zone and strongly undulated boundary between the zones. (c) from NMNS-0015726-F02-embryo-01 and (d) from CM-41). Scale bars in (c) and (d) equal 1 mm. mz – mammillary zone; sz – squamatic zone.

preserved tibia is exposed in medial view, missing the distal part. It may be from the right side. Its proximal end is expanded as in other oviraptorosaurians, showing a prominent ridge on the medial surface. The broken surface shows that the distal portion is also expanded but in different plan from that of the proximal end. There are may phalanges dislocated in the central region of the egg (Fig. 3b, f). It is obvious that they are not as well-ossified as in NMNS-0015726-F02-embryo-01 because detailed structures are not commonly formed. This again suggests

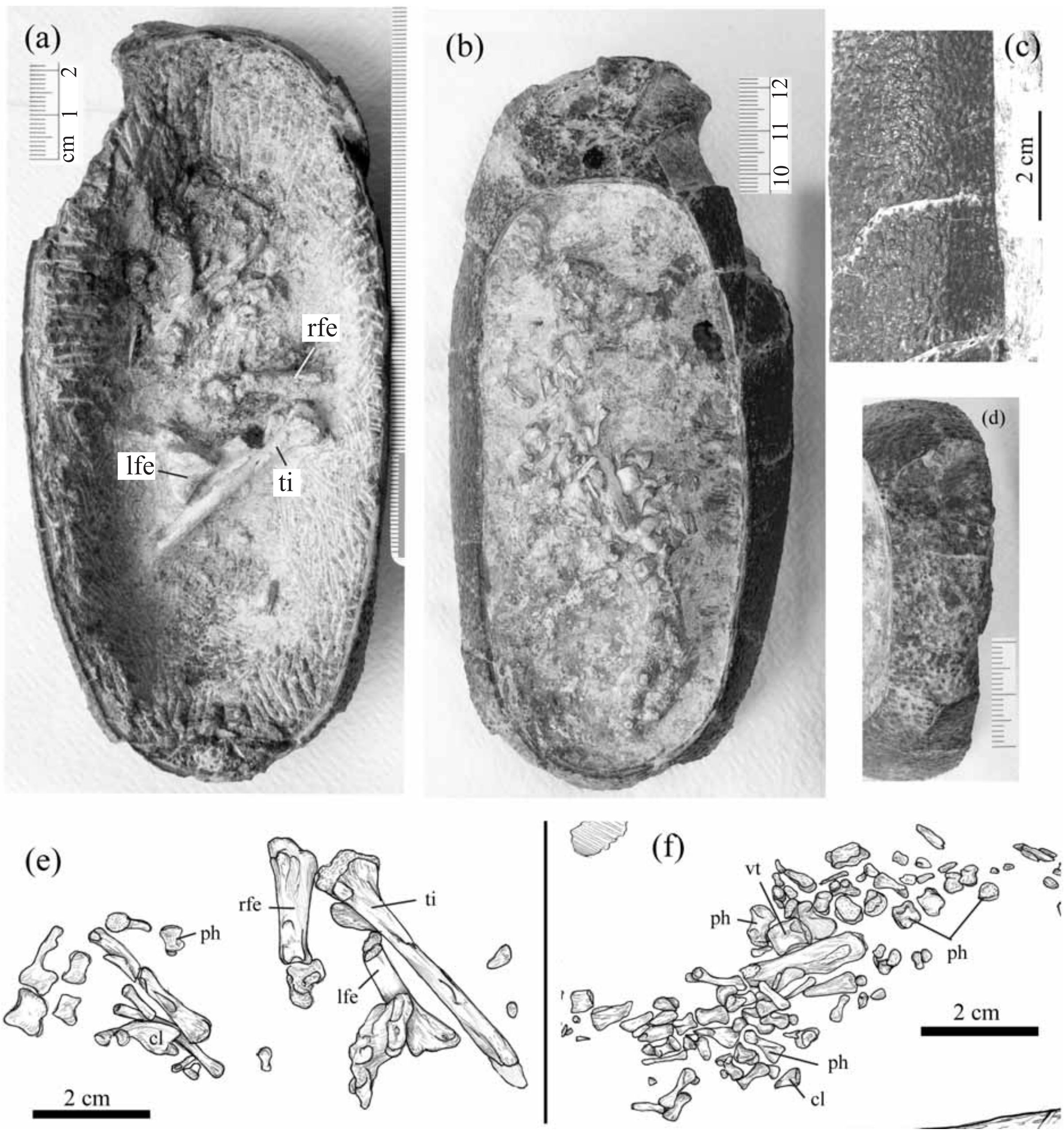

Fig. 3. One oviraptorosaurian egg with embryonic skeleton (CM-41).
(a) One side of the egg, showing ossified skeletal elements; (b) another side of the egg showing ossified skeletal elements; (c) midsection of the eggshell, showing that the area is dominated by ridges; (d) one end of the eggshell, showing that the end is dominated by nodes; (e) illustration of the skeleton elements of (a); (f) illustration of the skeletal elements of (b). cl – claw; ti – tibia; vt – vertebra; other abbreviations as in Fig. 1.

that the embryonic skeleton is not as old as in the latter.

3 Discussion

As described above, the egg shape, the pattern of the surfacial ornamentation and the shell microstructures suggest that the two eggs in question resemble elongatoolithids. As demonstrated by Sato et al. (2005), the pair of the eggs inside the pelvic girdle of an oviraptorosaurian from the same area (see Fig. 1 in Sato et al., 2005) also belongs to the Elongatoolithidae. The detailed macrostructures of the shell further suggest an affinity with *Macroolithus yaotunensis* from Guangdong, south of the locality of the studied eggs. The most characteristics of those features are that the squamatic zone is very thick and the mammillary zone is very thin and that the boundary line between the two layers is strongly undulating. These are exactly true in the NMNS-0015726-F02-embryo-01 and CM-41 (see Fig. 2c, d). On the other hand, these two eggs are similar too in size to the pair of the eggs inside the pelvic girdle. Both macro- and micro-features indicate that the NMNS-0015726-F02-embryo-01 and CM-41 are referable to *Macroolithus yaotunensis*. We know that the pelvic girdle with the pair of the eggs belongs to an oviraptorosaurian and that the morphology of the metatarsals of the NMNS-0015726-F02-embryo-01 is similar to that of *Heyuannia huangi* from a place not very far from the studied eggs. Therefore, it appears logical that the two eggs with embryonic skeletons were most probably laid by *Heyuannia huangi* or an oviraptorosaurian of similar kind. These oviraptorosaurians may have coexisted in the Ganzhou Basin, from which the two eggs were found. The shells of the two eggs lack the cone-shaped innermost portion of the mammillary zone as in the pair of the eggs inside the pelvic girdle. This may have been caused by decomposition during the development of the embryo, a similar situation comparable to a rotted egg (Sato et al., 2005).

4 Conclusions

(1) In China, NMNS-0015726-F02-embryo-01 and CM-41 are the only known oviraptorosaurian eggs containing embryonic skeletons.

(2) These two eggs resemble the pair of the eggs inside the pelvis from the same horizon of the same area in both macro- and micro-morphology, and belong to *Macroolithus yaotunensis* of Elongatoolithidae.

(3) The morphological evidence of the embryonic skeleton indicates that the two eggs may have been laid by *Heyuannia huangi* or a taxonomically similar oviraptorosaurian.

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