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DINOSAUR EGGS FROM THE CRETACEOUS GOSEONG FORMATION OF TONGYEONG CITY, SOUTHERN COAST OF KOREA

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Abstract : Dinosaur eggs found from the Upper Cretaceous Goseong Formation of Tongyeong City, southern coast of Korea are herein described as *Macroelongatoolithus goseongensis* oosp. nov. and *Dictyoolithus neixiangensis*. *M. goseongensis* is large (39 cm in length), elongate egg. Elongation index is 3.4 and shell thickness is 2.3-3.1 mm. Continuous layer to mammillary layer ratio ranges up to 4.8 : 1. *M. goseongensis* differs from *M. carlylei* in continuous to mammillary layer ratio, from *M. zhangi* in egg size, elongation index, and continuous to mammillary layer ratio, and from *M. xixiaensis* in elongation index and continuous to mammillary layer ratio. *D. neixiangensis* is a spherical egg with a diameter of 120 mm. Shell thickness is 1.5-1.7 mm. Outer surface of egg is smooth with grainy forms. It is characterized by basic microstructure of eggshell which displays irregular reticulate composed of two or three superimposed eggshell units. *M. goseongensis* represents fourth oospecies of *Macroelongatoolithus* and provides an evidence for extending paleobiogeographic distribution of this oogenus. Occurrence of *M. goseongensis* also suggests oviraptosaur or oviraptorosaur-like theropod, possible maker of *M. goseongensis*, lived on the Gyeongsang Basin of Korea during the Cretaceous. Occurrence of *Dictyoolithus neixiangenesis* from the Upper Cretaceous (Campanian) Goseong Formation represents the first record of *Dictyoolithus* outside of type locality, Henan, southeast of China and provides an evidence for widening its stratigraphic range from Early Cretaceous to Late Cretaceous and its paleogeographic distribution from southeast China to Korea.

Key words: Dinosaur eggs, *Macroelongatoolithus*, *Dictyoolithus*, Goseong Formation, Korea

Introduction

Since the first dinosaur eggs were described in southern France in 1859 (Buffetaut and Le Loeuff, 1994), numerous dinosaur eggs, clutches, and bones of babies and young dinosaurs have been discovered from the Triassic-Cretaceous strata of 237 localities in every continents except Antarctic (Carpenter, 1999).It is proved that undoubtedly, dinosaur eggs and eggshells by their shape, structure, and microstructures are excellent paleobiological indicatiors presenting innovative aspects of saurischian evolution (Grellet-Tinner *et al*., 2006).

The dinosaur eggs were first discovered in 1972 from the Early Cretaceous Hasandong Formation of Sumunri coast of Hadong County in Korea (Yang, 1976a). Since this first discovery, about 400 dinosaur eggs

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have been reported from the Cretaceous strata of seven localities in Korea (Yun and Yang, 1997; Yang *et al*., 2000, 2006; Lee *et al*., 2000; Lee, 2003, 2004; Yun *et al*., 2004; Huh *et al*., 1999, 2000, 2006a). Recently Huh *et al*. (2006b) reviewed the occurrence of dinosaur eggs in Korea. Paik *et al*. (2006) reported localities of dinosaur eggs, occurrence of dinosaur egg fossil-bearing strata, and sedimentary environment of the Goseong Formation. During the 2008 survey on fossil sites of south coast of Korea, over 55 dinosaur eggs forming at least six egg nests were discovered from the Cretaceous Goseong Formation of Tongyeong area (Yang *et al*., 2008). The purpose of this paper is to describe these dinosaur eggs.

Geological Setting

The Gyeongsang Supergroup is a ~9-km-thick succession of nonmarine, sedimentary and volcanic deposits accumulated in the Gyeongsang Basin which is the largest Cretaceous basin located in southeast of the Korean Peninsula (Fig. 1). Only terrestrial fossils such as plants, mollusks, algae, ostracodes, insects, tortoises, dinosaur skin impressions, bones and teeth, tracks of dinosaur, pterosaurs, and birds, charophytes and invertebrate trace fossils have been discovered from the Gyeongsang Supergroup (Yang, 1976b, 1982; Choi, 1990; Yi *et al*., 1993; Lee *et al*., 2000; Paik *et al*., 1988; 2001a, 2001b, 2001c; Kozai *et al*., 2005; Hayashi, 2006; Lockley *et al*., 2006; Kim *et al*., 2006, 2008, 2009, 2010).

The Gyeongsang Supergoup is divided into three major lithostratigraphic units: the Sindong, Hayang, and Yucheon groups in ascending order (Chang, 1975). The Sindong and Hayang groups are composed of conglomerate, gravelly sandstone, sandstone, mudstone or shale, and some carbonate rocks deposited in fluvio-lacustrine environments with local alluvial fans along the basin margins (Choi, 1986; Jo *et al*., 1997; Rhee *et al*., 1998; Jo and Chough, 2001; Jo, 2003; Houck and Lockley, 2006; Paik and Kim, 2006). The Yucheon Group consists mainly of volcaniclastic rocks and rare epiclastic sedimentary rocks (Reedman *et al*., 1989; Kim *et al*., 1991; Hwang and Kim, 1994; Paik *et al*., 1996; Yun, 1998).

The Goseong Formation (Chang *et al*., 1983) is distributed only in the Goseong area (Fig. 1). The Goseong Formation is characterized by thick beds (up to 1 m thick), intercalated purple beds, generally limited continuity of beds and volcaniclastic deposits which are not commonly observed in the underlying Jindong Formation, the uppermost formation of the Hayang Group (Paik *et al*., 2006). The strata of the Goseong Formation mainly composed of tuffaceous sandstone and fine-grained sandy to silty mudstone were interpreted to have been deposited in fluvial channel, crevasse splay, and floodplain environment during the Late Cretaceous (Campanian) (Paik *et al*., 2006).

As shown in Fig. 1, dinosaur eggs were discovered from fine-grained floodplain deposits of the Goseong Formation in Yeondo (small island), Ddabakseom (small inhibited island), and southestern coastal areas of Pyeongri which belong to Dosanmyeon, Tongyeong City of South Gyeongsang Province. Especially giant dinosaur eggs from Ddabakseom were first discovered by Han, Seok Un and briefly reported by Han *et al*. (2008).

Occurrence of Dinosaur Eggs

Dinosaur eggs occur at one site located in Yeondo, five sites located in southeastern coastal area of Pyeongri, and two sites located in Ddabakseom (Fig. 1). In the Yeondo egg site, fine-grained tuffaceous sandstone and siltstone intercalated with thin black mudstone (up to 20 cm thick). Two dinosaur egg nests

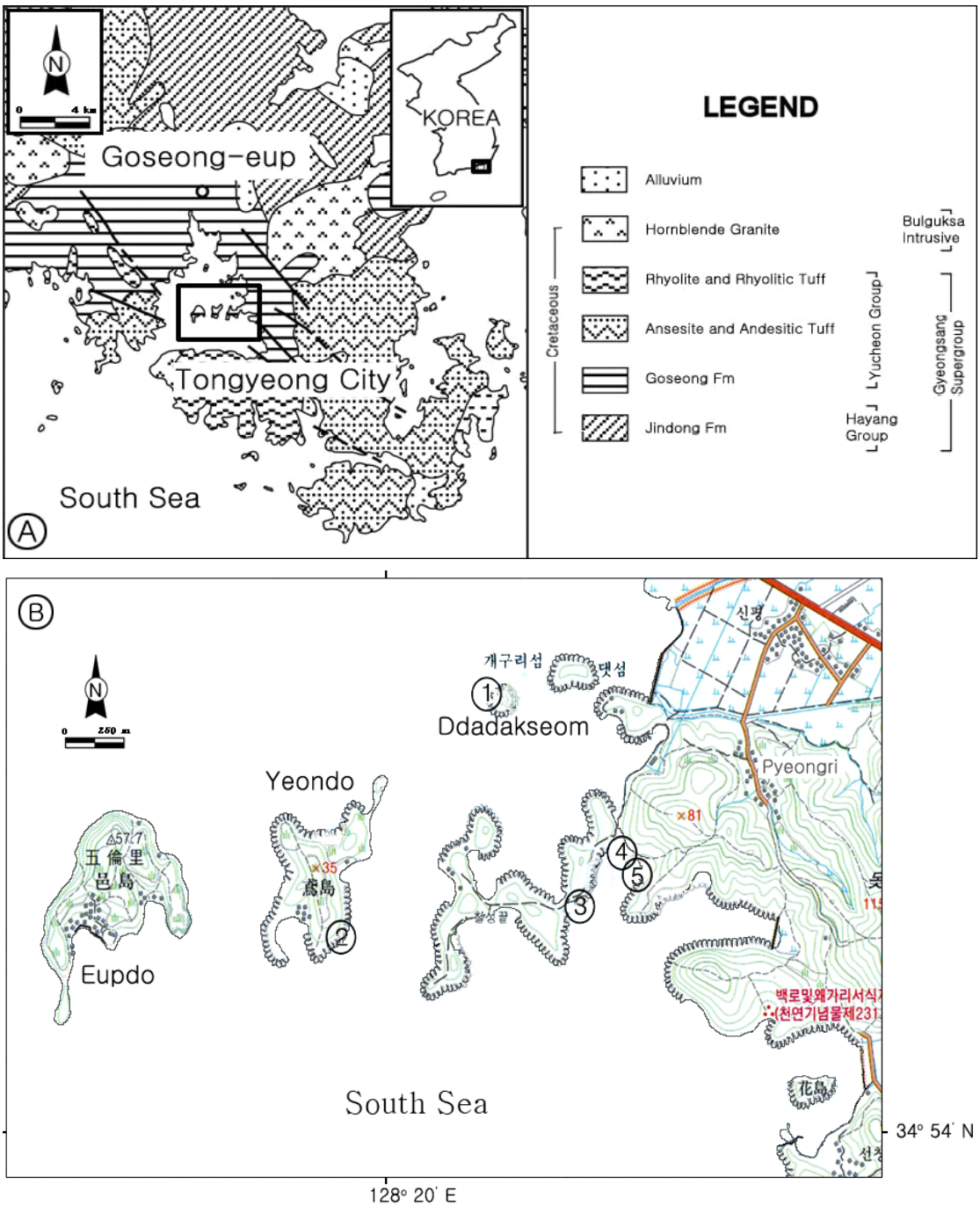

Fig. 1. Geologic map (A) and fossil localities (B).

composed of concentrated eggs in good preservation occur from the light green siltstone beds with strike of N60W and dip of 17SW (Fig. 2). In the southwest coast of Pyeongri, dinosaur egg-bearing strata are light green siltstone to mudstone which is intercalated with fine-grained sandstone. In this area twenty eight dinosaur eggs forming at least three egg nests were observed on the bedding plane or oblique to vertical section (Fig. 2). In a small inhibited island named Ddabakseom which is connected by land during the ebb

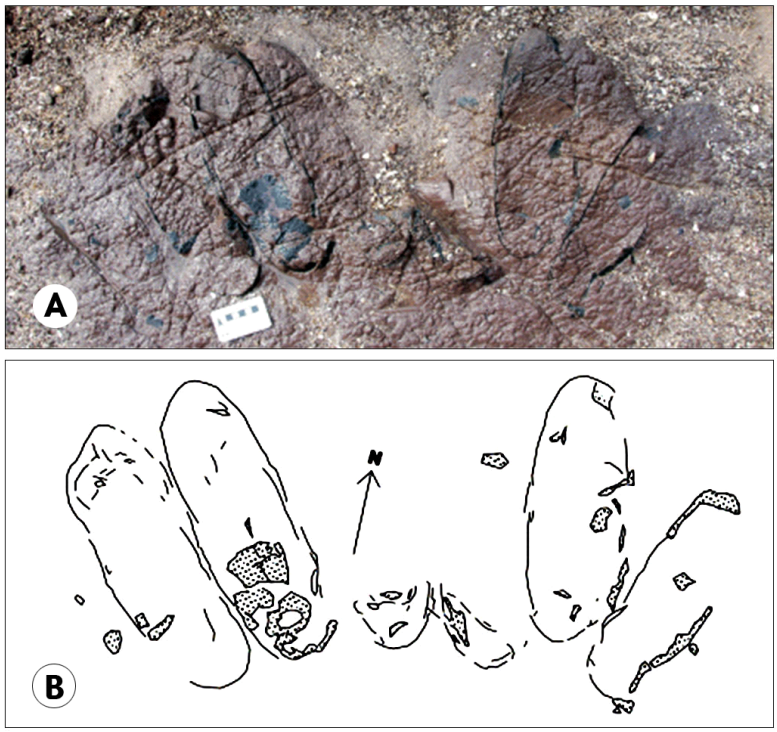

Fig. 2. Photograph (A) and sketch (B) of six giant theropod dinosaur eggs from Ddabakseom.

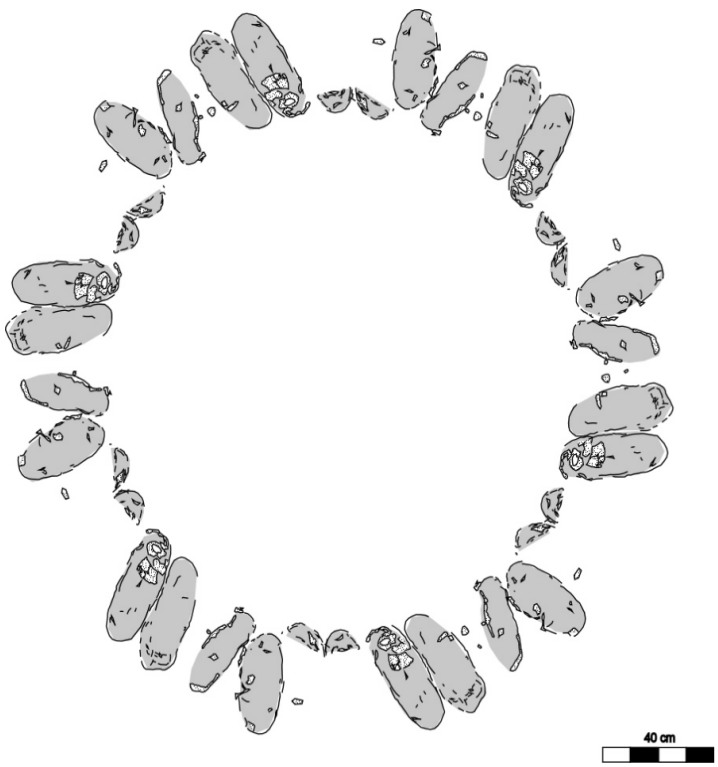

Fig. 3. Reconstruction of a giant theropod dinosaur egg nest on the basis of Fig. 2.

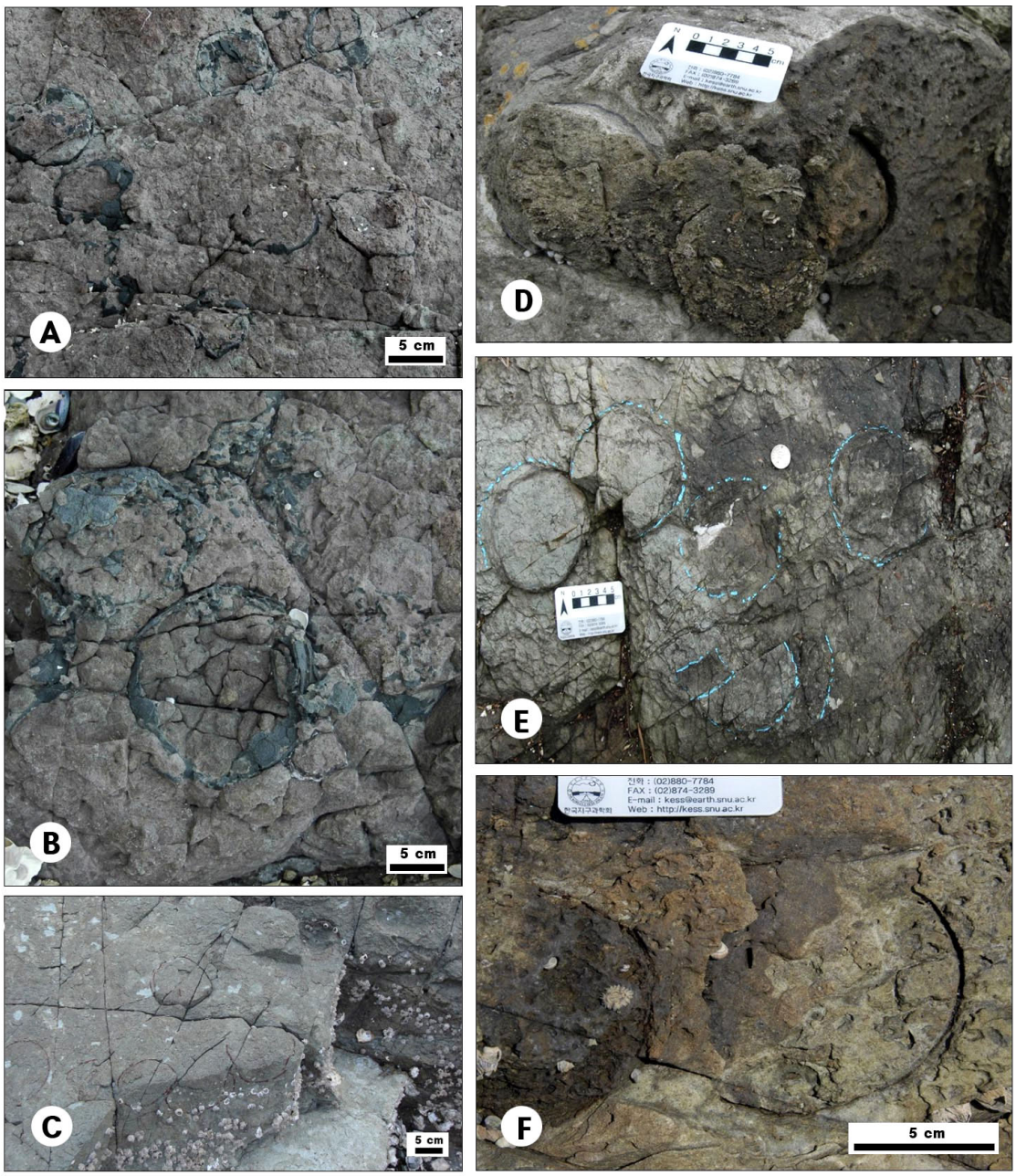

Fig. 4. Occurrence of sauropod dinosaur eggs. A-C: Yeondo site 2, D: Pyeongri site 3, E: Pyeongri site 4, F: Pyeongri site 5.

tide, a dinosaur egg nest composed of six giant eggs in good preservation were found (Fig. 3). These dinosaur eggs preserved in floodplain purple mudstone are usually covered by thick beach sands and submerged during spring tide. Longitudinal sections of four nearly complete and two incomplete eggs in radial arrangement are observed on a bedding surface. 3D orientation of eggs is not exactly known. However, it may be possibly regarded that elongated eggs were originally distributed with an arrangement forming a very large circular nest on the basis of the occurrence of arranged six eggs with a radial angle about 60°

(Fig. 3). This figure, if reconstruction is correct, is very comparable with *Macroelongatoolithus* nest reported from the Early Cretaceous of China (Carpenter, 1999).

Systemtic Paleontology

Oofamily Elongatoolithidae Zhao, 1975

Oogenus *Macroelongatoolithus* Li, Yin, and Liu, 1995

Oolithes Young, 1965; Jensen, 1970, p. 62-63, pl. 1, figs. 1, 2, 4, 6; pl. 2, figs. 3, 5, 6; pl. 3, figs. 4, 7, 8; text fig. 5.

Macroolithus Zhao, 1975, in part, p. 108.

Boletuoolithus Bray, 1998, in part, p. 221-222, figs. 1-3, 4A, 4B.

Type Oospecies: Macroelongatoolithus carlylei (Jensen, 1970)

Other Oospecies : M. xixiaensis Li *et al*., 1995; *M. zhangi* Fang *et al*., 2000.

Revised Diagonosis: Large, elongate eggs, 24-52 cm in length, possibly as long as 60 cm. Elongation index 1.6-3.4. Total range of shell thickness 1.38-3.2 mm. Continous to mammillary layer thickness ratio 1.5:1 to 6.5:1. Angusticanaliculate to oblequicanaliculate pore system. Typical elongatoolithid ornamentation with variable pattern over egg surface (slightly modified after Jin *et al*., 2007).

Macroelongatoolithus goseongensis oosp. nov.

Fig. 2, 5

Etymology: After the Goseong Formation from which type specimens were discovered.

Materials: Dinosaur eggs (Fig. 2, Holotype KNUE 10101)

Occurrence: Upper Cretaceous (Campanian) Goseong Formation, Ddabakseom, Pyeongri, Dosanmyeon, Tongyeong City, South Gyeongsang Province, Korea.

Diagnosis: Large, elongate eggs, 39 cm in length. Elongation index 3.4. Shell thickness 2.3-3.1 mm. Continuous to mammillary layer ratio 2.5:1-4.8:1. Eggs arranged within ring-like clutch.

Description: Long and short diameters of four nearly complete elongate eggs measure about 390 mm and 115 mm respectively, with an elongation index of about 3.4. The thickness of the egg fragments from the type locality ranges from 2.3 mm to 3.1 mm, which may indicate relatively thin shell around the equator of egg and relatively thick shell around the egg pole.

The outer surface ornamentation of egg fragments corresponds to linearituberculate type composed of sinuous ridges. Individual ridges are about 3 mm long and about 0.5 mm high. Ridge are about 0.5 mm separated from adjacent ridges by depressed areas (Fig. 5A-B).

Radial thin sections of eggshells show two ultrastructural layers composed of inner mammillary layer and outer continuous layer (Fig. 5C-H), which belong to the ratite morphology of the ornithoid basic type of eggshell structure (Mikhailov, 1991, 1997). The mammillary layers are thin and range from 0.4 to 0.8 mm in thickness. The mammillary layer exhibits closely packed, elongate cones with radiating acicular crystallites that originate from the former organic cores. A distinct contact separates the mammillary layer from the overlying continuous layer. The continuous layer varies from 1.9 mm to 2.0 mm in thickness. The continuous layer to mammillary layer thickness ratio ranges from 2.5:1 to 4.8:1. The continuous layer is characterized by undulose growth lines and columnar extinction patterns are also observed in the continuous layer. Overall microscopic structures of egg shells correspond to typical elongatoolithid microstructures (Zelenitsky *et al*., 2000; Jin *et al*., 2007).

Table 1. Comparison of *Macroelongatoolithus* species

Oospecies	Locality	Geologic Age & Formation	Egg Size (mm)	Shell Thickness (cm)	No. of Eggs	Elongation Index	C/M Ratio	Authors
M. xixiaensis	Henan, China	Upper Cretaceous Zoumagang Fm.	393-516 × 130-79	2.0-3.2	26	(3.1:1)*	3.1	Li *et al*., 1995
M. xixiaensis	Zhejiang, China	Mid-Cretaceous Liangtoutang Fm.	430 × 145	1.6-2.4	2	(3.0:1)*	1.6:1 to 2.3:1	Jin *et al*., 2007
M. zhangi	Zhejiang, China	Mid-Cretaceous Chichengshan Fm.	240 × 150	~2.0	unknown	(1.8:1)*	1.5:1	Fang *et al*., 2000
M. carlylei	Emery Co., Utah	Lower Cretaceous Cedar Mountain Fm.	unknown	1.38-3.0	unknown	unknown	2:1 to 4:1	Zelenisky *et al*., 2000
M. goseongensis	Tongyeong, Korea	Upper Cretaceous Goseong Fm.	390 × 115	2.3-3.1	6	3.4:1	2.5:1 to 4.8:1	This study

C/M ratio represents continuous to mammillary layer thickness ratio.
* Estimated values measured from figures in references by authors.

Remarks: Only three oospecies of *Macroelongatoolithus* such as *M. xixiaensis* (Li *et al*., 1995; Jin *et al*., 2007), *M. zhangi* (Fang *et al*., 2000), and *M. carlylei* (Zelenitsky *et al*., 2000) have been reported from the Lower to Upper Cretaceous strata of China and USA (Table 1), though Zelenitsky *et al*. (2000) regarded *M. xixiaensis* as a junior synonym of *M. carlylei*. Amongst these, however, only *M. xixiaensis* and *M. zhangi* were described based on complete eggs and *M. carlylei* was described based on eggshell fragments. Therefore, egg size, elongation index, and number of eggs in a clutch, which are directly related with morphology of eggs and clutch, were not known. Like *M. goseongensis*, only *M. xixiaensis*was described based on pairs of eggs in a clutch (Li *et al*., 1995).

As shown in Table 1, *M. goseongensis* described herein is similar in geological age, egg size, shell thickness, and arrangement of eggs in a clutch to *M. xixiaensis*. Arrangement of six eggs forming an arc with a central angle about 60° allows to reconstruct a clutch more than 30 eggs arranged as a circle with a diameter of 2.4 m (Fig. 5). The reconstructed clutch is much lager than the that of *M. xixiaensis* which has been known as the largest clutch of dinosaurs (Carpenter, 1999). *M. goseongensis* is extremely different in egg size, shell thickness, and elongation index from *M. zhangi*. It is difficult to compare *M. goseongensis* with *M. carlylei* of which egg size and elongation index are not known. Range of shell thickness of *M. goseongensis* nearly falls within that of *M. carlylei* (See Table 1).

Elongation index of *M. goseongensis* (3.0:1-3.1:1) is extremely larger than that of *M. zhangi* (1.8:1). In addition to elongation index, the continuous layer to mammillary layer ratio of *M. goseongensis* (2.5:1 to 4.8:1) is much larger than those of *M. xixiaensis* (1.6:1 to 3:1), *M. zhangi* (1.5:1), and *M. carlylei* (2:1 to 4:1) (See Table 1).

In summary, *M. goseongensis* is different in macro- and micro-structural features from previously-known oospecies of *Macroelongatoolithus*, *M. xixiaensis*, *M. zhangi*, and *M. carlylei*.

Oogenus *Dictyoolithus* Zhao, 1994

*Diagnosis:*Spherical eggs with a diameter of 120 mm, shell thickness 1.5-1.7 mm. Microstructure of radial thin section displays reticulate organization composed of superimposed shell units (Zhao, 1994).

Remarks: Dictyoolithus belongs to dendrospherulitic morphology (Mikhailov, 1991, 1997). *Dictyoolithus* attributable to sauropods (Mikahailov, 1996) was previously reported only from the Lower Cretaceous

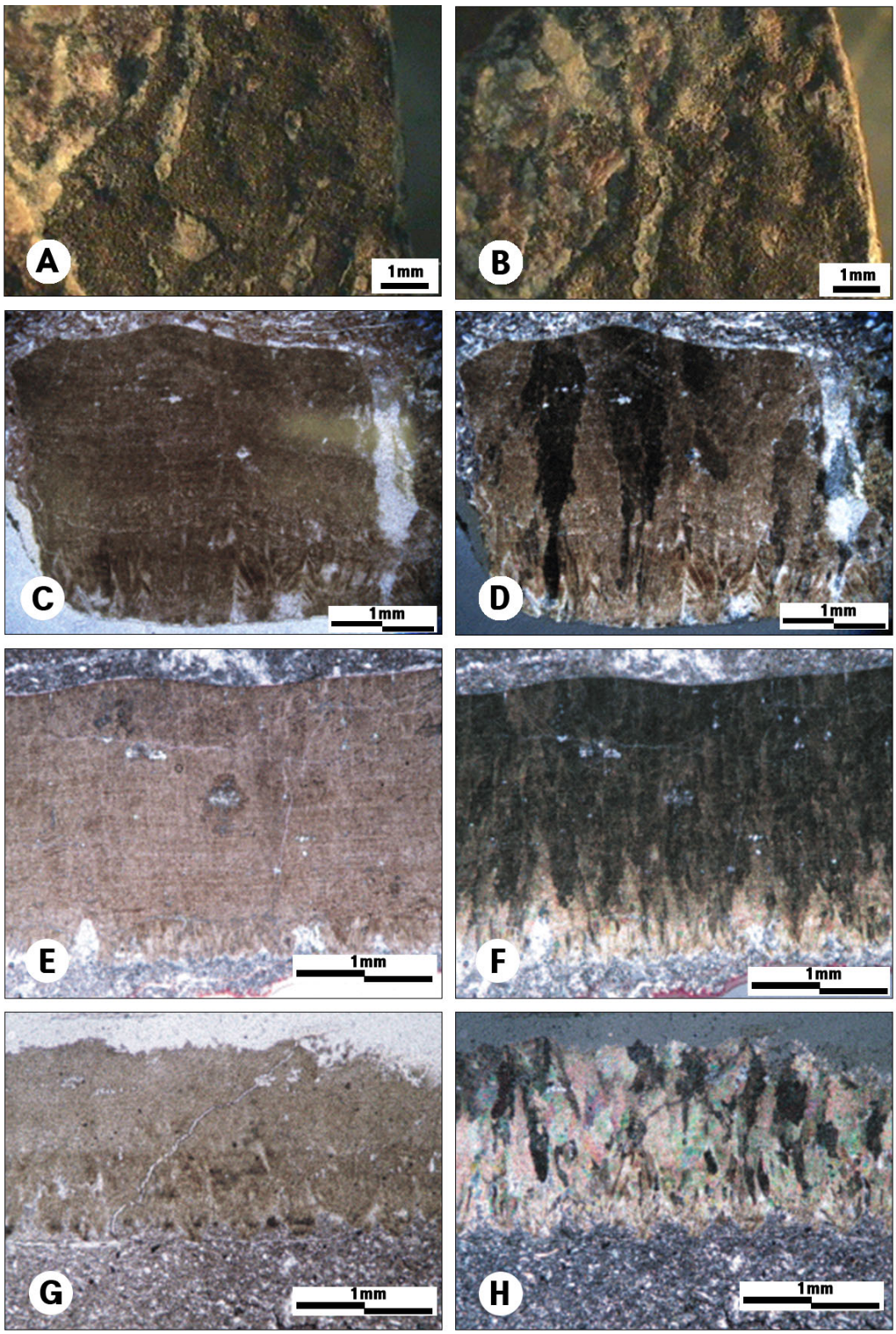

Fig. 5. Microscopic features of giant theropod dinosaur eggs. A, B: outer surface of shell, C-H: thin section view, C, E, G: open nicol, D, F, H: cross nicol

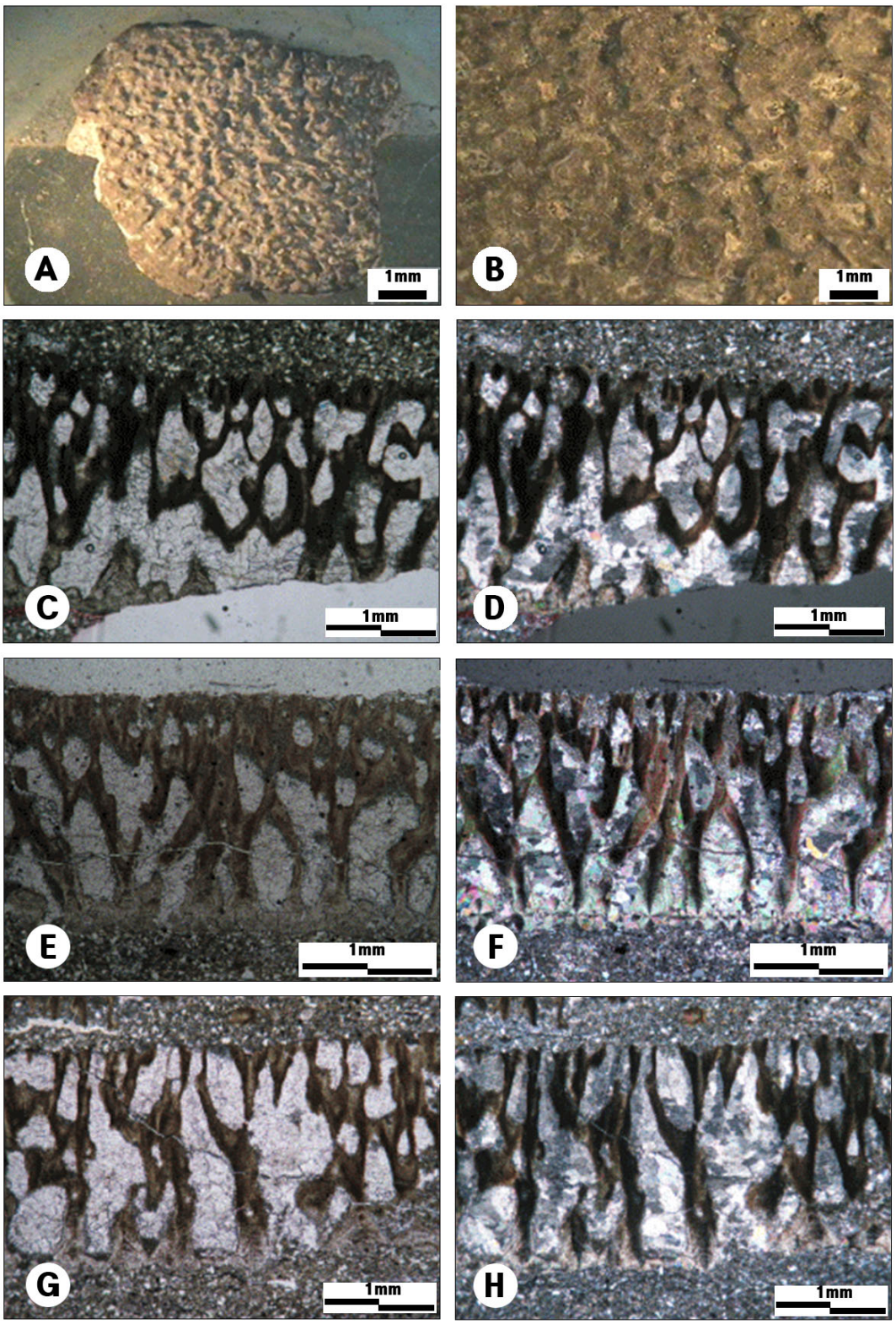

Fig. 6. Microscopic features of sauropod dinosaur eggs. A, B: outer surface of shell, C-H: thin section view, C. E. G: open nicol, D, F, H: cross nicol.

strata of China (Mikhailov, 1997).

***Dictyoolithus neixiangensis* Zhao, 1994**

Fig. 4, 6

Material: Dinosaur eggs (Fig. 4B, KNUE 10102)

Occurrence: Upper Cretaceous (Campanian) Goseong Formation, Yeondo and southwest coast Pyeongri, Dosanmyeon, Tongyeong City, South Gyeongsang Province, Korea.

Description: Spherical eggs with diameter ranging from 100 to 135 mm. Shell thickness varies between 1.0 mm and 1.7 mm. Outer surface ornamentation displays grainy appearance and generally smoothed form. Micro-sized grains about 0.3 mm are nearly uniformly distributed on the outer surface of shells (Fig. 6A-B).

Radial thin sections of eggshells show inner mammillary layer. The inner mammillary layers are up to about 0.3 mm thick and exhibit well-preserved mammilla. The outer continuous layers are about 1.4 mm thick and characteristically display dendrospherulitic morphotype features. Irregular reticulates composed of three superimposed eggshell units are characteristic microstructure of continuous layer (Fig. 6C-H). Due to increasing of branches, reticulates become smaller toward outer surface of the shell. Pore channels are very irregular and very dense.

Remarks: Egg size and shape, outer surface ornamentation and microstructures of radial thin sections of materials are nearly identical to those of *Dictyoolithus neixiangensis* from the Lower Cretaceous of Henan Province, China (Zhao, 1994). Until now, *Dictyoolithus* has been reported only from the Lower Cretaceous strata of South China (Zhao, 1994). Therefore, occurrence of *Dictyoolithus* from the Upper Cretaceous Goseong Formation provides an evidence for extending paleobiogeographic and stratigraphic range of *Dictyoolithus*.

Discussion

The occurrence of *Macroelongatoolithus goseongensis* and *Dictyoolithus neixixiangensis* from the Upper Cretaceous (Campanian) Goseong Formation has important implications for paleobiogeography and biostratigraphy of dinosaur eggs. *Macroelongatoolithus* has been described from Middle to Upper Cretaceous of southeast China (Li *et al*., 1995; Fang *et al*., 2000; Jin *et al*., 2007) and Lower to Middle Cretaceous of Utah (Zelenitsky *et al*., 2000).

The discovery of *Macroelongatoolithus* from the Goseong Formation of Korea represents the fourth record of this oogenus following its record from Henan, Zhejiang, and Utah. The occurrence of elongatoolithid oospecies is regarded to be suggestive of the presence of oviraptosaurs (Zelenitsky *et al*., 2000). In this respect, the presence of *Macroelongatoolithus goseongensis* in the Goseong Formation suggests that oviraptorosaurs or oviraptorosaurs-like theropods inhabited Korea during the Late Cretaceous .

The occurrence of *Dictyoolithus* described from the Upper Cretaceous Goseong Formation represents the second record of this oogenus and the first record of this oogenus outside of type locality, southeast China. The record of *Dictyoolithus* from the Goseong Formation also allows to extend the paleobiogeographic distribution of the oogenus and widen the stratigraphic range of *Dictyoolithus* from Early Cretaceous to Late Cretaceous.

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남해안 통영시에 분포한 백악기 고성층의 공룡 알 화석

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요 약: 남해안 통영시에 분포한 상부 백악기 고성층에서 산출된 공룡 알 화석을 *Macroelongatoolithus goseongensis* oosp. nov.와 *Dictyoolithus neixiangensis*로 기재하였다. *M. goseongsis*는 길이가 39 cm에 이르는 크고 신장된 공룡 알 화석이다. 신장 지수(elongation index)는 0.3이고 알 껍데기의 두께는 2.3-3.1 mm이다. 연속층과 유상층의 비는 4.8:1 이다. *M. goseongsis*는 *M. calylei*와 연속층과 유상층의 비가 다르며, *M. zhangi*와 크기, 신장 지수 및 연속층과 유상층의 비가 다르고, *M. xixiaensis*와는 신장 지수와 연속층과 유상층의 비가 다르다. *D. neixiangensis*는 120 mm의 직경을 갖는 둥근 공룡 알 화석이며, 알 껍데기의두께는 1.5-1.7 mm이다. 알의 외부 표면은 입상으로 매끄러운 상태이다. *D. neixiangensis*는 두개 또는 세개의 알 껍데기 단위(eggshell units)가 중첩된 불규칙한 망상 구조를 보이는 알 껍데기의 기본 미구조(basic microstructure)가 특징적이다. *M. goseongnsis*는 *Macroelongtoolithus*의 네번째 oospecies이며, 이 oogenus의 고생물지리적 분포를 확장시키는 증거이다. 또한 *M. goseongnsis*의 산출은 *M. goseongnsis*의 주인공으로 생각되는 오비랩토사우루 또는 오비랩토사우루와 유사한 수각류 공룡이 백악기의 경상 분지에 서식하였음을 지시한다. 상부 백악기(Campanian)의 고성층에서 산출된 *Dictyoolithus neixiangensis*는 *Dictyoolithus*의 표식지인 남동 중국 해난 이외의 지역에서 처음으로 기록된 것이며, 이 알 화석 종류의 층서적 산출 범위를 전기 백악기에서 후기 백악기로, 그리고 고생물지리적 분포를 남동 중국에서한국으로 확장하는 증거를 제공한다.

주요어: 공룡 알 화석, *Macroelongtoolithus*, *Dictyoolithus*, 고성층, 한국

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