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DINOSAUR BONES AND EGGS IN SOUTH KOREA

Yuong-Nam LEE

Geology Division, Korea Institute of Geoscience and Mineral Resources, Daejeon 305-350, South Korea

ABSTRACT

The Mesozoic beds in South Korea consist of an entirely non-marine, sedimentary succession associated with volcanic activity that increased through time. Dinosaur fossils are known so far from the Gyeongsang Supergroup. Specimens include dinosaur bones, eggs in nests, as well as footprints. Since 1973, dinosaur bones have been collected in road cuts, quarries, stream beds, and coastal exposures in Euiseong, Gunwi, Habcheon, Jinju-Sacheon, and Hadong areas. They are isolated teeth and incomplete or fragmentary bones. Abundant dinosaur eggs, however, have been recently discovered in Hadong, Boseong, Whaseong and Goseong coastal areas. In these areas, over 350 eggs have been observed in sandstone and conglomerate beds with at least five different morphotypes.

Key words: Cretaceous, dinosaurs, Gyeongsang Supergroup, Korea

INTRODUCTION

The Early Cretaceous is rapidly being recognized as a crucial time in the evolution and dispersal of vertebrates such as dinosaurs. An increase in the rate of discovery of vertebrate fossils in recent years has resulted in documentation of 38 localities from the entirely fluvio-lacustrine Gyeongsang Supergroup (Hauterivian to Campanian?) in Korea (Lee et al., 2001). Since the first discovery of dinosaur eggshell fragments from the Hasandong Formation in 1972, scattered dinosaur bones have been found in quarries, road cuts, stream beds, and coastal outcrops mostly as a result of individual surveys. Abundant dinosaur tracks have also been located from western and southern coastal areas (Lee et al., 2000a; Lee and Huh, 2002). They clearly indicate that a diversity of dinosaur communities existed during the time of Gyeongsang deposition in Korea. Except for some of the trackways, however, the dinosaur faunas remain inadequately published (Table 1). Therefore, the purpose of this paper is to review the dinosaur bones and eggs from the Gyeongsang Supergroup and to report their occurrence to the wider paleontological community.

GEOLOGICAL SETTING

The Gyeongsang Supergroup occurs within the Gyeongsang Basin and several small basins (Chough et al., 2000). The Gyeongsang Basin, the largest sedimentary basin of Korea, is widely distributed in the southeastern part of the Korean Peninsula (Fig. 1). The Gyeongsang Supergroup sequence (ca. 9 km thick) is divided into the Shindong and Hayang Groups, mainly comprised of thick siliciclastic sequences of alluvial, fluvial and lacustrine sediments, and the Yucheon Group characterized by the dominance of volcanic rocks (Fig. 2, Chang, 1975). The Shindong Group is confined to the western margin of the Gyeongsang Basin with general trends to the NNE (Nagdong Trough, 2,000 to 3,000 m thick). The Shindong Group consists of the Nagdong, Hasandong, and Jinju Formations, generally showing a fining-upward trend and three facies associations characterized as alluvial fan fringe, fluvial system, and shallow lake (H. I. Choi, 1986a, b, c). The age of the Sindong Group has been determined as Aptian to Albian by molluscan faunas (Yang, 1982) and as Hauterivian to Barremian by palynomorphs (D.K. Choi, 1985, 1989; Yi et al., 1994). Ion microprobe dating of a dinosaur tooth from the Hasandong Formation indicates that $^{238}U-^{206}Pb$ isochron age is 117±18Ma (Sano et al., 2002).

The Hayang Group overlies the Shindong Group in the western part of the Gyeongsang Basin and directly overlies pre-Cretaceous rocks in the northern part of the Gyeongsang Basin. The Hayang Group (1,000 to 5,000 m thick) was deposited through subsiding and eastward expansion of the basin. It is composed of shale, sandstone interbedded with marl and conglomerate, and partly volcanic rocks extruded within the sedimentary basin. The Hayang Group was deposited mainly in fluvio-lacustrine environments rather than alluvial plains, an

Phone: +82-42-868-3284, Fax: +82-42-868-3279
E-mail: ylee@kigam.re.kr

TABLE 1. Systematic list of dinosaur taxa from the Gyeongsang Supergroup.

Dinosaur taxa	Occurrence	Material	Systematics
Order Saurischia			
Suborder Theropoda			
Family Allosauridae	Hasandong Fm.	a tooth	Park et al., 2000
Gen. et sp. indet	Sumunri, Hadong		
	Hasandong Fm.	a tooth	Park et al., 2000
	Yusuri, Jinju		
Infraorder indet.	Hasandong Fm.	a tooth and a claw	
	Yusuri, Jinju		
	Hasandong Fm.	a tooth	
	Dapyeongri, Sacheon		
	Hasandong Fm.	three teeth	
	Juji Island, Hadong		
	Hasandong Fm.	an incomplete fibula	
	Daedo, Hadong		
Suborder Sauropodomorpha			
Infraorder Sauropoda			
Family Euhelopodidae	Hasandong Fm.	a tooth	Lee et al., 1997; Park et al., 2000
Chiayusaurus sp.	Yusuri, Jinju		
Family Titanosauridae (?)	Hasandong Fm.	a tooth	Lee et al., 1997; Park et al., 2000
Gen. et sp. indet.	Yusuri, Jinju		
Family Camarasauridae (?)	Hasandong Fm.	a tooth	Lee et al., 1997; Park et al., 2000
Gen. et sp. indet.	Yusuri, Jinju		
Infraorder indet.	Hasandong Fm.	a scapular and coracoid (?)	
	Doweonri, Euiseong		
	Gugyedong Fm.	a proximal end of humerus	Lee et al., 1997
	Tabri, Euiseong		
	Nagdong Fm.	a part of femur	
	Noyangri, Habcheon		
	Hasandong Fm.	5 cervicals, a caudal, 2 chevrons, a rib	
	Galsari, Hadong		
Order Ornithischia			
Suborder Ornithopoda			
Infraorder indet.	Hasandong Fm.	a humerus	
	Yusuri, Jinju		
	Hasandong Fm.	a tooth	
	Jangu Island, Hadong		
Order indet.	Hasandong Fm.	an elongate planar bone	
	Hwajeonri, Euiseong		
	Hasandong Fm.	a part of scapular blade,	
	Yusuri, Jinju	a proximal end of limb bone, skull elements(?),	
	Hasandong Fm.	a rib and a part of limb bone	
	Dapyeongri, Sacheon		
	Hasandong Fm.	a part of vertebra	
	Sumunri, Hadong		
	Nagdong Fm.	a rib	
	Noyangri, Habcheon		
	Jinju Fm.	a part of limb bone	
	Nahori, Guwi		
	Gugyedong Fm.	a complete femur and a part of vertebra	
	Tabri, Euiseong		

inference supported by abundant channel beds in association with floodplain sediments (H. I. Choi, 1986a). However, poorly sorted coarse grains of clastic rocks and prevalent red rock color suggest more purely fluvial environments sometimes. Angiosperm pollens such as *Retimonocolpites*, *Clavatipollenites*, and *Tricolpites* from the Geoncheonri and Iljik Formations suggest that the Hayang Group is Aptian to early Albian in age (D.K. Choi, 1985, 1989; Yi et al., 1993).

The Yucheon Group (2,000 to 3,000 m thick), unconformably overlying the Hayang Group, consists of volcanic and associated sedimentary rocks. No fossils are known so far from the Yucheon Group and its isotopic age is 83Ma by $^{40}K/^{40}Ar$ (Doh and Kim, 1994).

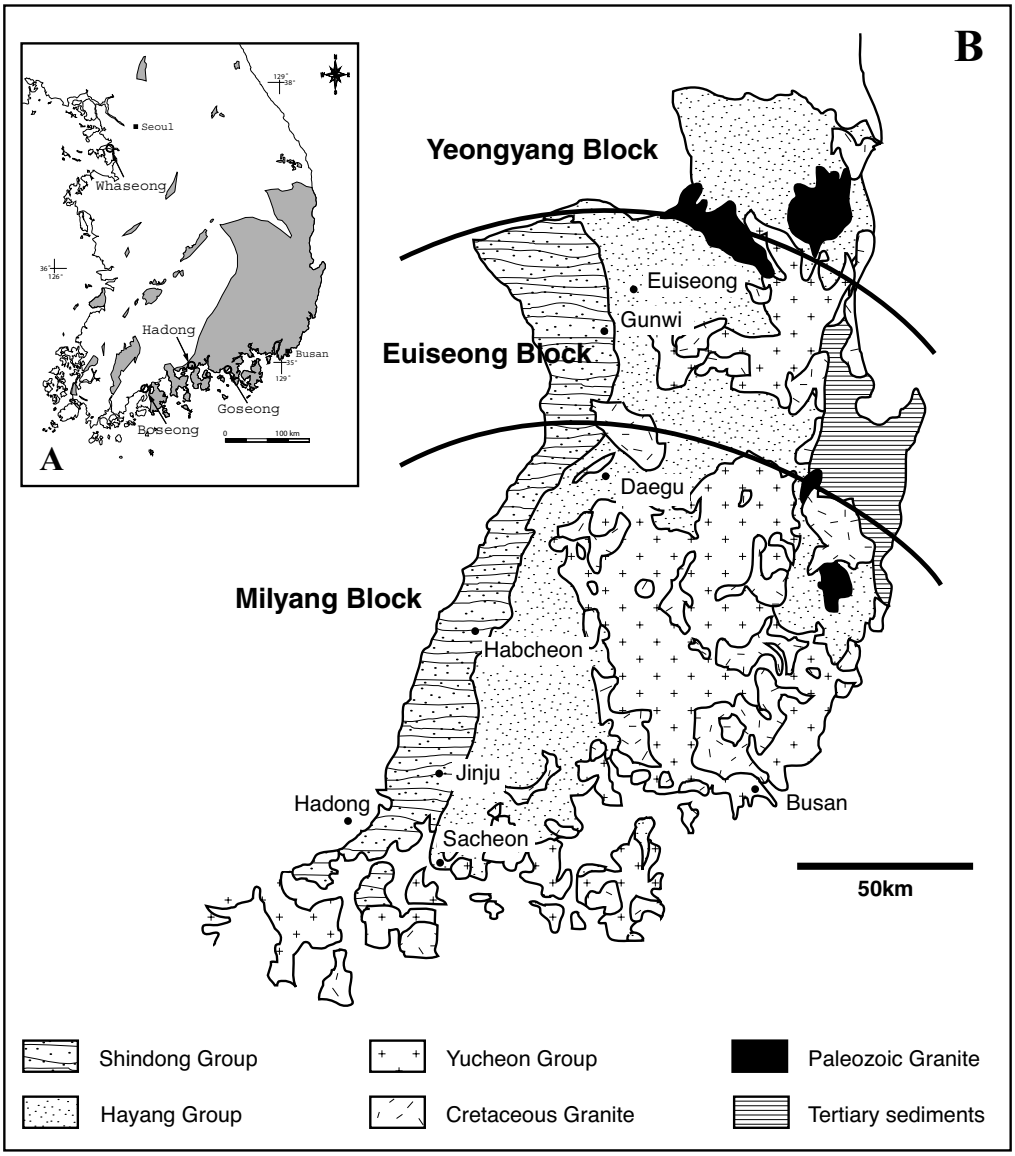

FIGURE 1. (**A**) Distribution of Cretaceous basins (shaded) in South Korea, (**B**) Simplified geological map of the Gyeongsang Basin.

DINOSAUR BONES

A total of eight localities have yielded dinosaur bones from the Shindong Group. Although they are isolated teeth and incomplete or fragmentary bones, the Hasandong Formation has produced the most abundant dinosaur materials from the Gyeongsang Supergroup. To date six localities are known from the Hasandong Formation in Euiseong and Jinju-Sacheon-Hadong areas. Near Euiseong the localities are at Doweonri and Whajeonri (Bongyang-myeon, Euiseong-gun, North Gyeongsang Province). A damaged scapula (?), discovered in a road cut at Euiseong toll booth (Doweonri) in 1995 has remained unexcavated in a light grey, gravelly sandstone bed of the upper Hasandong Formation. A half of the bone had already been lost by road construction when found.

The Jinju-Sacheon area (Yusuri, Naedong-myeon, South Gyeongsang Province) is one of the most important vertebrate fossil localities in the Gyeongsang Supergroup to date. Except during the rainy season (late June through mid-August) the bottom of the Gawha River channel (150 m wide) is well exposed from Yusuri southwest to Sacheon Bay (about 2 km). The stream bed at the Yusuri site consists of mainly upper Hasandong Formation and contains three dinosaur-bearing horizons which contain a number of unidentifiable bone

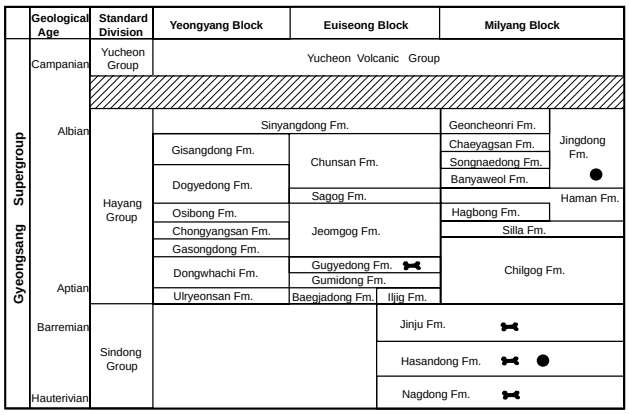

FIGURE 2. Stratigraphic correlation of the Gyeongsang Supergroup with the dinosaur fossil (bone and egg) horizons in the Gyeongsang Basin. Geological ages are based on palynomorphs (Choi, 1985, 1989; Lee et al., 2000b; Yi et al., 1994), paleomagnetism (Doh and Kim, 1994) and ion microprobe dating of the dinosaur tooth from the Hasandong Formation (Sano et al., 2002). Symbols represent dinosaur bone and egg, respectively.

fragments (Paik et al., 1998a). Recent prospecting of the exposed channel bed yielded ganoid scales, turtle shell fragments, three sauropod teeth, two teeth (5 cm long) and an ungual (4 cm) from a theropod, and a complete humerus. Excepting the sauropod teeth, these specimens have not been described in print. The sauropod teeth may represent three different morphotypes which would indicate that three sauropod taxa inhabited Korea at the time of deposition (Lee et al., 1997; Park et al., 2000).

Two dinosaur-bearing horizons were recognized from the upper Hasandong Formation where it is distributed along the west coastal outcrops in Dapyeongri, Seopo-myeon, Sacheon, South Gyeongsang Province (Paik et al., 1998b). The lower horizon (2 m thick) is greenish grey, sandy mudstone and produced a rib (1.8 m long) and an incomplete theropod tooth (1.5 cm long). Bones have partial micrite rims and are black in color. The upper horizon (50 cm thick) 150 m above the lower horizon yielded an incomplete limb bone (20 cm in diameter) and a few additional, fragmentary bones.

In Sumunri (Geumseong-myeon, Hadong, South Gyeongsang Province) the upper Hasandong Formation is exposed intermittently along sea cliffs. Unidentifiable bone fragments and an incomplete theropod tooth occur in a grey calcrete, intraclast conglomerates in association with fine-grained interlayers. Nine associated sauropod bones were found in an island of Galsari (Geumseong-myeon) in 2000. They include five incomplete cervical vertebrae, a caudal (?) vertebra, two chevrons and a rib.

In addition to the six localities from the Hasandong Formation mentioned above, new localities were found by a reconnaissance of islands of Hadong, Namhae, Sacheon areas in 2002. From 20 small islands, a variety of vertebrate fossils have been discovered mainly in grey sandy shale beds of the Hasandong Formation. They include three theropod teeth, and a fibula, a hadrosaurid tooth, a complete crocodyliform skull, fish scales, and two turtle humeri. They are now under preparation.

Two dinosaur localities are known from the Nagdong and Jinju Formations. A middle part of rib (45 cm long) and several unidentifiable fragmentary bones were collected from the Nagdong Formation in Noyangri and Wari (Yulgog-myeon, Habcheon-gun, South Gyeongsang Province). Isolated bone pieces plus an unidentifiable limb bone (20 cm long) were recovered from the Jinju Formation in Nahori (Ubo-myeon, Gunwi-gun, North Gyeongsang Province) within a greenish grey, gravelly sandstone bed (Son, 1989).

An incomplete dinosaur limb bone (42 cm maximum length at proximal end) excavated in the Gugyedong Formation of the Hayang Group near Tabri Station, Euiseong in 1973 turned out the proximal portion of a left humerus of an uncertain sauropod (Lee et al., 1997). From the same site, Kim (1983) recovered an almost complete femur (40 cm long) and an incomplete planar bone, which he referred to *Deinonychus*, as well as a caudal neural spine which he referred to *Ultrasaurus tabriensis* (now *nomen dubium*). Unfortunately, further systematic description of these fossils has yet to be published.

DINOSAUR EGGS

The first dinosaur eggshell was found in Sumunri (Geumseong-myeon, Hadong, South Gyeongsang Province) in 1972, which is the first find of dinosaur fossils of any kind in Korea. In 1996 the second find of eggshell pieces was made in greenish grey, sandy mudstone 50 m east of the first site. Six to seven elongate eggs (long axis 8.9 cm, short axis 6.9 cm) were reconstructed from the fragments, representing the ovaloolith-type eggs (Yun and Yang, 1997).

Very recently (1999 and 2000), dinosaur eggs and nests have been found at Shiwha Bay (Whaseong City, Gyeonggi Province) and at Deokryang Bay (Boseong-gun, South Chulla Province) and also Goseong Bay (Goseong-gun, South Gyeongsang Province) (Fig. 1A, Table 2).

The Whaseong site is a colonial dinosaur nesting ground in the southern part (16 km^2) of the reclaimed intertidal flat within the Shiwha Lake, Gyeonggi Province. It is located within the Shiwha Basin, which consists of conglomerates, sandstone, purple siltstone, and cherty mudstone, interlayered with rhyolitic tuff and andesitic volcanic breccia, showing an upward-thinning and fining trend (Chough et al., 2000). To date, 139 dinosaur eggs including 20 clutches have been discovered in the reddish conglomeratic sandstone beds ("mid-Cretaceous" Shiwha Formation) of nine small islands (Fig. 3). The islands consist of a series of alternating poorly sorted medium or coarse sandstones and conglomerates with clasts up

TABLE 2. Comparisons of four dinosaur egg sites in South Korea.

Sites	Hadong	Boseong	Goseong	Whaseong
Formations	Hasandong	Seonso	Jindong	Shiwha
Lithologies	Light gray siltstone	Red mudstone and sandstone	Red and gray sandstone	Red conglomeratic sandstone
Localities	2	4	5	24
Stratigraphic levels	2	5	4	Over 10
Clutches	2	10	3~4	20
Number of eggs	6~7	100	19	139
Eggshell morphologies	Ovaloolithid	Faveoloolithid Spheroolithid	at least two morphotypes	Faveoloolithid Dendroolithid Elongatoolithid
Associated eggshells		Turtle	Turtle	

to boulders. These sediments were deposited mainly in alluvial fan environment, an inference supported by compositionally immature sediments, which have a great range of grain sizes and types. At least three morphotypes of eggs (faveoloolithid, dendroolithid, and elongatoolithid) have been identified by the shell thickness and surface ornamentation (Lee et al., 2000a; Lee and Jeong, 2002).

The first type is the largest (average 11 cm in diameter with 1 mm thickness) and most abundant (95%) in the site (Fig. 4A–C). They occur in eight localities within at least ten different stratigraphic levels. The eggs are subspherical in shape, with an estimated maximum length of 13.5 cm and width of 11.5 cm. The eggshell thickness ranges from 0.85 to 1.23 mm, including ornamentation. The pores are large (0.34~0.45 mm in diameter), round or oval in cross section. They are numerous and evenly distributed on the eggshell surface (1,200~1,400/cm^2). The pore system is similar to multicanaliculate of the faveoloolithid-type eggs (Zhao and Ding, 1976). In radial view, however, the pore canals are strongly irregular in development and some canals exhibit large lacunae as seen in prolatocanaliculate pore system (Mikhailov, 1997). They are filled with secondary calcite. The boundary between the columnar layer and mammillary layer is not clear with the lack of resorption craters at the base of the spherulites. Many clutches are a loose cluster pattern of six up to nine eggs in random distribution, but some eggs are scattered or aligned in a linear pattern.

Smaller, at least seven spherical eggs are also found in two different stratigraphic levels of one island where the first type egg is not found (Fig. 4D–F). The eggs are elongate and range in size from 10.3 × 8.5 to 9.5 × 7.8 cm. The shell thickness ranges between 3.4 and 4.9 mm, including ornamentation. Ornamentation is closest to the heavy lineartuberculate type comprising thick ridges. Eggshell units grow from a single or from multiple mammillae. Shell units are narrow and branching fans in shape. The basal cap zone is nearly 1/20 of the shell unit. Growth-lines are shallow and slightly arched and follow contours of outer surface. The pore system is similar to prolatocanaliculate of the dendroolithid-type eggs. The pore canals originate mainly in interspaces between the shell units. Smaller canals form a long, straight network within the shell units.

The third type of eggs is represented by several pieces of eggshells in one spot. These eggshells are 1 mm thick and have linearituberculate surface texture, which differs from sagenotuberculate ornamentation of the first type of egg. This egg type may belong to non-avian theropods.

At least 10 nests and 100 eggs were found from four main sites along 3 km of Seonso coastline at Deokryang Bay (Zelenitsky and Huh, 2001). The eggs are associated with paleosols and are found within at least five different stratigraphic levels of the Seonso Conglomerate. At least 10 clutches of eggs are present with at least two dinosaur egg types (faveoloothid and spheroolith) (Huh and Zelenitsky, 2002).

Goseong eggs were found in the Jindong Formation along the coastline near Goseong Downtown in 2000. Nineteen eggs with three clutches have been observed in red and gray sandstone beds from five sites. Although detailed study is not conducted, the eggs appear to be at least two different morphotypes.

DISCUSSION

Although not yet widely reported to the international community, a diversity of dinosaur remains have been recognized from the thick sequences of the non-marine Gyeongsang Supergroup by teeth and bones, eggs, and tracks. On the basis of tooth morphology at least three kinds of sauropods appear to have lived in Korea during early Cretaceous time. Theropods are also confirmed by teeth and an ungual. It is remarkable, however, that ornithopod bones are extremely rare, considering that ornithopods account for over 80% of dinosaur tracks recorded from the Gyeongsang strata. This bias may be from lack of extensive (or at least systematic) prospecting in the Gyeongsang rather than from depositional or preservational events.

Most bones occur as scattered, broken, and isolated pieces. Sometimes the disarticulated bone fragments are enclosed in micrite, which appears as calcareous nodules. Although spongy bone textures were preserved, the compact bone is often damaged, probably due to weathering before burial, so that a

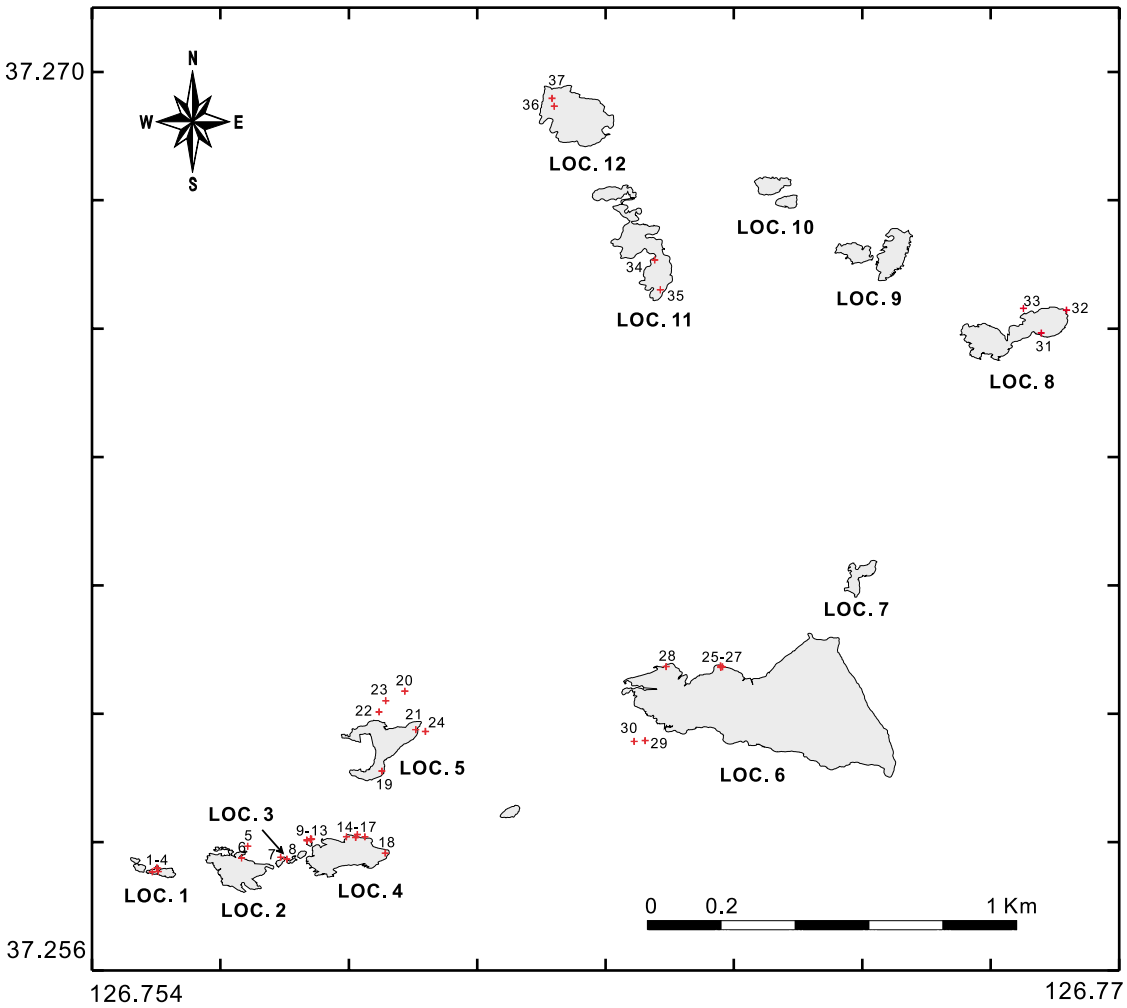

FIGURE 3. Distribution of small islands showing dinosaur egg localities of the Whaseong site.

large proportion of specimens are difficult or impossible to identify. This type of preservation occurs mainly in the lower horizons of Hasandong Formation in Yusuri and Dapyeongri, frequently associated with reddish brown calcic paleosols developed in floodplains (Paik et al., 2001). It indicates that these bones had probably undergone long aerial exposure, transportation, and scattering into lower land in the floodplain before burial. The Hasandong Formation is nevertheless the most productive so far for vertebrate specimens, which is probably related to its abundant calcic paleosols as seen in Galsari specimens (Paik et al., 1998a). Meanwhile, skeletal elements from channel deposits of the Nagdong and Gugyedong Formations have better preservation than those from the Hasandong Formation. Although isolated and broken, they retain their compact bone and original shapes so that most of them are identifiable.

Among four dinosaur egg sites, the Whaseong site is the largest egg site in Korea. The dinosaur eggs and nests occur in the reddish conglomeratic sandstone beds deposited mainly in alluvial fan environment. It is different from other three sites which represent channel and floodplain deposits. An unidentified piece of bone was found in this area, which is waiting for excavation. The first type of eggs in the Whaseong site occurs in a single plane. The tops of many eggshells are missing and their fragments are present in the bottoms of the eggs. Pebbles are also observed inside eggs. It indicates that many eggs in this area died before incubation, possibly due to crushing pushed the shell inward by high-density clastic sediment flows in alluvial fan environment rather than predation (Carpenter, 1999) or hatching. The fact that they are found within many different stratigraphic levels within nine islands suggests multiple egg laying events. The second type is

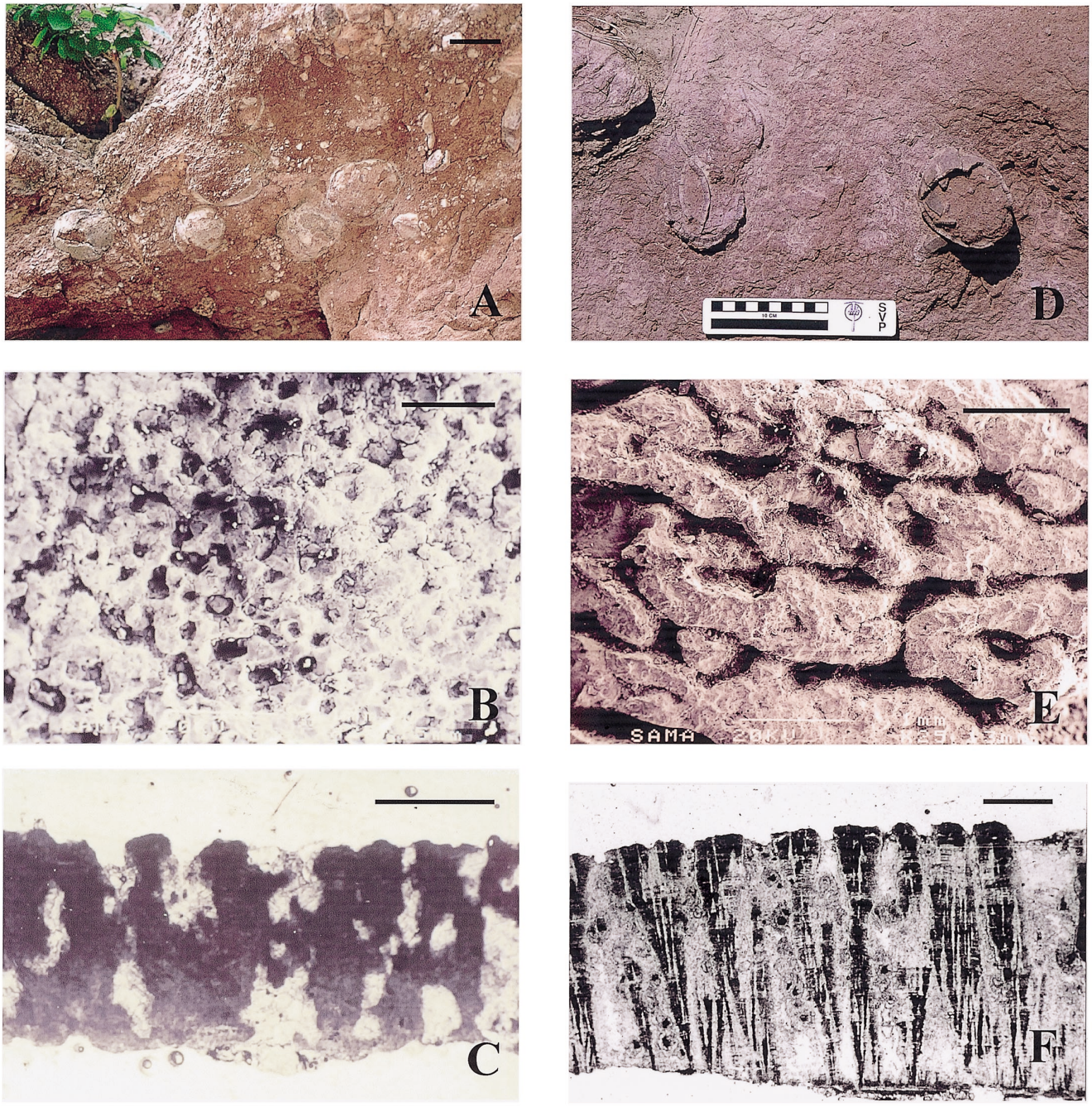

FIGURE 4. Two types of eggs from the Whaseong site. (**A**) A clutch containing eight eggs of type A egg, scale bar equals 100 mm, (**B**) Outer surface ornamentation (SEM) of type A egg, scale bar equals 1 mm, (**C**) Radial view (PLM) of type A egg, scale bar equals 50 mm, (**D**) A clutch containing four eggs of type B egg, (**E**) Outer surface ornamentation (SEM) of type B egg, scale bar equals 1 mm, (**F**) Radial view (PLM) of type B egg, scale bar equals 10 mm.

comparable to that of *Megaloolithus megadermus* (Mohabey, 1998), which is one of the thickest dinosaur eggshells (4.0~4.8 mm), but the egg size is much smaller than the latter (13~18 cm in diameter). Based on the microstructure and surface ornamentation, they represent a new type of dendroolithid egg.

Most bones, teeth, and eggshells from the Gyeongsang Supergroup are dark grey to black in color, possibly indicating some degree of thermal maturity. Alteration would probably be caused by extensive volcanic activities during deposition of the Yucheon Group.

CONCLUSIONS

The Gyeongsang Supergroup has one of the richest Mesozoic dinosaur ichnological records in the world. By comparison, a few of isolated bones have been found in quarries, road cuts, stream beds, and coastal outcrops by sporadic individual prospecting. Sedimentary facies known to contain bones indicate that better preserved, more fully associated specimens of dinosaurs may be found with persistent searching. Further encouragement may be taken from recent discoveries of large egg nest sites at Whaseong and Boseong, and new vertebrate fossil localities in islands of Hadong area. The time period represented by the Gyeongsang Supergroup is especially critical for understanding the evolution of dinosaurs. Korea is and was situated geographically upon possible coastal migration routes between Asia and North America. Therefore, Korean dinosaurs would provide further important data for our understanding of dinosaur evolution in Asia.

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