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Impressions of dinosaur skin from the Cretaceous Haman Formation in Korea

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ABSTRACT

The occurrences and features of two specimens of fossil dinosaur skin from Cretaceous Haman Formation in South Korea, including a new type of skin texture (development of micropolygons within scales) are described here for the first time, and several types of sedimentological aberrations of inorganic origin that are similar in appearance to fossil skin and therefore have the potential to be misidentified as fossil skin. The features and origins of fossil dinosaur skin found in South Korea with those of a diverse range of geological aberration structures resembling fossil skin are also compared.

It is interpreted that dry climate, the presence of torn skin, and episodic sheetflood on an alluvial plain were related with the preservation of the Haman skin fossils. The preservation condition of the Haman skin fossils suggests that sheetflood deposits on a floodplain to mudflat environment under dry climatic condition are potential candidates for dinosaur skins to be found. The results of this study not only provide additional information that is helpful in understanding dinosaur skin, but also are useful in discriminating between true fossil skin and enigmatic sedimentological aberration structures resembling skin.

1. Introduction

The low preservation potential of soft tissue means that it is rare to find information in the rock record regarding dinosaur skin, although the fossilised integuments of several hadrosaurs and tyrannosaurs have been documented in association with bones and footprints (Currie et al., 2003; Wegweiser et al., 2004, 2006; Platt and Hasiotis, 2006) and some integumentary structures were described in carnivorous dinosaurs (Chen et al., 1998; Gohlich and Chiappe, 2006). Most of these fossil skins have been identified in North America, with few reported elsewhere. The discovery of new fossil dinosaur skins is therefore important in understanding the features of the skin and biology of dinosaurs.

Dinosaur skins found to date include the skin from a hadrosaur foot (Currie et al., 1991), hadrosaur skin (Anderson et al., 1998), hadrosaur skin with radiating grooves (Anderson et al., 1999), hadrosaur tail skin (Gillete et al., 2002), skin from the chin of a duckbill dinosaur (Wegweiser et al., 2006), mineralised skin from the scapular area of a lambeosaurine (hadrosaur) dinosaur (Wegweiser et al., 2004), sauropod foot skin (Platt and Hasiotis, 2006), and theropod and sauropod skin from the Nemegt Formation in the Gobi of Mongolia (Currie et al., 2003). Most skin preservations show impressions of typical reptilian scales, except for those from feathered dinosaurs. The scales are tuberculate rather than imbricated, as seen in many types of lizards and snakes, and tubercle size varies with body part. Tubercle shape is thus used as a means of identification.

The Cretaceous non-marine deposits of South Korea contain numerous dinosaur tracks (Lim et al., 1989; Huh et al., 2001, 2003; Paik et al., 2001a; Hwang et al., 2002, 2004; Huh et al., 2006a; Paik et al., 2006), dinosaur eggs (Lee et al., 2000; Paik et al., 2004; Yun et al., 2004; Huh et al., 2006b), bones (Paik et al., 1998; Dong et al., 2001; Paik et al., 2001b), and teeth (Yun et al., 2007; Lee, 2008) suggesting that many dinosaurs inhabited the Korean Peninsula during the Cretaceous, in turn raising the possibility that fossil dinosaur skin might be found in Korea. *Paleodictyon*, a marine invertebrate trace fossil with a hexagonal pattern, described from the Haman fluvial deposits in association with dinosaur footprints (Yang et al., 2003) is apparently a mis-identification and may represent an impression of dinosaur skin (Lockley and Jenkins, 2005).

The present study describes the occurrences and features of two specimens of fossil dinosaur skin from the Lower Cretaceous fluvial-lake margin deposits (Haman Formation in the Gyeongsang Basin) in South Korea, including a new type of skin texture described here for the first time, and several types of sedimentological aberration structures of inorganic origin that are similar in appearance to fossil skin and therefore have the potential to be misidentified as fossil skin. We also compare the features and origins of fossil dinosaur skin found in South Korea with those of a diverse range of the aberration structures. In addition the preservational condition of these dinosaur skin fossils is provided. The results of this study not only provide additional information

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that is helpful in understanding dinosaur skin, but also they are useful in discriminating between true fossil skin and enigmatic sedimentological aberration structures.

2. Geological setting

In South Korea, several continental basins formed during the Cretaceous due to transtensional tectonic movements related to sinistral strike-slip fault systems (Lee, 1999; Chough et al., 2000). These basins are filled by alluvial fan, fluvial and lacustrine deposits, and volcanics. The Gyeongsang Basin is the largest one and comprises a 9000-m-thick sequence assigned to the Gyeongsang Supergroup, which is divided into the Sindong, Hayang, and Yucheon Groups in ascending stratigraphic order (Chang, 1975) (Fig. 1). The Haman Formation is the upper part of the Hayang Group. The Hayang Group also consists of alluvial fan, fluvial, and lacustrine deposits (Choi, 1985).

The Haman Formation overlies the Silla Conglomerate (alluvial fan deposits) and underlies the Jindong Formation (lake deposits). Main lithology of the Haman Formation is tabular sandstone with thin mudstone drape which was deposited by sheetflood on an alluvial plain. Lake margin deposits occur in the uppermost part of the Haman Formation and tuffaceous deposits are intermittently intercalated. Polygonal desiccation cracks and ripples are common in these sheetflood deposits. The Haman Formation has previously yielded dinosaur tracks, bird tracks including the oldest known webbed tracks, pterosaur tracks, and dinosaur eggs (Kim, 1969; Baek and Yang, 1998; Yun et al., 2004; Kim et al., 2006). The tuff deposits (Gusandong Tuff) intercalated in the uppermost part of the Haman Formation was measured as 96–97 Ma by U–Pb age measurement on zircons (Jwa et al., 2009). The Haman Formation is thus correlated with the Cenomanian.

3. Impressions of dinosaur skin

In this study two specimens of fossil dinosaur skin are described for the first time from the Early Cretaceous (Aptian) Haman Formation of South Korea. One specimen of fossil skin was found in abandoned rock pile of the Haman Formation. The fossil skin is preserved as negative relief on purple sandy mudstone in sheetflood deposits. The fossil-bearing mudstone is draped upon grey medium- to fine-grained sandstone that contains traces of small invertebrate trails (Fig. 2A). The fossil skin occurs as an irregular patch of 5 × 5 cm in size, and the skin impression consists of a regular pattern of interlocking polygons, mostly hexagonal in shape in a honeycomb-like pattern (Fig. 2B). The scales are in edge-to-edge contact, and show no sign of overlap or imbrication. The size of tubercles is remarkably uniform, being 10–12 mm wide (maximum, 18 mm). Diamond-shaped micropolygons of 1–2 mm in size and with pointed ridges are observed within the hexagonal tubercles (Fig. 2B and C).

Fossil skins with similar features to that found in the Haman Formation are interpreted to represent the skin of a hadrosaur (Lockley et al., 2003) or sauropod dinosaur (Lockley and Jenkins, 2005). The development of micropolygons within tubercles in the fossil from the Haman Formation is a new feature of dinosaur skins, reported here for the first time. The tracks of ornithopod dinosaurs are common in the Haman Formation, indicating that the skin found in the Haman Formation could indeed be that of a hadrosaur. The preservation of the skin as a small patch upon a mudstone surface suggests that the imprint was made by a piece of skin fragment deposited on a floodplain.

A second specimen of fossil skin was found within the same abandoned rock pile of the Haman Formation. The skin impression is observed in positive (Fig. 2D and E) and negative (Fig. 2F) relief within interlaminated fine-grained sandstone to siltstone and

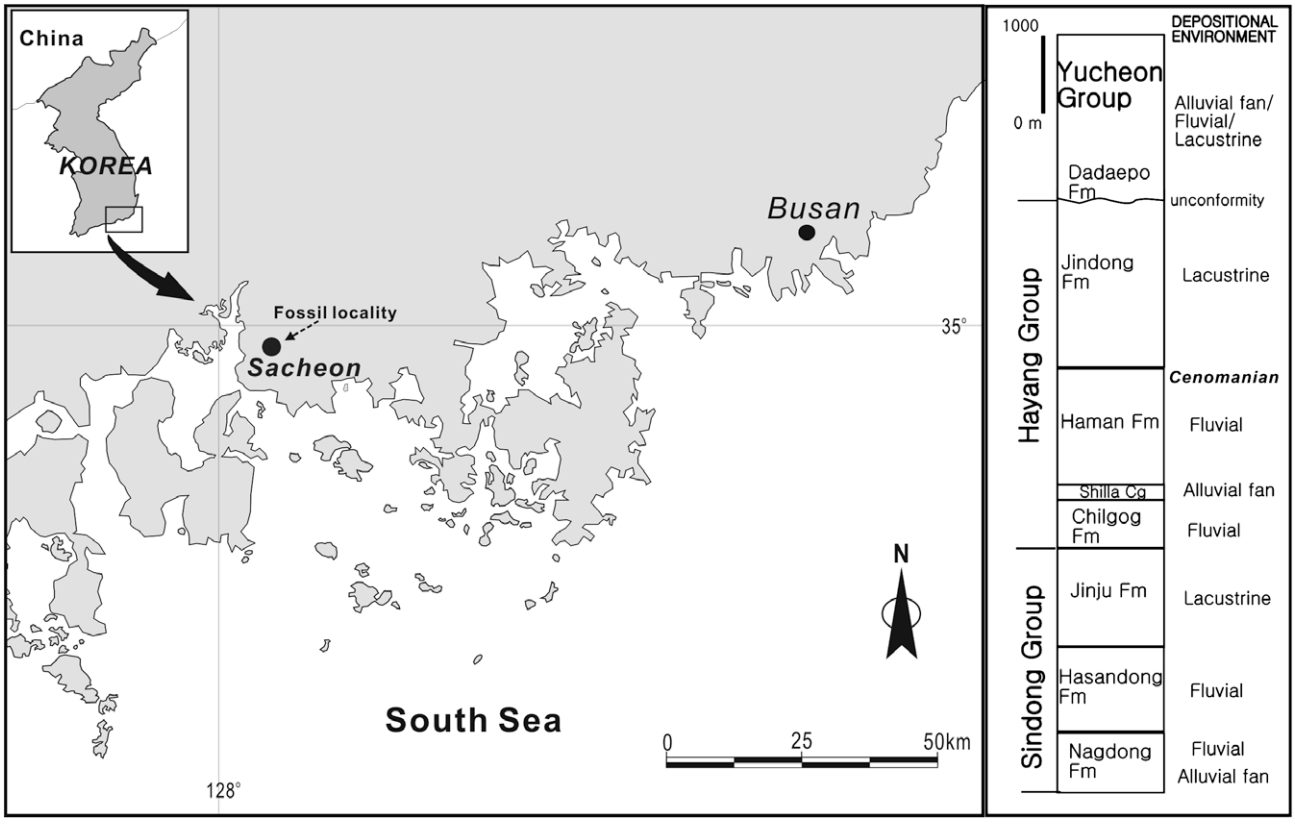

Fig. 1. Fossil locality map with stratigraphy and depositional environments of the Gyeongsang Supergroup.

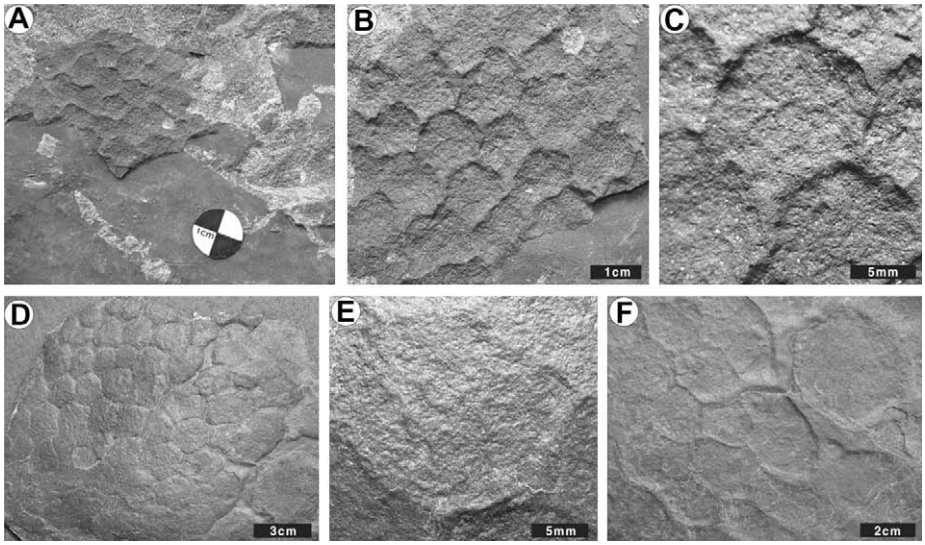

Fig. 2. Dinosaur skin fossils from the Cretaceous flood plain (A–C) and lake margin (D–E) deposits: (A) skin impression on sandy mudstone with interlocking polygons (mostly hexagonal) in a honeycomb-like pattern. Invertebrate traces are associated, (B) closer view of (A). Diamond-shaped micropolygons are observed within the hexagonal polygons, (C) closer view of (B), (D) skin impression in positive relief on mudstone with interlocking hexagonal polygons, (E) closer view of (D). Micropolygonal texture is also observed within the polygons, (F) counter part of (D).

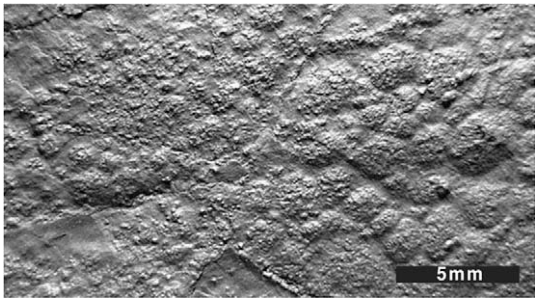

Fig. 3. Skin-like impression in positive relief on floodplain mudstone with unknown origin.

mudstone deposited on a mudflat. The preserved area of skin is about 20 × 15 cm in size, and the impression consists of interlocking polygons or elliptical scaly texture. Microtexture is also observed within the scales as microrelief (Fig. 2E). The diameter of the scales varies from 1.5 to 5 cm. The smaller scales are hexagonal in shape and the larger scales ovate to rounded, generally oriented at a low dip relative to the fossil surface. The polygonal scales are in edge-to-edge contact and do not overlap, and the ridges of the polygons are pointed. A similar texture has been documented previously for a sauropod dinosaur (Platt and Hasiotis, 2006).

Skin-like impressions in positive relief are also observed on the underside of mudstone from the Haman Formation (Fig. 3). The impressions are polygonal (pentagonal to hexagonal), elliptical, or circular forms of tuberculate texture. Tubercles are 1–3 mm in diameter, and some are in edge-to-edge contact, as observed in dinosaur skins. The impressions are associated with mudcracks and small invertebrate burrows. The origin of these impressions is problematic.

4. Sedimentological artifacts resembling dinosaur skin impression

Artifacts in the rocks may under some circumstances be mistaken for dinosaur skin (e.g. Chadwick, 1943). The Cretaceous dinosaur-fossil-bearing deposits in Korea also contain inorganic sedimentologic structures resembling the texture of reptile skin.

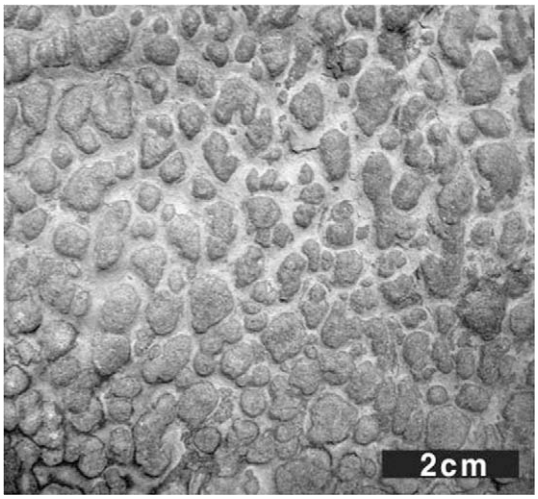

Fig. 4. Skin-like sole mark of load structure with irregular knobbles.

Diverse modes of these sedimentological artifacts that could be mistaken for dinosaur skin impressions are observed upon the bedding surfaces and soles of floodplain and lake margin deposits, appearing as polygonal or subcircular to elliptical imprints on bedding surfaces within mudstone and sandstone. The most common skin-like features found in these deposits are load structures and rainprints (Figs. 4 and 5). Their highly irregular, circular, or elliptical shapes and lack of close edge-to-edge contact indicate that they are artifacts or aberrations rather than true skin impressions.

One skin-like feature in negative relief is observed in the rainprint-bearing mudstone of lake margin deposits from the Jindong Formation. This feature is unique in that the impressions have linear patterns and grooves, unlike rainprints (Fig. 5D); however, these features lack interlocking polygons, edge-to-edge contacts, and pointed ridges. Polygonal rainprints observed on recent fluvial sediments also resemble dinosaur skin (Fig. 5F). Some interference ripples with wavelengths of 1–4 cm possess honeycomb-like polygonal features that resemble dinosaur skin (Fig. 6).

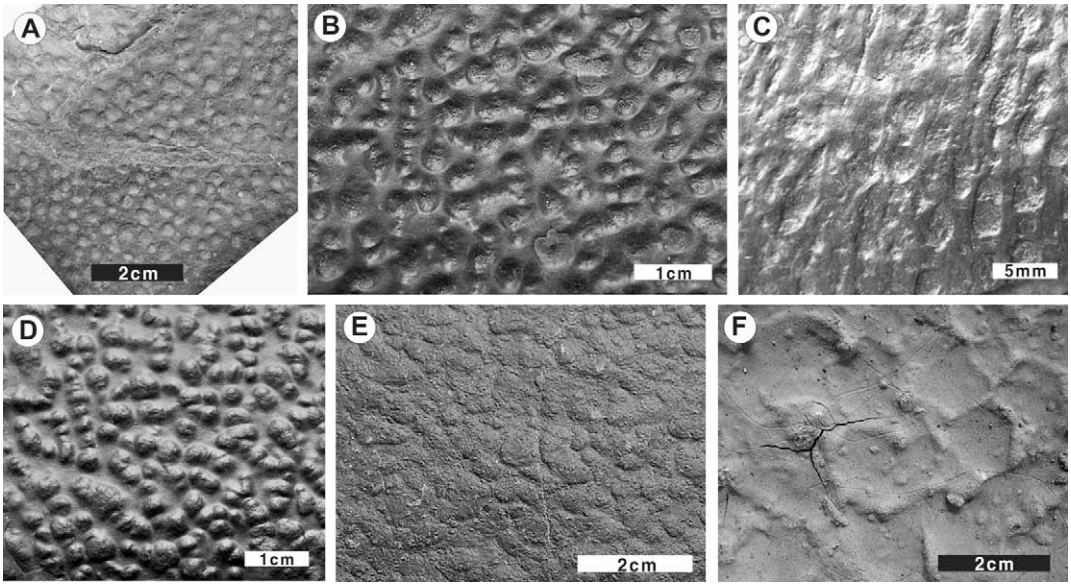

Fig. 5. Occurrence of rainprints in diverse modes resembling dinosaur skin in: (A–C) rainprints on mudstone showing skin-like features, (D–E) sole marks of rainprints, (F) recent rainprints on muds with sub-polygonal features.

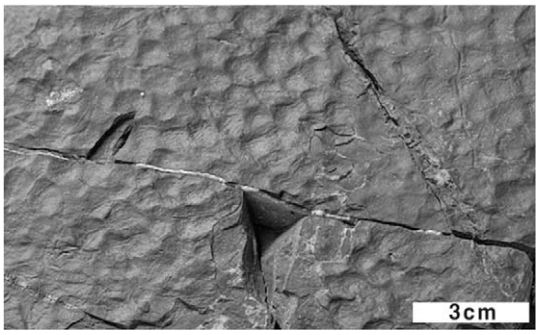

Fig. 6. Skin-like interference ripple with polygonal features.

5. Discussion and summary

The dinosaur fossils found in the Cretaceous continental deposits of Korea show selective occurrence in lithology and palaeoenvironments in general. The dinosaur bones usually occur in floodplain deposits with pedogenic calcretes (Paik et al., 2001b). The dinosaur eggs are common in alluvial fan deposits with pedogenic calcretes (Paik et al., 2004). The dinosaur footprints are mostly concentrated in lake margin deposits with desiccation cracks and some pedogenic calcretes (Paik et al., 2001a; Huh et al., 2003). It suggests that calcareous pedogenesis under semi-arid climate was a main cause to the preservation of dinosaur fossils irrespective of fossil types.

Although dinosaur fossils, in particular dinosaur footprints, are common in the Cretaceous continental deposits of Korea, dinosaur skin fossils are rarely associated with them. It implies that the preservation potential of skins is very low compared with that of bones and footprints. The preservation of Haman skin fossils in the floodplain and lake margin deposits indicates that subaerial exposure was related with their preservation. The burial of Haman skin fossils by sheetflood deposits suggests that episodic deposition was related with the preservation. The occurrence of the Haman skin fossils as small patches suggests that they were not preserved *in situ* but removed from the carcass. Consequently, it is interpreted that dry climate, the presence of fragmented skin, and episodic sheetflood on an alluvial plain were related with the preservation of the Haman skin fossils.

As described above and shown in the figures, certain load structures and rainprints preserved on floodplain and mudflat deposits have the potential to be misidentified as dinosaur skin if not subjected to close scrutiny. It is therefore possible that some of the dinosaur skins reported previously from Mesozoic deposits may in fact be inorganic skin-like records. On the basis of the comparison of dinosaur skins and skin-like sedimentological artifacts presented in this study, true skins can be discriminated from the artifacts on the basis of the pattern, contact, interlocking state, edge shape, and internal microfabric of the scales. Dinosaur scales consist of interlocking polygons and have a regular pattern, edge-to-edge contact, pointed edges, and internal microtexture; in contrast, the artifacts have irregular patterns and lack edge-to-edge contact, interlocking polygons, pointed edges, and internal microtexture within the scaly fabric.

In summary, this study is the first to describe fossil dinosaur skin from Korea and the occurrence of internal microfabric within dinosaur scales. The preservation condition of the Haman skin fossils suggests that sheetflood deposits on a floodplain to mudflat under dry climate are potential candidates for dinosaur skins to be found. In addition, diverse modes of skin-like sedimentological aberration structures of inorganic origin are described, suggesting that the identification of polygonal scaly fabric preserved in dinosaur-fossil-bearing Mesozoic deposits provides insufficient criteria in terms of positively identifying fossil dinosaur skin.

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