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Short communication

Small scale scrapes suggest avian display behavior by diminutive Cretaceous theropods

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ABSTRACT

A set of about 25 diminutive sub-parallel scrapes in the Cretaceous Haman Formation of South Korea fit the morphology of the small theropod track *Minisauripus* which is also known from this formation. The scrapes are interpreted as evidence of display behavior, and suggest that the trace maker was an adult engaged in avian-like courtship behavior. Although avian theropods are also known from this formation, the scrapes are inconsistent with their foot morphology. Although large theropod scrapes have been interpreted as evidence of display behavior they are only known from North America. Thus, the scrapes described here are the first reported from Asia, and the first interpreted as evidence of display behavior in such a diminutive species.

1. Introduction

A recent report of large scale scrapes made by Cretaceous non-avian theropods in Colorado (Lockley et al., 2016) has raised interesting questions about "nest scrape display" behavior and its potential to be preserved as traces in the fossil record. As shown by these authors several sites in the track-rich, Dakota Sandstone of Colorado (Lockley et al., 2014) reveal multiple, paired scrapes made by the hind feet of large non-avain theropods. In one case more than 50 large scrapes, some up to 2 m in diameter occur in a small area of 750 m^2, suggesting a display arena site. These large paired or bilobed scrapes represent a new type of trace fossil named *Ostendichnus bilobatus* (Lockley et al., 2016).

These authors show that the Cretaceous trace fossil evidence is consistent with the nest scrape display behavior of a number of modern ground-nesting bird species (Cairns, 1982; Harris, 1984; Bomford, 1986; Bergstrom, 1988; Whitfield and Brade, 1991; Powesland et al., 1992), and with the lekking behavior of a number of modern species (Armstrong, 1942; Merton et al., 1984; Payne, 1984; Thery, 1992; Jiguet et al., 2000). The Cretaceous evidence suggest that nest scrape display behavior can be traced back for at least 100 million years, raising the obvious question of whether other examples of this kind of scrape behavior might be preserved elsewhere.

The purpose of this paper is to report a single isolated set of scrapes found on a surface in the Cretaceous Haman Formation of Korea (Fig. 1) which is well-known for its abundance and diversity of avian theropod, non-avian theropod and other dinosaur traces. The tracksite, now unfortunately lost, is only about 3 km south of the famous Gajin-ri tracksite, described by Kim, J-Y. et al. (2012a). The set of scrapes, described here, was made by a very small trackmaker with very fine claws.

2. Description of material

The complex of scratches described here is known only from photographs and personal observation by one of us (KSK). Attempts to re-locate and recover the specimen after it was first observed and photographed at close range proved unsuccessful due to the specimen having been moved to an unknown location, presumably by persons unaware of the specimen's significance. However, the

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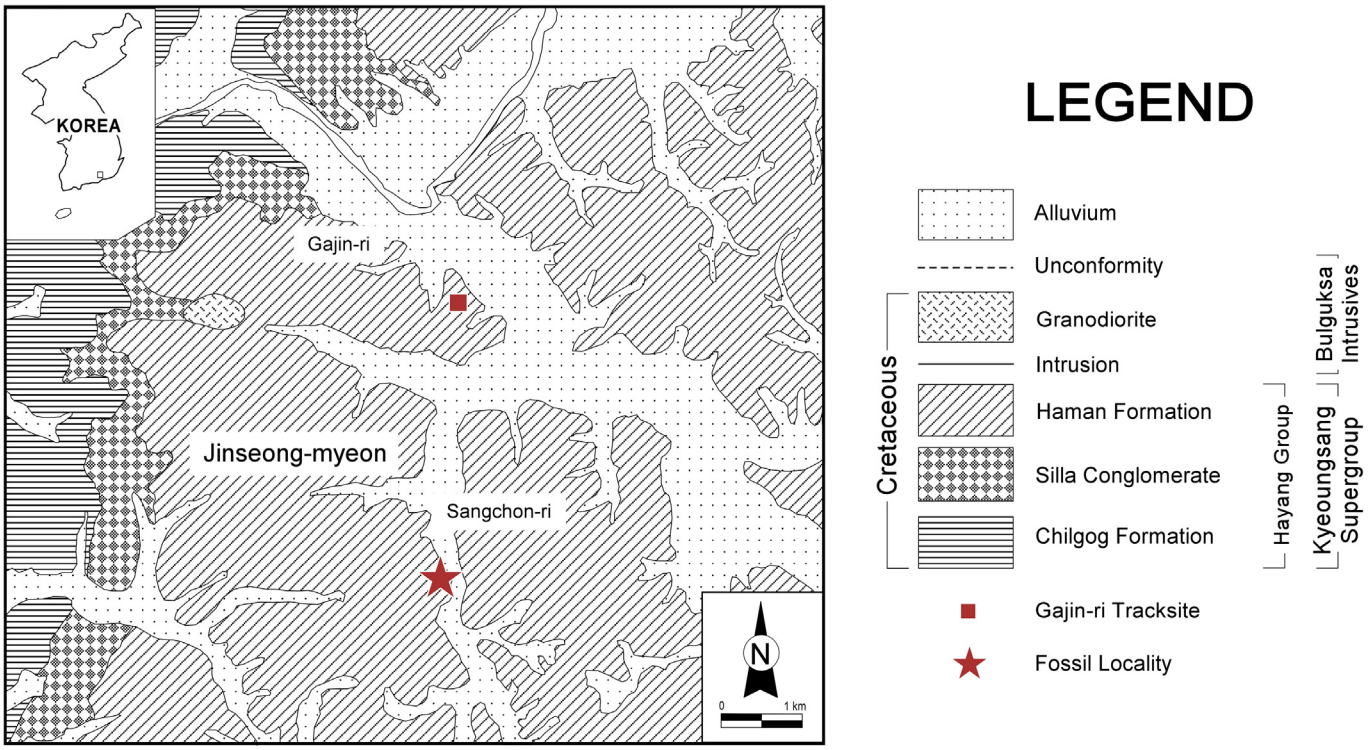

Fig. 1. The scrape site locality in Haman Formation, marked with a star, is only about 3 km south of the well-known Gajin-ri tracksite.

available photographs show a number of very distinctive features. These include a complex of sub-parallel scratch marks about 11 cm long and 7 cm wide with at least 25 separate very fine scratch marks. All these traces have a similar orientation, sub-parallel to the long axis of the complex (Figs. 2 and 3) and none are more than 1–2 mm wide. Two other scratches aligned with the long axis of the complex occur about 3 cm away. The complex has a roughly bilobed shape, with the longest scratches on the outside. In contrast, the center of the complex contains shorter overlapping scratches and an indented area that may represent a track, comparable in size to

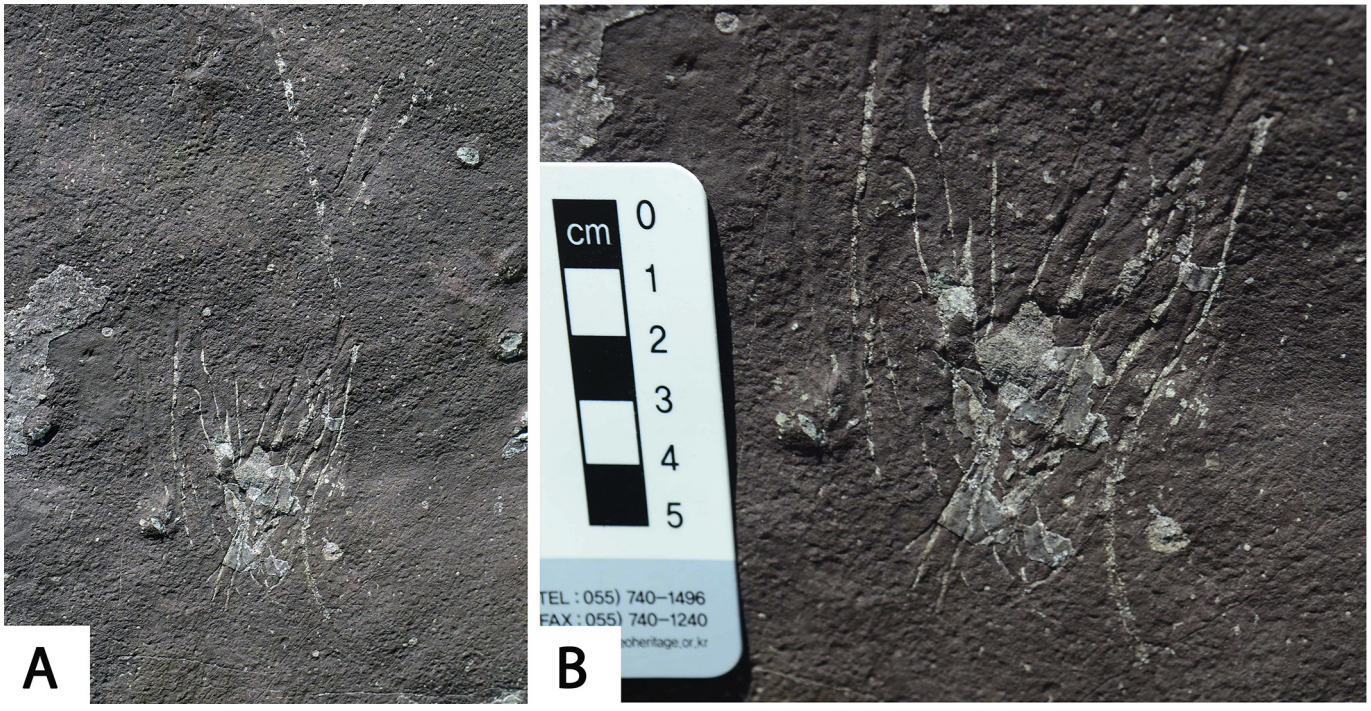

Fig. 2. A: Photograph of scratch marks, with detail (B) of main complex. Note mineralized veneer on part of surface and in some scratches. Compare with Fig. 3.

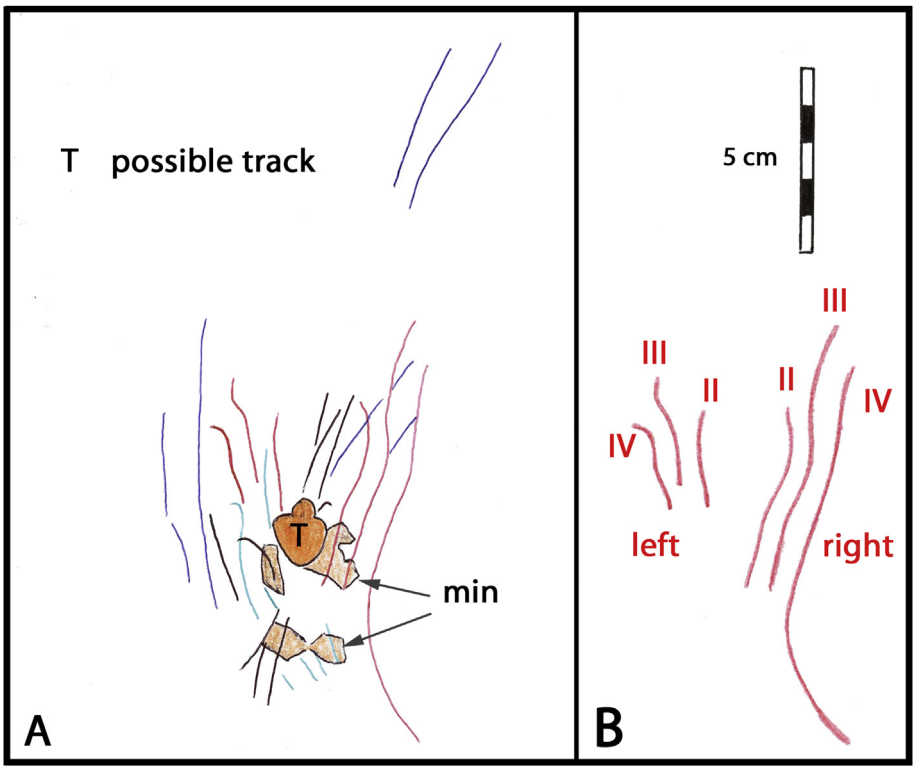

Fig. 3. A: Drawing of scratch marks showing bilobed pattern, and central area with possible track. B: shows pair of isolated scratches showing tridactyl pattern suggestive of the left and right feet of a mesaxonic trackmaker, with inferred digit traces II, III and IV indicated.

Minisauripus (Kim, K-S et al., 2012b). Although we cannot be certain this is a track, the inferred track area, outlined in Fig. 3A, is ~2.0 cm long and ~1.5 cm (l/w = 1.33) which is a typical size for *Minisauripus* (Kim et al., 2012b; Xing et al., 2016). The width is also consistent with the width of the two sets of three scratch marks (Fig. 3B) described below. Many of the scratch marks contain remnants of a light colored mineral veneer that is also seen in the central indented area, as well as elsewhere on the surface at some distance from the scratch marks. This veneer, may represent the remnants of a drape of fine-grained sediment, or mineralization that separated the underlying surface from the overlying layer that has since been removed by natural erosion. Such separation layers representing clay drapes between sandy depositional units are typical of the Haman Formation and facilitate very clean splitting of the bed. All Korean occurrences of *Minisauripus* described to date come from the Haman Formation in facies consistently described as "lake margin" (Kim et al., 2012b, table 1).

As shown in Fig. 3, it is possible to separate sets of subparallel scratch marks from others within the complex. The two most conspicuous sets are shown in red and appear to indicate the left and right scrapes made by a small, tridactyl trackmaker. Support for this interpretation comes from measuring the width or spacing between the outer and inner scratch marks, which is similar at about 1.0–1.5 cm in both cases. Moreover, in both cases the middle scrape is longest indicating a trackmaker with a distinctly mesaxonic foot in which digit III was the longest.

3. Trackmaker interpretation

Based on the known track-record from Korea, there are only a few small trackmakers capable of making tridactyl scrapes only 1.0–1.5 cm wide. These include the trackmaker of *Minisauripus* which left tracks about 1.0 and 2.5 cm wide. Even the largest *Minisauripus* track from China are no more than 3.2–4.0 cm wide (Kim et al., 2012b). By contrast, the smallest bird tracks from Korea, assigned to ichnogenus *Koreanornis* are between 2.5 and 3.0 cm wide, with the largest tracks (*Jindongornipes*) being up to 7.0 cm wide. As shown in Fig. 4, *Minisauripus* typically has a narrow footprint with low digit divarication angles, whereas all known Cretaceous bird tracks from Korea have wide digit divarication angles. It is possible that birds with widely divergent toes would bring their toes together into a narrow configuration in when scraping the substrate, but this is conjectural. Most of the Korean bird tracks reveal trackways with inward rotation of the individual tracks, based on the orientation of digit III relative to the trackway mid line. By contrast, the scrapes described here indicate a slight outward rotation.

The scratch or scrape marks described here best fit the size and shape of the trackmaker of *Minisauripus*. Support for this inference comes from the evidence that the *Minisauripus* trackmaker had very, sharp, narrow claws, which sometimes splayed outward. In some cases the distal claw scrape marks described here show an outward curvature relative to the orientation of the digit trace. This is notable in the outer scrape of the left side tridactyl trace.

4. Discussion

If we assume the scrapes were made by the *Minisauripus* trackmaker, as fits the morphological evidence, it is also possible to infer that the trace maker was an adult, because it engaged in courtship behavior. This assumes that juveniles or subadults did not engage in courtship behavior. This is an argument in favor of regarding *Minisauripus* trackmakers as adult, rather than juveniles (cf., Kim et al., 2012b: Xing et al., 2016). As discussed in this latter

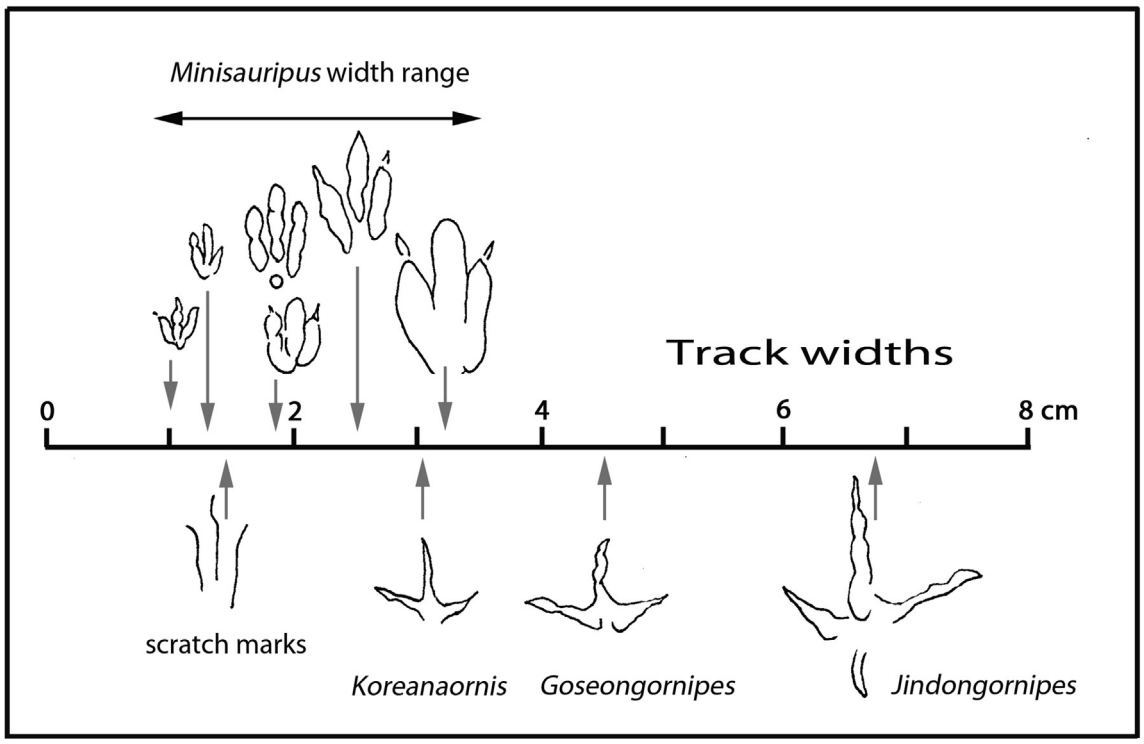

Fig. 4. Widths of small, non-avian theropod (*Minisauripus*) and avian theropod (bird) tracks from Korea and China.

paper, most ichnological literature dealing with assemblages of small tracks attributed to small avian and non-avian theropods assumes that small tracks represent adults not juveniles (Leonardi, 1981; Xing et al., 2016). However, we acknowledge that such an interpretation is not proven. It is also possible that even if the trace maker was a small adult, it could have engaged in scrape behavior for other reasons: i.e., it could simply be a random impulse to engage in instinctual or stereotypical behavior of the type described by Armstrong (1942), especially in a case where it appears in isolation and cannot be placed in the context of a possible lek or display arena.

We have considered the possibility that these scrapes might have been made by an invertebrate, but can find no surface trace ichnotaxa or morphotype described in standard texts (e.g. Häntzschel, 1975) displaying such morphology.

5. Conclusions

1) A very small set of ~25 scrapes from the Cretaceous Haman Formation of Korea are only about 1–2 mm wide and therefore indicate a very small, theropod trackmaker with fine claws.
2) These are the first small theropod scrapes reported from Asia.
3) The best-preserved scrapes occur as a left and right pair with a diagnostic configuration consistent with the morphology of the theropod track *Minisauripus* which occurs locally.
4) Although various bird tracks are known from the Haman Formation, they are too large to be consistent with the scrape morphologies.
5) Thus, the scrapes are interpreted as evidence of scrape display behavior by a diminutive non-avian theropod rather than a bird, probably as part of a courtship ritual.
6) This interpretation implies that the trackmaker was a mature individual engaged in adult breeding behavior.

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