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First report of lacertiform (lizard) tracks from the Cretaceous of Asia

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ABSTRACT

The well-preserved trackway of a lacertiform, lizard-like trackmaker from the Haman Formation (Cretaceous) of Korea is described as *Neosauroides koreaensis* ichnogen. et ichnosp. nov. This is the only example of a Cretaceous lacertiform or lizard-like trackway currently known in the global track record. Although lacertiform trackways, mostly assigned to the ichnogenus *Rhynchosauroides*, are common in the global Triassic, they are almost entirely absent in the Jurassic and Cretaceous. Moreover, ichnological classification criteria allow that *Neosauroides* is morphologically distinct from *Rhynchosauroides* at the genus level, and more like the tracks of the extant lizard *Sceloporus*. The reasons for the conspicuous lack of post-Triassic occurrences are not certain, but not due to a post-Triassic lack of potential lizard trackmakers. Thus, the preservation biases are likely due to paleobiological factors such as trackmaker ecology and paleoenvironmental preference.

1. Introduction

Tracks of lizard-like (lacertiform) species are abundant in the Upper Triassic in many regions, especially in Europe, North America, Africa and South America, where the classic lacertiform morphotypes are represented by the well-known and well-studied ichnogenus *Rhynchosauroides*. They are also reported from the Upper Permian of Italy (Valentini et al., 2007). However, tracks of this type are mysteriously absent in most of the track record of these and other regions in the Jurassic and Cretaceous, even though skeletal remains of Cretaceous lizards are known from Asia (Gao and Cheng, 1999; Evans and Wang, 2010; Xu et al., 2014) and other regions (Nydam and Voci, 2007). Most of these reports deal only or primarily with cranial elements (teeth and jaws), providing no information on foot morphology. However, the report by Evans and Wang (2010) describing the new species *Liushusaurus acanthocaudata* is particularly instructive because it deals with exquisite preservation of the whole skeleton, including both manus and pes. The aforementioned sudden disappearance of a previously-common track type is not easily explained by any obvious paleobiological interpretation and, as discussed below, remains an open question. However, it cannot be attributed to the disappearance of lizard like trackmakers.

Thus, the discovery of a well-preserved lacertiform trackway in the Cretaceous Haman Formation fills a large gap in the global track record of lizard-like tracks. Not only is this the first report of this general track morphotype from the Cretaceous of Korea, it is also the first report of this type from the Cretaceous of Asia and indeed from the Mesozoic of Asia. We herein describe this trackway in detail and compare it with similar morphotypes from the track record.

2. Geological setting and associated ichnofaunas

The tracks described here are preserved as natural casts on a small slab of fine-grained sandstone found at the Gain-ri tracksite, Changseon Island, Gyeongnam District, designated as Korea Natural Monument No. 499 (Fig. 1). The Haman Formation belongs to the Hayang Group of the Gyeongsang Supergroup comprised conformably of the Chilgog Formation, Silla Conglomerate, and Haman and Jindong formations in ascending order (Fig. 2). The Kusandong Tuff (1–5 m thick) occurs in the uppermost part of the

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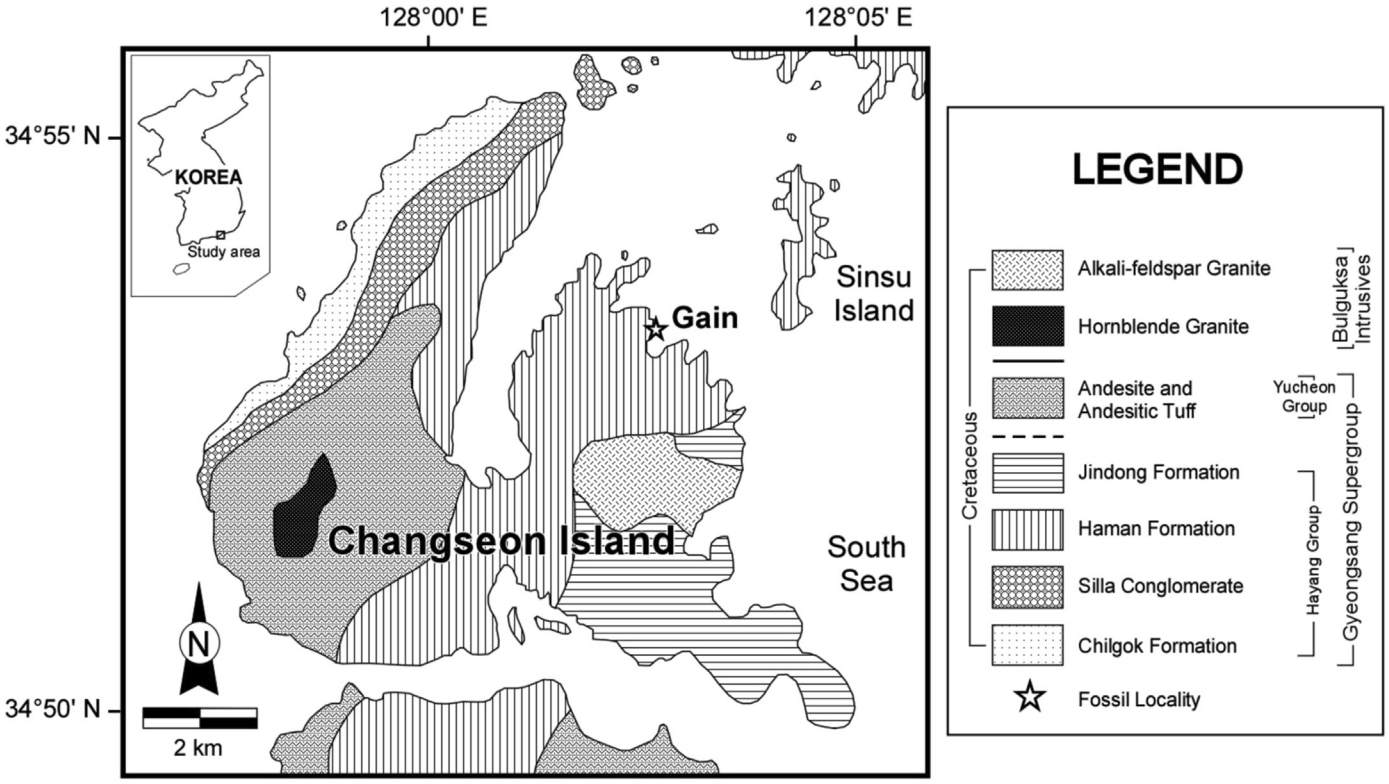

Fig. 1. Geologic map of the fossil locality (Choi et al., 2002).

Haman Formation and has been regarded as a key bed for the subdivision and basinwide correlation of the Upper Cretaceous strata in the Gyeongsang Basin (Chang, 1975; Chang et al., 1997, 1998). The results of radiometric analyses in the Kusandong Tuff were 97.1 ± 2.0 Ma and 97.3 ± 1.8 Ma (zircon U–Pb age using LA-ICP-MS; Jwa et al., 2009) and 103 ± 1.2 Ma and 103.0 ± 2.3 Ma (zircon SHRIMP U–Pb age; Kim et al., 2011). The Haman Formation is inferred to be of "mid" Cretaceous, Albian – Cenomanian age (105–97 Ma) by Kang and Paik (2013). The dominant Haman Formation lithologies are reddish shale, sandy shale, and white to greenish and gray sandstone with minor intercalating tuffaceous and pebbly sandstone (Chang, 1975). In the study area, the non-biogenic sedimentary structures such as ripple marks, desiccation cracks, raindrop imprints, and cross stratifications indicate marginal lacustrine environments.

In addition these facies are well known for yielding abundant vertebrate footprints and invertebrate traces. Many dinosaur and bird tracks including *Koreanaornis hamanensis* (Kim, 1969; Baek and Yang, 1997; Lim et al., 2000, 2002) have been reported from the Haman Formation. Recently described vertebrate tracks include the smallest known dinosaur tracks (ichnogenus *Minisauripus*; Lockley et al., 2008; Kim et al., 2012a), didactyl dromaeosaurid tracks *Dromaeosauripus hamanensis* and *Dromaeosauripus*. ichnosp. (Kim et al., 2008), sauropod tracks *Brontopodus pentadactylus* (Kim and Lockley, 2012), bird tracks *Ignotornis yangi* and *I. gajinensis* (Kim et al., 2006, 2012b), and pterosaur tracks *Pteraichnus* ichnosp., and *Haenamichnus gainensis* (Kim et al., 2006, 2012c). In addition to these reports, the formation has yielded various new dinosaur track assemblages containing didactyl dromaeosaurid, bird and pterosaur tracks in abundance (Lim et al., 2010; Moon and Kim, 2013; Son et al., 2014; Kim et al., 2015). In short the Haman Formation is proving to be a rich source of hitherto unrecognized tetrapod tracks which add significantly not just to the Cretaceous track record of Korea, but more widely to the Asian and global track records.

3. Description of trackway

3.1. General features

The lacertiform trackway described here has the specimen number CUE 130304L (CUE = Chinju National University of Education). It consists of the natural casts of four consecutive manus pes sets (Figs. 3 and 4). The pes tracks, situated behind, and slightly lateral to the manus tracks are incomplete showing only three clear digits traces, inferred to represent digits II, III and IV, of a pentadactyl pes. However, pes trace morphology is consistent in all three tracks with the outer digit trace IV being the longest, with a pronounced outward rotation of the digit long axis, and terminating in a hook-like terminal toe (claw) trace directed anteriorly. Incomplete pes tracks are common in trackways attributed to lizard-like (lacertiform) trackways as shown in the illustrated summary of 21 ichnospecies of the Triassic ichnogenus *Rhynchosauroides* (Baird, 1957, fig. 9; Haubold, 1984, fig. 98). In fact it could be argued that the incompleteness of many pes tracks is "typical" and reflects the postural behavior of the lizard during foot registration. This is easily confirmed by reference to the small number of modern field guides and other studies that illustrate the variability and incompleteness of the trackways of extant lizards (Murie, 1974; Stuart and Stuart, 2000; Farlow and Pianka, 2000). Given these constraints the Korean trackway is remarkably consistent and complete in the registration of consecutive manus pes sets, and superior in terms of completeness to many lacertiform trackways assigned ichnotaxonomic labels. The manus impressions, for example, are complete and quite symmetrical about the axis of the longest digit (III). They