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EDITORIAL

Recent Advances in Korean Vertebrate Ichnology: The KCDC Comes of Age

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Vertebrate tracks were first reported from the Cretaceous of South Korea in 1969 by B. K. Kim. His discovery of bird tracks, appropriately named *Koreanaornis hamanensis*, not only signaled the first bird tracks discovered in Asia and the second formally named avian ichnogenus from the Mesozoic, but it also was an indication of the vast wealth of vertebrate tracks that would be discovered a generation later in the Haman Formation and other Cretaceous formations of Korea, particularly in the large Gyeongsang Basin. This landslide of discovery has resulted in a proliferation of papers on vertebrate tracks from the Cretaceous of South Korea and the growing recognition that as a region it reveals multiple track-rich sequences of unique quality and scientific utility. Because of the outstanding ichnological resources in this region, it has been dubbed the Korean Cretaceous Dinosaur Coast (KCDC). Many sites of national and international significance have been designated as national natural landmarks, and the best of these have been nominated for World Heritage Inscription.

In this editorial introduction, we attempt to summarize the present state of tetrapod ichnology after four decades of vertebrate track research. This synopsis serves as an introduction to a dozen short papers that focus attention on new discoveries at key sites. These reports, in turn, provide a promise of abundant material for future decades of research. At the present time, there are at least five ichnological research groups working on vertebrate tracks from the Cretaceous of Korea, both independently and collaboratively. Almost all researchers from these groups have contributed to this volume. The result has been the naming of five new tetrapod ichnospecies (Fig. 1), adding to the ten previously named.

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Following the historic 1969 discovery of *Koreanaornis* (Kim, 1969), the second report of vertebrate tracks from South Korea was made by Seong-Young Yang, to whom this volume is dedicated. Yang (1982) reported a variety of tracks from the Jindong Formation, which overlies the Haman Formation in the Gyeongsang Basin. Yang was instrumental in stimulating interest in a detailed study of the Jindong sequences by Korean and international colleagues (Lim et al., 1989, 1994; Lockley et al., 1992, 2006, 2008). This work revealed diverse assemblages of dinosaur and bird tracks including footprints attributed to abundant sauropods and ornithopods, rare theropods and a variety of birds including the ichnospecies *Koreanaornis hamanensis*, *Jindongornipes kimi* and *Goseongornipes markjonesi*. The majority of these tracks are remarkably well-preserved due to a combination of factors, including optimal substrate conditions in the Cretaceous and subsequent conversion of the sediments into highly resistant lithologies by various degrees of metamorphism.

A significant advance was made in the 1990s when the sedimentologist Seung Soo Chun (1990) reported new bird tracks assemblages from the Uhangri Formation of the Haenam Basin in the southwestern corner of the Korean peninsula. These tracks, named *Hwangsanipes choughi* and *Uhangrichnus chuni,* and were the first bird footprints reported from the Mesozoic with traces indicating webbed feet (Yang et al., 1995). Other important discoveries followed in 1997 when giant pterosaur tracks were discovered (Lockley et al., 1997) and subsequently named *Haenamichnus uhangriensis* (Hwang et al., 2002). These were also the first pterosaur tracks of any type reported from Asia, and they have since proved important in debates about pterosaur locomotion. Other tracks from the Uhangri Formation

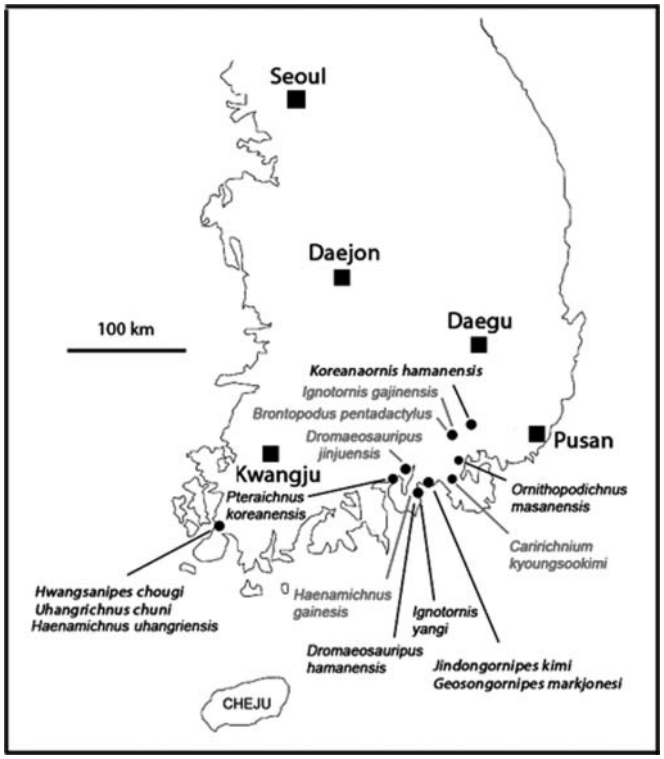

FIG. 1. Locality map showing the locations of tetrapod ichnospecies type localities along the Korean Cretaceous Dinosaur Coast (KCDC). Red indicates new ichnotaxa described in this volume. (See Color Plate I.)

also proved interesting and controversial because of their unusual preservation in associations with radial ridge features (Fig. 2). The interpretation of these tracks has been as hotly debated as almost any Mesozoic footprints (Thulborn, 2004; Hwang et al., 2008; Song, 2010 and references therein). As biogenic sedimentary structures tracks should always be studied in the context of the successions in which they occur; therefore, since the mid 1990s (Chun and Chough, 1995; Chough et al., 1996) there has been an upsurge in sedimentological study led by In Sung Paik and colleagues (Paik and Kim, 2006: Houck and Lockley, 2006; Paik et al., 2012 and references therein).

Further significant advances in Cretaceous Vertebrate ichnology in Korea occurred in 2000–2010. Among these were discoveries of more important sites (Huh et al., 2003). These include the Hwasun site (Huh et al., 2006; Lockley et al., 2012a), where the assemblages are dominated by theropods, and a series of sites in the beautiful Yeosu Island archipelago, which yield multiple assemblages of theropod, sauropod, ornithopod and bird tracks (Huh et al., 2012; Lockley et al., 2012b). New ornithopod track morphotypes have also been reported from a number of formations including *Ornithopodichnus masanensis* (Kim et al., 2008) and *Caririchnium kyungsookimi* (Lim et al., 2012). Other significant discoveries include a new bird track ichnospecies (*Ignotornis yangi*) and small pterosaur tracks, ichnogenus *Pteraichnus* (Kim et al., 2006) and independent discoveries of other small pterosaur tracks named *Pteraichnus koreanensis* (Lee et al., 2008). At the other end of the size spectrum, giant pterosaur tracks (*Haenamichnus*) first reported in 1997 (Lockley et al., 1997) have since been discovered at other locations, where creationists interpret them as human footprints. In this volume (Kim et al., 2012a), examples of *Haenamichnus gainensis* pes tracks with four discernable digit traces are described for the first time.

The ichnogenus *Minisauripus*, previously known only from a single locality in China, was reported for the first time from South Korea (Lockley et al., 2008). Further discoveries (Kim et al., 2012) include the smallest known dinosaur tracks (foot length only ∼1.0 cm). Kim et al. (2009) reported the first deinonychosaurid tracks from Korea assigned to the new ichnospecies *Dromaeosauripus hamanensis*, and we report a new ichnospecies *Dromeosauripus jinjuensis* (J.-Y. Kim et al., 2012b). Likewise, some of the first reports of Cretaceous sauropod skin impressions come from Korea (Lockley and Jenkins, 2005; Lockley et al., 2006; Kim et al., 2010).

There are few countries where more than a handful of paleontological PhD dissertations have been devoted to vertebrate tracks. Due to the superior vertebrate tracks resources, Korea ranks highly in this field, with dissertations having been devoted to the Jindong Formation (Lim, 1990), the Uhangri Assemblages (Hwang, 2001) and bird tracks (Kim, 2008).

Korea also ranks high in the attention it pays to the protection of its vertebrate tracksites both at the local and national level. In 2009 the following four tracksite areas, together with a fifth eggsite, were put forward for inscription as a serial World Heritage site, under the collective label of the Korean Cretaceous Dinosaur Coast:

The Goseong Tracksite: Korea Natural Monument No. 411
The Haenam Tracksite: Korea Natural Monument No. 394
The Hwasun Tracksite: Korea Natural Monument No. 487
The Yeosu Tracksite: Korea Natural Monument No. 434
The Boseong Eggsite: Korea Natural Monument No. 418

Although this is an impressive list, the nomination was not successful. It is nevertheless a significant testimony to the importance of vertebrate ichnology that these sites should have been seriously considered. (Two other tracksite regions have also been nominated in recent years, one in Bolivia, which was not successful, and another in Spain, which has been deferred.) It is partly because of the importance of the Korean sites, to which we should undoubtedly add the Gajin tracksites (Natural Monument 395: see Kim et al., 2012c), that we have compiled this special issue. As far as we know, there are no other countries that have elevated so many vertebrate tracksites to the status of national natural monuments. Further international interest in the Korean tracksites will be generated in August 2012 when Korea hosts the 11th Symposium on Mesozoic Terrestrial Ecosystems, with excursions to many of these sites.

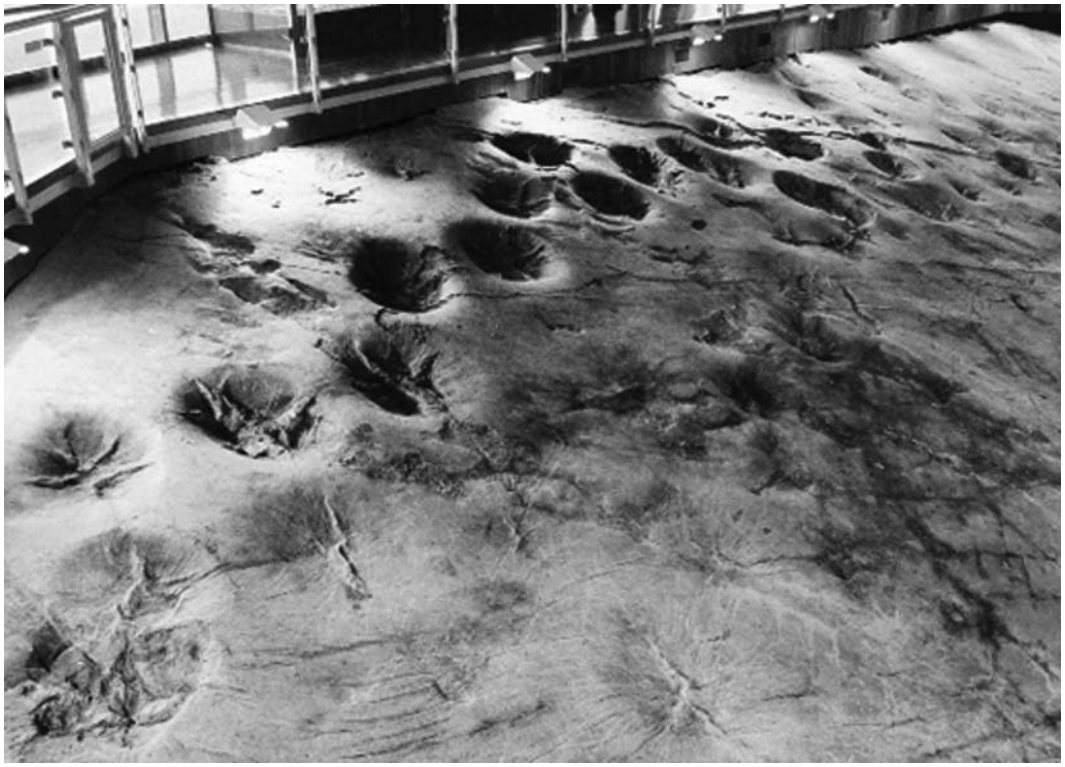

FIG. 2. Unusual tracks from the Haenam tracksite show distinctive radial features that have generated much controversy. Initially attributed to swimming sauropods, these tracks are now considered to be large ornithopod under tracks showing casts of radial cracks (Hwang et al., 2008). (See Color Plate II.)

CONCLUSION

South Korea is one of the richest and most exciting regions on earth for the study of vertebrate ichnology. It is the global epicenter for the study of the Cretaceous bird tracks (Kim, 1969; Lockley et al., 1992; Yang et al., 1995; Lim et al., 2000, 2002; Kim et al., 2006), and sites such as Gajin are aptly named as an avian paradise (Kim et al., 2012c). So far many of the Korean ichnogenera, for example, the web-footed bird tracks *Uhangrichnus* and *Hwangsanipes,* appear indigenous to Korea, and on present evidence there is nowhere else in the world were such densities and diversity of bird tracks have been reported.

Sites such as Goseong reveal the highest density of bird and dinosaur track levels anywhere in the world, with more than 2 levels per meter accurately documented in continuous sections more than 100 meters in thickness (Lim et al., 1994). The Namhae region has also become important for the discovery of multiple *Minisauripus* sites as well as a source of dromaeosaurid tracks (Kim et al., 2012b). These occurrences suggest possible correlations with the Cretaceous sequences in China and suggest that the *Minisauripus* trackmaker may be indigenous to Asia.

It has only been about 40 years since the first bird tracks were found in the Cretaceous of Korea (Kim, 1969) and 30 years since the first dinosaur tracks were documented (Yang, 1982). Thanks to the dedication of ichnologists surveying the rocky coastal exposures, many sites have come to light. When added to discoveries arising from development of Korea's communication infrastructure, especially quarries, roads and road cuts, the rate of discovery has been impressive. The result has been the emergence of the concept of a spatial and temporal mosaic of track-rich Cretaceous deposits christened the Korean Cretaceous Dinosaur Coast or KCDC, embracing many natural monuments and scientifically important ichnological sites and, moreover, rising to a level of significance that made the region worthy of nomination as a World Heritage site. This application came at a time when two other tracksite areas were nominated. Thus, Korea leads the way in raising global awareness of the rich potential of vertebrate ichnology. Given this history and context, we hope and anticipate that the KCDC will become a landmark concept in the history of vertebrate ichnology.

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