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Dinosaur-dominated footprint assemblages from the Cretaceous Jindong Formation, Hallyo Haesang National Park area, Goseong County, South Korea: Evidence and implications

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Abstract

The track-rich Cretaceous Jindong Formation comprises part of an intra-arc basin, fluvio-lacustrine succession that represents a late stage in the evolution of the Kyongsang Basin. This formation is replete with track-bearing levels indicating the activity of many generations of dinosaurs and birds. The track-rich beds occur in the upper part of the Hayang Group (Kyongsang Supergroup), which also contains other, underlying dinosaur-track-bearing formations. However the Jindong Formation and underlying formations have produced few age-diagnostic body fossils. Altered volcaniclastic sediments such as are found the Jindong Formation complicate interpretation of the age of the tracks as discussed in the accompanying companion paper. Nonetheless such settings provided near optimal conditions for the formation and preservation of abundant track assemblages (ichnofaunas), and the Jindong Formation has become an ichnological "cause celebre" producing impressive statistics on the number of track-bearing sites, number of track-bearing levels and number of measured trackways. These data allow various inferences about certain aspects of the population structure, behavior and distribution of the dinosaurian track makers in these dinosaur-dominated paleocommunities.

The Jindong Formation and underlying Haman Formation have also yielded many bird tracks. The complete lack of avian body fossils in Korea and the rarity of dinosaur skeletal remains means that the footprint record currently provides the vast majority of the Mesozoic vertebrate evidence available for the entire Korean peninsula. Thus, the tracks represent a highly significant addition to the national paleontological heritage of Korea, as well as being a very important component of the East Asian and global footprint records. Detailed studies of a 100–200-m-thick succession at the Sangjok Dinosaur Tracksite National Monument in the Hallyo Haesang National Park area in Kosong County reveal an average of about two track-bearing levels per meter, making it one of the richest track-bearing sections on record and providing evidence of the activity of hundreds of individuals. Many other track sites are found locally in the Jindong Formation in Kosong County (about 500 km^2) including one described herein from near Gohyeon village where the Jindong Formation type section is situated. Other track sites can be traced laterally over larger distances within the Gyeongsang Basin. The composition of ichnofaunas throughout this region appears remarkably consistent.

The Jindong Formation is one of the few localities where sauropod, ornithopod, and bird tracks all occur in abundance, probably due to latitudinal/climatic controls. The sauropod tracks, which include wide-gauge forms allied to *Brontopodus*, form the largest brontosaur trackway sample yet reported but are characterized by a high proportion of small individuals. Such unusual size-frequency distributions raise interesting ecological and taphonomic questions about the biasing of the body fossil record towards large individuals by various physical (preservational) or biological/ ecological controls.

The most abundant dinosaur trackways are those of iguanodontids (cf. *Caririchnium* or *Iguanodontipus*) that often traveled in herds. By contrast, sauropod tracks show little or no evidence of gregarious behavior and rarely occur on the same bedding planes as ornithopod trackways. This suggests a pattern of mutual exclusion or geological segregation between these two herbivore groups, which indicates that they probably

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frequented the area at different times. Sauropod and ornithopod track size-frequency distributions are also fundamentally different, suggesting that the ornithopods were mainly sub-adults and adults, whereas the sauropods were predominantly juveniles. Theropod tracks are uncommon suggesting a low predator:prey ratio of 1:20.

Bird tracks including the large ichnospecies *Jindongornipes kimi*, an intermediate-sized form, *Goseongornipes markjonesi* ichnosp. and ichnogen. nov., and a small ichnospecies *Koreanaornis hamanensis* occur at several dozen stratigraphic levels in association with nematode trails (*Cochlichnus*) and other invertebrate traces. These three ichnospecies are assigned to the respective ichnofamilies Koreanornipodidae ichnofam. nov., Ignotornidae, and Jindongornipodidae ichnofam. nov. All these avian footprints are typical of bird track assemblages in lake shoreline deposits, and indicate the activity of many generations of waders or shorebirds. We also recognize other, much less common, small footprint types tentatively attributed to a perching bird or a diminutive theropod. Collectively the bird tracks indicate the considerable potential of avian ichnites to provide insight into avian paleoecology at an early stage in the evolution of Class Aves.

Keywords: Dinosaur tracks; Jindong Formation; Cretaceous; South Korea; East Asia

1. Introduction

In recent years the study of vertebrate ichnology has matured into a mainstream science, spawning an unprecedented spate of new literature, particularly on dinosaur tracks (Gillette and Lockley, 1989; Thulborn, 1990; Lockley, 1991a,b, 1998, 1999; Lockley and Hunt, 1995; Lockley and Meyer, 2000). Of primary relevance to the present study is the literature on Mesozoic track sites in East Asia, especially those that are of Cretaceous age (as summarized in Matsukawa et al., 2006). This focus informs us that South Korea is of prime importance in vertebrate ichnology. It has the largest concentration of Cretaceous vertebrate dinosaur track sites reported from anywhere on the Asian continent. The stratigraphic frequency of track-bearing levels is also greater than that reported for any other region in Asia, and the diversity and abundance of named bird tracks is greater than for any other region. Thus there is a rapidly growing literature, both in Korean and English, on these bird and dinosaur track sites (Kim, 1969; Yang, 1982a; Lim, 1985, 1990; Lim et al., 1989, 1994, 1995a,b; Lockley et al., 1991b, 1992a; Yang et al., 1995; Baek and Yang, 1997; Lee et al., 2000, 2001; Huh et al., 2003, and references therein).

Historically, North America and Europe have been epicenters for dinosaur track studies. Important Cretaceous sites such as those in the Glen Rose Formation of Texas (Bird, 1939, 1941, 1944, 1985; Farlow, 1987; Farlow et al., 1989; Pittman, 1989; Pittman and Lockley, 1994), the Dakota Group of Colorado and New Mexico (Lockley, 1987; Lockley et al., 1992b; Lockley and Hunt, 1994a,b, 1995) provide points of comparison for track identification and interpretation of track makers and their behavior. Similarly, Cretaceous sites in Australia (Thulborn and Wade, 1984), Europe (Moratalla et al., 1992; Dalla Vechia et al., 2000; Lockley and Meyer, 2000) and South America (Leonardi, 1984, 1989, 1994) are also useful in this regard.

Prior to the publication of this special issue of Cretaceous Research, there had been very few attempts to review and compare track sites throughout Asia. Most attempts have been restricted within national frontiers (e.g., Zhen et al., 1989, 1996 for China). Lockley and Matsukawa (1998) briefly reviewed the Lower Cretaceous of the whole region and Huh et al. (2003) recently presented a summary for the Cretaceous of the southern part of South Korea. In this paper we focus only on the coastal exposures in the Samcheonpo area (Hai district) and integrate our results with ongoing studies of the sedimentology and stratigraphy of the Jindong Formation (Houck and Lockley, 2006) and the underlying Haman Formation (Kim et al., 2006). However, we stress that for historical reasons these sections have become the ‘‘type’’ area for Jindong Formation vertebrate ichnology and may serve as a model for future studies, at least in Korea, where comparable track-rich outcrops are found.

The purpose of this paper, therefore, is to describe and interpret the large amount of fossil footprint data that has been obtained from the coastal exposures of the Jindong Formation south of Samcheonpo town (Sacheon City area) in the Hai District, Kosong County, Kyeongsangnam Province, South Korea (Fig. 1). The area has been designated as a Dinosaur National Monument within the Hallyo Haysang National Park Area.

1.1. Historic, scientific, and educational utility of the Samcheonpo track sites

The Samcheonpo track sites are important for various reasons: (1) They were the first discovered in Korea. (2) They remain the center of the area with the greatest concentration of dinosaur and bird tracks known from the Jindong Formation, both in terms of the number of tracks exposed on bedding plane surfaces, and in terms of the number of recorded track-bearing levels (Lim et al., 1994). (3) Because body fossil remains are sparse or absent in comparison with tracks, the latter allow inference about population structure (Lockley, 1994), individual and social behavior (gregariousness) and relationship of track makers to the paleoenvironment (Lim et al., 1994). (4) They provide a large amount of relatively accessible, though taxonomically generalized, data on the faunas of the region. These in situ records of indigenous faunas, help define important vertebrate ichnofacies (Lockley et al., 1994a). However, the special, mixed nature of the ichnofacies, at this paleolatitudinal setting, suggests that this region may represent an important paleogeographic crossroads. (5) These track sites have considerable didactic value because they make for good outdoor laboratories or interpretive centers

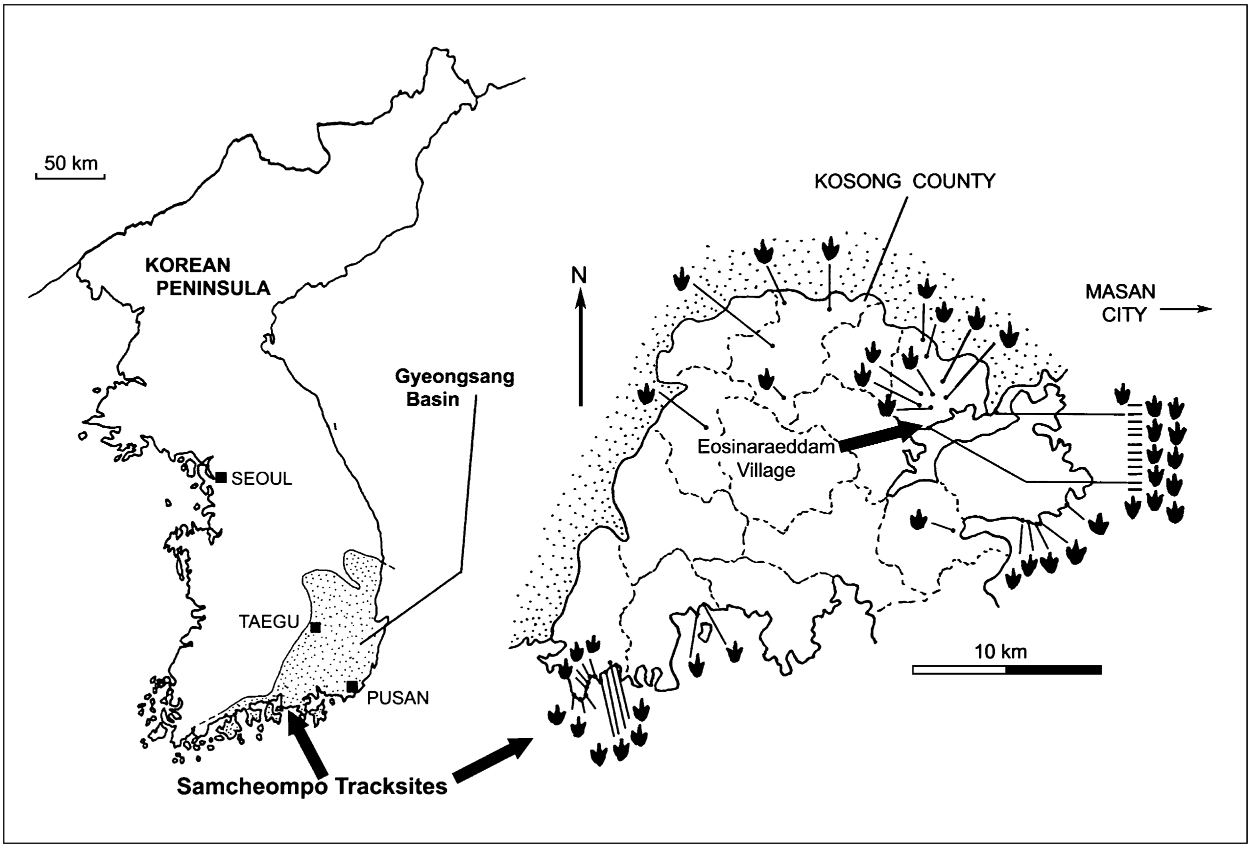

Fig. 1. Location of Samcheonpo track site area, in relation to other track sites in Goseong County and the greater Gyeongsang Basin, Korea. Kosong (=Gyeongsang) County map modified after Lee et al. (2000).

for public education, as is the case at the present study site (Sangjok area, Hallyo Haesang National Park). At this location the large Goseong Dinosaur Museum has recently been constructed, and there is a long walkway with interpretive signs that follows the entire Sangjok section (see below). In a recently completed pictorial atlas of Korean fossils (Yang et al., 2003), 32 of the 181 plates show fossil dinosaur, bird and pterosaur footprints, mostly from the Jindong Formation. Using this criterion Cretaceous tracks make up about 18% of the entire Phanerozoic fossil heritage selected for showcasing as measure of current knowledge of the Korean fossil record.

Not withstanding the utility and potential of these track sites, they are also problematic in a number of ways. First, during the early days of Korean vertebrate ichnotaxonomy there were a number of unsuccessful attempts to introduce names without adequate attention to the material being described, the attendant rules of zoological nomenclature (see Appendix) and previously described material from other regions. Thus we stress that ichnotaxonomic nomenclature must be used with caution. Second, these track sites are far too big to be excavated and brought into museums, and so they pose special problems of conservation, especially as many, indeed most, are found in the intertidal zone and, despite the indurated nature of the rocks, they are likely to erode and weather significantly over the course of months, years and decades, if left exposed to the elements and coastal construction activities.

1.2. Note on geographic place names, derived geologic terminology, and specimen repositories

When Korean place names are transcribed into English, a number of different spellings may appear. For example the letters "g" and "k" may be interchangeable. Thus the Gyeongsang Basin and supergroup (sensu Lim et al., 1995a; Lee et al., 2000) was also previously referred to as the Kyongsang or Kyungsang Basin and supergroup (sensu Lee, 1987; Chang and Son, 1994). This is a "k to g" shift for word initial syllables that represents formal government policy to "romanize" such geographic names (note accompanying vowel modification). Similarly the Chilgok Formation may appear as the Chilgog, the Nakdong as Nagdong, the Sangjok as the Sangjog and so on, representing and opposite "g to k" shift at the end of words/syllables. For consistency we have generally followed the new usage, except where use of alternate spellings is necessary, as in the case of certain specific quotations or citations. The different spellings do not represent different localities.

As discussed in the companion paper (Houck and Lockley, 2006) stratigraphic nomenclature varies regionally and moreover has changed through time. In addition, formations have been named after sections in general geographic areas without their bases and tops having been precisely defined by measurement of clearly defined stratigraphic sections. There is also a hierarchy of geographic names to consider. For example, the track-bearing coastal exposures described in our stratigraphic sections all have local names, such as Sangjok and Deokmyeongri (formerly Dukmeongri or Dukmyeongri), which derive from local villages (e.g., Lim et al., 1994). The sites all occur in the Hai District, Goseong (formerly Kosong) County, Gyeongangnam (formerly Kyeongsangnam) Province, South Korea. They are located around the coastal village of Deokmyeongri, not far from Samcheonpo town (Sacheon City area), and so the general label "Deokmyeongri" or "Samcheonpo" track sites has also been used somewhat informally. The other track site described herein is from near Eosinaraeddam village, in Hoewha district, Kosong County, which is in the area considered to be the type section of the Jindong Formation.

All specimens collected during the course of this study were reposited in the Kyungpook National University, Earth Science Department (with prefix KPE), or in the University of Colorado at Denver Dinosaur Tracks Museum (with the prefix CU or CU-MWC).

2. History of research

2.1. Dinosaur track discoveries

Dinosaur tracks were first reported from the Jindong Formation by Yang (1982a), who suggested a possible Late Cretaceous age, and recognized distinct tracks at "32 stratigraphic horizons at 13 localities around the beach area" of Dukmyeongri (Yang (1982a, p. 37). Yang also referred to many different track morphotypes, though he did not formally assign ichnotaxa to any of the tracks. Detailed studies by Lim (1985, 1990), and Lim et al. (1989) led to the recognition of many more track-bearing levels, some of which were mapped out (Lim, 1990). Kim (1986) made a crude attempt to describe distinctive tracks from this area, but as discussed below, we consider Kim's ichnotaxa to be nomina dubia (see Lockley et al., 1994b, and systematic section below). This led us to the realization that a comprehensive study would be necessary if the sites were to be documented adequately.

Beginning in 1988 we undertook a joint US-Korean project, funded by the National Science Foundation (NSF) and the Korean Science and Engineering Foundation (KOSEF), aimed at documenting the type and stratigraphic distribution of fossil footprints in the Dukmyeongri area. After several seasons of fieldwork (1989–1992) and subsequent field visits, a preliminary report was published by Lim et al. (1994) which outlined the stratigraphy of the main track-bearing outcrops in the study area, and presented some preliminary interpretations of distinctive patterns of trackway distribution. As noted below, this report rectified some minor errors of stratigraphic interpretation introduced by Lim (1990). The Samcheonpo track sites have since been briefly mentioned by Lockley (1999), Lee et al. (2000, 2001), Lockley and Peterson (2002) and Huh et al. (2003).

Other results of our work included the discovery of multiple bird track horizons (Yang et al., 1990; Lockley et al., 1991a,b, 1992a; Yoon and Soh, 1991), and an improved understanding of track types and the stratigraphic distribution track-bearing layers (Lim, 1990; Lockley et al., 1991b; Lim et al., 1994), and a preliminary indication that the distribution of some Jindong lithofacies are fractal (Fleming et al., 1991). The bird tracks were assigned to two ichnotaxa including the small track *Koreanaornis hamanensis*, already known from a single locality in the underlying Haman Formation (Kim, 1969), but now known from other sites (Baek and Yang, 1997), and a new much larger ichnospecies *Jindongornipes kimi* (Lockley et al., 1992a). Herein, we also report a new bird track of intermediate size that we name *Goesongornipes markjonesi*. We also reported on the unusual occurrence of brontosaur track replicas discovered by the senior author in a porphyritic igneous sill (Yang et al., 1992; Lockley et al., 1992b). During the course of our studies the Sangjok track site area, near Samcheonpo, was designated as a National Monument within the Hallyo Haesang National Park area.

In the latter sections dealing with the stratigraphic occurrence of these various track types we present descriptions and illustrations of the main track types according to a generalized systematic classification, i.e., theropods, sauropods, ornithopods (and birds). This organization is also followed in the formal systematic section.

2.2. Possible track makers

Ideally one would hope to compare dinosaur and bird tracks with contemporary body fossils from the Jindong Formation. Unfortunately none is known, although a bird, *Proornis coreae* (Paek and Kim, 1996), was described from the Lower Cretaceous of North Korea (Chiappe, 1997). Kim (1983) introduced the name *Ultrasaurus tabriensis* to describe undiagnostic dinosaur bones from the lower part of the Hayang Group Gugyedong Formation) but this name has been declared a nomen dubium (Lee et al., 2001), and the same authors have rejected his use of the label *Deinonychus* for an unidentified femur. One must examine the older, underlying Sindong Group, and especially the Hasandong Formation (Fig. 2) for dinosaur body fossils and eggs. Even here the record is very sparse consisting of sauropod teeth assigned to *Chiayusaurus asianensis* a euhelopodid sauropod and unidentified camarasaurids, titanosaurids and allosaurids (Lee et al., 1997; Park et al., 2000; Lee, 2003).

2.3. Synthesis of trackway statistics

Preliminary syntheses of the dinosaur track data indicated 516 discrete dinosaur trackways of which 252 were attributed to ornithopods, 120 to sauropods, 16 to theropods, and 128 to indeterminate track makers (Lim et al., 1994). This proportion of indeterminate tracks is not a reflection of poor preservation in most cases. Many indeterminate tracks are those seen only in cross section in cliff exposures or at or below the low tide mark were they are covered by barnacles, seaweed, and other encrusting marine organisms. Distinctive dinoturbated layers also occur in Jindong (Lockley, 1991a, 1992) and were also discussed by Paik et al. (2001). Size-frequency histograms

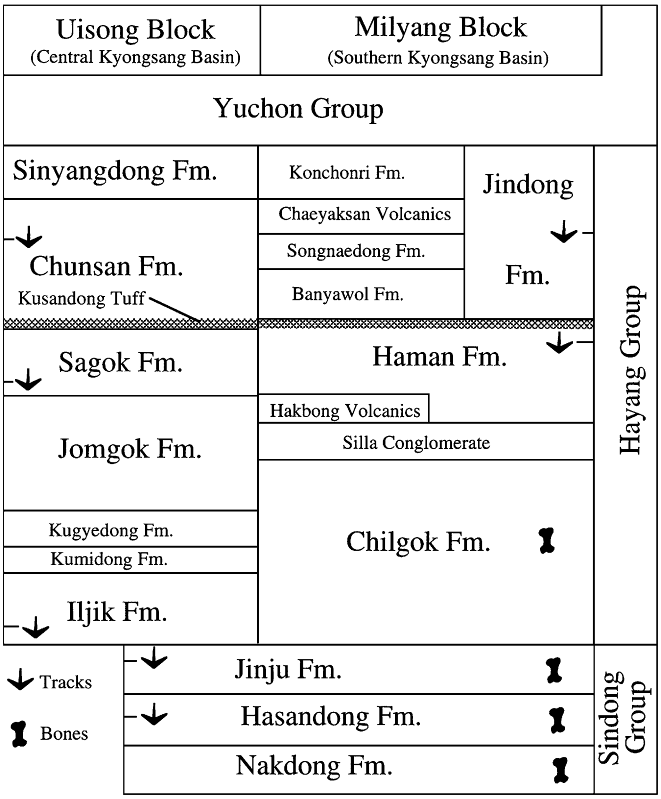

Fig. 2. Stratigraphy of the Gyeongsang Basin (after Choi, 1986). Compare with Houck and Lockley (2006, fig. 2).

for 217 ornithopod trackways and 102 sauropod trackways from within this sample were presented by Lockley (1994), who showed that the two distributions were very different, as discussed below. Bird tracks were generally too dense allow us to discriminate and count individual trackways (Lockley et al., 1992a), although the minimum number of stratigraphic levels with bird tracks was recorded as 32 (Lim et al., 1994). Statistics were given on the total number of track bearing levels (329) and the frequency of levels with ornithopod (97) and sauropod (102) tracks.

As noted in Matsukawa et al. (2006), tracks are so abundant in the Cretaceous of Korea that quite a craze developed for compiling the type of data summarized in the previous paragraph. Thus, Lee et al. (2000) reported 410 mapped trackways, including 250 trackways counted from the Samcheonpo area, in the Hai District, and an additional 160 trackways from seven other districts in Goseong (=Kosong) County, an area of about 500 km^2 (Fig. 1). However, few maps of these "mapped" trackways have appeared in publications other than Lim's PhD thesis (Lim, 1990), which deals only with the Samcheonpo sites (Hai District). Exceptions are the small maps of three levels presented by Lim et al. (1989) and a map of an additional level in Lockley (1989, 1991a). Even photographs of many of these sites are relatively scarce in the literature and mainly confined to popular books and magazines (Lim et al., 1989, fig 35.2; Lockley, 1991a, pls. 2 and 4 and fig 11.8; Yoon and Soh, 1991; Lockley and Peterson, 2002, p. 71). By contrast, significant efforts have been made to document the frequency of track-bearing levels in Jindong Formation sections from Samcheonpo (Lim et al., 1989, 1994; Lockley, 1991a, fig. 11.6; Lockley et al., 1992a). There have also been studies of the sedimentology (Paik et al., 2001; Houck and Lockley, 2006).

Huh et al. (2003) presented a much broader survey of dinosaur tracks from 27 localities in the Gyeongsang Basin, and the Haenam and Neungju Basins. As noted elsewhere (Matsukawa et al., 2006), their combination of track and trackway data is difficult to compare directly with the data given by Lim et al. (1994), Lee et al. (2000), and herein. Nonetheless, the proportion of theropod, sauropod, and ornithopod tracks seems to remain similar for the district, county, and regional censuses. This point is of considerable interest because it raises fundamental questions concerning the value of ichnological data (see discussion of the ichnofacies paradigm).

3. Regional and local geological setting

3.1. Regional framework

The geological setting of the Jindong Formation is outlined in Houck and Lockley (2006), where the sedimentary geology is discussed in detail. Thus, it is unnecessary to do more than outline the geologic and stratigraphic framework of the track-bearing beds described herein. The Jindong Formation forms part of a thick pile of sediments that fills the Cretaceous Kyongsang Basin. According to Lee (1987, p. 177), "the sedimentary and volcanic fill of the Kyongsang Basin was initially designated as the Kyongsang Formation" (in 1903), but "later it was divided into ten formations and was called Kyongsang Group." Still later this unit was raised to the Kyongsang Supergroup. According to Chang (1975) and Choi (1986), the succession is about 7 km thick, excluding the 2 km thick overlying Yucheon volcanic sequence, and consists of the Sindong Group overlain by the Hayang Group (cf. Lee, 1987) (see Fig. 2) This stratigraphic scheme differs from an older classification used by Tateiwa (1929), Chang (1966), and Choi (1985), in which the Kyongsang Group is divided into the older Naktong Subgroup and the overlying Silla Subgroup (cf. Yang, 1978). This "older" classification has also been used recently by Lim et al. (1995b). However, the aforementioned stratigraphic scheme used by Lee (1987), Chang (1994a,b), Chang and Son (1994), and Lim et al. (1995a), contra Lim et al. (1995b), now appears to be widely used in Korea (cf. Lee et al., 2001).

According to Lee (1987) the Kyongsang Supergroup is unequivocally Cretaceous in age, and charophytes from the basal Nakdong Formation indicate a Hauterivian to Barremian age, based on correlations with Japan. Bivalves from the overlying Hasandong Formation generally appear to confirm this age assignment, by suggesting an Aptian-Albian age based on correlations with the Kitidani alternation zone of the Akaiwa Subgroup of Japan (Yang, 1982b). Choi (1985) reported that pollen from the Jindong Formation (Konch'onri subdivision) was "not younger than early Albian and not older than

Hauterivian, presumably of Aptian to Early Albian'' age (cited in Lee, 1987, p. 187).

The Gyeongsang Basin formed as part of the NE-SW to ENE-WSW trending tectonic provinces that developed along the continental margin of East Asia as the Pacific (Kula) plate was subducted. This resulted in a typical arc-trench configuration along the continental margin during the Cretaceous. The Gyeongsang Basin has a graben like configuration and has been interpreted as a fault-bounded continental, back-arc basin that was situated in a marginal zone of extensional tectonism caused by the subduction of the Kula plate beneath the Eurasian plate (Choi, 1986).

In the study area, near Jinju (see Chang and Son, 1994 and Fig. 2 herein) the Sindong Group consists, in ascending order of the Nakdong, Hasandong, and Jinju formations, which were assigned a Hauterivian–Barremian age by Lee et al. (2001). The overlying Hayang Group consists of the Chilgok Formation, overlain by the Silla Conglomerate and the Haman and Jindong formations, which are purportedly Aptian-Albian in age. In the older stratigraphic scheme this would be equivalent to Nakdong and Silla Groups, with the lower Nakdong sequence including all units (named Yeonhwadong, Hasandong, Dongmyeong, Chilgog, and Paldal) up to the base of the Haman Formation, which together with the Jindong Formation comprises the upper Silla Group (Choi, 1986, fig. 5; Lim et al., 1995a).

While Lee et al. (2000, 2001) continue to infer an Albian age for the Jindong Formation Recent studies by Paik et al. (2001) suggest that the formation is Late Cretaceous in age, but the basis for this determination is not given. Huh et al. (2003) cite Paik et al. (2001), stating that the age determination (Santonian) is based on a potassium-argon date. Whole rock K-Ar dating of the volcaniclastic-rich Uhangri Formation and other deposits west of the Geyongsang Basin have produced a number of Late Cretaceous ages (Huh et al., 2003). However, given the influence of thermal metamorphism in the area and the severe alteration and reworking that has affected the volcaniclastic sediments in the Jindong Formation (Houck and Lockley, 2006), we remain skeptical about confidently accepting some of these younger dates until further compelling evidence is available. The dating of terrestrial sediments in the Cretaceous of Korea, and in much of East Asia remains problematic.

Each subgroup has been interpreted as a fining upwards sequence of alluvial sediments consisting predominantly of coarse alluvial fan and fluvial sediments in the lower part, and towards the basin margins, and finer lacustrine sediments in the upper part, and towards the center of the basin. Tectonic activity was greatest during Sindong (=Naktong) time, when the proto-Gyeongsang Basin was strongly fault controlled with well-defined margins. During Hayang (=Silla) times however, the basin expanded far beyond its proto-Gyeongsang margins and a ''shallow lake environment covered a vast area of the basin'' during the late Hayang (=Silla) period, i.e., during accumulation of the lacustrine Jindong Formation (Choi, 1986, p. 36). Volcanism also began to increase at this time, and ultimately reached a climax with the accumulation of the post- Hayang (Silla), Yucheon volcanic sequence. Choi (1986) also pointed out that in contrast to the Sindong (Naktong) Group succession where channel sandstones are recorded, the later Hayang (Silla) succession is characterized by a lack of channel sandstones, indicating that ephemeral streams died out before reaching the center of the basin. Thus the only mechanism for transporting sand to the basin center was sheet flooding caused by intermittent but torrential rains (Choi, 1986). Many of the sediments in the Haman and Jindong formations have been interpreted as evidence semi-arid to arid environments with a lack of perennial stream channels. However, Houck and Lockley (2006) note that the apparent lack of stream channels may be due to their being rapidly filled by large quantities of easily reworked volcaniclastic sediment. The high incidence of small-scale ripple, marks, mud cracks, and tracks indicate depositional environments where water was never very deep, and periodic wetting or flooding, which redistributed much volcaniclastic sediment, alternated with periods of subaerial exposure. The presence of algal, laminae, imbricated mud clasts and charophytes supports these interpretations.

3.2. Local geology

The local geology in the study area is not well known, in part because of poor exposure away from the coastline. The track-rich beds at the study site in the vicinity of Deokmyeongri, near Samcheonpo (Fig. 1), are only well exposed along the coast where the gently dipping strata (about 10° east) forms a series of intertidal wave cut platforms that are easily accessible (Fig. 3) with steep cliff sections on the shoreward side (Fig. 4). Even these exposures are not continuous, and are, in places, interrupted by massive igneous intrusions. Elsewhere well-exposed outcrops on headlands are separated from each other by shingle beaches across which it is often difficult or impossible to correlate with confidence due to evidence of faulting.

Correlation problems are in part a result of the superficial homogeneity of the succession, and the lack of many well-defined marker beds. At first sight the track-bearing beds consist of a monotonous series of dark grey to medium dark grey (N3 to N4 on Geological Society of America Rock Color Chart) siltstones and mudstones that weather to a medium grey to medium light grey color (N5 to N6). Closer inspection however reveals that the lithology is quite varied, and includes various siliciclastic and carbonate units, as well as volcanic ash. Thin section analyses have shown that altered volcaniclastic material comprises a significant component of the succession in this area (Houck and Lockley, 2006).

3.3. Local stratigraphy and sedimentology

3.3.1. General framework

In order to attempt to understand the track-bearing beds in their correct stratigraphic and sedimentological context we measured the stratigraphic section in detail along about 3 km of coastline (Fig. 5). We use this stratigraphic framework as

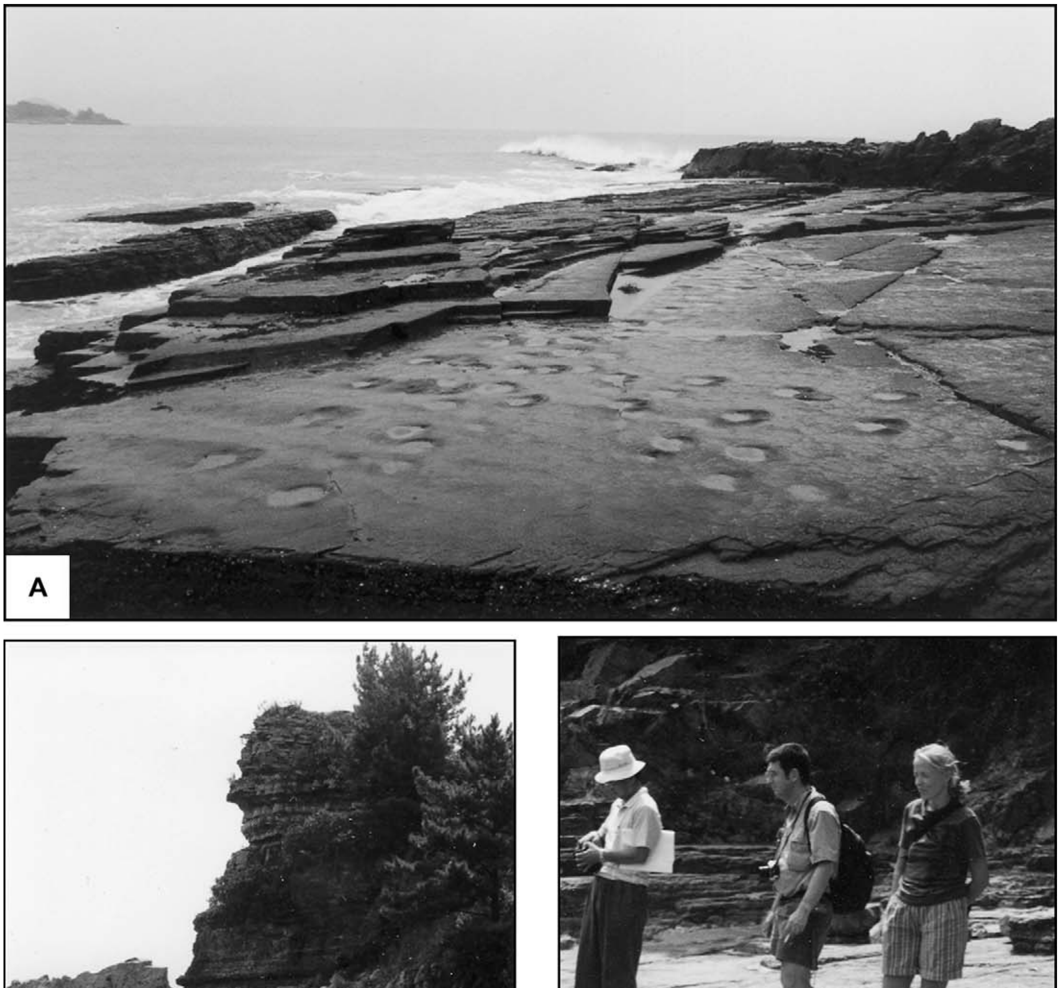

Fig. 3. Photographs of track sites on wave cut platforms, Sangjok section 2. A, multiple ornithopod trackways. B, single sauropod trackway. C, single ornithopod trackway.

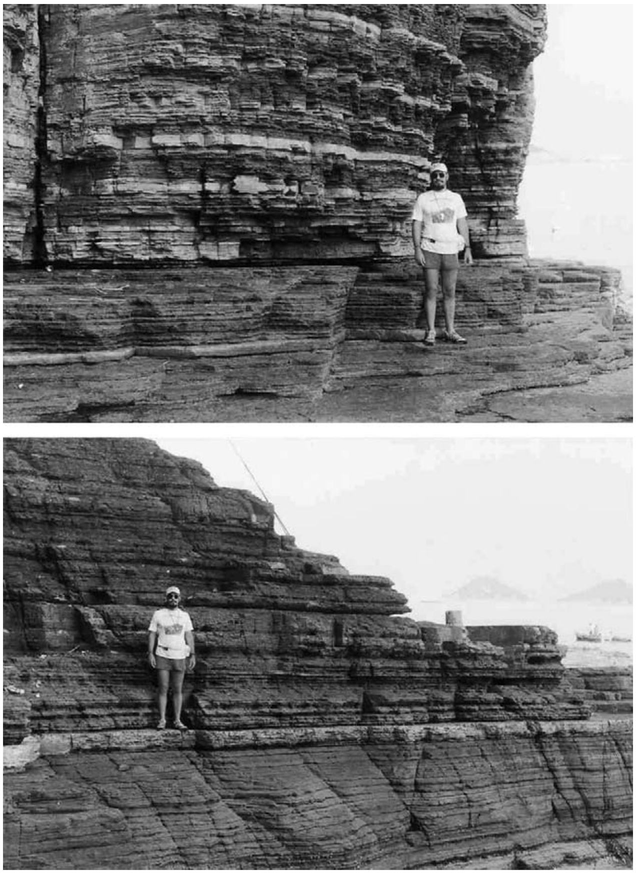

Fig. 4. Photographs of track-bearing sections. Lower photograph shows geologist standing on volcanic ash bed base of Sangjok section 1; upper photograph shows continuation of Sangjok section 1 a few meters higher. Compare with Fig. 5.

a reference point for locating important track sites mentioned in the text. This also allowed us to identify a few key marker beds, including various limestone and volcanic ash units, that prove useful for local correlation of track beds throughout the area. This approach proved essential when it became evident that the section is complicated by local faulting which repeats certain track-bearing beds. An excellent example of how minor faulting can confuse local stratigraphic correlation is seen in the Sangjok section (Fig. 6). This site is in effect the type locality for the track site area, being the main access point for tourists and the location where the National Monument interpretive sign has been installed (=Locality 1 of Yang, 1982a and Lim, 1990).

In his initial report, Yang (1982a) identified 13 geographic track site localities numbered from north to south. He estimated that they fell within approximately 300 m of stratigraphic section. Lim (1990) followed Yang in using these locality designations in his doctoral thesis (Lim, 1990). For the purposes of this study however we began by measuring the section in the south, at the inferred lowest exposed stratigraphic level, and proceed northward to the highest stratigraphic levels in the Sangjok area (Fig. 5). We gave each section a geographic designation as follows: Silbawi 1-6, Bonghwagol, Dukmyeongri 1-4 and Sangjok 1-2 (see Fig. 5 and Houck and Lockley, 2006), and were able to successfully correlate a little over 100 m of section on a bed by bed basis and identify over 204 track-bearing levels in this interval, while we identified an estimated 329 track-bearing levels in the whole area (Lim et al., 1994, and Appendix herein). The Bonghwagol and Silbawi sections 1-5 could not be correlated with the remaining sections. However, the correlation of the Silbawi 6 section with the Sangjok section proves that significant fault displacements occur, and that adjacent outcrops may not always be in close stratigraphic proximity.

3.3.2. Eosinaraeddam section: the Jindong type section area

We also measured a track-rich section at coastal exposures in the Eosinaraeddam village area, about 40 km east Samcheonpo, near the Jindong Formation type locality (Fig. 7). To date, we have been unable to correlate between the two areas, although it is clear from lithology and trackway types that there are genetic similarities between the two areas. The presence of about thirty other known track sites in the Jindong Formation in Kosong County alone (Lee et al., 2001; Fig. 1 herein) underscores the rich potential for further stratigraphic correlation and acquisition of more ichnological data throughout the Gyeongsang Basin.

3.3.3. Silbawi section

Following our measured sections from the south to the north, in inferred ascending stratigraphic order, we first recorded sections designated as Silbawi 1 through Silbawi 4 (see Houck and Lockley, 2006). Although we were able to correlate between sections 1, 2, 3, and 4, we were unable to demonstrate the relationship of these sections to sections 5 and 6. Similarly we were unable to unequivocally correlate sections 1-5 with other parts of the stratigraphic sequence. Only section 6 correlates with the Sangjok sections (Fig. 5).

From an ichnological point of view there are few important track beds in the Silbawi 1 section. In fact only 11 track levels have been recorded in a 37 m succession, and only one with multiple trackways (three sauropods); see Appendix. An equally low density is recorded in Silbawi sections 2 and 3, though this is in part a reflection of the sea cliff exposures that lack wave cut platform bedding plane exposures. The alternating dark and light beds used in a fractal analysis (Fleming et al., 1991) were measured at the top of section 2. One badly weathered bedding plane exposure on the foreshore between sections 1 and 2, shows evidence of several ornithopods that traveled in the same direction. Only one bird track horizon is known from section 2 (Fig. 8 in Matsukawa et al., 2006, and Figs. 8, 9 herein) and Lim (1990) recorded one probable theropod track (Fig. 10).

By contrast to the relatively sparse track record in Silbawi sections 1 to 3, the Silbawi 4 section, in an area of wave cut platform exposures, reveals 13 track bearing beds in an 8 m section − an average frequency of about one level per 62 cm. Similarly Silbawi 5 section also reveals a similar high frequency of track beds (14 in 10 ms of section = average interval of 71 cm). In his thesis, Lim (1990) designated the

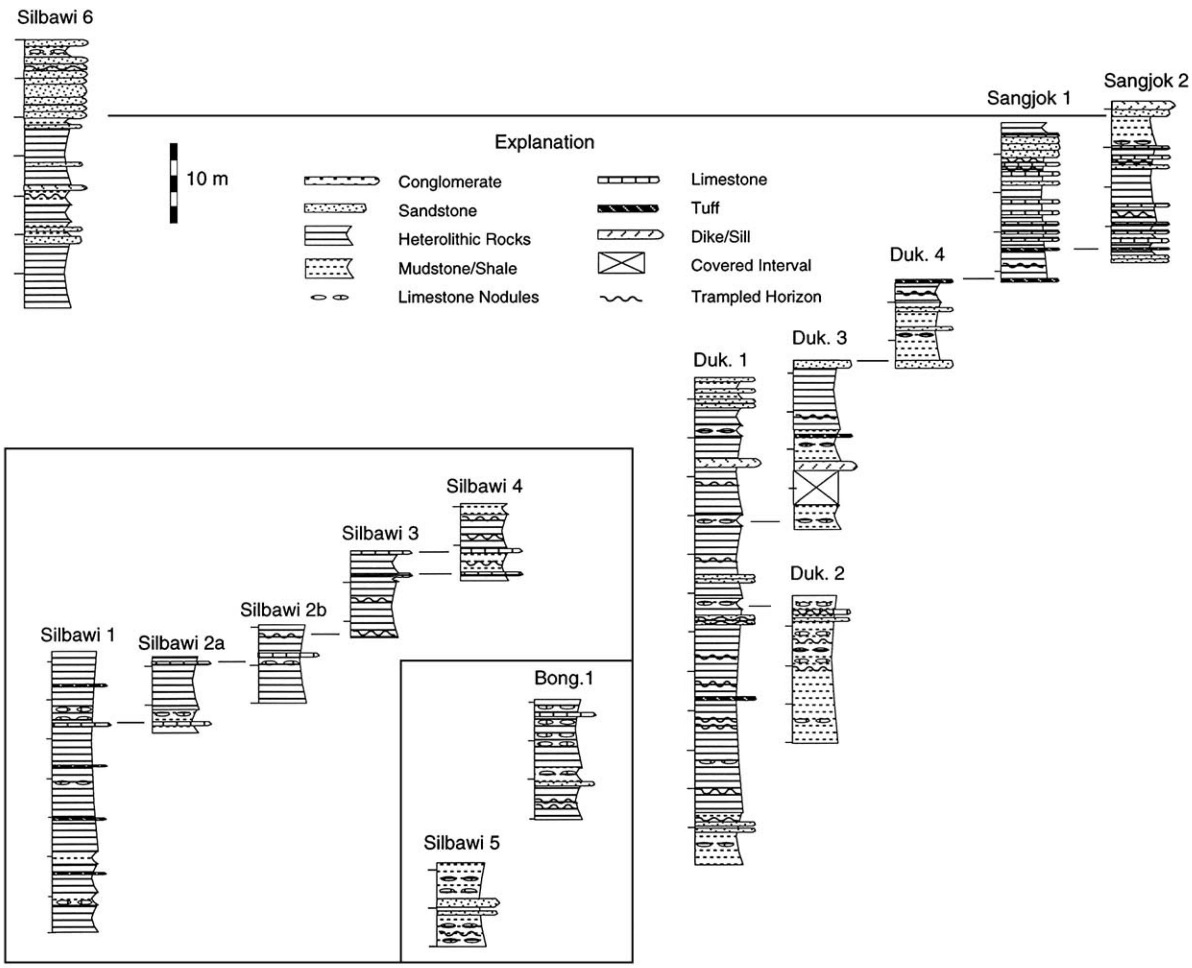

Fig. 5. Local stratigraphy of the track site area, simplified after Houck and Lockley (2006, figs. 3, 4).

Silbawi 4 site as locality 10 and illustrated 11 trackways from 11 different stratigraphic levels (six sauropod, four ornithopod, and one theropod). One of the trackways is that of a sauropod with crescent shaped manus tracks (Fig. 11). Most of the track levels reveal isolated trackways, and no evidence of herding by any of the track making groups. This may be in part a function of limited exposure of bedding plane surfaces. To the north the Silbawi 6 section can be correlated with the youngest known beds in the study area (the Sangjok 2 section, Lim et al., 1994, fig. 2; Fig. 5 herein). Therefore, its stratigraphic relationship to the rest of the Silbawi section is unknown.

In recent years several other track-rich stratigraphic sections have been identified in the Jindong Formation elsewhere in Geosong County. It is outside the scope of this paper to discuss these in detail but some tracks are worth mentioning. For example the baby sauropod trackway (Fig. 11A) was found to the east of the main study area (see Lee et al., 2000; Yang et al., 2003). Further discussion is presented below in the section on sauropod footprints.

3.3.4. Bongwagol section

The Bonghwagol section lies to the north of the Silbawi sections (Fig. 5, Houck and Lockley, 2006). It also consists of wave cut platform exposures with a high frequency of track-bearing levels (14 in lowest 10 ms of section). The Bonghwagol section has many features of note including the first horizon with bird tracks discovered in the Jindong Formation. The discovery slab (KPE 50002), found by M.G.L. was illustrated by Lim (1990, fig. 8; Fig. 9 herein). The Bonghwagol section also contains the horizon from which the nomen dubium "*Koseongosauripus kimi*" was inadequately described by Kim (1986); see Appendix. This section also reveals at least one track bed with multiple ornithopod trackways. This horizon (Fig. 12G) also reveals one sauropod trackway. However, the sauropod trackway is shallower than the ornithopod trackways, suggesting that these different track maker types may not have traversed the area at the same time.

3.3.5. Deokmyeongri and Sangjok sections

Generalized stratigraphic sections of the Dukmeongri and Silbawi sections have already been published (Lockley et al., 1992a, fig. 23, and Lim et al., 1994, fig. 2, respectively) but without detailed descriptions. These sections are more important than the Silbawi and Bongwhagol sections in terms of ichnological yield, having produced many more important bird and dinosaur-track-bearing levels, and considerably more bedding plane exposures (Fig. 3). The sections are also more

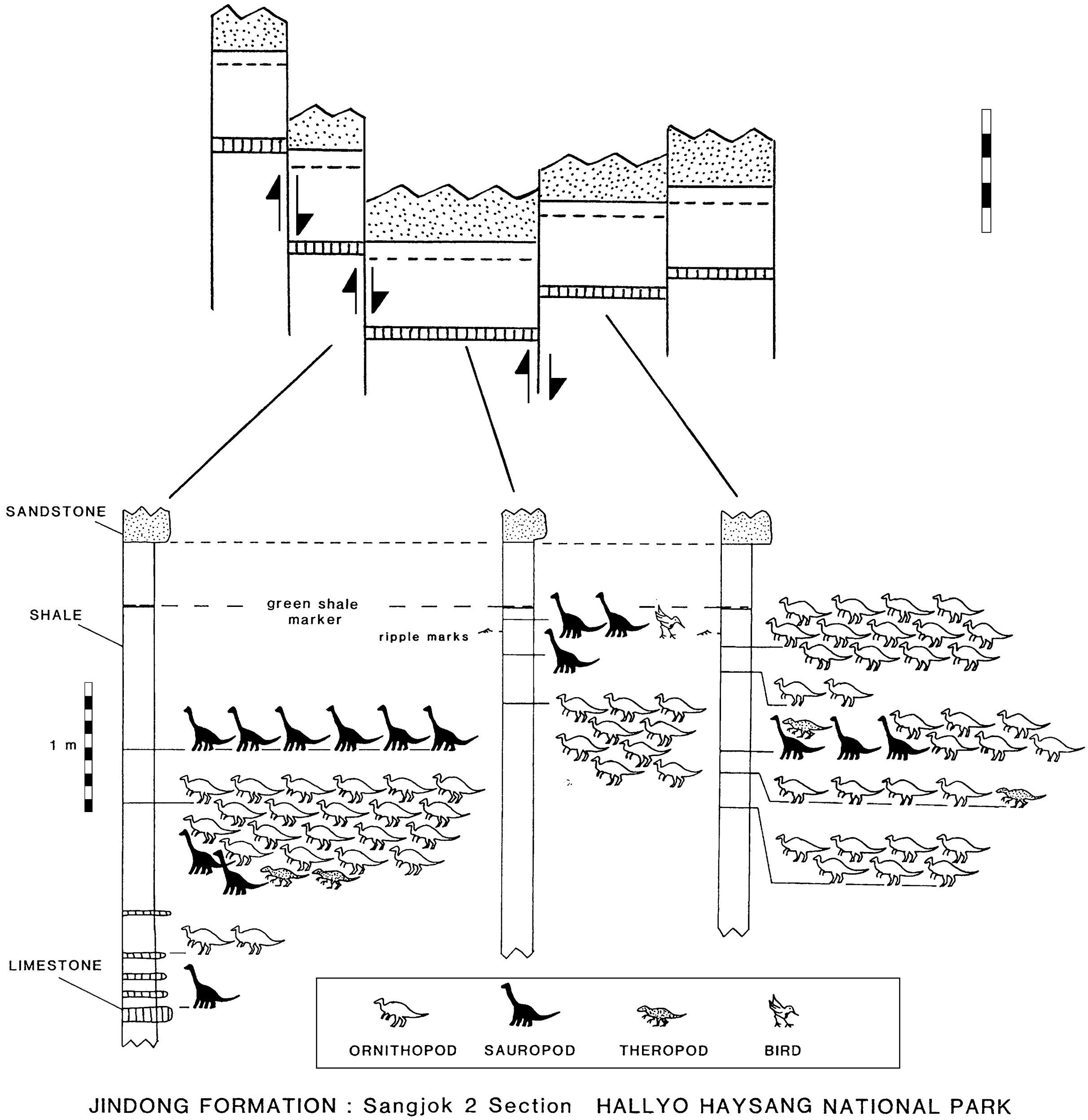

Fig. 6. Stratigraphy of the Sangjok section showing how local faulting complicates correlation of closely spaced track-bearing beds. Scale bar top right = 5 m.

easily accessible to visitors, more continuously correlated, and linked to the Silbawi 6 section.

Examples of important track-bearing horizons from the Dukmeongri section include the type locality for *Jindongornipes* (Fig. 9). Other bird track sites yield a *Goseongornipes markjonesi* ichnogen. and ichnosp. nov. (Fig. 9C) and large concentrations of *Jindongornipes* footprints (Lockley et al., 1992a, fig. 24). The latter horizon has also yielded an excellent example of very small sauropod footprints (Lockley et al., 1992a, fig. 24; Fig. 11C herein). Similar small sauropod footprints are also known from another horizon in the Dukmeongri section (Fig. 11B and Lim et al., 1989 fig. 35.4A).

The Dukmeongri and Sangjok sections also contain may surfaces with multiple ornithopod trackways many in parallel configurations suggesting gregarious behavior (Figs. 12, 13).

In contrast to the traditional method of tracing track outlines, with acetate overlays, Lim (1990) experimented with a simple, manual contouring technique. Track replicas were placed in a watertight tank and the water level raised a millimeter at a time, each time tracing the "shoreline" contour (Figs. 10, 14). The results are visually impressive and consistent with high tech methods such as those used by Farlow and Chapman (1997) through these authors used a much "coarser" 1 cm interval. The examples included here effectively discriminate between many of the finer points of tridactyl biped morphology. For example theropod tracks (Fig. 10) are typically longer than wide, with pointed claw impressions and somewhat asymmetric heels that reveal a posterior-medial indentation behind the proximal metatarsal-phalangeal pad of digit II. By contrast ornithopod tracks are typically wider than long

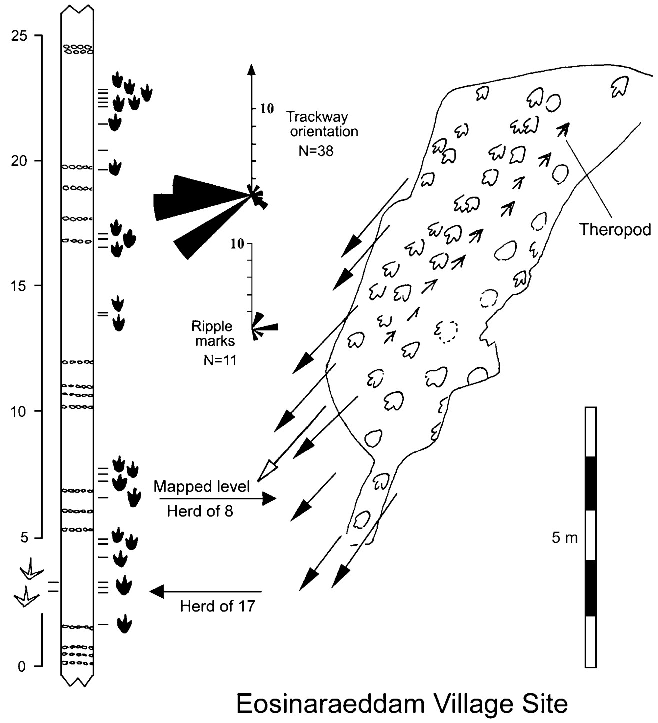

Fig. 7. Stratigraphic section showing track-bearing beds in the Eosinaraeddam village area (Jindong type section area) with map of level with herd of eight ornithopods.

with wide, rounded toe impressions and symmetrical rounded or bilobed heel impressions (Fig. 14). All these diagnostic features show up clearly in the tracks illustrated by this labor intensive, but cheap, contouring technique.

4. Sedimentological observations

Houck and Lockley (2006) describe the sedimentology of the Samcheonpo sections in detail. It is therefore only necessary to add a few general observations on biogenic and non- biogenic sedimentary structures, which may help integrate our understanding of trackway patterns with the paleoenvironments in which they were made. In addition to the abundant tracks and various invertebrate traces (Lockley et al., 1992a), the section is also replete with ripple marks, mud cracks and other non- biogenic sedimentary structures such as rain drop impressions. All these point to evidence of cycles of shallow water deposition and emergence, and confirm the interpretation of a lacustrine paleoenvironment, proposed by Choi (1986) and others. To date the only body fossils found in the study area are a few reworked bivalve shell fragments recovered from local fluvial sandstone units and a few charophyte stems (Houck and Lockley, 2006). However, there are also a number of invertebrate traces. These include sinuous small-scale surface trails resembling *Cochlichnus* (Lockley et al., 1992a, fig. 12a) and small vertical burrows that resemble those made by modern insect larvae (Fig. 8A–C).

In contrast to these observations, and those of Houck and Lockley (2006) and Paik et al. (2001) suggest that the Jindong

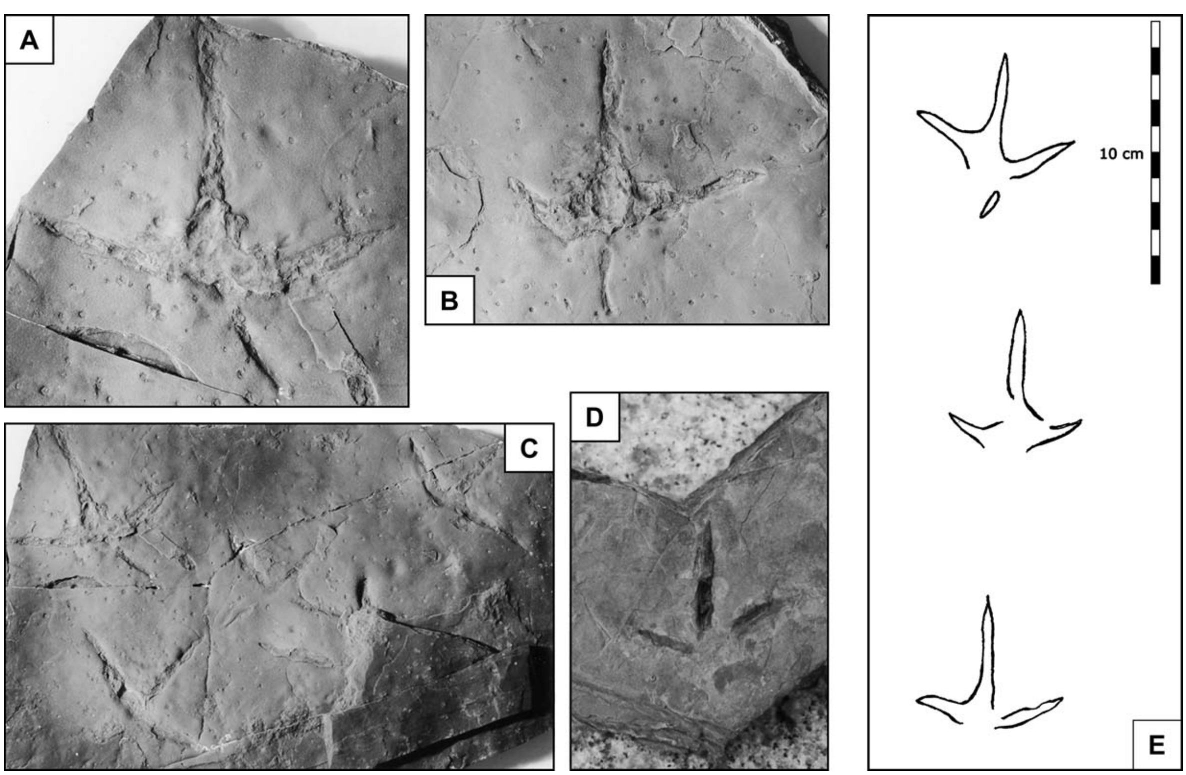

Fig. 8. Bird tracks from the Jindong Formation. A–C, type material of *Jindongornipes kimi* (modified after Lockley et al., 1992a, figs. 8, 21, 22). D, *J. kimi* from Gohyeon. E, *J. kimi* trackway from Sangjok section 2.

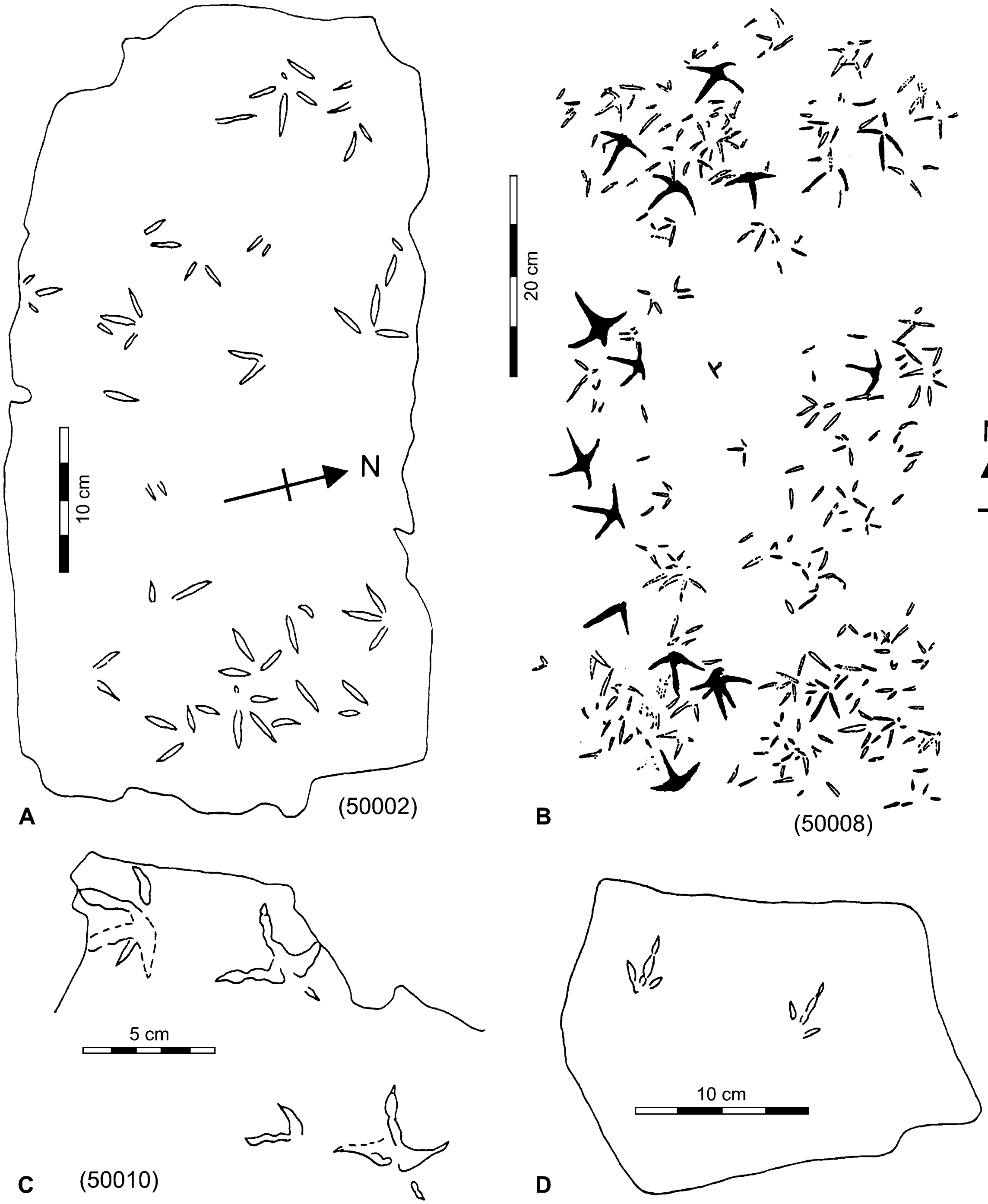

Fig. 9. Bird tracks from the Jindong Formation. A, discovery slab consisting of *Koreanornis* tracks from the Bongwahgol section. B, co-occurrences of *Jindonogornipes* (black) and *Koreanornis* (white) from the Deokmyeongri section. C, a hitherto undescribed, intermediate sized shorebird tracks, with hallux, from the Deokmyeongri section named *Goseongornipes* in Appendix. D, undescribed tridactyl tracks from the Deokmyeongri section.

formation represented a perennial lake subject to periodic sheet flooding and subsequent calcareous pedogenesis under arid climatic conditions. These conclusions were considered in agreement with the suggestions of Ishiga et al. (1997), based on geochemical data (high sulfur content and metal enrichment), that the Gyeongsang Supergroup generally represents deposition in a saline lake basin under arid conditions. However, as noted by (Houck and Lockley, 2006) the identification of pedogenic deposits is rejected for the sections examined in this study.

Another distinctive component of the sedimentological successions in the study area is the presence of both continuous and discontinuous, or nodular, carbonate horizons. These units range from 1–2 to as much as 20–30 cm thick, and often occur in packages of from two to as many as ten beds. Although some of the carbonate beds consist of isolated nodules, and are

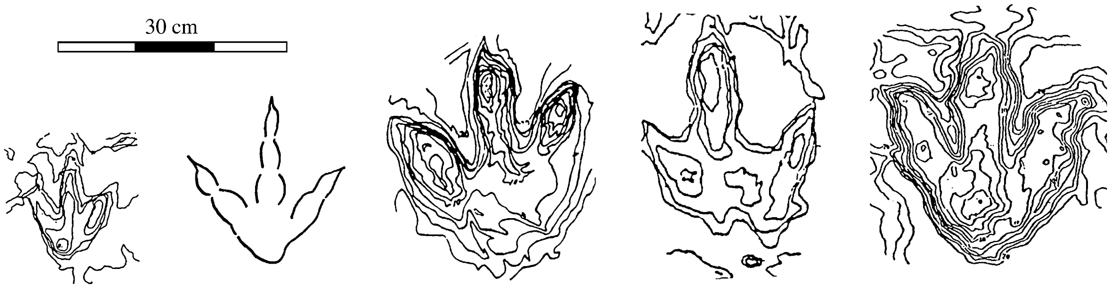

Fig. 10. Theropod tracks from the Jindong Formation, arranged in order of increasing size; from left to right specimens correspond to figs. 18.25, 18.30, 18.24, 18. 23, and 18.26 in Lim (1990), from the Sangjok, Bongwhagol, Sangjok, Sangjok and Deokmyeongri sections respectively.

not strictly speaking continuous, they may be laterally continuous in the sense that they can be traced for several kilometers within the study area without showing any obvious sign of lateral variation. In many instances the carbonate beds are deformed by dinosaur tracks thus showing that they formed as primary accumulations or during very early diagenesis.

Our analysis of the ripple marks reveals that they are predominantly small scale (wavelength 2–3 cm), symmetrical wave ripples with a strong WNW-ESE trend (Fig. 15). Such ripple marks can only have formed around the margins of a shallow lake in which paleohydrological conditions remained very constant. Presumably prevailing winds from the NNE and/or SSW generated a consistent pattern of waves breaking along the WNW-ESE trend. If the waves broke parallel to the shoreline, then we can infer that this was also the shoreline trend. In contrast to the wave ripple marks in the finer grained deposits, some of the sandstone units reveal linguoid current ripples that indicate flow towards the east and northeast, from western and southwestern source areas (Houck and Lockley, 2006).

Several authors have attempted syntheses of ripple mark data. Lim (1990) presented a synthesis of 88 measurements of ripple crest orientations, which is in agreement with our larger sample of 110 measurements obtained during a concurrent study (Fig. 15). Paik et al. (2001) also presented a similar synthesis for only 54 measurements, suggesting a trend that was somewhat more strongly NW-SE, though the difference in orientation is slight. Paik et al. (2001) also provide

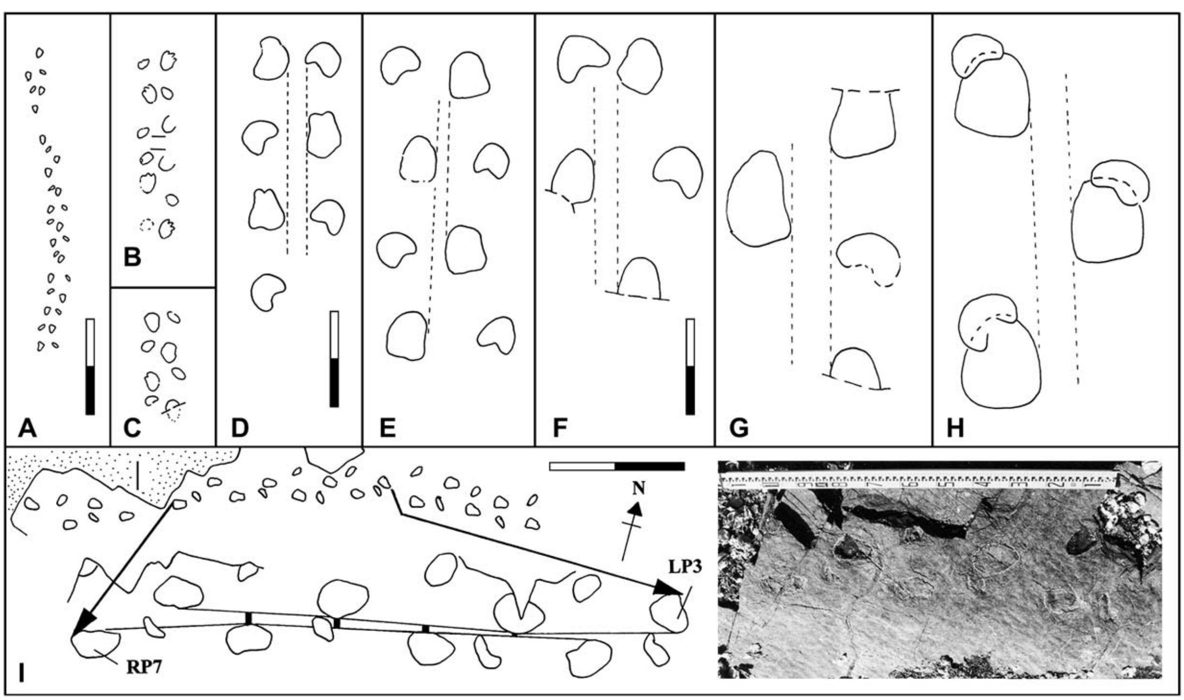

Fig. 11. Sauropod tracks from the Jindong Formation arranged in increasing order of size. Note that all larger examples (D–G) are wide gauge, as shown by dotted lines that show inner, inter-pes trackway width (after Lim, 1990, with his numerical designations). A, smallest known sauropod trackway, from Hoewha District, Kosong County (after Lee et al., 2000, fig. 8A; Yang et al., 2003, pl. 89). B–G, tracks from Samcheonpo track site, Hai District, Goseong County. B, from Deokmyeongri section after Lim et al. (1994, fig. 2). C, from Deokmyeongri section after Lockley et al. (1992a). D, trackway 2-6-1 from Sangjock section. E, trackway 10-22-1 from Silbawi section. F, trackway 2-3-1 from Sangjok 2 section. G, trackway 8-1-1 from Deokmyeongri section. H, 8-9-1 trackway from Deokmyeongri section. I, detail of small sauropod trackway shown in Fig. 11A (after Yang et al., 2003, pl. 89) with detail (enlarged × 3) of middle section showing left pes 3 (LP3) to right pes 7 (RP7), and margin of outcrop. Midlines and transverse black bars show variable trackway width. All scale bars represent 1 m.

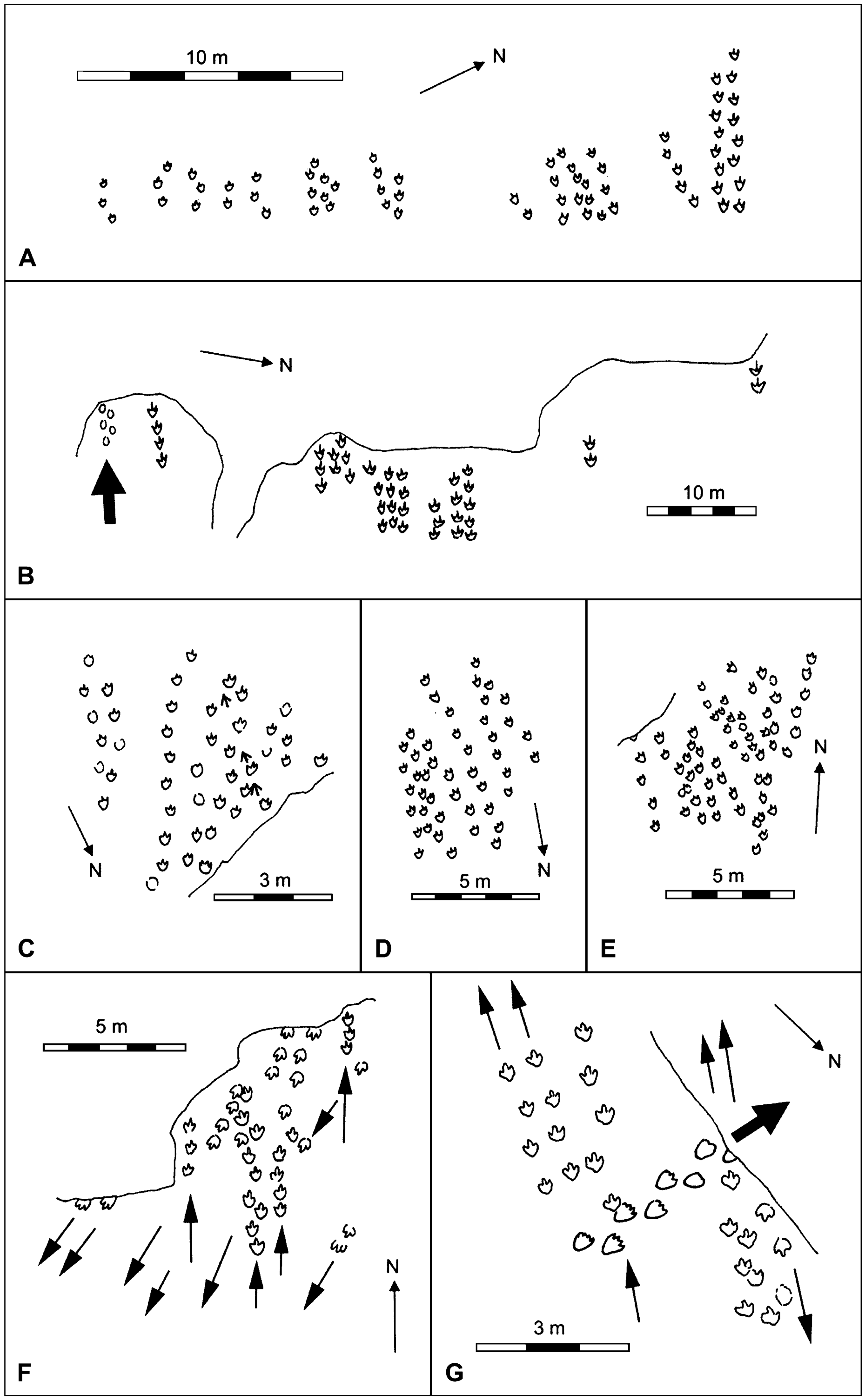

Fig. 12. Maps of parallel and sub-parallel ornithopod trackways. A–E, tracks from the Sangjok section showing 19, 11, 8, 7 and 10 individuals respectively (after Lockley, 1989, fig. 3C; Lim, 1990; Lim et al., 1989, fig. 35.1). F, trackways from Deokmyeongri section (remapped by MGL after Lim, 1990, fig. 16.49) showing seven trackways heading south west and four to the north. G, trackways from Bongwhagol section (after Lim, 1990, fig. 16.89) showing five trackways heading southwest and one northeast, with a sauropod trackway heading west-northwest. However, the ornithopod trackways are much deeper than the sauropod trackways at this locality. See text for details.

a synthesis of 13 measurements that indicate that flow directions were mainly southward. Their data was presumably derived from current ripples (and/or or cross sets) but provided no discussion of the type of evidence. Ito (unpublished data) has obtained measurements for 53 wave-ripple and 18 current-ripple sets that are broken down by sections (Silbawi, Bonghwagol, Deokmyeongri and Sangjok). His wave ripple data shows "flow" or water circulation direction rather than

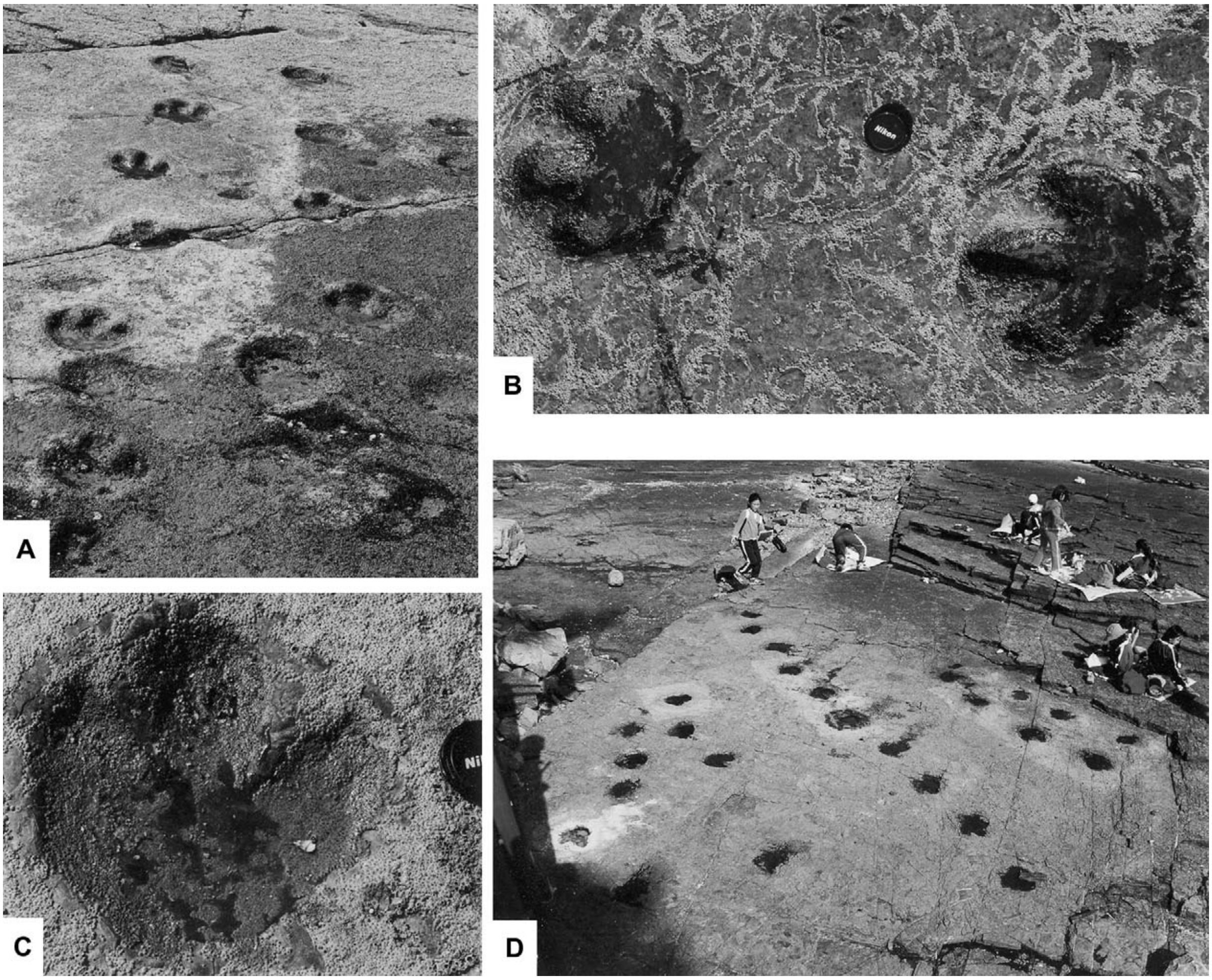

Fig. 13. Photographs of ornithopod trackways from Sangjok section. A, parallel ornithopod trackways (after Lockley, 1989); compare with two trackways at right side of map in Fig. 12A. B and C, details from same trackways as A. D, trackways corresponding to map in Fig. 12C.

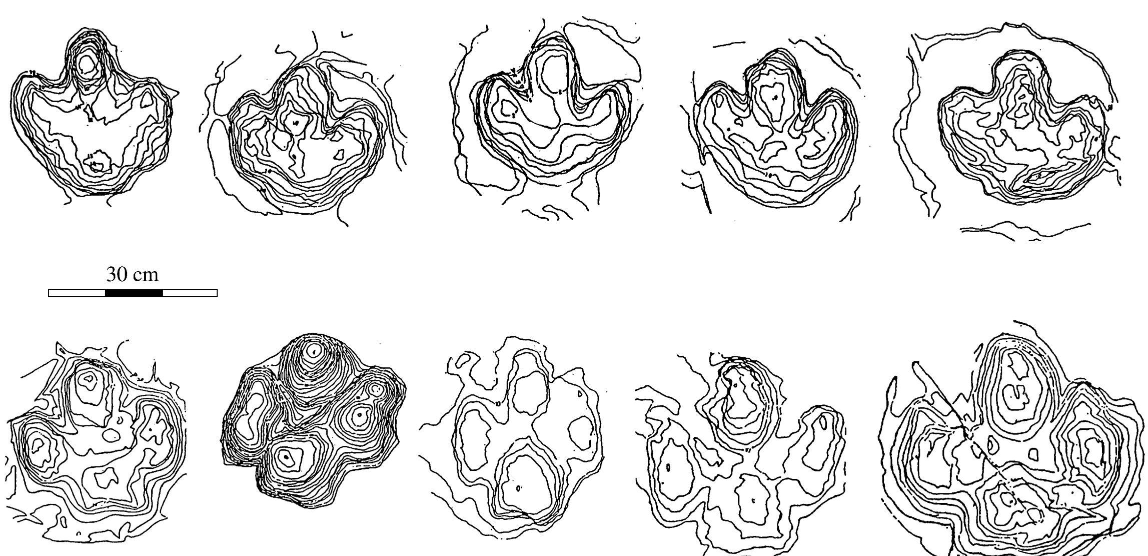

Fig. 14. Contour maps of ornithopod tracks; compare with Fig. 10.

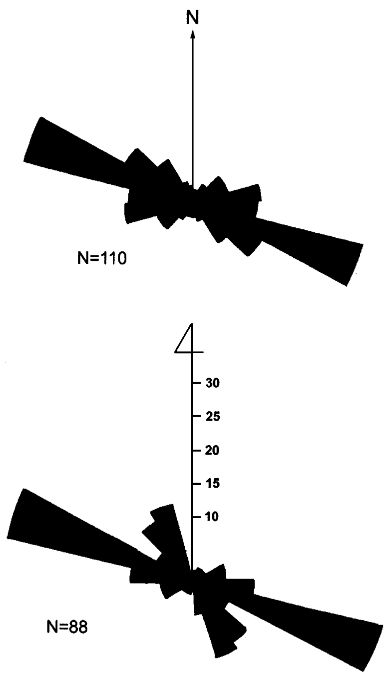

Fig. 15. Summary of wave ripple crest orientations. Upper diagram based on 110 stratigraphic levels in the Jindong Formation, near Samcheonpo. Lower diagram shows similar, but smaller data set after Lim (1990, fig. 4).

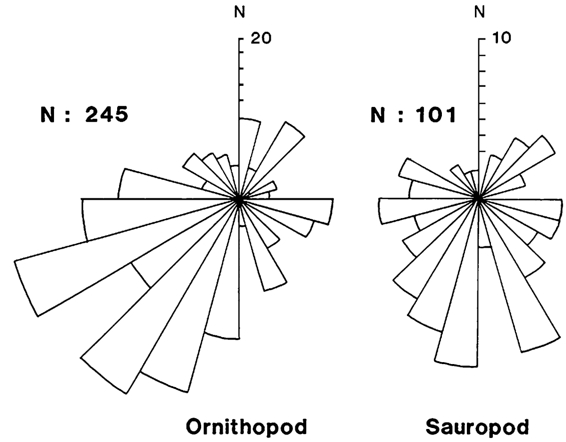

Fig. 16. Trackway orientations for ornithopods and sauropods.

ripple crest orientation, and so is at 90° to our rose diagrams, but otherwise in very close agreement. His current ripple data suggest predominantly southward flow in the Silbawi section, with sparse and variable data in the other sections.

5. Trackway orientations

Lim (1990) presented trackway orientation data in two categories (type B = bipeds and type Q quadrupeds). He recorded 185 and 60 trackways respectively in these categories (Fig. 16). The former category includes ornithopod and theropod trackways. We also obtained orientation measurements in two categories: ornithopods (n = 245) and sauropods (n = 101). This total of 346 trackways excludes a few (16) theropod trackways. The synthesis (Fig. 16) indicates that ornithopods were traveling predominantly to the southwest, whereas the sauropods were moving mainly southwards. As noted by Lim et al. (1994) the difference in trackway orientation pattern between sauropods and ornithopods may be significant given that patterns of gregariousness and size-frequency are also quite distinct. Lee et al. (2000) also presented separate trackway orientation data sets for ornithopods, sauropods, and "all footprints," but in this case the data for all Goseong County is pooled. It is not explicitly stated whether this data includes all the 410 trackways they recorded (Lee et al., 2001, Table 1). However, they also noted the SW trend for ornithopods and the southerly trend for sauropods, as might be expected given that the Samcheonpo data comprised 61% of their data set. Smaller data sets were presented by Paik et al. (2001) for a total of 231 trackways. However, as this data is undifferentiated it provides no information that adds to that presented herein.

It is perhaps noteworthy that the main trackway trends (SW and S) are more or less perpendicular to the wave ripple crest trends. This could imply that the animals were moving into, or with their backs to, the wind. If the wind was driving waves on shore, rather than along shore, or at an oblique angle, then these trackways indicate a shore perpendicular orientation (as suggested by Paik et al., 2001, p. 90). Thus, while we infer that the preferred ornithopod trackway orientations were probably in large part the result of gregarious behavior, i.e., the preferred directions chosen by the animals, the presence of physically controlled pathways (sensu Ostrom, 1972) cannot be ruled out especially in the case of the sauropod where there is less clear evidence of gregariousness.

Many general statements have been made about the utility of parallel trackways of large herbivorous dinosaurs as indicators of gregarious behavior (e.g., Lockley, 1995). It is outside the scope of this paper to discuss this topic in detail. However as noted elsewhere, although parallel trackways of sauropod often suggest gregarious behavior (Lockley et al., 1986, 1994d) such evidence is rare in the Jindong Formation (Lim et al., 1989, 1994). However there are abundant examples of the parallel trackways of ornithopods, which we take to be evidence of gregarious behavior (Lim et al., 1994). These parallel trackways invite comparison with sites in North America (e.g., Currie, 1983, 1995; Matsukawa et al., 2001).

6. Systematic ichnology

6.1. General considerations

In general we advocate a conservative approach to the assignment of ichnotaxonomic names, especially when dealing with tracks that are common, abundant, not well-preserved, and lacking in distinctive morphological features. Rare, highly distinctive, and well-preserved tracks may be easier to name without creating future ichnotaxonomic problems. There are good scientific reasons for exercising such caution. First, there has been a trend away from the proliferation of ill-conceived ichnotaxonomic names. Second, an increasing body of evidence shows that most large track assemblages contain only a few distinctive ichnotaxa (Lockley, 1997), and that large numbers of ichnospecies within particular ichnogenus or ichnofamily rarely co-occur together. For example only one ichnospecies of sauropod track has been recognized in the extensive Lower Cretaceous track-bearing beds of Texas (Farlow et al., 1989), and only one ichnospecies of ornithopod track occurs in the Lower Cretaceous Dakota Group of Colorado, New Mexico, and Oklahoma (Lockley et al., 1992b). This realization is consistent with general paleoecological observations that indicate a rarity of congeneric species in most fossil assemblages, particularly in vertebrate ichnological assemblages. The classic Jurassic assemblages from New England (Hitchcock, 1858) might appear to be an exception until one realizes that they are probably overly split (Olsen, 1980; Olsen et al., 1998).

For these reasons we are skeptical of reports that describe many poorly differentiated ichnites as new ichnotaxa, as in the case of the many new ichnogenera and ichnospecies described by Yang and Yang (1987) and Azuma and Takeyama (1991) from China and Japan, respectively. These ichnotaxonomies have been challenged by Lockley and Matsukawa (1998) and Lockley et al. (2003) on the basis that many are junior synonyms of better known taxa or poorly preserved and incomplete, undiagnostic material that displays extramorphological variation attributable to variable preservational factors. Several authors have stressed that new ichnotaxa should only be named when an adequate supply of well-preserved material is available (Peabody, 1955; Baird, 1957; Sarjeant, 1989).

Nevertheless we must attempt to differentiate ichnotaxa. The dinosaur tracks fall into three broad categories: sauropod, ornithopod and theropod tracks. Within these categories there is some variation in morphotypes that maybe noteworthy from a systematic viewpoint. However it is outside the scope of this paper to undertake a detailed systematic study of these tracks, though an ichnotaxonomic appendix is provided. Rather it is helpful to summarize the available morphometric data and present some preliminary discussion of its ichnotaxonomic significance.

Lim (1990) made informal attempts to differentiate tracks into two categories: Q = quadrupedal (presumably all sauropods) and B = bipedal (ornithopods and theropods). He further subdivided these categories into subcategories Q1–Q4 and B1–B9. We have not found this scheme very effective, because there is too much disagreement, among independent observers as to which category a particular track belongs. Moreover it seems probable that the subtle differences observed by Lim (1990) are due, at least in part, to preservation or perhaps to allometric variation.

6.2. Sauropod tracks

The sauropod tracks (Fig. 11) are wide gauge and assigned to *Brontopodus* sp. pending further study. The trackways of the very small individuals vary between narrow and wide gauge. For example, the trackway of the smallest sauropod (Fig. 11A, I) has an inner trackway width, measured between the inner margins of the left and right pes, that varies between 0.5 and 4.7 cm. These measurements are for an individual that has a mean pes length of 12. 2 cm and mean width of only 8.3 cm ($n = 8$). Gauge differences are in part a function of size and growth (Lockley et al., 2001, 2002). *Brontopodus birdi* is well known as the wide gauge sauropod trackway type first reported from the Glen Rose Formation, at Dinosaur Valley State Park Texas. These trackways are of Albian age and are generally well preserved with respect to morphological details of claw impressions. Among the significant differences between the Samcheonpo sample (102 trackways), and the Texas sample (83 trackways), is that the Jindong tracks are smaller in average size, and much less deeply impressed, thus showing less morphological detail in most cases. However, many show three faint claw traces corresponding to digits I, II, and III.

Kim (1986) made ill-conceived attempts to name sauropod tracks from the Jindong Formation and other parts of Kyongsang Group. We made careful efforts to understand Kim's work and reviewed his report and the corresponding field evidence, but to no avail. As stated explicitly by Lockley et al. (1994b) both the ichnotaxa *Koreanosauripus cheongi* and *Hamanosauripus ungulatus* of purported sauropod origin (Kim, 1986) are incomprehensible for several reasons and must be regarded as nomina dubia. Kim's ichnology lacks credibility and, moreover, was not presented in a recognized scientific publication. Concern over the comprehensibility and validity of the ichnotaxa was also expressed by Farlow et al. (1989). The specific problems are as follows: (1) These ichnotaxa were named in abstracts with no illustration or designated holotypes. (2) The information was circulated in an unpublished report by H. M. Kim. (3) The former ichnotaxon (*Koreanosauripus cheongi*) is not even visible at the type locality, which was in a roadway that had been subject to severe damage, making it entirely undiagnostic. It was later paved over, making it completely inaccessible. No replicas exist. (4) Kim appears to have selected two holotypes, and a second type locality for *Koreanosauripus cheongi*, where the second set of tracks are clearly under-prints. (5) There is also considerable uncertainty about the type locality and formation from which the latter ichnotaxon (*Hamanosauripus ungulatus*) was reported. In 1986, at the First International Symposium on Dinosaur Tracks and Traces, Kim (1986) reported that it was from the Haman Formation, as the name would suggest, whereas in an unpublished report, Kim stated that it is from the Jindong Formation, thus making the name doubly confusing. (6) In his unpublished report, H.M. Kim's "figure captions are confused, and terminology such as holotype, paratype, topotype, lectotype are use nonsensically" (Lockley et al., 1994b). (7) Kim misidentified digit impressions I–III as II–IV, an error also noted by Farlow et al. (1989). (8) Kim also failed to compare his proposed ichnotaxa with any other sauropod ichnites from around the world (Sarjeant, 1989; Lockley et al., 1994c).

Given this inauspicious start to Jindong dinosaur ichnotaxonomy we have attempted to provide more thorough descriptions of the material, but as no new dinosaur ichnotaxa are named, we confine these descriptions to an Appendix. These descriptions are based on large samples of measured tracks from which we obtained basic size-frequency data (pes track length and width) for 101 trackways (Lockley, 1994; Fig. 17 herein) as well as detailed measurements for 60 trackway segments (see Appendix, section 2). The data show that the Jindong sauropod tracks, although representing a wide size range (Fig. 17) are much smaller on average than any previously recorded from well-known track assemblages in North America. A similar conclusion was reached by Lee et al. (2000) in their survey of tracks from all sites in Goseong County.

Hwang et al. (2004) report several long sauropod trackways up to 40 m in length from the Jindong Formation in Changnyeon County (east of Goseong County). According to these authors, these trackways often exhibit a manus impression in which the impression of digit I is visible. Pes digit impressions are also visible. This locality is about 55 km north east of the Sangjok area and so it is not possible to correlate the track-bearing beds with sites in Kosong County.

6.3. Ornithopod tracks

Yang (1982a) and Lim (1990) recognized several different tridactyl track morphotypes, attributable to both ornithopods and theropods. However they did not assign them formal ichnotaxonomic names. The most distinctive ornithopod track types, which Lim (1990) designated types B1 and B2 (B = biped), made up approximately 75% of his entire sample of tridactyl tracks. B1 and B2 are generally very similar except that B1 typically reveals a rounded to square heel impression, whereas B2 is a form that more frequently displays a distinctive bilobed heel impression (Fig. 14). The former morphotype is reminiscent of so-called *Iguanodon* tracks from the Wealden of England (Delair, 1989) now named *Iguanodontipus* (Sarjeant et al., 1998). Similar tracks are known from the Lower Cretaceous of Spain (Moratalla et al., 1992) and other similar tracks from the Lower Cretaceous of Canada have been named *Amblydactylus* (Currie and Sarjeant, 1979).

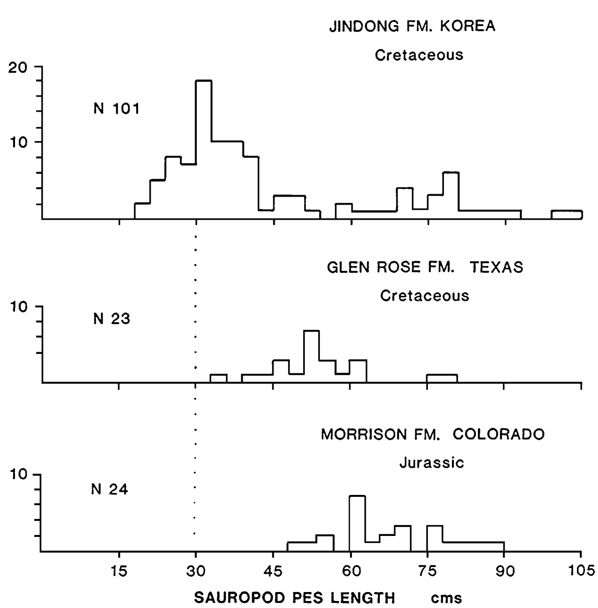

Fig. 17. Size-frequency histogram for sauropod pes track length, based on Jindong sample, with data from the Lower Cretaceous of Texas and the Upper Jurassic of Colorado for comparison (after Lockley, 1994).

Ornithopod ichnites from the Lower Cretaceous of Brazil were assigned the name *Caririchnium* (Leonardi, 1984). These are very similar to ornithopods from Colorado (Lockley, 1987; Lockley and Hunt, 1995; Matsukawa et al., 1999) and South Dakota (Lockley and Wright, 2001). It is important to note that *Caririchnium* and a similar ichnite (*Sousaichnium*) from South America (Leonardi, 1984, 1989, 1994) are the trackways of quadrupedal ornithopods with distinctive small manus impressions. *Amblydactylus* track assemblages from Canada also reveal manus tracks (Currie, 1983, 1995). Such trackways, though common in the Americas and Europe (Moratalla et al., 1992; Lockley and Wright, 2001) are rare in Asia, occurring at only one locality in China (You and Azuma, 1995; Lockley and Matsukawa, 1998) . To date, we have never observed manus impressions in ornithopod trackways from the Jindong beds. However it is theoretically possible that the track makers were quadrupedal and that they overprinted their manus tracks with pes footprints (cf. Paul, 1991). However there is no double printing that would provide evidence for this supposition.

The contrast between the single rounded heel and the distinctive bilobed pattern may represent individual variation in a given population, size (age), sexual dimorphism or preservation (Lockley et al., 1992b; Matsukawa et al., 1999). However for the purposes of the present study we have pooled all ornithopod trackway measurements for the purposes of our size-frequency analysis (Fig. 18). This synthesis shows that most trackways fall in the medium size range (25–35 cm; range 15–50 cm) as reported by Lockley (1994). Lee et al. (2000) reported a very similar size range for all of Goseong County, again with a marked concentration in the 30–35 cm interval.

The high frequency of track-bearing beds in the thinly bedded Jindong succession leads to differences in preservation for true tracks and under-prints from successively deeper levels (cf. Lockley, 1989). For example, one trackway consisting of a series of under-print natural casts, found on a fallen block, reveals well-defined ungual impressions (Fig. 19). It is interesting that these ungual impressions are clearly seen in a cast because almost all other ornithopod tracks are positive impressions, without clear ungual traces.

Kim (1986) named one of the Jindong Formation trackways *Goseongosauripus kimi*, but as discussed above, we consider Kim's ichnotaxonomy invalid for several reasons. Not least of the problems with Kim's ichnotaxon is that it was not presented in recognized publications or compared with any other known ichnotaxa such as *Amblydactylus* (Currie and Sarjeant, 1979) or *Caririchnium* (Leonardi, 1984), which could easily be considered as subjective senior synonyms. Moreover, the

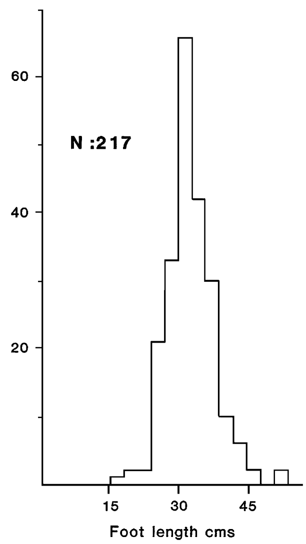

Fig. 18. Size-frequency histogram for ornithopod tracks from the Jindong Formation, Samcheonpo area (after Lockley, 1994).

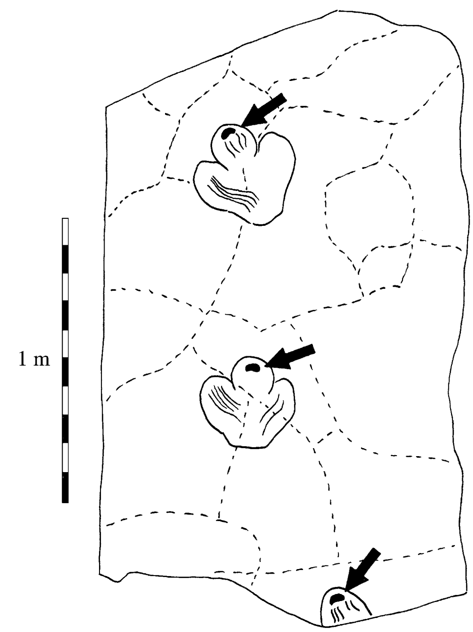

Fig. 19. Detail of an ornithopod trackway (cf. *Caririchnium*) with ungual impressions (black arrows) associated with digit III. The ungual impression is about 3 cm long and 7 cm wide in relation to a track that is 40 cm long by 57 cm wide. The trackway is preserved as casts of under-prints on a fallen block, Dukmyeongri section, but reversed here to show topside view. Note that the specimen also reveals longitudinal wrinkles sub-parallel to the axis of the digit impressions. Such wrinkles are not uncommon in tracks and under-tracks preserved in fine-grained sediments.

spelling of the name was later changed to *Koseongosauripus kimi* by Kim in an unpublished report, and in this unpublished account, Kim sketched a pad configuration that is at variance with any known pattern of iguanodontid morphology. The previous publication (Kim, 1986) is an abstract without any illustration or connection to an identifiable type specimen, and the sketch is unpublished. For these reasons we consider the originally proposed name an invalid nomen nudum.

Given the observed variation in large ornithopod track assemblages, and the need for careful study of the ichnotaxonomy of Cretaceous ornithopod tracks, we consider it premature to erect any new ichnotaxa for the Jindong ornithopod tracks. We conclude that it is best to provisionally assign the tracks to *Caririchnium* sp. This ichogenus name has been used to describe ornithopod tracks from the Cretaceous Uhangri Formation, in the Haenam Basin of western South Korea (Huh et al., 2003).

6.4. Theropod tracks

Theropod tracks are generally uncommon and have not been assigned to any ichnotaxon. Lim (1990) recognized a distinctive category of trackways of bipeds that he designated as type B3. Some of these are evidently attributable to theropods, and show the typical elongate, slender toed morphology and digit impression configurations seen in most footprints assigned to this group (see Fig. 10). In general the theropod tracks are small to intermediate in size (range of foot length = 15–34 cm). According to Lim (1990), the B3 type is quite common comprising 25 out of 185 bipeds (=29% of the biped sample and 25/247 of the total sample = 10.1%). We have not been able to identify such a high proportion of theropod tracks, and in a previous study we identified only 16 trackways out of a total of 268 bipeds (=6.0%) or a total of 16/388 (=4.1%) for all trackways. This latter figure represents the carnivore:herbivore or predator:prey ratio (about 1:25) for the total Jindong sample in the study area (see Table 1). By

Table 1
Statistics from identified trackways reported from the Jindong Formation in Hai District, Goseong County and all areas, based on 388, 410, and 424 trackways respectively

Geographic area and trackway total	Theropod tracks	Sauropod Tracks cf. *Brontopodus*	Ornithopod tracks cf. *Caririchnium*	References
Hai District Samcheonpo **388 trackways**	16 (=4%)	120 (=31%)	252 (=65%)	Lim (1990) Lim et al. (1994) Lockley (1994)
Goseong County **410 trackways**	16 (=5%)	139 (=34%)	249 (=61%)	Lee et al. (2000)
Goseong and other areas **424 trackways**	26 (=6%)	146 (=34%)	252 (=60%)	Huh et al. (2003)

contrast theropod tracks are very abundant in Cretaceous of southwestern Korea (Huh et al., 2006).

6.5. Bird and bird-like tracks

Bird tracks (Figs. 8, 9) are abundant in the Jindong Formation and have been reviewed in some detail by Lockley et al. (1992a) and Yang et al. (1997), who recognized two common morphotypes: a larger form *Jindongornipes kimi* and a smaller form *Koreanaornis hamanensis* attributed to shorebirds. We have been able to quantify the abundance of bird tracks to some degree by recording over 30 different stratigraphic levels in the study area, and documenting track densities on the order of 65 tracks per m^2 for *Jindongognipes*, and in excess of 100 per m^2 for *Koreanaornis* (Lockley et al., 1992a). Both these track types are characteristic of shorebirds. The smaller variety (*Koreanornis*) rarely shows a hallux trace, but a very short one may be present in a few specimens. On the basis of the footprints the track maker would have been hard to distinguish from a modern killdeer or small sandpiper. By contrast *Jindongornopes* is the track of a much larger bird. In size and hallux configuration it more closely resembles the track of a modern Godwit or Curlew (Jaeger, 1948; Elbroch and Marks, 2001). Both ichnogenera are sufficiently distinctive to form the basis of their own ichnofamilies (see Appendix).

We have also recognized another shorebird-like track type, herein named *Goseongornipes markjonesi* (see Appendix) that is intermediate in size between *Koreanornis* and *Jindongornipes*. The characters of its hallux are also intermediate (Fig. 20).

We recognized one other distinctive bird-like track type (Fig. 9D) that is reminiscent of avian tracks in some features, but not in others. Specifically we note that it the track maker was very small (foot length about 3.5 cm) with very slender digits. However, the tracks show relatively small divarication angles between digit impressions (about 75°). Wide digit divarication is typical of Mesozoic shorebird-like tracks and shorebird tracks in general (Lockley et al., 1992a) whereas low divarication angles are more typical of passerine birds (Order Passeriformes) or small theropod dinosaur tracks, though the former typically have a long posteriorly directed hallux. Thus, the tracks are more reminiscent of diminutive theropods than passerines. However such passerine-like or perching birds are now known from Lower Cretaceous skeletal remains (Sanz et al., 1988; Rao and Sereno, 1990), and their tracks are not unknown from the fossil record (cf. Weidmann and Reichel, 1979) even though they are conspicuously scarce and have yet to be found in the Mesozoic. It could be argued that the rarity of passerine track morphotypes amongst so many other Cretaceous through modern tracks, indicates that such species rarely frequented shoreline environments.

7. The ichnofacies paradigm

The ichnofacies paradigm is one of the central tenets of invertebrate ichnology (Bromley, 1996). It has also been applied in vertebrate ichnology (Lockley et al., 1994a; Lockley and Meyer, 2000). The principle, which is not always well understood, is as follows. If multiple track sites (ichnocoenoses) are sampled from similar sedimentary facies and consistently produce similar data sets (i.e., similar ichnofaunal "associations"), we can speak of distinctive ichnofacies. In such cases, the repeatedly similar proportions of ichnotaxa appear to be a reflection of the taxonomic structure of the paleocommunities and cannot be considered as random distributions.

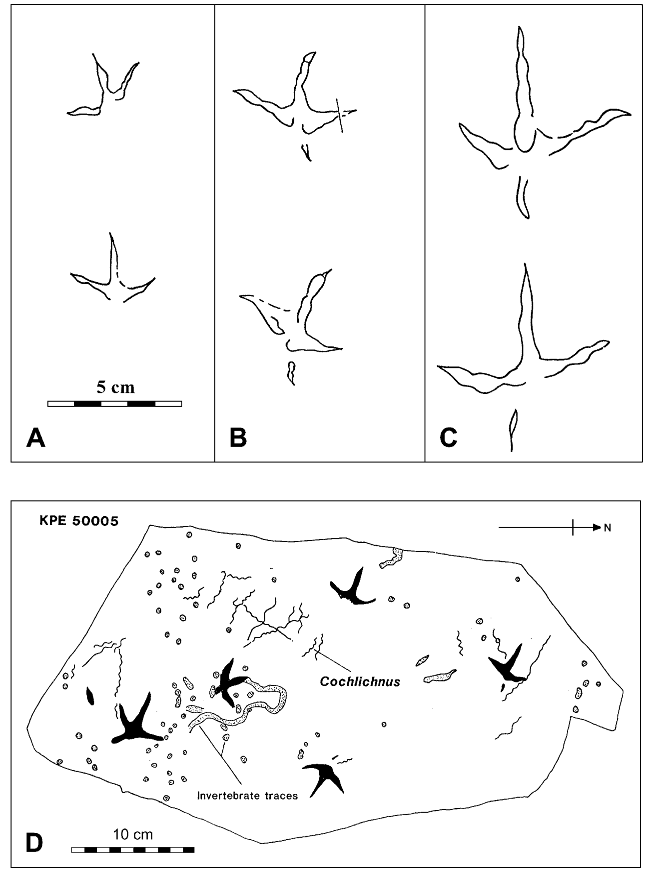

Fig. 20. Comparison of bird track types. A, *Koreanornis hamanensis*, two tracks in sequence without hallux. B, two apparently consecutive tracks of *Goseongornipes markjonesi*. C, two separate tracks of *Jindonornipes kimi*. D, *G. markjonesi* tracks associated with *Cochlichnus* and other invertebrate traces (redrawn with modifications after Lockley et al., 1992a, fig. 19).

The Jindong Formation presents us with an excellent opportunity to consider this question. We have already argued that although individual track-bearing levels may have quite different ichnotaxonomic composition (e.g., sauropod-, ornithopod-, or bird-dominated), there are repeat patterns in the size-frequency data and trackway orientation trends through time (Lim et al., 1994; Lockley, 1994). Given that separate sauropod and ornithopod ichnofacies have already been identified in other parts of the world and shown to have recognizable relationships to substrate and paleolatitude (Lockley et al., 1994a–c) the question arises as to whether the Jindong ichnocoenoses represent a mixed ichnofacies, or some form of interfingering of discrete ichnofacies. This question can only be addressed adequately by with careful study of the sedimentary facies. For this reason this paper is presented with a companion article (Houck and Lockley, 2006) that focuses attention on the sedimentary geology and its relation to different ichnofaunal assemblages.

In general it appears that there are not many marked differences between the ichnofaunas associated with the subtly different sedimentary facies (or subfacies) within the Jindong. However, we note quite marked facies and facies fauna differences when we compare the Jindong Formation with other formations within the Gyeongsang Group. Thus the presence of dinosaur eggs and skeletal remains in pre-Jindong formations that contain red beds, paleosols and various coarse classic units (Paik et al., 2004) suggests significant facies-fauna variation within the region. Likewise the high proportion of theropod tracks in distinctive facies in southwestern Korea (Huh et al., 2006) also serves to emphasis intra-regional ichnofacies variation.

Another facet of ichnofacies analysis involves understanding of the paleogeographical distribution of sites with similar associations and how the ichnotaxonomic composition of these sites may vary. This can only be addressed adequately if adequate good-quality data is available from many areas. This is perhaps not yet the case for all known sites in Korea. Nevertheless, as noted above, data summaries are beginning to appear which break down the proportion of known trackways, by formation, for local districts, counties and regions. Thus, for the purposes of ichnofacies analysis we can compare the proportions of trackway types derived from various pooled data sets. For example, Table 1 shows the proportion of theropod, sauropod, and ornithopod trackways reported in three different studies. All studies rely quite heavily on the data sets derived from Lim (1990), Lim et al. (1994), and Lockley (1994) that represent work by the present authors over many years.

The most notable aspect of this synthesis is that very similar proportions of ichnotaxa are obtained regardless of the size of the area sampled. This is not entirely due to the repeat sampling of the same trackways or data sets from Samcheonpo (Hai District). For example, only 250 of the 388 trackways identified by Lim et al. (1994) from Hai District were counted in the survey of all Goseong County (Lee et al., 2000). Nevertheless, the proportions of the three track types in the resulting census are very similar. A possible check on this conclusion is suggested by Huh et al. (2003, 2006), who note that the ratio of sauropod to ornithopod trackways is quite different in western and southwestern Korea (Yeosu area) where the sedimentary facies are quite different, i.e., the rocks are more heavily dominated by volcaniclastics in which ornithopod tracks predominate over rare sauropod tracks. The data presented in Table 1 suggest that the relative abundance of Jindong dinosaurs was constant over a large area, and that it was reflected in the track record. For example the most recently described Jindong track site (Hwang et al., 2004) reveals 10 sauropod trackways indicative of gregarious behavior. Such results imply that large-scale diversity and distribution patterns in dinosaur communities may leave a residual biological imprint in vertebrate ichnofacies. In any event it is certain that the wealth of data from the Jindong Formation has great potential to further test such inferences.

8. Conclusions

The abundance of tracks in the Jindong Formation makes thorough documentation of all sites a challenging task. Other challenges lie in placing the tracks in proper context in successions where the stratigraphy is complicated by faulting and the sedimentary petrology is complicated by alteration and regional and/or thermal metamorphism (Houck and Lockley, 2006). Nevertheless, the sediments are not much deformed and the tracks, which were originally quite well preserved, have evidently been rendered more resistant by low-grade metamorphism. The tracks also reveal a consistency of preservation that appears to indicate that they were repeatedly made under similar paleoenvironmental conditions.

The presence of three species of bird tracks, not only attests to the preservation potential of small tracks but it also points to the importance of South Korea as the most important region currently known for diversity and abundance of Cretaceous bird tracks, all of which are morphologically similar to modern shorebird footprints. However, it appears that pterosaur tracks are not so common. They are unknown in the Jindong Formation and occur at only one locality in the Uhangri Formation, where they are represented by very large track makers (Lockley et al., 1997; Hwang et al., 2002), and at another locality in the Haman Formation (Kim et al., 2006), where they are represented by much smaller tracks. Based on these different distribution patterns it is possible that birds tolerated these terrestrial environments better than pterosaurs.

The near mutual exclusion of sauropod and ornithopod tracks at many localities and their different mean orientations and size-frequency distributions has previously been noted (Lim et al., 1994), but no causal explanation has been proposed other than conjecture about different, possibly seasonally controlled, migration patterns. Such ecological, behavioral, or paleoenvironmental factors may help explain the differences in bird and pterosaur track distributions. In the meantime tracks remain the only abundant evidence of vertebrate life on the Korean peninsula, as the skeletal record still remains confined to very few specimens, and egg remains have yet to reveal much information about the species that produced them.

There is no doubt that the Jindong Formation exhibits the world's greatest concentration of track-bearing horizons hitherto documented (cf. Lim et al., 1994; this paper). The original track discoveries (Yang, 1982a) have turned a few sleepy fishing villages into a twenty-first century tourist attraction, along what we might characterize as the "dinosaur coastline" of Goseong County. In the meantime, abundant new discoveries at many other track sites in Korea, in formations inferred to be both older and younger than the Jindong Formation, have turned the Cretaceous of southern Korea into a veritable stomping ground, not just for dinosaurs but also for birds and a few pterosaurs. Track sites still predominate over sites with eggs and/or bones. With such an abundance of data various future challenges remain. Not least of these is to synthesize and present such abundant data coherently, as attempted here. Factors that compromise such synthesis include the problems of stratigraphic correlation, type section definition and sedimentary facies analysis, often made difficult by faulting and localized exposure in terrain that is heavily vegetated away from the immediate vicinity of the rocky, intertidal zone, and sporadic artificial exposures such as quarries and road cuts. Further future challenges will involve finding and identifying additional skeletal remains and interpreting egg and nest sites so as to show the relationship between all the available fossil evidence of dinosaurs, birds, pterosaurs, other vertebrates, invertebrates, and plants.

Acknowledgements and dedication

This paper is dedicated to Mark Jones, a graduate of the University of Colorado at Denver, Geology Department. Mark helped with fieldwork and data collection in the early days of this project and was a friend to all the authors of this paper.

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Appendix

As noted in the text, no previous attempt has been made to provide adequate morphological descriptions of tracks from the Jindong Formation, even though many papers have commented on the great abundance of tracks, and several papers have given actual numbers of tracks or trackways counted and/or measured (e.g. Lim et al., 1994; Lockley, 1994). For this reason this appendix is divided into two sections, the first ichnotaxonomic and the second, a data tabulation.

1. Ichnotaxonomy

General observations. Several hundred trackways of sauropod and ornithopod dinosaurs and birds are known from the study area. Lim (1990, fig. 19) tabulated a substantial amount of morphometric data on dinosaur tracks and trackways, which he divided informally into nine bipedal morphotypes (B1–B9) and four quadrupedal types (Q1–Q4). Types B1 and Q1 however made up the majority of the sample (59%, n = 185 and 84% n = 62 respectively). However, his tabulations and identifications were incomplete, and in a minority of cases incorrect. Revised data based on re-measured sections and trackway identifications are given by Lockley (1994) and below (Appendix, section 2).

As noted in the text, dinosaur track identifications are generally conservative. All sauropod tracks appear to be the *Brontopodus* type and all ornithopods the *Caririchnium* type. Despite Lim's identification of several informal morphotypes, most were represented by only one or two specimens, and the distinctions are not recognized here.

By contrast a variety of distinctive bird track types are known. For this reason, and for consistency with other papers in this issue (Kim et al., 2006; Lockley et al., 2006), we herein name a new species and emend systematics at the ichnofamily level.

Ichnogenus *Brontopodus* Farlow et al., 1989.

Brontopodus ichnosp.

Description. Small to large sauropod ichnites with pes tracks rotated outward and averaging 83% as wide as long (n = 52). Known pes length ranging from 18–85 cm, and pes width ranging from 16–60 cm. Manus tracks rotated outwards and averaging 65% as long as wide, and ranging in length from 8–29 cm and in width from 14–43 cm. Pes tracks often show three equidimensional anterior claw impressions representing digits I–III. Manus tracks lacking claw impressions with semicircular or transversely elongate oval outline. Trackway broad (wide gauge) with inside margin of pes tracks close to or outside the trackway midline and manus tracks outside the midline. Pace angulation low averaging 107° for pes strides (n = 50) and 80° for manus strides (n = 39).

Representative material. See Fig. 11 and trackway segments illustrated by Lim et al. (1989, fig. 35.4A) and Lockley et al. (1992a, fig. 24). Only trackways from the Jindong Formation (Samcheonpo area) were included.

Discussion. In small specimens *Brontopodus* sp. has a distinctive transversely elongate oval manus which is consistently wider than long (w/l ratio = 1.54). There is also no sign of a concave posterior margin to the manus tracks, but this may be due to preservation, as the manus tracks are not deeply impressed, and the sediment gives the impression of being firm. Overall, small tracks are quite typical of the sample (Lockley, 1994) and they provide an interesting point of comparison with the sauropod body fossil record, which is dominated by large individuals (Dodson, 1990).

Lim (1990) suggested that in addition to the common small sauropod ichnite (his Q1 morphotype) there was a second, less common, large sauropod ichnite characterized by a crescentic manus showing the concave posterior margin, as seen in *B. birdi* Farlow et al. (1989) and Fig. 11D–H herein. Analysis of these larger trackways reveals mean manus length and width of 48 and 50 cm respectively (n = 4) compared with 15 and 23 for the smaller form. (Note difference in respective manus l/w ratios of 0.96 and 0.65.) Corresponding mean pes track dimensions are 63 and 54 cm (n = 6) compared with 35 and 29 cm. Thus, the manus and pes of the larger morphotype are two to three times larger on average. It could be argued that the differences in manus morphology, and manus-pes differential (heteropody) are real (i.e. biologically significant) or due to ontogenetic variation, or preservation. It is possible to distinguish two morphotypes in the Late Jurassic sauropod tracks sample from Colorado, based on pes track shape: ''a larger, broad-footed form'' and ''a smaller, narrow footed form'' (Lockley et al., 1986, p. 1169). In general, wide and narrow gauge varieties (with corresponding large and small manus) are now well known (Lockley, 1999, 2001). In this respect the larger Korean morphotype has a pes that is only very slightly wider than the smaller morphotype (pes w/l ratios of 0.86 and 0.83 respectively). Thus, probably only a single species was present that showed slight allometric change in shape during ontogeny.

At least one sauropod pes track with skin impressions is known from the Cretaceous of Korea. However, this specimen illustrated by Yang et al. (2003, pl. 116) is from the Haman Formation. The impressions show a polygonal pattern of regular hexagons almost 2 cm in diameter. At first this trace was incorrectly interpreted as an examples of the invertebrate trace *Paleodictyon*. These footprint skin impressions are evidently the first reported from the Cretaceous although they are very similar to examples recently reported from Late Jurassic sauropod tracks from Utah (Lockley and Hunt, 1995), Spain (García Ramos et al., 2002, p. 110) and Wyoming (Platt and Hasiotis, 2003). Illustrated skin impressions from the Spanish sites are characterized by small sub-symmetrical hexagons 5–7 mm in diameter associated with a manus track cast, similar to those reported by Lockley and Hunt (1995) from Utah. However, several undescribed Spanish pes tracks reveal much larger hexagons up to about 20 mm in diameter (personal observation by MGL of specimens in the Museum of the Jurassic, Asturias, and in the field). Thus, there is considerable variability in the size of sauropod skin impressions, which are probably related to differences in the size of the animal and to differences in size and skin patterning between the hind and front feet. These impressions are very similar to those reported from in situ sauropod skin remains (Czerkas, 1994). This confirms the identification and the generality of the pattern on other parts of the body.

Ornithopod tracks. There have been a number of significant problems with the naming of large Cretaceous ornithopod tracks (Lockley et al., 2004). However, early Cretaceous tracks formerly and informally referred to as ''*Iguanodon*'' tracks, now formally named *Iguanodontipus* (Sarjeant et al., 1998) have been know since early in the nineteenth century (Delair, 1989). Likewise tracks named *Amblydactylus* (Currie and Sarjeant, 1979) and *Caririchnium* (Leonardi, 1984) have been named from North and South America respectively, and have been used for trackways with associated manus impressions in some cases. These latter names predate *Goseongosauripus kimi*, named by Kim (1986). As discussed above, we consider Kim's ichnotaxonomy invalid for several reasons, including the fact that he changed the name to *Koseongosauripus kimi* in an unpublished report and sketched a pad configuration that is at variance with any known pattern of iguanodontid morphology. For this, and other reasons related to the informal nature of the publications, we consider the name invalid. We note that several authors have used the name *Caririchnium* for Korean tracks (Lockley, 1994; Huh et al., 2003).

Bird tracks. The Jindong Formation is the type locality for the bird track *Jindongornipes kimi* (Lockley et al., 1992a), and the underlying Haman Formation is the type locality for *Koreanornis hamanensis* (Kim, 1969), which also occurs in the Jindong Formation. Both species were originally included in the ichnofamily Ignotornidae (Lockley et al., 1992a). However, subsequent studies have revealed that other bird tracks are known in Korea (Yang et al., 1995; Lim et al., 2000, 2002; Kim et al., 2006) that require a re-evaluation of the ichnofamily level classification.

Thus, the ichnofamily Ignotornidae has been emended (Kim et al., 2006), providing a definition that restricts the concept to bird tracks that have a slight proximal web and a well-developed hallux that is directed posteromedially. We include the newly defined *Goseongornipes markjonesi* (described below) in this ichnofamily, with *Ignotornis*. However, this revision requires that both *Koreanornis hamanensis* (Kim, 1969) and *Jindongornipes kimi* (Lockley et al., 1992a) be removed from the Ignotornidae and assigned to their new ichnofamilies, Koreanornipodidae and Jindongornipodidae.

Other Cretaceous avian ichnogenera such as *Aquatilavipes* (Currie, 1981; Zhen et al., 1995), *Shandongornipes* (Li et al., 2005) *Pullornipes* (Lockley et al., 2005) and *Sarjeantopodus* (Lockley et al., 2004), the former three known from the Lower Cretaceous of China, have yet to be positively identified in the Cretaceous of Korea. Thus, the Korean avian ichnofauna is quite distinctive (as noted by Kim et al., 2006).

Koreanornipodidae ichnofamily nov.

Referred material. *Koreanornis hamanensis* Kim, 1969; *Koreanornis hamanensis* Lockley et al., 1992a.

Diagnosis. Small, wide (typically 2.5–3.0 cm) sub-symmetric functionally tridactyl tracks with slender digit impressions, and wide (90–115°) divarication between digits II and IV. Small hallux occasionally present, and posteromedially directed about 180° away from digit IV. Digital pad impressions (excluding sharp claw traces) show a 2-3-4 phalangeal formula corresponding to digits II, III and IV. Trackway shows positive (inward rotation).

Type ichnogenus and ichnospecies. *Koreanornis hamanensisi*.

Jindongornipodidae ichnofamily nov.

Referred material. *Jindongornipes kimi* Lockley et al., 1992b.

Diagnosis. Medium-sized (6.5–7.5 cm wide) tetradactyl tracks with slender digit impressions, and very wide (125–160°) divarication between digits II and IV. Digit II shorter than IV. Moderately long hallux usually impressed and directed posteriorly about 180° away from digit III. Digital pad impressions (excluding sharp claw traces) mostly indistinct but with the probable 2-3-4 phalangeal formula corresponding to digits II, III and IV (Fig. 20C). Trackway shows little rotation, i.e., digit III directed anteriorly parallel to trackway axis.

Type ichnogenus and ichnospecies. *Jindongornipes kimi* Lockley et al., 1992b.

Ichnofamily Ignotornidae (Kim et al., 2006).

Goseongornipes ichnogen. nov.
Figs. 9C, 20B, D

Derivation of name. Meaning bird track from Kosong County, South Korea.

Types. Holotype, KPE 50010; Paratype, KPE 50005.

Referred material. Specimen KPE 50005 labeled as *Koreanornis* (Lockley et al., 1992a, Fig. 12).

Type horizon locality. Jindong Formation, Dukmeongri section 1 (bed 27).

Diagnosis. Slightly semipalmate tetradactyl bird track with three widely splayed digit (II–IV) and a small posteriorly directed hallux. Web traces subtle, confined to proximal hypex between digits III and IV.

Goseongornipes markjonesi ichnosp. nov.
Figs. 9C, 20B, D

Derivation of name. In honor of Mark Jones, a geologist who studied with the authors.

Holotype, *paratype*, and *referred material*. As for ichnogenus.

Type horizon and locality. As for ichnogenus.

Description. Shorebird-like avian track with wide digit divarication angles between digits II and IV (140–150° in two holotype tracks) divarication between digits II and III and III and IV sub-equal (about 70°). Width of two holotype specimens between 4.2 and 4.5 cm; length, with hallux, between 4.1 and 4.5 cm. Length without hallux 3.0–3.5 cm. Digit II shorter than IV. Hallux length between 22 and 25% of foot length. Slightly semipalmate web traces between digits III and IV. Angle between hallux and digit II about 75°.

Discussion. The diversity of Korean bird tracks is notable, and the quality of preservation is generally very good. This allows for detailed description of morphological variation. In reference to the Jindong Formation alone, *Koreanaornis hamanensis*, *Goseongornipes markjonesi* and *Jindongornipes kimi* are clearly different and distinctive ichnospecies. Their respective sizes (widths) are in the range of about 2.5–3.0, 4.0–4.5 and 6.5–7.5 cm. They also show progressively larger (longer) hallux impressions corresponding to this size increase, and it is striking that *J. kimi* has its mid toe (digit III) directed anteriorly and the hallux directed posteriorly, both in line with the trackway axis (Fig. 8E). For this reason the three ichnospecies are assigned to distinct ichnofamilies (Koreanornipodidae ichnofam. nov., Ignotornidae and Jindongornipodidae ichnofam. nov. respectively; see Kim et al., 2006, for further discussion).

The *Goseongornipes markjonesi* holotype specimen shows at least three tracks. The two most complete are shown in Fig. 20B. Based on comparison with all known shorebird tracks, both ancient and modern the hallux is posteromedially directed, on the side of digit II. (No known bird tracks have a hallux rotated past the fully posterior position, i.e., postero-laterally.) The two *G. markjonesi* holotype tracks illustrated in Fig. 20C both have the hallux directed in the same direction. Thus the proximal, semipalmate, web trace is found between digits III and IV only, as is the most common case among modern semi-palmate shorebirds.

In comparison with the other named tracks from the Jindong Formation *G. markjonesi* is distinctive in size and morphology. We note that almost all shorebird tracks represent adults and their footprint and track size does not vary significantly throughout life. The size range of *K. hamanensis* tracks was given as between 23–27 mm by Kim (1969) and the length for *Jindongornipes kimi* was given as about 8 cm (with hallux) with a corresponding width of 6.5–7.5 cm (Lockley et al., 1992a). Thus, there is a significant size gap between the two ichnospecies. Lockley et al. (1992a, p. 124) suggested that the width of *Koreanornis* could range from "about 2.5 to 4.4 cm." This is evidently incorrect. Further study of tracks in this size range suggests that more than one ichnospecies must be represented. Specimen KPE 50010 is particularly revealing (Figs. 9C, 20). Two tracks up to 4.5 cm wide and long show a moderately well-developed hallux and a slight semipalmate web. By contrast the ten specimens of *Koreanornis hamanensis* measured by Kim (1969) and the eight illustrated in detail by Lockley et al. (1992a, fig. 19) have length width measurements in the range of 2.5–3.5 cm, with the hallux very short, if even impressed at all. We therefore infer that specimen KPE 50005, which gives larger measurements in the range of 3.5–4.5 cm, was incorrectly labeled as *Koreanornis* (Lockley et al., 1992a, fig. 12). Re-examination of this specimen suggests that the tracks are not assignable to the diminutive ichnospecies *K. hamanensis*, and therefore belong to *G. markjonesi*. Likewise these specimens cannot belong to *J. kimi*. Which is always much larger with a longer hallux that is directed even more strongly towards the posterior parasaggital plane (trackway axis).

As specimen KPE 50005 (Fig. 20D) indicates the *G. markjonesi* hallux trace is not always present. However, when seen, it is far too large to be confused with the diminutive *K. hamanensis* hallux, which is very rarely impressed. Even the well-developed hallux of *J. kimi* is sometimes not impressed (Fig. 8E), though it is prominent in the majority of specimens

(Lockley et al., 1992b). Thus, it is important to have sufficient well-preserved material to assess such preservational variability. The Jindong Formation provides just such large Cretaceous samples that are the largest available and arguably the best-preserved of any currently known.

Ichnogen. et ichnosp. indet.
Fig. 13D.

Description. Small, elongate, slightly asymmetric, tridactyl tracks ranging from 3.3–3.5 cm long by about 2.3 cm wide. Digit impressions slender with at least three pad impressions visible on digit III. Digit three longest extending about 2.0 cm beyond the anterior most impressions of digits II and IV (i.e., extending anteriorly beyond the other digits by 55–60% of total foot length). Digit divarication angles between digits II and III and between III and IV about equal (37–40°) giving and angle of about 75° between digit impressions II and IV.

Discussion. It is not certain that these are avian tracks or that they are attributable to passerine birds. The tracks are slightly asymmetric with one of the lateral digit impressions (probably IV) situated more posteriorly than the other. This is a feature seen in dinosaur tracks as well as in avian tracks (Zhen et al., 1995). The lack of a hallux (Digit I) impression is also a feature that could be used to argue against a passerine or affinity for these tracks, since in passerines the hallux is usually very well developed, with impressions visible in tracks. However it is also known that hallux impressions are very variably impressed in bird footprints, and it is therefore quite possible that these tracks had hallux impressions associated with a sub- or superjacent horizon in this thinly bedded succession. If the tracks are interpreted as dinosaurian in affinity then we may conclude that the track makers stood only about 14–17.5 cm tall at the hips (=4 to 5 × foot length). Such diminutive creatures clearly fall within the size range of small birds, whatever their affinity).

Material and abbreviations. KPE, Kungpook National University, Department of Earth Science, collections that house most of the original specimens as well as replicas; CU, the University of Colorado at Denver specimens, which are mostly replicas. Specimens KPE 50003-500012 correspond to CU 214.60-69. KPE 50015 = CU 214.70, and CU 214.71-72 correspond to specimens from Deokmyeonongri section 1 beds 1-13.

2. *Data tabulation*

Data on dinosaur tracks from the Jindong Formation are arranged in stratigraphic order for localities (Silbawi, Bongwhagol, Deokmyeongri and Sangjok sections) and their numbered horizons. Tway No. refers to Trackway number for any given horizon. Length P(M), length of pes (and manus); Width P(M), width of pes (and manus). Step/str., step and stride; Pace ang, pace angulation given for pes only; Orient., trackway orientation. Data substantially modified and amended after Lim (1990) and Lim et al. (1994).

	A	B	C	D	E	F	G	H
1	Loc./Horizon No.	Tway No.	Type	Length P(M)	Width P(M)	Step/str	Pace ang	Orient.
2	Silbawi 1 - 9	1	sauropod	40	50			
3	13	1,2,3	sauropod	40	28	-100	90	285/265/250
4	13	1	sauropod	60	60	-110		220
5	17	1	ornithopod	25	25			245
6	17	2	ornithopod	25	25			240
7	22	1	sauropod	40(15)	30(18)	0		
8	24	1	sauropod	70	45			70
9	Silbawi 2b - 1	1	sauropod	45	35	70/110		45
10	1	1	sauropod	80	60	130/225		90
11	Silbawi 3 - 10	1	sauropod	85	60			
12	Silbawi 4 - 8	1	sauropod	40(23)	28(16)			
13	12	1	sauropod	32	23			
14	14	1	ornithopod	51	38			
15	15	1	sauropod	47	35			
16	18	1	ornithopod	25	22			
17	20	1	ornithopod	30	29			
18	21	1	sauropod	29(18)	21(11)			
19	22	1	sauropod	58	45			
20	23	1	sauropod	40(22)	37(14)			
21	23	2	ornithopod	42	31			
22	23	3	ornithopod	45	35			
23	23	4	ornithopod	43	34			
24	23	5	ornithopod	43	34			
25	23	6	ornithopod	43	34			
26	25	1	ornithopod	31	25			
27	Silbawi 5 - 4		ornithopod	20	29			55
28	-6		ornithopod	28	28	77/-		205
29	8		theropod	42	32	113/-		10
30	Silbawi 6 - 10		ornithopod	32	35			310
31	13		sauropod	27(10)	20(12)	50/85	110	180
32	14		sauropod	28	18			65
33	16		sauropod	80	60			115
34	16		sauropod	40	28			345
35	Bongwhagol 1- 1		sauropod	45(10)	35(17)	106/203		
36	Bongwhagol 1- 3		ornithopod	37	37	100/-		300
37	3	1	sauropod	36	32	72/108	110	276

Appendix (*continued*)

	A	B	C	D	E	F	G	H
1	Loc./Horizon No.	Tway No.	Type	Length P(M)	Width P(M)	Step/str	Pace ang	Orient.
38	3	2	ornithopod	33	27	81/159	159	210
39	3	3	ornithopod	34	32	87/155	160	210
40	3	4	ornithopod	38	36	91/170	147	210
41	3	5	ornithopod	34	30	86/172	165	200
42	3	6	ornithopod	36	29	86/169	169	210
43	3	7	ornithopod	37	31	83/177	156	30
44	3		ornithopod	38	38	100/-		105
45	3		ornithopod	32	33	94/-		
46	4	1	ornithopod	34	26	76/150	156	202
47	4	2	ornithopod	32	25	72/145	164	25
48	5		ornithopod	30	26	82		200
49	5	1	sauropod	20(15)	16(11)	39/55	95	74
50	6	1	ornithopod	34	30	103/198	163	14
51	6	2	ornithopod	32	27	87/172	160	14
52	7	1	ornithopod	33	28	55/118	148	204
53	8	1	sauropod	23(17)	8(13)	45/74	105	188
54	10	1	sauropod	24(22)	18(12)	54/82	97	104
55	10	2	sauropod	30(22)	23(12)	47/81	108	59
56	11	2	ornithopod	38	35	95/180	150	110
57	8 - 3		ornithopod	32	30			
58	Dukmeyongri 1-1	1	sauropod	75(50)	60(50)		134	220
59	3	1	sauropod	34	29	58/95	90	195
60	3		ornithopod	28	24	82		210
61	3		ornithopod	27	24	70		210
62	3		ornithopod	30	28	80		210
63	3		ornithopod	30	29			210
64	4	1	sauropod	89(67)	77(63)	203		334
65	5	1	ornithopod	34	28	83/174	153	279
66	5	2	ornithopod	30	25	91		279
67	5	3	ornithopod	30	25			279
68	5	4	ornithopod	30	25			279
69	5	5	ornithopod	30	25			279
70	6		ornithopod	28	24	72/-		235
71	7	1	ornithopod	31	24	79/151	141	249
72	7	2	ornithopod	30	26	70/139	158	240
73	7	3	ornithopod	29	24	77/153	155	242
74	9		ornithopod	32	28	74/-		20
75	9	1	sauropod	60	72			319
76	10	1	sauropod	38	33	58/95	110	234
77	10		ornithopod	32	32	69/-		140
78	14		sauropod	102(31)	82(46)			
79	14	1	ornithopod	32	28			
80	14	2	ornithopod	32	29			
81	15	1	ornithopod			80/152		199
82	15	2	ornithopod	36	32	103/200	138	202
83	15	3	ornithopod	33	28	92/173	138	
84	16	1	ornithopod	38	38	114/208	160	244
85	16	2	ornithopod	32	31			
86	16		sauropod	38	35			
87	16		ornithopod	38	35			290
88	20		ornithopod	30	25	78/-		105
89	20		ornithopod	37	32	103/-		
90	20	1	sauropod	33	24	66/97	92	268
91	21		ornithopod	36	34			180
92	21		sauropod	90	60			
93	21		sauropod	82(40)	70(50)			255
94	22		ornithopod	32	30	92/-		190
95	22	1	sauropod	32	28	63/99	103	250
96	24	1	ornithopod	35	25	87/166	144	0
97	26		sauropod	24(9-10)	20(12-13)	79	100	190
98	26	1	sauropod	28(21)	24(16)	64/121	133	199
99	27	1	sauropod	70	70	250		
100	27	2	ornithopod	35	30	85/165	151	289

(*continued on next page*)

Appendix (*continued*)

	A	B	C	D	E	F	G	H
1	Loc./Horizon No.	Tway No.	Type	Length P(M)	Width P(M)	Step/str	Pace ang	Orient.
101	27	3	ornithopod	35	30	86/165	152	289
102	27	4	ornithopod	34	29			
103	27		ornithopod	32	28	77		180
104	27		sauropod	21(9-10)	16(13)	35/64	120	105
105	27		ornithopod	35	33	94		180
106	27		sauropod	35	20			245
107	28	1	ornithopod	41	38	85/167	149	180
108	29	1	sauropod	36(25)	28(18)	58/94	117	58
109	7 - 10		ornithopod	28	24			
110	Dukmyeongri 2-12		sauropod	26(16)	22(13)			
111	2	1	ornithopod	35	35	87/161	144	319
112	3	1	ornithopod	40	37	97/185	146	
113	6	1	ornithopod	29	26			
114	6	2	ornithopod	41	40	103/-		151
115	6	3	ornithopod	34	30	82/-		145
116	6	4	ornithopod	34	30	97/-		146
117	7	1	ornithopod	38	26	101/203	173	34
118	7	2	ornithopod	39	28	100/197	176	36
119	8	1	ornithopod	31	28	92/167	128	218
120	6 - 3	1	ornithopod	36	32	91/-		219
121	3	2	ornithopod	35	30	93/-		214
122	5	1	ornithopod	42	30	99/-		38
123	6	1	ornithopod	27	24	60/112	138	342
124	7	1	ornithopod	30	25			
125	7	2	ornithopod	29	22			
126	9	1	ornithopod	29	32	82/-		240
127	10	1	sauropod	38(17)	28(12)	59/86	88	199
128	10		ornithopod	28	24	69		140
129	12		sauropod	26(16)	22(13)	48/75	100	155
130	12		ornithopod	38	32	98/-		190
131	15	1	ornithopod	37	27	83/162	166	37
132	15	2	ornithopod	37	27	88/173	155	50
133	15	3	ornithopod	37	27	88/171	147	37
134	15	4	ornithopod	37	27	80/165	163	37
135	15	5	ornithopod	37	27			31
136	17	1	ornithopod	28	24	91/172	142	184
137	18	1	ornithopod	31	30	71/137	147	144
138	18	2	sauropod	28(19)	24(12)	48/72	107	338
139	18	3	sauropod	22(17)	17(10)	42/71	118	47
140	18	4	sauropod	21(16)	15(10)	41/71	113	35
141	19	1	sauropod	36(22)	27(16)	60/98	110	31
142	20	1	ornithopod	33	28	91/-		182
143	22	1	ornithopod	36	34	97/190	168	330
144	23	1	ornithopod	29	24	81/160	146	324
145	24	1	ornithopod	38	34			304
146	24	2	ornithopod	27	21			
147	Dukmyeongri 3- 3		ornithopod	33	29	76/-		240
148	3		ornithopod	33	29			240
149	4		sauropod	29(14)	23(18)	68/100	100	10
150	5		ornithopod	32	30	93/-		285
151	6		ornithopod	33	29	93/-		333
152	Dukmyeongri 4- 2		sauropod	40	25	65/120		110
153	2		ornithopod	30	30	80/-		270
154	3	1	ornithopod	30	30	77/146	136	249
155	3		sauropod	50	20	65/103	110	235
156	3	1	sauropod	75(40)	75(25)	175/-		
157	4	1	ornithopod	20	16	55/-		84
158	6		theropod	25	25			190
159	11	1	sauropod	39(25)	30(17)	61/107	121	296
160	12	1	sauropod	32	32	78/146	167	272
161	14	1	ornithopod	30	24	76/106	106	216
162	15	1	ornithopod	39	36	110/-		182
163	16	1	ornithopod	39	34	105/205	155	194
164	17	1	sauropod	30(20)	24(13)	50/85	116	174

Appendix (*continued*)

	A	B	C	D	E	F	G	H
1	Loc./Horizon No.	Tway No.	Type	Length P(M)	Width P(M)	Step/str	Pace ang	Orient.
165	18	1	ornithopod	35	31	84/171	173	272
166	Sangjok 2A - 6	1	sauropod	42	37	75/115	102	169
167	7	1	sauropod	30(26)	25(16)	64/116	120	232
168	9	1	ornithopod	34	30	82/140	133	348
169	9	2	sauropod	39(21)	33(14)	71/95	87	192
170	9	3	ornithopod	36	28	102/203	163	240
171	9	4	ornithopod	30	24	82/159	165	226
172	9	5	ornithopod	31	27	80		238
173	12	1	sauropod	23(18)	22(11)	64/77	69	199
174	13	1	ornithopod	30	28	88		238
175	13	2	ornithopod	35	29	85/165	162	252
176	13	3	ornithopod	39	32	86/170	168	259
177	13	4	ornithopod	39	36	100/165	113	249
178	13	5	ornithopod	34	30	106/194	141	259
179	13	6	ornithopod	39	31	100/201	160	262
180	13	7	ornithopod	36	32	90/167	157	239
181	16	1	ornithopod	34	30	109		224
182	16	2	sauropod	32(23)	30(15)	52/96	106	138
183		1	ornithopod	29	24	76/-		308
184	Sangjok 1B - 2	1	ornithopod	29	27	122/-		318
185	3	1	sauropod	38(23)	25(12)	69/113	110	208
186	3	2	ornithopod	37	30	98		220
187	3	3	ornithopod	35	29	95/193	170	216
188	3	4	ornithopod	34	30	94/-		207
189	3	5	ornithopod	36	30	97/-		210
190	3	6	ornithopod	37	29	103/-		194
191	4	1	sauropod	30(21)	26(11)	51/88	113	118
192	5	1	sauropod	38(27)	32(14)	61/111	127	38
193	5	2	ornithopod	34	28	86/176	152	357
194	7	1	sauropod	38(26)	30(18)	68/102	100	79
195	7	2	sauropod	31(29)	27(16)	71/101	102	329
196	7	3	sauropod	30(21)	24(14)	54/65	81	164
197	8	1	sauropod	38(27)	22(15)	67/101	102	90
198	8	2	sauropod	52(38)	45(30)	155/239	102	350
199	12	1	ornithopod	35	30	83/158	144	218
200	13	1	sauropod	36(21)	22(15)	56/81	92	68
201	13	2	ornithopod	28	24	71/142	156	159
202	13	3	ornithopod	31	29	89/177	163	159
203	13	4	ornithopod	32	30	89/178	163	158
204	15	1	ornithopod	51	43	134/257	144	299
205	14	2	ornithopod	33	25	87/173	162	236
206	14	3	ornithopod	30	29	86/171	145	277
207	14	4	sauropod	28(18)	26(12)	63/101	97	259
208	Sangjok 2A - 3	1	sauropod	50(46)	40(48)	113/198	115	23
209	3	2	sauropod	58(43)	61(29)	116/187	92	185
210	4	1	sauropod	50	40			
211	5	1	sauropod	30(19)	26(10)	49/88	128	164
212	6	1	sauropod	45(35)	32(31)	90/146	108	145
213	7	1	sauropod	24(15)	18(10)	39/55	89	198
214	8	1	sauropod	32(30)	30(21)	88/172	111	148
215	9	1	ornithopod	15	15			
216	10	1	sauropod	19(17)	17(10)	51/80	101	158
217	11	1	ornithopod	32	30	94/186	159	224
218	13	1	ornithopod	37	35			278
219	14	1	sauropod	25(19)	24(12)	55/83	99	234
220	Sangjok 2B - 4	1	ornithopod	36	24	83/161	158	189
221	4	2	ornithopod	27	24	77/150	156	250
222	5	1	ornithopod	33	29	74/152	171	208
223	5	2	ornithopod	30	27	68/131	158	209
224	5	3	ornithopod	33	30	74/143	156	215
225	5	4	ornithopod	32	26	59/115	156	229
226	5	5	ornithopod	29	24	54/-		205
227	5	6	ornithopod	26	24	82/160	174	8

(*continued on next page*)

Appendix (*continued*)

	A	B	C	D	E	F	G	H
1	Loc./Horizon No.	Tway No.	Type	Length P(M)	Width P(M)	Step/str	Pace ang	Orient.
228	5	7	ornithopod	36	32	115/224	153	256
229	5	8	ornithopod	31	27	82/159	153	220
230	5	9	ornithopod	31	26	72/139	162	201
231	6	1	sauropod	25(14)	18(8)	45/67	97	194
232	6	2	sauropod	31(21)	25(16)	49/84	113	147
233	6	3	ornithopod	30	26	76/-		153
234	6	4	ornithopod	26	21	97/194	164	22
235	6	5	ornithopod	30	20	82/171	166	74
236	6	6	ornithopod	25	22	104/206	173	81
237	6	7	ornithopod	32	25	90/181	165	234
238	6	8	ornithopod	22	21	74/145	160	323
239	6	9	ornithopod	30	31	89/175	161	169
240	6	10	ornithopod	31	30	69/134	162	174
241	6	11	ornithopod	35	32	89/171	162	161
242	6	12	ornithopod	34	35	83/160	144	143
243	6	13	ornithopod	36	33	85/169	162	157
244	6	14	ornithopod	31	26	78/152	154	160
245	6	15	ornithopod	32	32	89/169	143	143
246	7	1	ornithopod	28	27	68/136	176	276
247	7	2	ornithopod	29	29	66/126	157	272
248	7	3	ornithopod	24	19	68/133	148	262
249	7	4	ornithopod	24	22	72/143	159	272
250	7	5	ornithopod	25	24	63/125	158	268
251	7	6	ornithopod	27	26	66/130	155	283
252	7	7	ornithopod	29	28	78/152	162	282
253	7	8	ornithopod	44	32	88/176	155	19
254	7	9	ornithopod	24	23	70/-		255
255	7	10	sauropod	32(24)	30(18)	51/79	105	216
256	7	11	sauropod	26(16)	25(11)	47/68	94	158
257	7	12	ornithopod	36	34	96/191	158	205
258	7	13	ornithopod	23	24	62/119	175	274
259	7	14	ornithopod	25	24	60/116	116	284
260	7	15	ornithopod	26	22	67/-		302
261	7	16	ornithopod	24	24	66/127	144	264
262	7	17	ornithopod	25	23	71/136	175	271
263	7	18	ornithopod	27	25	68/133	143	266
264	7	19	ornithopod	27	26	77/138	155	303
265	7	20	ornithopod	27	26	61/124	129	273
266	7	21	ornithopod	34	27	91/180	159	193
267	7	22	ornithopod	32	30	67/125	133	287
268	7	23	ornithopod	27	26	69/128	146	264
269	8	1	sauropod	24(19)	18(11)	42/72	110	293
270	8	2	sauropod	34(24)	28(13)	61/93	118	200
271	8	3	sauropod	30(23)	24(13)	55/90	116	165
272	8	4	ornithopod	40	36	94/200	152	269
273	8	5	ornithopod	34	24	96/185	164	216
274	8	6	sauropod	29(18)	24(10)	51/87	120	124
275	8	7	ornithopod	31	28	72/138	159	199
276	8	8	ornithopod	34	32	92/186	164	209
277	8	9	?theropod	27	21	160/-		
278	9	1	sauropod	38(27)	37(24)	56/93	110	210
279	9	2	sauropod	33(23)	30(16)	61/98	117	156
280	9	3	sauropod	34(29)	30(17)	67/99	101	94
281	9	4	sauropod	35(20)	29(11)	63/88	86	333
282	9	5	sauropod	31(24)	31(17)	63/106	115	214
283	9	6	sauropod	35(27)	31(16)	81/114	108	318
284	10	1	ornithopod	30	28	68/140	161	10
285	10	2	ornithopod	37	30	102/202	148	19
286	10	3	ornithopod	32	27	122/239	161	357
287	10	4	ornithopod	30	28	74/141	157	335
288	10	5	ornithopod	29	27	66/132	159	328
289	10	6	ornithopod	31	31	65/124	159	341
290	10	7	ornithopod	33	29	68/133	157	327

Appendix (*continued*)

	A	B	C	D	E	F	G	H
1	Loc./Horizon No.	Tway No.	Type	Length P(M)	Width P(M)	Step/str	Pace ang	Orient.
291	10	8	ornithopod	33	27	62/125	155	3
292	10	9	ornithopod	39	29	86/169	162	349
293	10	10	ornithopod	29	29	65/126	158	323
294	10	11	ornithopod	25	23	52/99	166	306
295	10	12	ornithopod	30	31	92/184	173	303
296	10	13	ornithopod	31	30	97/185	161	301