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A PRELIMINARY REPORT ON TWO NEW VERTEBRATE TRACK SITES INCLUDING DINOSAURS FROM THE EARLY CRETACEOUS HEKOU GROUP, GANSU PROVINCE, CHINA

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Abstract: Two track sites were discovered in the Hekou Group(Early Cretaceous), Yanguoxia, Yongjing County, Gansu Province, China. More than 108 dinosaur and pterosaur trackways occur on the same gray fine sandstone surface of the two sites. Site 1 (600 m^2) contains 245 dinosaur, 25 pterosaur, and 4bird tracks. A total of 1,392 dinosaur tracks with one pterosaur track are preserved in the Site 2 (1,000 m^2). Dinosaur tracks attributable to theropods, sauropods, and ornithopods in occur both sites. One of the theropod trackways in the both site consists of an unusual didactyl footprints, suggestive of a dromaeosaurid theropod such as *Deinonychus*. Unusual sauropod and ornithopod trackways are also found at both sites, which appear to have been made by swimming sauropods and ornithopods in shallow water. These include unusual ornithopod trackways that have tail-drag marks between left and right footprints. A pterosaur trackway in Site 1 represents the first record of pterosaur footprints in China, which consists of six pairs of manus and pes and one isolated manus impression. This pterosaur trackway is also the first record from the Early Cretaceous in Asia. A comprehensive analysis of the tracksites deduced from overlapping trackway sequences indicates that the sedimentary environment changed gradually from terrestrial into lacustrine condition. The co-occurrence of dinosaur tracks such as theropods, sauropods, and ornithopods with pterosaur and bird tracks shows a unique faunal association in this area in the Early Cretaceous of China.

Key words: Vertebrate tracks, swimming, tail-drag, Gansu, China

INTRODUCTION

Teilhard and Young (1929) found the first Chinese dinosaur track in Shaanxi Province, which was later given the scientific name *Sinoichnites youngi* by Kuhn (1958). The second Chinese dinosaur tracks were collected from Chaoyang City, Liaoning in 1939 by a Japanese geologist, and Yabe *et al*. (1940) gave the name *Jeholosauripus s-satoi* to a small coelurosaurian theropod dinosaur track. Since then, a number of dinosaur tracks have been recovered from the Mesozoic beds in China. Since Zhen *et al*. (1989, 1996) reviewed Chinese dinosaur tracks, many new discoveries of dinosaur and Mesozoic bird tracks have been made in China (Matsukawa *et al*., 1995; You and Azuma, 1995; Lockley and Matsukawa, 1998; Yu *et al*., 1999; Li *et al*., 2002; Lockley *et al*, 2002; Dong *et al*., 2003).

In 2000, the Research Center of Paleontology, Bureau of Geology and Resource Exploration of Gansu Province discovered ten dinosaur track sites in the Hekou Group, Yanguoxia County, Gansu Province (Du *et al*., 2001; Li *et al*., 2002). These sites (36°02′40″-36°03′45″N, 103°15′-103°15′40″E) are located approximately 50 km west of Lanzhou City, Gansu Province, in upper reaches of the Yellow River (Fig. 1). Two Sino-Japanese and Sino-Japanese-Korean joint expeditions worked at the Yanguoxia dinosaur track site from October to November in 2002 and in October in 2004, respectively. These sites contain di-

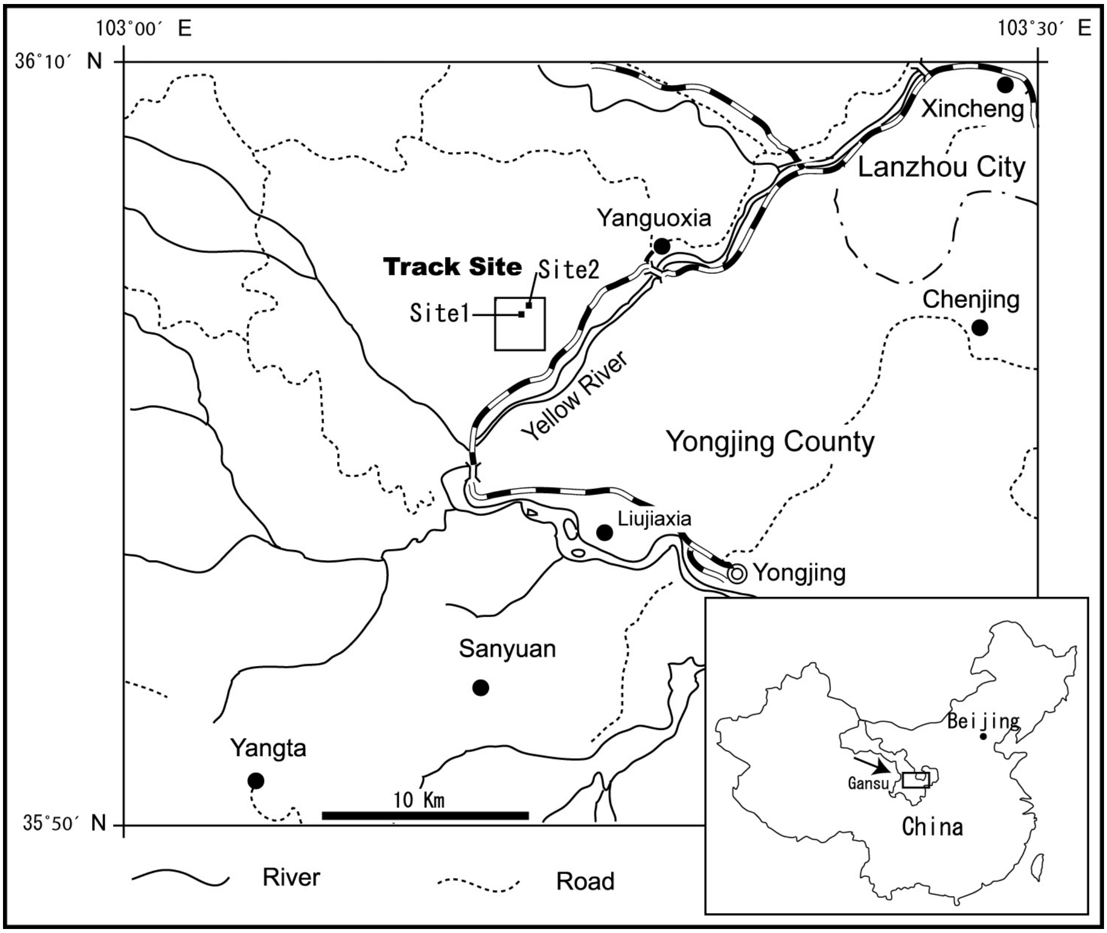


Fig. 1. Location map of the Early Cretaceous Yanguoxia dinosaur track site, Gansu Province in central part of China. Square area shown the Geologic Park including the dinosaur site 1 and 2.

nosaur, pterosaur and bird tracks.

To date, sauropod tracks havebeen described from the Chabu area, Inner Mongolia Province and the Chuxiong area, Yunnan Province (Lockley *et al*., 2002). The Yanguoxia dinosaur tracksite, Gansu Province is the third Chinese sauropod track site and the first record of the co-occurrence of sauropod, theropod and large ornithopod tracks on the same surface in China. Three theropod, two ornithopod, and one pterosaur trackways show unique morphological characters. Therefore, the purpose of this paper is to describe briefly the Yanguoxia dinosaur tracksite and to investigate these important vertebrate trackways in situ.

GEOLOGICAL SETTING

The Early Cretaceous Hekou Group occurs in the southeastern part of Gansu Province, central China. The Hekou Group unconformably overlies Ordovician beds and contacts with the Middle and Upper Jurassic systems by faults. The Hekou Group has a thickness of 4,000 m and is composed of sandstone, mudstone, and conglomerate (Editional Committee of Chinese Stratigraphic Standard, 2000). The Hekou

Group is formally divided into Lower and Upper Formations.

Dinosaur footprints described here occur on a gray fine sandstone surface in the lower part of the Upper Formation (Fig. 2). The track bearing surface contains sedimentary structures such as ripple marks and polygonal mud cracks. Invertebrate traces and large plant stems are also observed on the same bed-

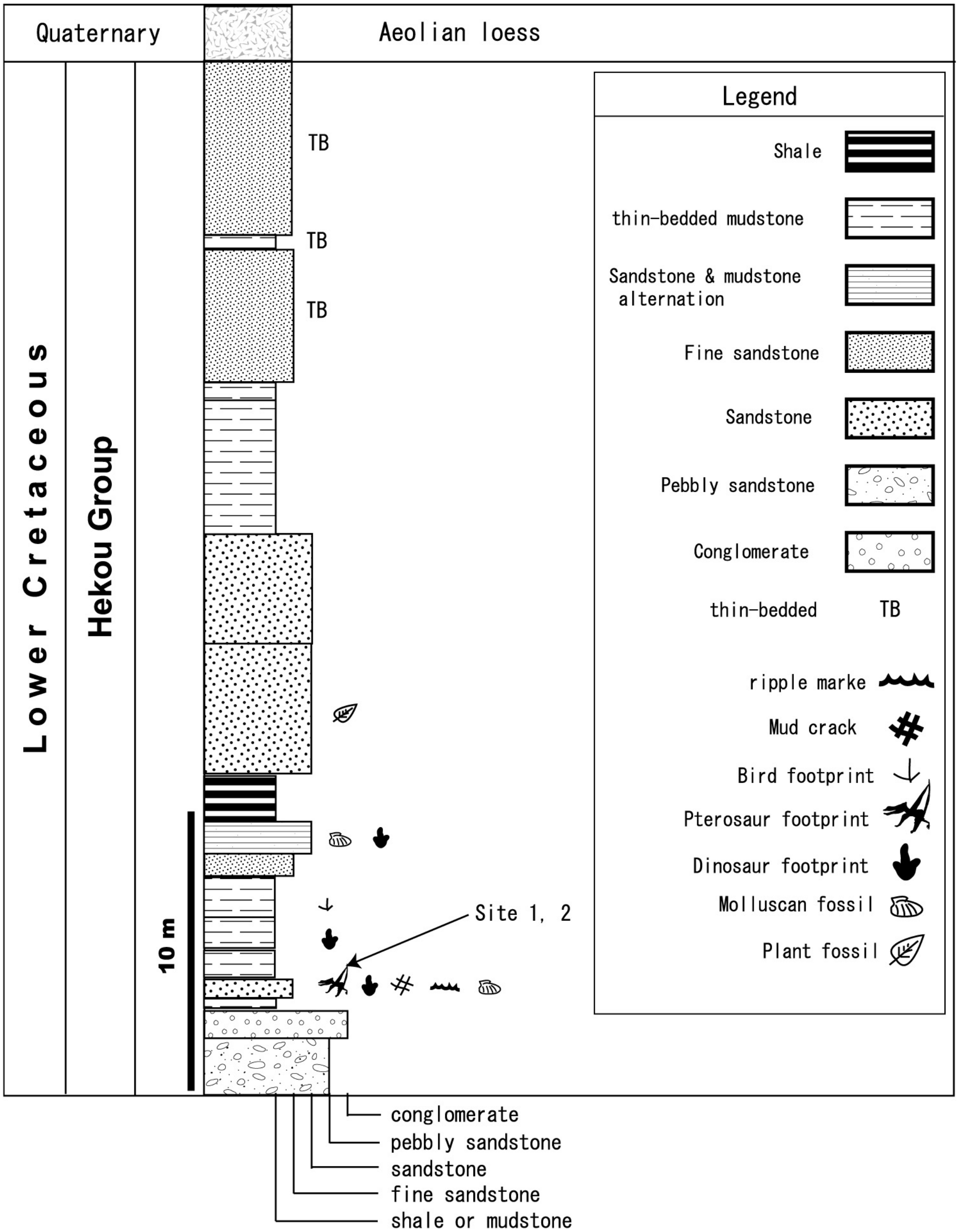


Fig. 2. Simplified stratigraphic section of the Yanguoxia dinosaur track site. Dinosaur tracks found in three horizons and the lowest horizon is preserved dinosaurs and pterosaur tracks.

ding plane. The sedimentary structures and trace fossils indicate that the gray fine sandstone of the formation was deposited in a shallow lake environment. During deposition, these sites at the margin of the lake must have frequently alternated between subaerial and subaquatic environment.

Fig. 3. Photograph showing the Site 1 and 2.

Fig. 4. Photograph showing the Site 1; red arrow indicates the pterosaur trackway point.

OUTLINE OF TRACK SITE 1 AND 2

Site 1 (about 600 m^2) is about 100 m from Site 2 (1000 m^2) (Fig. 3). At Site 1, a total of 55 theropod, 124 sauropod, 65 ornithopod, and 25 pterosaur tracks are observed comprising 7 theropod, 5 sauropod, 6 ornithopod, and 1 pterosaur trackways (Figs. 4, 5). Site 2 contains 350 theropod, 364 sauropod, 628 ornithopod, 1 pterosaur, and 53 unidentified tracks comprising 28 theropod, 14 sauropod, 45 ornithopod, and 2 unidentified trackways (Figs. 6, 7). The bedding planes of Site 1 and Site 2 are regarded as of the same horizon same horizon judging from the stratigraphical sequences.

The tracks are deeper in the northeast portion of the bedding plane than in the northwest, suggesting a wetter substrate to the northeast. Consistent with this interpretation, mud crack sand ripple marks observed are more abundant in the northeast area than the northwest.

DESCRIPTION OF TRACKWAYS

THEROPODS

Type 1: Didactyl tracks (Fig. 8) One trackway of Site 1 and six trackways of Site 2 belong to this type (Figs. 5, 7). Each print shows two digits (Figs. 8A, B). Digit III is slightly longer than Digit IV (Fig. 8C). The range of values of footprint length and width are 135-153 mm (n=43) and 53-82 mm (n=43) respectively. The straight Digit III is parallel to Digit IV, which slightly curves inward. Several well-preserved tracks show three digital pads on Digit III and four on Digit IV. A distinct, small, round pad between the first and second phalanges of Digit II juxtaposes Digit III postero-medially. The didactyl trackways are linear or curved. Didactyl tracks named *Velociraptorichunus sichuanensis*, a likely dromaeosaurid, are from the Early Cretaceous of Chuanzhu Village, Emei County, Sichuan Province (Zhen *et al*., 1995). *V. sichuanensis* is 110 mm in footprint length and 60 mm in footprint width, and the ratio of pace to the length of foot is 4.4:1. Didactyl tracks from Yanguoxia in this study are more elongated and the ratio of pace to the length of foot is 2.7:1. The maker of the tracks was probably dromaeosaurid, but the differences with the tracks reported by Zhen *et al*. (1995) implies a new ichnotaxon for the Gansu tracks.

Type 2: Tridactyl tracks (Fig. 9) Seventeen tridactyl trackways are preserved on Sites 1 and 2 (Figs. 5, 7). Average footprint length, width, and stride length are 147 mm (n=22), 110 mm (n=22), and 1,158 mm (n=22), respectively.

Trackways TA and TB from Site 1 appear to be representative of Type 2 theropod tracks. Trackway TA and TB consist of consecutive 7 and 16 tracks, respectively. Almost all tracks have tridactyl digits with Digits II, III, and IV. However, some right footprints of TA show traces of Digit I behind the Digit II impression. Digit III is the longest and Digit IV is longer than Digit II. Digital pad impressions and claw marks can be observed on Digit IV. No metatarsal-phalangeal pads were observed in the shallowly depressed tracks. Three digital impressions diverge distally and the angle between Digit III and IV is larger than that of II and III. Average footprint length and width are 215 mm and 178 mm in TA, and 266 mm and 207 mm in TB, respectively. Many theropod ichnotaxa have been reported in China Ichnogenera *Grallator*, *Schizograllator*, *Paracoelurosaurichnus*, *Zizhongpus*, *Chongqingpus*, *Tuojiangpus*, *Velociraptorichnus*, *Shensipus*, *Eubrontes*, *Youngichnus*, *Megaichnites*, *Jinlijingpus*, *Chonglongpus*, *Changpeipus*, *Xiangxipus*, and *Hunanpus* (Zhen *et al*., 1989, 1996). Tracks of TA and TB are similar to *Changpeipus*, judging from their shape, size, divarication of Digit II and III, and relative position of Digit I and II. However, the taxonomic designation of these tracks will be studied later by comparisons with known Chinese theropod ichnotaxa.

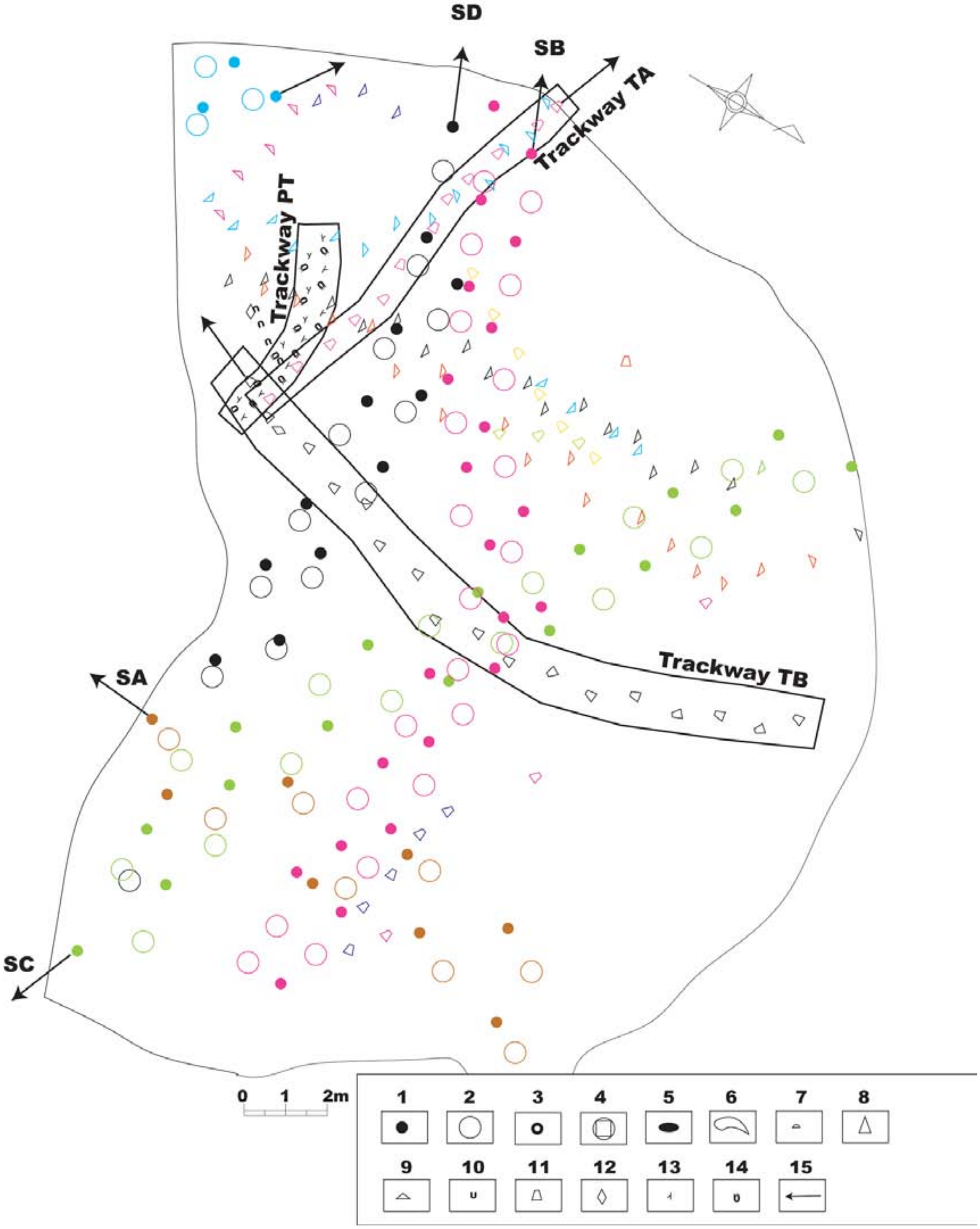


Fig. 5. Map of the Site 1 of the Yanguoxia dinosaur site. Track outlines are symbolized. 1-6: sauropod track (1, manus of Type A-1; 2, pes of Type A-1; 3, manus of Type A-2; 4, pes of Type A-2; 5, manus of Type B; 6, pes of Type B), 7-9: ornithopod track (7, manus of Type A 8, pes of Type A 9, pes of Type B), 10-11: theropod track (10, pes of Type 1; 11, pes of Type 2 and 3), 12: uncertain (three digits track), 13-14: pterosaur track (13, manus; 14, pes), 15: direction of trackways.

Fig. 6. Photograph showing the Site 2.

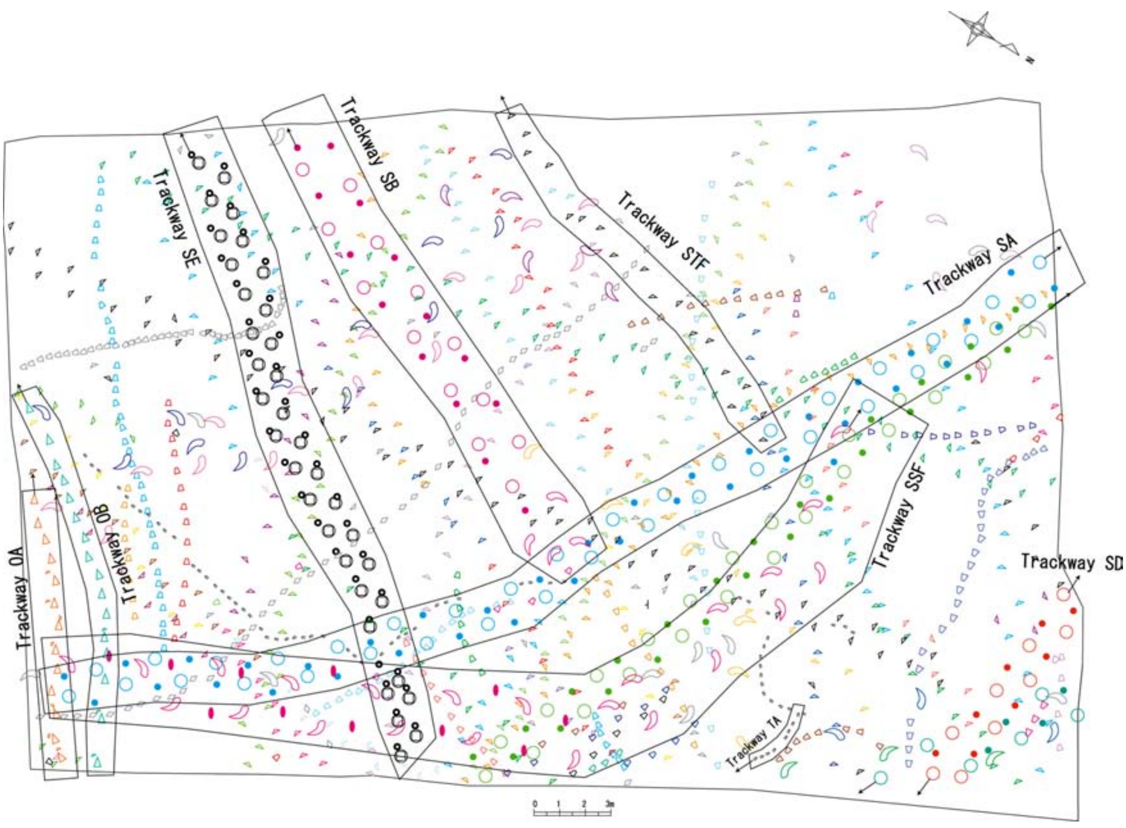


Fig. 7. Map of the Site 2 of the Yanguoxia dinosaur site. See legend of Fig. 5 for symbols of each trackway.

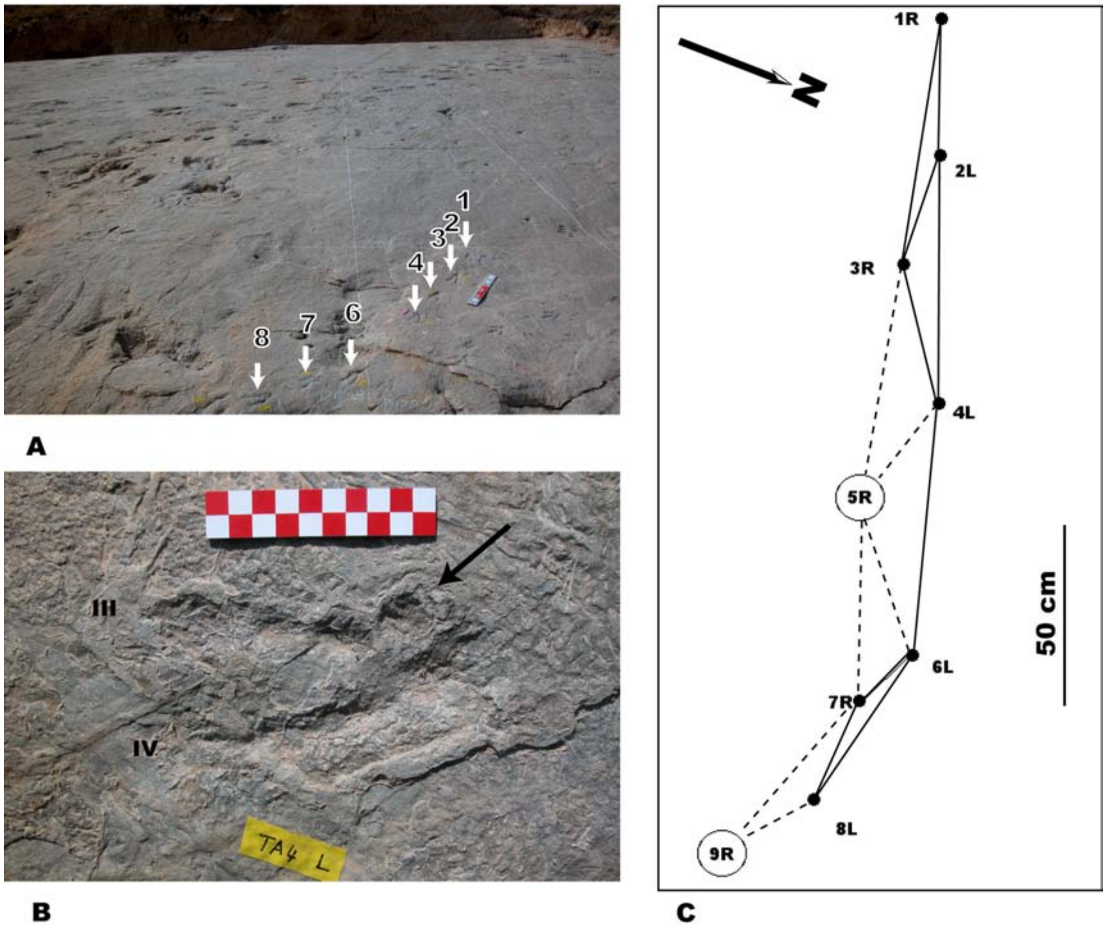


Fig. 8. A: photograph of a didactyl digits theropod trackway (Trackway TA) at Site 2; white arrows indicate each pes impression points. Scale bar equal 50 cm. B: photograph of one didactyl digits theropod pes impression (Track no. is 4 in the trackway TA of photograph A). Scale bar equals 10 cm. C: the trackway of TA of photograph A.

Type 3: Tridactyl tracks (Fig. 10) These trackways, found at Sites 1 and 2, are similar to Type 2 tracks, especially because the impressions taper anteriorly into sharp claw marks, and digit II is shorter than digit IV. The phalangeal pads of each digit are well defined. These tracks are smaller and relatively narrower than Type 1 prints. Metatarsal-phalangeal pads were imprinted. Averages foot length, foot width and stride length are 118 mm (n=13), 67 mm (n=13) and 1,724 mm (n=13), respectively. The width to length ratio of this type (FW/FL = is 0.6) is lower than that of Type 2 (FW/FL = 0.9). The average stride length of this type is 1,724 mm, longer than that of Type 2. Thus, it can be distinguished between the Type 2and the Type 3 ichnites (Fig. 11), and the Type 3 trackmaker is assigned to be Ichnogenus *Grallator.*

SAUROPODS

Type A: Normal gait sauropod tracks (Fig. 12) There are 124 sauropod tracks from five trackways at Site 1 and 267 tracks from six trackways at Site 2. These sauropod tracks from both sites can be divided into two types by means of their morphologies.

First type (Type A-1) tracks are found five trackways (e.g. Trackway SA) in Site 2 (Fig. 12). First type

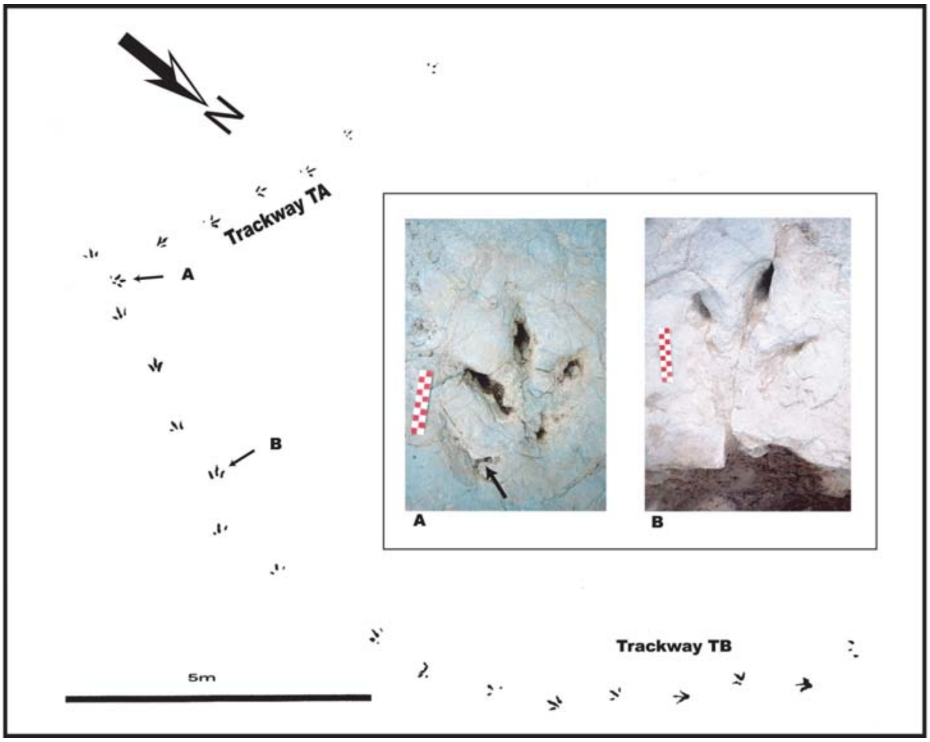


Fig. 9. Map showing theropod trackways TA and TB at Site 1. A: a right pes impression of the Trackway TA. Arrow indicate the digit I. B: a left pes impression of the trackway TB.

Fig. 10. Photograph of theropod track (Type 3).

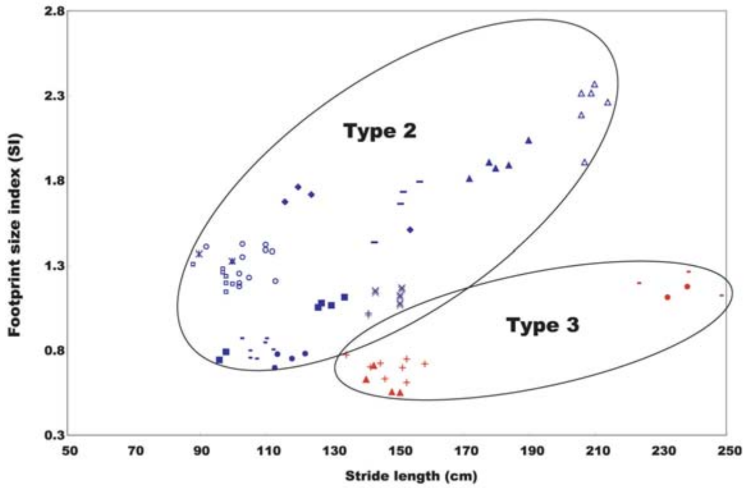


Fig. 11. Scatter diagram showing the relationship between footprint size index (SI) and stride length for pes prints of theropod Type 2, and 3 in Site 1 and 2. Solid and open triangle symbols indicate data from Site 1 and other symbols from Site 2.

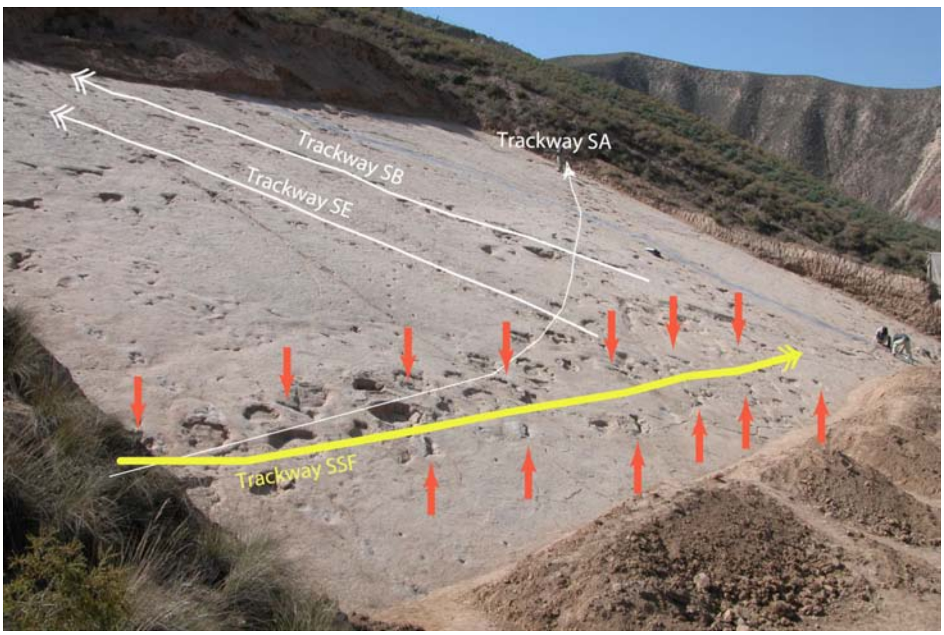


Fig. 12. Photograph of Site 2. White and yellow arrows showing a normal and three unusual gait sauropod trackways and their directions. Red arrows indicate pes of Trackway SSF of a unusual gait trackway.

(Type A-1) pes prints are oval in shape with five claw marks and wider at anterior margin than at posterior (Fig. 13A). Outline of pes print of Type A-1 is longer than wide and its lateral margin is slightly convex. Claw marks are curved laterally. The pes prints of Trackway SA are 840 mm (n=32) long and 632 mm (n=32) wide in average.

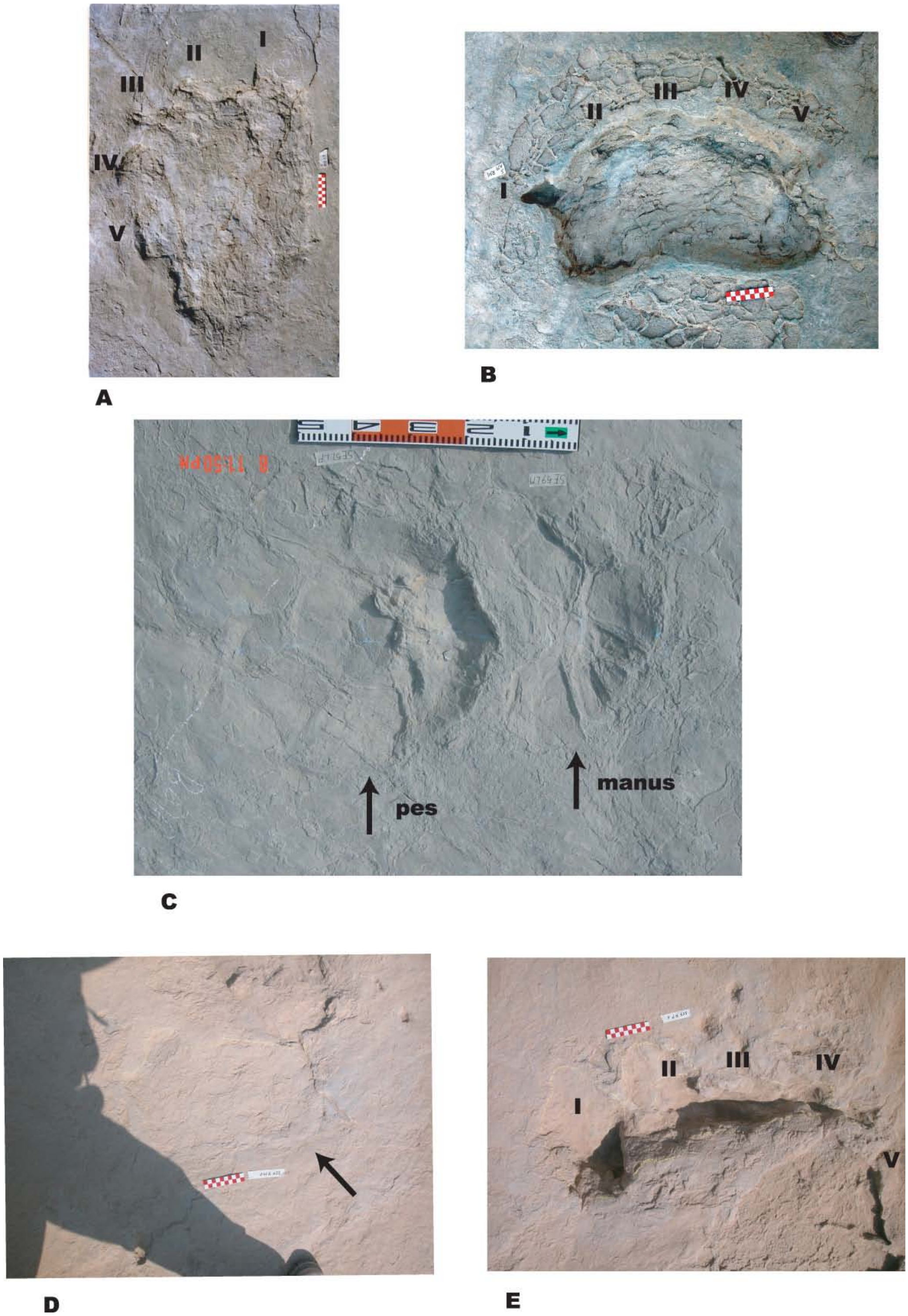


Fig. 13. Photographs of sauropod impressions in Site 2. A: pes of Trackway SA (SA28). B: manus of Trackway SA (SA7). C: manus (SE59) and pes (SE57) impressions of Trackway SE. D: manus impression (SSF5) of Trackway SSF. E: pes impression (SSF6) of Trackway SSF. Scale bars equal 10 cm in photograph A, B, D, and E, and 50 cm in photograph C.

The manus prints of Type A-1 are horseshoe-shaped, convex anterior margin, and concave posterior margin (Fig. 13B). A claw mark of Digit I is distinct and medially perpendicular to the axis of the manus print. Toe marks of Digits II, III, and IV are short and wide at the anterior margin. The manus prints of the Trackway SA are 416 mm (n=30) long and 547 mm (n=30) wide in average.

These sauropod tracks are very similar to *Brontopodus birdi* which were described from the Early Cretaceous of Texas in USA (Farlow *et al*., 1989). *Brontopodus* was reported from the Early Cretaceous of Inner Mongolia and the Late Cretaceous of Yunnan Provinces in China (Lockley *et al*., 2002), and the Late Cretaceous Gyeongsang Supergroup in Korea (Lockley, 1994; Huh *et al*., 2003).

Second type (Type A-2) tracks are found in one trackway (SE) of Site 2 (Fig. 12). The pes prints are nearly circular, having five claw marks at the anterior margin (Fig. 13C). The anterior portion of the track is depressed deeper than at the posterior. Footprint length is somewhat longer than wide (FL/FW=1.2, n=16) with 500 mm (n=16) and 430 mm (n=16), respectively.

The manus prints are typical horseshoe-shaped, having a convex anterior margin and a strongly concave posterior margin (Fig. 13C). Five blunt digits can be recognized. Manus print length and width are 330 mm (n=13) and 380 mm (n=13) in average. They are positioned in front of the corresponding pes prints.

Type B: Unusual sauropod tracks and trackways (Fig. 12) Two unusual sauropod trackways (SB and SSF) and 50 isolated unusual sauropod tracks were recognized at Site 2. A quadrupedal trackway SSF runs from south to north for about 22 m. Manus prints are very faint or absent anterior to pes prints (Fig. 13D). Pes prints are elongated transversally and crescent shaped, with distinct claw marks (Fig. 13E). They are wider (800 mm) than long (400 mm). The anterior part of each track is distinctly and deeply imprinted, but the posterior part of the print is not observed. The pes prints seem to have been left only by the anterior part of sauropod hind feet. The pes print SSF-6 (Fig. 13E) is about 320 mm long and 790 mm wide, and the depth of Digit I is 140 mm. Compared to normal gait sauropod tracks (Type A, SA 28, Fig. 13A), the distance between Digit I and V of SSF is almost the same size as that of SA 28 (Fig. 13A). The digital arrangement of SA 28 is concordant with that of SSF pes prints. Therefore, it seems reasonable that a trackmaker of the Trackway SSF could be the same kind of animal as Trackway SA. Moreover, it is noticeable that the unusual gait pattern of SB has the SSF and SA track pattern.

These unusual gait patterns suggest aqueous locomotion of these sauropods. Several studies described tracks attributed to swimming sauropods based on mainly manus-only or manus dominant sauropod trackways (e.g., Bird, 1944; Coombs, 1975; Ishigaki, 1989; Thulborn, 1990 Lee and Huh, 2002). In these cases, it is considered that the center of gravity of the sauropod was situated in the forequarter while the hindquarter was floating (Lee and Huh, 2002). Recently Henderson (2004) used 3D computer modeling to demonstrate that some floating sauropods such as *Diplodocus* and *Apatosaurus* could have produced pes-only trackways. Getting out of the water to approach the lake shore, the sauropods that left Trackway SB and SFF first touched their hind feet to the bottom (bipedal) and later walked using four feet (quadrupedal) when water became shallow enough to touch the bottom with their fore feet (Fig. 14A). Therefore, it is assumed that Trackway SB and SSF were made by sauropods that walked in water on tip toes of their hind feet.

ORNITHOPODS

With two typical, or normal ones, and forty six peculiar ornithopod trackways are recognized in Sites 1 and 2.

Type A: Ornithopod tracks and trackways (Fig. 15) Two trackways (OA and OB) are preserved on the south part of Site 2 (Fig. 7). Pes prints are characterized by tridactyl footprints having Digit II subparallel to Digit IV, and a big metatarsal-phalangeal pad impression (Fig. 15). The two trackways parallel each

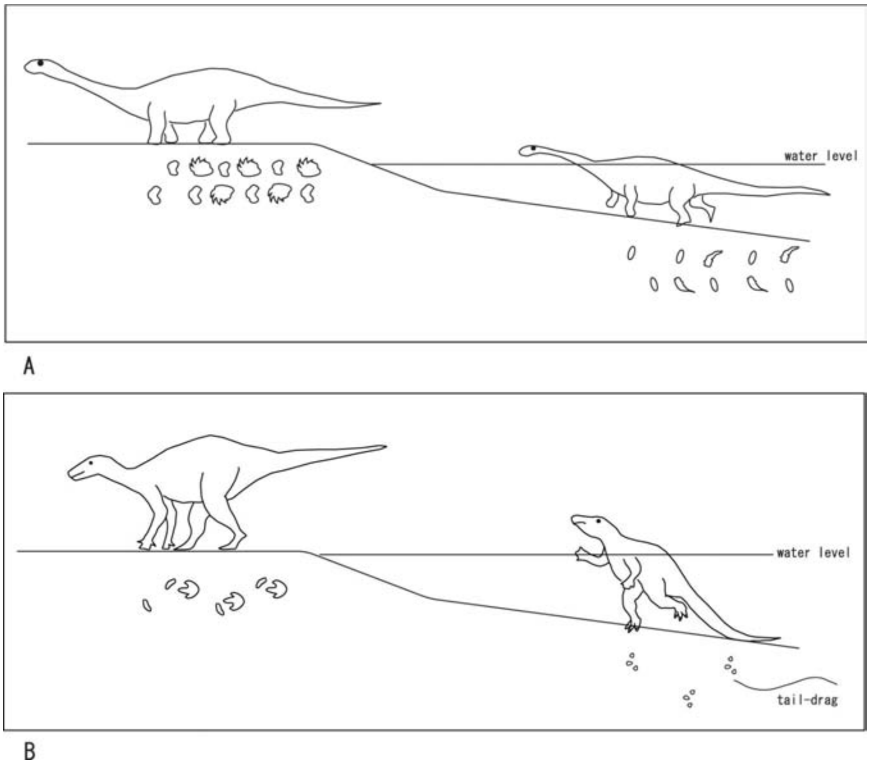


Fig. 14. The restoration of trackmakers of unusual gait sauropod and ornithopod at Site 2. A and B: Trackway attributed floating sauropod and ornithopod with a conjectural restoration of trackmaker (top right: sauropod, bottom right: ornithopod) and their trackway of normal gait sauropod (top left: sauropod, bottom left: ornithopod).

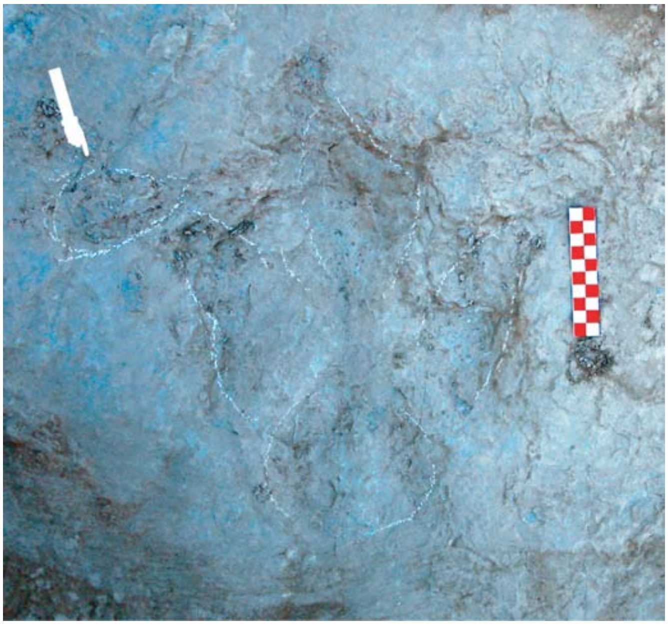


Fig. 15. Photograph of a pair of manus and pes impressions of the ornithopod trackway OB in Site 2. Arrow indicates manus impression. Scale bar equal 10 cm.

other from northeast to southwest. Manus prints, which are oval in shape, are positioned in front of the corresponding pes prints (Fig. 15). Pes prints of OA are 360 mm (n=12) long and 287 mm (n=12)wide in average, and those of OB are slightly smaller than those of OA (length, 286mm (n=11) and width, 226mm (n=11)). They are very similar to *Caririchnium* from North and South America (Leonardi, 1984; Lockley, 1986) and Korea (Huh *et al*., 2003).

Type B: Ornithopod tracks and trackways (Fig. 16) The unusual trackways are formed only by pes prints (bipedal) at Site 1 and 2 (Figs. 5, 7). The pes prints are mainly composed of three separate digits (digits II, III, and IV) with inward rotation (Fig. 16B). Digit III is more deeply impressed than digits II and IV, and often shows retro-scratches. The average width of pes prints is 23.0 cm (N=460). These tracks are similar to *Wintonopus*, an ornithopod ichnotaxon from the mid-Cretaceous of Queensland, Australia (Thulborn and Wade, 1984). Interestingly, these trackways also have sinuous tail-drag marks between the left and right footprints (Fig. 16A). The depth of the tail-drags is up to 10 cm. These could have been made by semi-swimming ornithopods which touched the bottom with the tips of toes (Fig. 14B). As their tails touched the bottom, they could have had increasing stability of semi-swimming gait under water.

Semi-swimming bipedal dinosaur tracks were reported from the East Berlin Formation (Lower Jurassic) of Connecticut (Coombs, 1980) and the Dakota Formation (Cretaceous) of Kansas, United States (McAllister, 1989), but these tracks do not have tail-drags. These unusual ornithopod trackways from the Yanguoxia site are the first report of semi-swimming ornithopods dragging their tails.

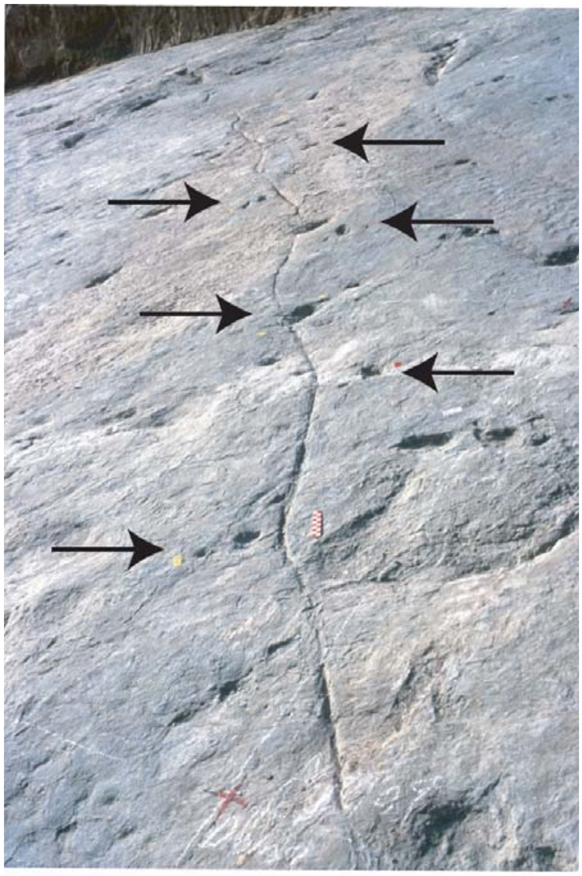
PTEROSAURS (Fig. 17)

Pterosaur tracks occur as one trackway at Site 1 (Fig. 5) and an isolated manus print at Site 2 (Fig. 7). The trackway of Site 1 consists of 13 manus prints and 11 pes prints over a length of about 5 meters (Fig. 17A). Several well-preserved pes prints show a distinct V-shape outline with pointed heel impressions (Fig. 17B). Four digit impressions diverge anteriorly, and the Digit V impression is about the middle of the lateral side. Although overall pes prints are shallowly depressed, the ankle region is impressed deeply. These pes prints are clearly plantigrade and are located antero-medially to the manus prints. They all show outward rotation to the trackway axis. Averages of pes print length and width are 123 mm (n=10) and 36 mm (n=10), respectively.

All of 13 manus prints are tridactyl and strongly asymmetric. Digit I is approximately the same length as Digit II, and both are impressed laterally (Fig. 17C). Digit III is the longest, having a small claw mark at the distal end. Manus prints are 122 mm long (n=13) and 48 mm wide (n=12) in average. The gleno-acetabular length of the trackmaker of this trackway is estimated to be approximately 370 mm.

Pterosaur tracks have been discovered from North America (Lockley, 1999; Lockley and Rainforth, 2002; Lockley *et al*., 1995, 1996), South America (Calvo and Lockley, 2001), and Europe (e.g., Delair and Lander, 1973; Mazin *et al*., 1995; Lockley *et al*., 1995; Wright *et al*., 1997). However, previously there was no report of pterosaur tracks in China before now. In Asia, azhdarchid pterosaur tracks, named *Haenamichnus uhangriensis*, were described from the Late Cretaceous Uhangri Formation of South Jeolla Province in Korea (Hwang *et al*., 2002). Therefore, Yanguoxia pterosaur tracks represent the second occurrence of pterosaur ichnites in Asia. Yanguoxia Site is very similar to the Uhangri Formation of Korea in terms of co-occurrence of pterosaur, bird, theropod, sauropod, and ornithopod tracks at a single formation, but the latter is different from the Early Cretaceous Yanguoxia Site in age.

The pterosaur tracks from Yanguoxia Site may represent a new ichnotaxon belonging to a rhamphorhynchoid pterosaur. Recently, many rhamphorhynchoid pterosaurs were reported from the Early Cretaceous of Liaoning Province, China, such as Anurognathidae (*Denfrorhynchoides curvidentatus* and *Jeholopterus ningchensis*) and Rhamphorhynchidae (*Pterorhynchus wellnhoferi*) (Czerkas and Ji, 2002;



A

B

Fig. 16. A: Unusual ornithopod trackway (Trackway STF) with a sinuous tail-drag. B: Unusual ornithopod pes impression (STF4). Tips of three digits are separated each other.

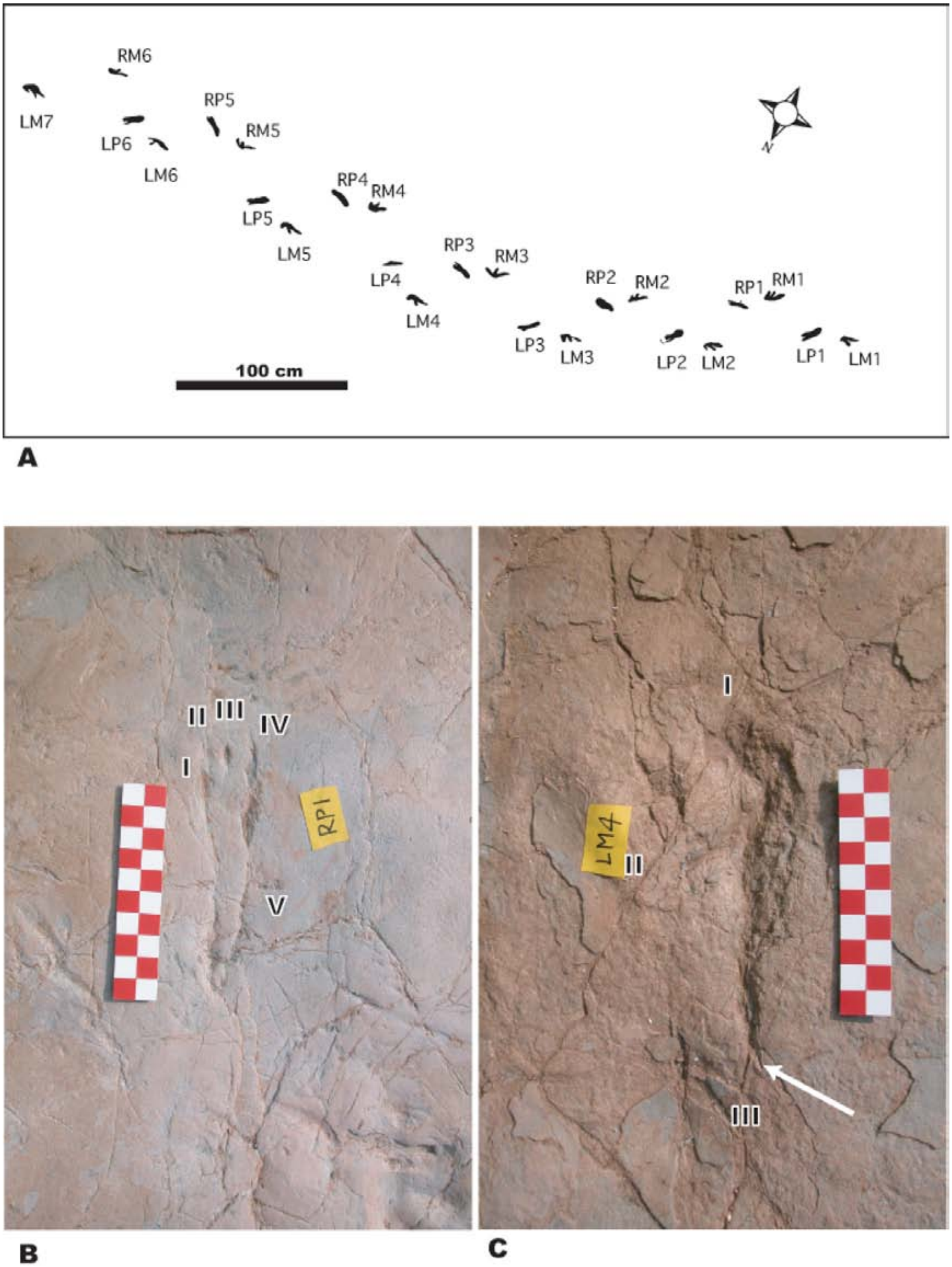


Fig. 17. A: Map showing a pterosaur trackway PT at Site 1. B: a right pes impression (RP1) of the Trackway PT. C: a left manus impression (LM4) of the trackway PT. White arrow indicates the claw mark of the digit III. Scale bars equal 100 cm in A and 10 cm in B and C.

Ji and Ji, 1998; Wang *et al*., 2002). Therefore, rhamphorhynchid pterosaurs could have been trackmakers in the Early Cretaceous tracks in Gansu Province.

BIRD

A slab with four preserved positively impressed bird tracks were collected from the red shale bed at 2 m above the Site 1 in 2000 (Fig. 18). The mean length, width and divarication between Digit II and IV are 32 mm, 43 mm, and 113^o, respectively. They show a close relationship to Ichnogenus *Koreanaornis* from Korea (Li *et al*., 2002), in terms of separation the proximal parts of the three digits impressions.

PALEOENVIRONMENTS AND PALEOECOLOGY

The ichnocoenoses at Site 1 and 2 includes theropod, sauropod, ornithopod, and pterosaur tracks on the same bedding surface, indicating a diversity of vertebrate animals. The directions of more than 100 trackways on both sites vary randomly. However, analysis of over printed tracks and across trackways makes it possible to clarify the track-made sequences. At Site 1, it is interpreted that sauropods walked over mud cracked substrate where theropods and pterosaurs left their foot prints, and then as water became higher, swimming ornithopods passed later. At Site 2, it is interpreted that after sauropod, theropod, ornithopod, and pterosaur prints were left on the surface, sauropods arrived the lake shore from water, followed by "swimming"ornithopods (Fig. 19).

In summary, there were sauropods, theropods, ornithopods, and pterosaurs in a dried lake margin with

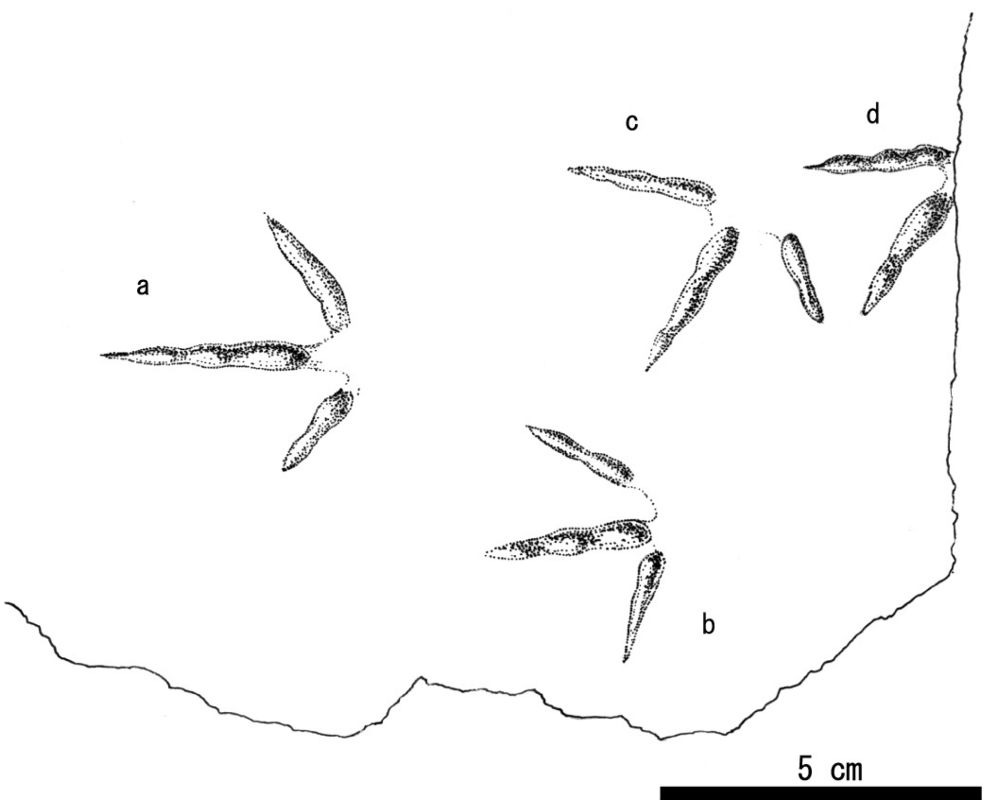


Fig. 18. A drawing of bird tracks (Li *et al*., 2002).

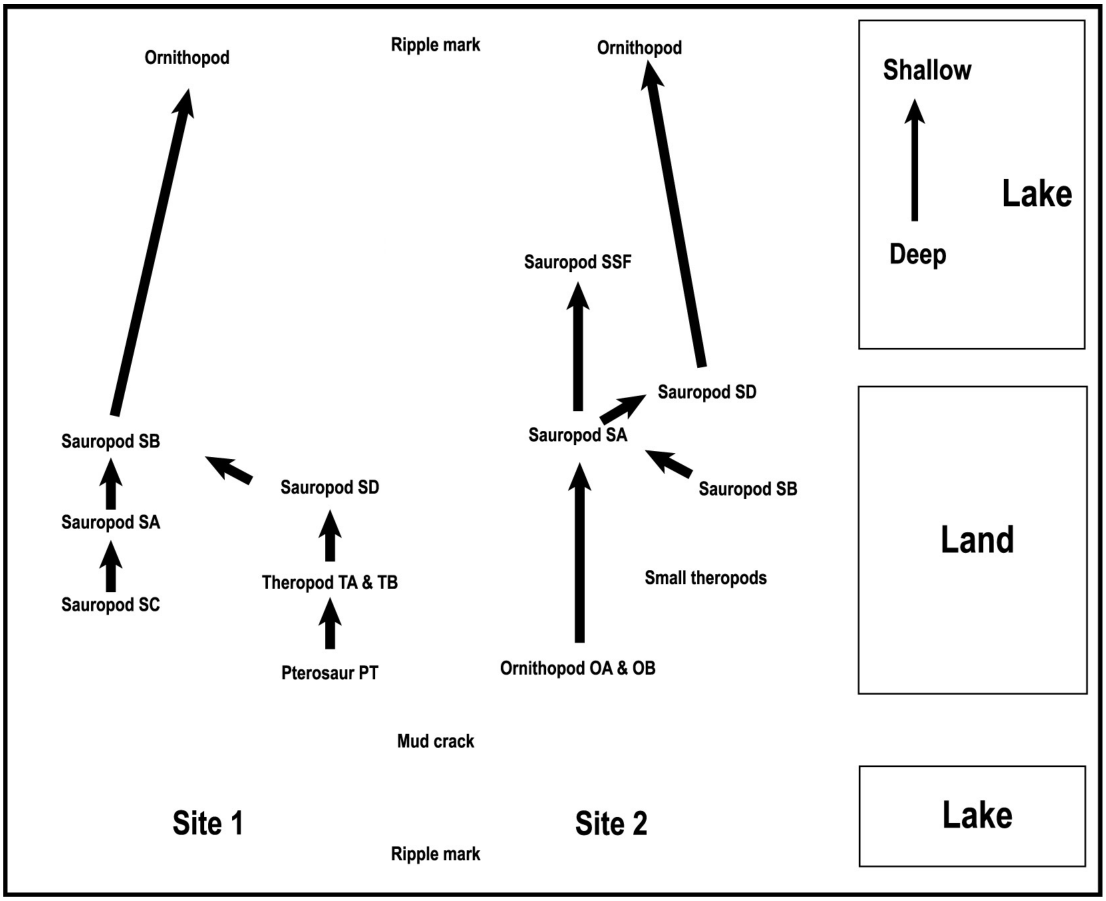


Fig. 19. The sequence in which the track makers traversed the Site 1 and 2 ascertained from the overlapping of trackways and the environmental change.

water level falling. Thereafter, the water level rose several meters enough for only large sauropods to walk under water. Finally, the water depth decreased to 2-3 m and ornithopods left their prints while tip-toe walking in moderate deep water.

CONCLUSIONS

The Yanguoxia dinosaur track site includes 270 tracks of dinosaurs and pterosaurs in about 600 m^2 at Site 1 and 1,393 tracks in about 1,000 m^2 at Site 2. These sites are significant because:

1) The theropod trackways with unusual didactyl prints are likely attributable to dromaeosaurid theropods, and are morphologically different implying a new ichnotaxon.
2) The pterosaur trackways are the first occurrence in China. Compared with *Haenamichnus uhangriensis* from Korea, pterosaur tracks of the Yanguoxia Site are better defined and are the first report in the Early Cretaceous of a pterosaur ichnite in China. In addition, Yanguoxia pterosaur tracks represent a new ichnotaxon belonging to rhamphorhynchid pterosaurs based on characteristics of pes prints.

3) The tridactyl ornithopod trackways consist of only toe prints with “tail-drags”. This is suggestive of “semi-swimming” gait. This is the first report of ornithopod tracks to show the ability to walk under water using their tails.
4) Swimming sauropod trackways show a continuous progress from the lake to the land. These trackways show these sauropods touched the bottom with hind feet first.
5) Based on the tracks, it is possible to analyze trackmaker’s activities and paleoenvironmental changes from subaqueous (lacustrine) through subaerial to subaqueous in both sites.

In terms of quantity and diversity of tracks, and uniqueness of track pattern to imply animal’s behavior, Yanguoxia Site is one of the most important tracksites in the world. Further work will provide additional insights into the nexus between behavior of trackmakers and paleoenvironment.

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중국 Gansu 지방 전기 백악기 Hekou 층군에서 산출된 공룡을 포함한 새로운 척추동물 발자국화석 두 산지에 대한 예비 보고

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요 약: 2001년과 2003년, 중국 Gansu 지방의 Yongjing 군, Yanguoxia의 Hekou 층군 (전기 백악기)에서 발자국 산지 두 곳이 최근 발견되었다. 이곳에서 108개 넘는 공룡과 익룡발자국 보행렬이 회색 세립질 사암에서 산출된다. 산지 1 (600 m^2)은 247개 공룡발자국, 25 익룡발자국, 4개의 새발자국을 포함한다. 한 개의 익룡발자국을 포함해 총 1396개의 공룡발자국이 산지 2 (1,000 m^2)에서 산출된다. 공룡발자국은 수각류, 용각류, 조각류 발자국이 두 산지에 모두 나타난다. 두 산지에서 수각류 보행렬 중 한 개는 독특한 두 개 발가락 발자국으로 *Deinonychus*같은 dromaeosaurid 수각류에 속할 것으로 추정된다. 또한 특이한 용각류와 조각류 발자국 보행렬이 발견되는데 이들은 얕은 물속에서 수영을 하며 남겨진 것으로 보인다. 특히 몇몇 조각류 보행렬은 균형을 맞추기 위해 왼쪽 발자국과 오른쪽 발자국 사이에

꼬리를 끈 자국이 남겨져 있다. 게다가 산지 1에서 발견된 익룡발자국은 중국에서 발견되는 첫 번째 익룡발자국이며 6쌍의 앞발자국과 뒷발자국, 그리고 한 개의 분리된 앞발자국으로 구성된다. 이 익룡발자국은 아시아에서 처음 발견되는 전기 백악기 익룡발자국이다. 여러 개의 겹치는 보행렬을 종합적으로 분석한 결과 발자국이 만들어질 당시 퇴적환경은 육성에서 호수 환경으로 점차 변하고 있었던 것으로 사료된다. 수각류, 용각류, 조각류 발자국들과 익룡과 새 발자국이 함께 산출된다는 것은 이 지역이 전기 백악기에 독특한 화석군을 갖고 있었음을 지시한다.

주요어: 척추동물발자국, 수영, 꼬리흔적, Gansu, 중국

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