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DINOSAUR FOOTPRINTS FROM THE LOWER CRETACEOUS OF INNER MONGOLIA, CHINA

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ABSTRACT

More than a thousand dinosaur footprints, ranging in size from 2 cm to more than 20 cm, have been discovered in the Lower Cretaceous of the Ordos Plateau, Inner Mongolia. Each was measured and mapped, and enough specimens were excavated to fill 180 crates. The majority of footprints represent tridactyl, bipedal dinosaurs, and represent six different types, comprising a “footprint fauna” remarkably similar to those from Early Cretaceous sites in Korea, Japan and Canada. Numerous localities in the Ordos have produced Early Cretaceous dinosaur skeletons, but depositional environments favoring preservation of footprints were significantly different from those preserving body fossils.

Key words: dinosaur footprint, theropod, Zhidan Group, Ordos Basin, Early Cretaceous

東洋一・李栄・フィリップ J．カリー・董枝明・呂君昌（2006）中国内モンゴル自治区の下部白亜紀層からの恐竜足跡．福井県立恐竜博物館紀要 5 ： 1 – 14.

中国内モンゴル自治区オルドス卓状地の下部白亜紀層から，足印長 2 cm～20cm のおびただしい数の恐竜足跡化石が発見された．その多くは三指性，二足歩行の恐竜足跡化石で，６つの異なるタイプに分けられ，総じてその足跡動物相は韓国，日本，カナダにおける下部白亜紀のものと著しく類似する．オルドス盆地で，白亜紀前期の恐竜骨格を産出する場所は足跡化石産地とは堆積環境が異なり，生息環境も恐竜動物相も相違する．

INTRODUCTION

Dinosaur footprints were first reported from China in 1929 by Teilhand de Chardin and C. C. Young. By 1989 an additional 27 localities had been discovered (Zhen et al., 1989). Studies of dinosaur and bird footprints dramatically increased in China after the 1990s (Chen and Huang, 1993, 1994 ; Dong et al., 2003 ; Li et al., 2002a, b ; Lockley et al., 2002 ; Matsukawa et al., 1995 ; You and Azuma, 1995 ; Yu et al., 1999).

The first discovery of dinosaur footprints in the area reported in this paper was made by local residents in the mid-1970s. For several years, beginning in 1976, the Museum of Inner Mongolia collected footprints and data from the site. In September and October of 1984, the museum mounted a major expedition to systematically record and recover a significant sample of these footprints from Site III (Fig. 1 ; Site 7 of Lockley et al., 2002). Specimens were measured and mapped (Figs. 2, 3), and approximately 50 footprints were excavated and shipped back to Hohhot in 180 crates. Twenty-seven footprints from one of the trackways were reassembled for display in the Museum of Inner Mongolia, along with an enormous cast of a large slab with 45 footprints (Fig. 4).

A party of the China–Canada Dinosaur Project, which included three of the authors of this paper, visited this area again

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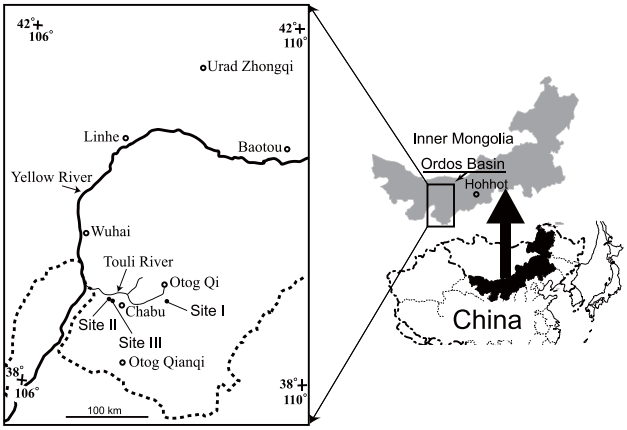

FIGURE 1. Map of part of Inner Mongolia, Peoples Republic of China, showing the Ordos Plateau (Basin) and the location of Chabu Sumu and the associated footprint sites.

in 1987. More data were collected, but no further footprints were excavated.

The footprints were from two localities west of Chabu Sumu and another locality south to Otog Qi (Fig. 1). One site (Site I : 38°55′N, 108°5′E) is close to the Touli River (an eastern tributary of the Yellow River ; Fig. 2), and it produced a turtle (Brinkman and Peng, 1993) and an atoposaurid neosuchian (Wu et al., 1996) in addition to the footprints. The main site (Site II, Fig. 3) is known as Hadetu (38°58′N, 107°10′E), and produced more than 400 footprints. The site is bound on one side by erosion and covered on the other by a thin layer of bedrock. The third site, Ahrubulage (Site III : 38°50′N, 107°15′E), lies south of Hadetu and is the locale where the large slab was moulded to produce the cast for display in the Museum of Inner Mongolia, Hohhot (Fig. 4).

All measurements of footprints for Sites I and II were taken in the field by the second author. Footprints at Site III were measured by Currie based on the cast on display in the Museum of Inner Mongolia. Here, we present the first detailed report of theropod and ornithopod trackways from the Ordos Basin.

GEOLOGICAL SETTING

The Early Cretaceous Zhidan Group crops out along the western side of the Ordos Basin, where theropod footprints reported in this paper have been found. The Zhidan Group is 1,200–7,000 m thick and consists of the Yijun, Luohe, Huachi, Huanhe, Luohandong, Jingchuan and Lamawan formations in ascending order (Dong, 1992). Dinosaur footprints are preserved in the Jingchuan Formation. The Zhidan Group is composed of mainly grayish-green and purplish-red sandstones and mudstones, with interbedded thin shale layers. The Jingchuan Formation consists of gray and yellow sandstones and reddish-green mudstones (Dong, 1992).

The Zhidan Group in the Ordos Basin has yielded dinosaur skeletal fossils of *Predeinodon* sp., *Mongolosaurus hoplodon, Microceratopus gobiensis, Psittacosaurus mongoliensis* and *Sauroplites scutiger,* along with enantiornithine birds (Dong, 1992).

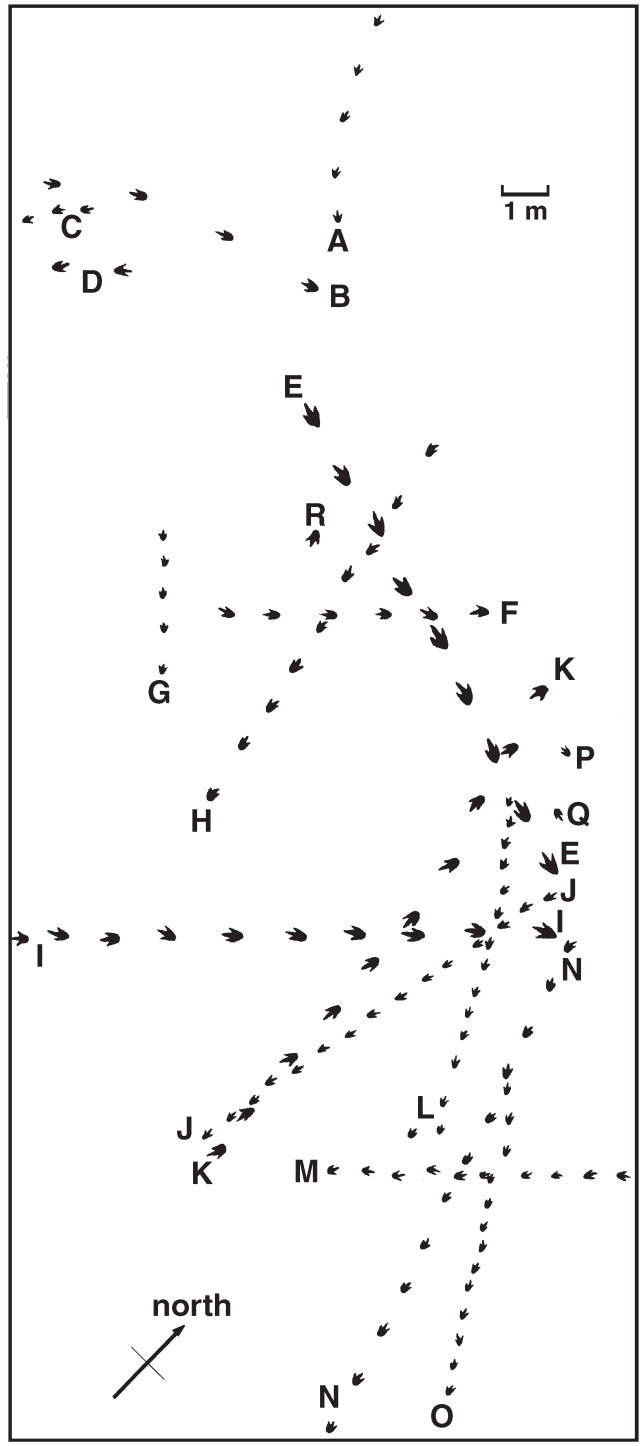

FIGURE 2. Site I, west of Chabu Sumu at Touli.

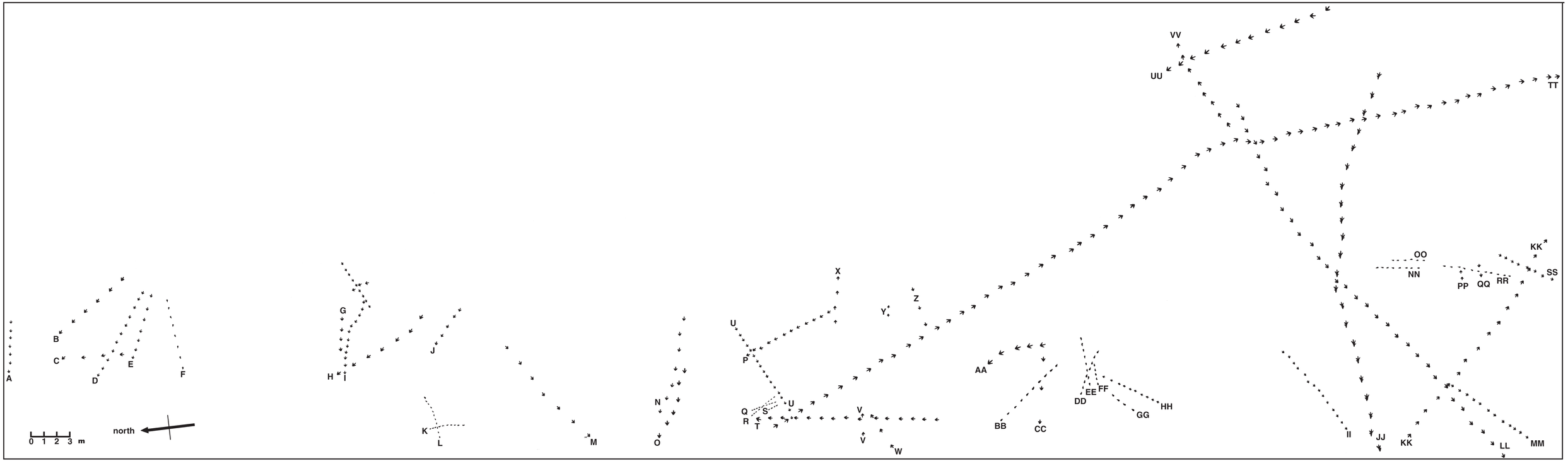

FIGURE 3. Map of Site II, Hadetu.

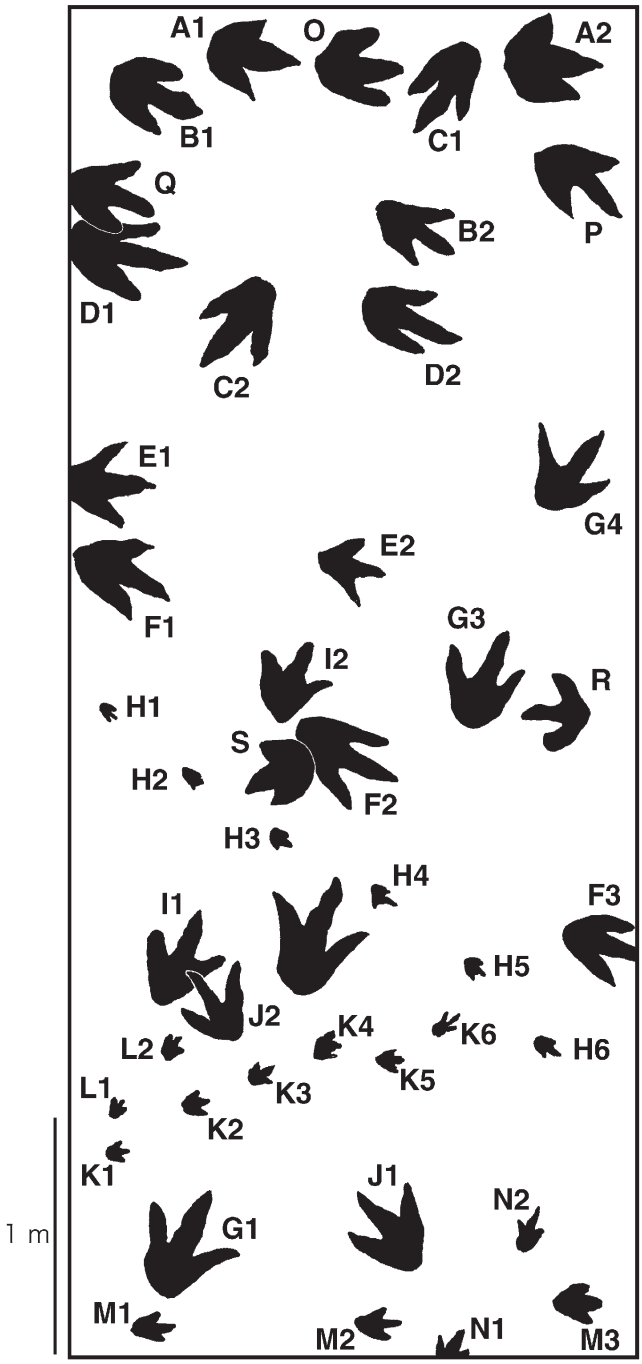

FIGURE 4. Trackway map of cast of section of Site III (Ahrubulage) as displayed in the Museum of Inner Mongolia, Hohhot.

DESCRIPTION

Footprints of Chabu Sumu, apparently made by theropods (Types 1, 2, 5 and 6) and ornithopods (Types 3 and 4), represent at least six different types, based on morphology (Tables 1, 2, 3 and 4).

Type 1 footprints are relatively large with an average width and length of 31 cm and 41 cm, respectively. They are tridactyl, with well preserved digital pads and claw marks. Type 2 footprints are of moderate size, tridactyl and have an average width and length of 24 cm and 33 cm, respectively. They also have preserved digital pads and sharp terminal claw marks. This type of footprint is smaller with a narrower divarication angle between digits II and IV than in Type 1. Type 5 footprints are large with an average width and length of 31 cm and 59 cm, respectively. This footprint type has a posterior extension into the metatarsal impression of the hallux ; Types 1 and 2 have with no trace of a hallux. Type 6 footprints do not have distinct toe impressions and are teardrop-shaped with an average width and length of 6 cm and 9 cm, respectively. This type of footprint has quite a distinct morphology from Types 1, 2 and 5. Types 1, 2, 5 and 6 were clearly produced by bipedal theropods.

Type 3 footprints are of small size and tridactyl. Their average width and length are 8 cm and 11 cm, respectively, with a single, large pad situated under each digit and broad metatarsal “heel” pad. Type 4 footprints are large, tridactyl, and have a single, large digital pad and broad metatarsal “heel” pad. They average 30 cm in width and 26 cm in length. Type 4 differs from Type 3 in that the toes taper uniformly from their base to a blunt claw impression in Type 4. Types 3 and 4 footprints belong to ornithopods.

Footprint Type 1 (Fig. 5-A1, 2) : Footprints of the first type are found at Site I (E, ?I), Site II (T, TT) and Site III (A, B, E, G, I, J, ?O, ?P, ?R). A large theropod with footprints nearly half a meter long made the most distinct impressions. Trackway G from Site III (Fig. 4) is so well preserved that even the digital pads are preserved. There are two distinct pads on the ventral side of the second digit, three under the third and at least two, less distinct pads under the fourth toe. Toe impressions taper anteriorly and end in sharp points, where the unguals sunk into the mud. The middle ungual points forward, whereas the unguals of the second and fourth digits are rotated somewhat outward from the midline of the track. The metatarsal “heel” impression has a smoothly rounded posterior margin with no trace of a hallux. In trackway G, the length of the third digit is 48 cm, the second 37 cm, and the fourth 39 cm. The footprints average 38 cm in width in trackway G. The second digit is slightly thicker at its base (8.5 cm) than the third and fourth (which are each 7.5 cm wide). Pace length along the trackway averages 123 cm, and stride length 251 cm. The distal ends of the metatarsals and the first phalanx of each toe are not distinct in these footprints and appear to have been supported ventrally by a thin metatarsal pad. The pads on the underside of each toe appear to have been intraphalangeal in position. The size and morphology of this type of print suggest an assignment to the ichnogenus *Eubrontes.*

Footprint Type 2 (Fig. 5-B1, 2) : Examples of the second footprint type are found at Site III (?C, D, F, M, N, Q). They are similar to Type 1 footprints in most respects, especially in that

TABLE 1. Distribution of left and right footprints and measurements of each from Site I, Chabu Shamu Touli.

#	R/L	FW	FL	P	S	SA	#	R/L	FW	FL	P	S	SA
A1	R	183	220	––	––	––	J14	L	151	204	600	1300	173
A2	L	180	221	1000	––	168	J15	R	151	206	600	1200	––
A3	R	180	220	1250	2020	174	K1	L	260	300	––	––	––
A4	L	176	218	1050	2030	176	K2	R	251	310	1495	––	171
A5	R	182	220	1150	2025	––	K3	L	240	306	1490	2800	173
B1	L	220	270	––	––	––	K4	R	245	300	1500	2850	162
B2	R	218	272	2150	––	174	K5	L	250	305	1500	2850	175
B3	L	221	271	2100	3200	163	K6	R	241	306	1300	2750	172
B4	R	210	270	1930	2900	––	K7	L	240	310	1350	2800	173
C1	L	130	180	––	––	––	K8	R	250	315	1400	2750	173
C2	R	127	181	700	––	168	K9	L	241	305	1550	2950	178
C3	L	131	180	650	1320	––	K10	R	243	308	1000	2520	––
D1	L	252	290	––	––	––	L1	L	140	160	––	––	––
D2	R	250	291	1320	––	––	L2	R	143	161	600	––	105
E1	R	400	480	––	––	––	L3	L	140	161	600	1200	166
E2	L	410	486	1350	––	177	L4	R	141	163	650	1495	178
E3	R	400	482	1495	2800	178	L5	L	138	160	660	1550	174
E4	L	399	480	1360	2750	178	L6	R	139	161	550	1203	169
E5	R	400	480	1490	2700	174	L7	L	134	160	530	1160	176
E6	L	404	481	1495	2750	173	L8	R	136	159	650	1150	168
E7	R	401	480	1490	2850	171	L9	L	146	161	500	1150	174
E8	L	403	485	1485	2750	177	L10	R	142	160	700	1200	173
E9	R	400	480	1495	2800	––	L11	L	140	162	550	1230	167
F1	L	230	290	––	––	––	L12	R	141	160	550	1110	171
F2	R	233	294	1120	––	173	L13	L	139	161	500	1050	174
F3	L	230	291	1050	2100	174	L14	R	144	160	500	1000	168
F4	R	228	290	1150	2200	179	L15	L	141	162	496	950	––
F5	L	230	292	1300	2495	177	M1	R	140	170	––	––	––
F6	R	235	293	1020	2250	––	M2	L	140	171	790	––	172
G1	R	150	190	––	––	––	M3	R	135	169	750	1450	160
G2	L	147	190	990	––	176	M4	L	130	169	800	1420	156
G3	R	138	193	750	1650	175	M5	R	141	170	630	1400	165
G4	L	154	191	750	1500	171	M6	L	139	168	570	1150	176
G5	R	148	190	600	1500	––	M7	R	140	172	950	1500	178
H1	L	270	380	––	––	––	M8	L	137	170	700	1580	177
H2	R	273	381	1400	––	173	M9	R	130	171	720	1350	179
H3	L	280	379	1000	2400	172	M10	L	140	173	750	1430	––
H4	R	265	380	1050	2000	174	N1	R	210	230	––	––	––
H5	L	270	380	1100	2100	173	N2	L	206	230	1170	––	178
H6	R	260	379	1200	2300	164	N3	R	200	228	1230	2320	179
H7	L	280	383	1320	2000	169	N4	L	208	230	1070	2270	179
H8	R	270	381	1150	1950	174	N5	R	213	235	1050	2100	176
H9	L	269	380	1350	2002	––	N6	L	205	229	1100	2180	174
I1	L	280	390	––	––	––	N7	R	210	230	970	2060	177
I2	R	300	400	1503	––	176	N8	L	195	227	1050	2000	170
I3	L	300	410	1305	3200	175	N9	R	190	229	1060	2100	174
I4	R	290	395	1300	3000	179	N10	L	205	230	1030	2050	178
I5	L	300	400	1250	2950	178	N11	R	200	230	1140	2200	178
I6	R	310	395	1350	3003	178	N12	L	203	231	985	2100	––
I7	L	300	412	1500	3200	178	O1	L	140	160	––	––	––
I8	R	298	401	1250	3005	176	O2	R	135	160	600	––	170
I9	L	296	410	1150	2024	175	O3	L	116	150	550	1200	178
I10	R	294	389	890	2004	––	O4	R	130	160	570	1102	171
J1	R	150	200	––	––	––	O5	L	115	150	600	1155	172
J2	L	160	220	700	––	176	O6	R	132	161	490	1050	178
J3	R	140	200	650	1300	175	O7	L	126	157	520	950	163
J4	L	150	210	550	1150	157	O8	R	132	162	500	980	166
J5	R	140	200	650	1150	162	O9	L	141	165	550	985	165
J6	L	140	200	700	1350	169	O10	R	131	160	580	1100	158
J7	R	145	210	750	1400	170	O11	L	126	158	700	1200	160
J8	L	145	215	700	1350	170	O12	R	113	152	710	1300	168
J9	R	143	210	650	1400	179	O13	L	135	164	650	1350	––
J10	L	151	210	700	1495	178	P	R	110	160	––	––	––
J11	R	145	210	550	1250	178	Q	R	130	170	––	––	––
J12	L	146	200	800	1350	178	R	R	260	320	––	––	––
J13	R	150	201	700	1500	179							

: footprint number
R/L: right/left
FW: footprint width (mm)
FL : footprint length (mm)
P : pace (mm)
S : stride (mm)
SA : stride angle (°)

their impressions taper anteriorly into sharp claw marks, the second toe is shorter than the fourth and the phalangeal pads are well defined. Made by theropod dinosaurs, these footprints are smaller and relatively narrower than those of Type 1. More importantly, ungual impressions of the second and fourth digits are aligned with the longitudinal axes of the associated toes, rather than diverging away from the midline of the footprint. It is conceivable that the trackmaker was a younger individual of the form that made the Type 1 footprints. F2 from Site III (Fig. 4) is a typical example of this footprint type. It is 38 cm long and 26 cm wide, with a second digit that is 28 cm long and a fourth that is 30 cm. Pace length along the trackway averages 128 cm and the stride 255 cm. The size and morphology of this type are similar to footprints of both *Anchisauripus* and *Grallator.*

Footprint Type 3 (Fig. 5-C1, 2) : The third type of footprints was made by small bipedal ornithopods. Trackways H (plus K and L) from Site III includes six examples of this type of footprint, the best examples of which are 10.6 cm long and 7.7 cm wide. There is a prominent, wide metatarsal “heel” pad, and

TABLE 2. Distribution of left and right footprints and measurements of each from Site II, Chabu Sumu Hadetu.

#	R/L	FW	FL	P	S	SA	#	R/L	FW	FL	P	S	SA	#	R/L	FW	FL	P	S	SA
A1	L	116	190	––	––	––	L4	R	42	76	350	750	171	U8	L	91	120	530	1030	178
A2	R	135	206	750	––	169	L5	L	41	75	340	700	172	U9	R	92	120	480	1000	176
A3	L	130	200	740	1450	177	L6	R	42	76	330	650	174	U10	L	91	122	500	997	175
A4	R	120	196	738	1300	178	L7	L	43	76	330	680	171	U11	R	91	124	490	950	177
A5	L	134	200	745	1350	178	L8	R	42	77	350	650	169	U12	L	90	120	500	955	178
A6	R	135	202	725	1250	176	L9	L	41	76	350	700	176	U13	R	89	120	497	1000	177
A7	L	131	200	745	1245	––	L10	R	43	78	300	650	160	U14	L	91	122	496	980	177
B1	L	230	300	––	––	––	L11	L	42	76	350	590	––	U15	R	90	122	502	1000	178
B2	R	230	305	1300	––	177	M1	L	240	290	––	––	––	U16	L	91	123	452	1050	177
B3	L	233	300	1350	2550	176	M2	R	243	290	1580	––	178	U17	R	92	120	505	980	––
B4	R	235	306	1260	3000	177	M3	L	241	292	1600	3150	179	V1	R	160	280	––	––	––
B5	L	234	308	1300	3050	178	M4	R	240	290	1570	3120	170	V2	L	163	282	1450	––	––
B6	R	230	300	1260	2650	––	M5	L	243	290	1550	3070	177	W1	R	220	300	––	––	––
C1	L	240	320	––	––	––	M6	R	242	293	1500	3050	176	W2	L	228	305	1300	––	176
C2	R	247	325	1550	––	177	M7	L	240	290	1600	3130	176	W3	R	220	302	1500	2300	––
C3	L	245	325	1500	3050	178	N1	R	150	280	––	––	––	X1	R	150	160	––	––	––
C4	R	245	320	1495	2950	––	N2	L	150	281	1150	––	176	X2	L	151	164	1100	––	173
D1	L	80	130	––	––	––	N3	R	152	280	1100	2250	171	X3	R	150	162	1170	2300	170
D2r	R	89	133	650	––	174	N4	L	151	283	1300	2320	178	X4	L	150	160	1080	2250	––
D3	L	90	130	750	1495	172	N5	R	150	280	1500	2800	174	Y1	L	70	130	––	––	––
D4	R	95	135	850	1600	172	N6	L	152	280	1270	2750	171	Y2	R	70	131	680	––	––
D5	L	89	130	780	1580	173	N7	R	151	282	1250	2500	––	Z1	L	230	270	––	––	––
D6	R	90	130	750	1500	176	O1	R	290	330	––	––	––	Z2	R	230	270	1350	––	178
D7	L	94	133	755	1500	177	O2	L	275	329	1100	––	176	Z3	L	230	271	1270	2850	––
D8	R	90	132	750	1505	179	O3	R	286	331	1000	2080	167	AA1	L	310	400	––	––	––
D9	L	89	130	850	1550	178	O4	L	289	330	1080	2000	165	AA2	R	310	403	1120	––	158
D10	R	98	130	750	1550	179	O5	R	280	330	1300	2330	159	AA3	L	312	401	1220	2700	171
D11	L	90	132	600	1300	––	O6	L	285	328	1080	2320	––	AA4	R	311	400	1030	2750	177
E1	R	110	132	––	––	––	P1	L	120	180	––	––	––	AA5	L	311	406	1000	2010	––
E2	L	115	133	650	––	174	P2	R	122	180	650	––	157	BB1	L	70	100	––	––	––
E3	R	115	131	750	1495	176	P3	L	121	181	610	1150	158	BB2	R	72	100	680	––	176
E4	L	116	135	800	1525	175	P4	R	120	183	700	1250	175	BB3	L	71	101	730	1490	177
E5	R	110	130	950	1700	177	P5	L	122	181	630	1300	178	BB4	R	71	103	720	1450	177
E6	L	110	134	900	1800	178	P6	R	121	180	750	1350	179	BB5	L	72	100	640	1350	178
E7	R	115	135	1050	1930	178	P7	L	121	180	610	1350	174	BB6	R	70	101	650	1300	177
F1	L	105	130	––	––	––	P8	R	122	181	600	1245	178	BB7	L	71	104	700	1350	175
F2	R	100	129	680	––	178	P9	L	120	180	740	1310	176	BB8	R	72	106	670	1380	174
F3	L	98	129	700	1350	177	P10	R	123	180	615	1270	175	BB9	L	71	104	640	1250	175
F4	R	98	127	680	1400	177	P11	L	120	182	608	1250	177	BB10	R	70	100	600	1220	––
F5	L	100	130	800	1500	178	P12	R	120	181	650	1300	––	CC1	L	180	250	––	––	––
F6	R	96	129	900	1750	177	Q1	R	51	70	––	––	––	CC2	R	189	252	2300	––	176
F7	L	90	128	890	1750	178	Q2	L	54	72	200	––	175	CC3	L	180	248	2580	4850	––
F8	R	103	130	850	1700	––	Q3	R	50	70	245	400	173	DD1	R	80	100	––	––	––
G1	L	200	250	––	––	––	Q4	L	51	70	250	450	172	DD2	L	81	104	500	––	176
G2	R	204	253	800	––	176	Q5	R	52	71	350	553	156	DD3	R	80	101	490	950	175
G3	L	201	250	750	1550	174	Q6	L	54	71	255	510	157	DD4	L	79	100	492	956	174
G4	R	200	250	850	1600	––	Q7	R	53	73	253	495	173	DD5	R	80	100	600	1050	175
H1	R	240	320	––	––	––	Q8	L	50	72	250	498	174	DD6	L	81	102	500	1100	177
H2	L	235	305	1400	––	177	Q9	R	51	72	252	500	––	DD7	R	80	102	520	1000	169
H3	R	230	300	1350	2720	175	R1	L	54	72	––	––	––	DD8	L	81	104	550	1030	––
H4	L	234	305	1400	2700	174	R2	R	56	74	310	––	178	EE1	L	81	102	––	––	––
H5	R	240	310	1430	2800	176	R3	L	53	73	280	551	176	EE2	R	80	102	490	––	177
H6	L	242	315	1250	2600	154	R4	R	54	72	275	550	173	EE3	L	81	104	500	940	176
H7	R	240	320	1350	2550	––	R5	L	52	72	350	620	175	EE4	R	80	102	520	1020	177
I1	L	90	140	––	––	––	R6	R	54	73	300	680	178	EE5	L	78	101	560	1070	175
I2	R	89	140	580	––	178	R7	L	51	71	310	620	177	EE6	R	80	100	546	1050	174
I3	L	91	142	590	1150	173	R8	R	52	71	250	550	175	EE7	L	81	104	570	1060	176
I4	R	92	141	540	1050	177	R9	L	50	72	254	450	––	EE8	R	81	102	550	1080	––
I5	L	90	140	520	980	175	S1	L	72	90	––	––	––	FF1	R	79	101	––	––	––
I6	R	91	140	540	1020	174	S2	R	72	91	522	––	174	FF2	L	81	103	420	––	177
I7	L	90	141	650	1080	164	S3	L	71	91	251	510	172	FF3	R	81	100	400	800	176
I8	R	92	142	520	1100	160	S4	R	72	90	230	498	––	FF4	L	80	104	385	700	178
I9	L	90	140	540	950	161	T1	L	230	330	––	––	––	FF5	R	81	101	400	750	––
I10	R	90	140	600	1080	169	T2	R	235	334	900	––	177	GG1	R	81	100	––	––	––
I11	L	92	141	550	1100	163	T3	L	240	330	1000	1850	176	GG2	L	80	101	750	––	177
I12	R	90	140	590	1100	163	T4	R	240	336	1050	2000	178	GG3	R	78	101	650	1400	173
J1	L	110	152	––	––	––	T5	L	238	335	1000	2050	177	GG4	L	81	103	600	1200	––
J2	R	100	150	750	––	174	T6	R	230	335	1030	2000	176	HH1	LL	90	120	––	––	––
J3	L	110	154	850	1600	175	T7	L	235	334	950	1950	168	HH2	R	93	121	700	––	176
J4	R	112	154	950	1800	173	T8	R	250	340	1050	1900	170	HH3	L	92	121	650	1350	172
J5	L	110	150	700	1650	––	T9	L	256	351	1050	2000	169	HH4	R	91	120	480	1100	173
K1	R	49	82	––	––	––	T10	R	260	355	1080	2350	168	HH5	L	90	121	520	1000	169
K2	L	45	80	250	––	175	T11	L	260	350	950	2150	168	HH6	R	92	123	442	980	164
K3	R	45	80	245	490	172	T12	R	262	356	1050	1900	173	HH7	L	91	124	570	1020	171
K4	L	46	82	350	550	178	T13	L	250	345	1000	2000	175	HH8	R	90	123	498	1000	172
K5	R	45	81	300	600	176	T14	R	251	342	1000	1850	176	HH9	L	91	121	520	980	172
K6	L	44	80	350	650	171	T15	L	250	350	1030	1860	––	HH10	R	94	123	497	950	177
K7	R	46	83	320	650	172	U1	R	90	120	––	––	––	HH11	L	90	120	610	1050	––
K8	L	48	80	300	670	176	U2	L	91	124	600	––	163	II1	L	90	150	––	––	––
K9	R	46	80	255	550	178	U3	R	90	121	620	1250	176	II2	R	92	150	600	––	177
K10	L	49	82	400	680	178	U4	L	90	122	500	1100	175	II3	L	91	152	620	1200	178
L1	L	42	76	––	––	––	U5	R	92	120	450	998	172	II4	R	89	151	598	1120	174
L2	R	44	78	400	––	178	U6	L	90	120	530	995	173	II5	L	90	150	700	1300	173
L3	L	41	76	380	680	176	U7	R	91	123	510	1050	177	II6	R	92	150	650	1370	175

TABLE 2. (continued)

#	R/L	FW	FL	P	S	SA	#	R/L	FW	FL	P	S	SA	#	R/L	FW	FL	P	S	SA
II7	L	93	153	580	1170	171	LL25	L	302	402	1270	2300	161	TT14	L	302	415	800	1900	173
II8	R	91	152	570	1080	164	LL26	R	300	400	1100	2300	150	TT15	R	290	389	1350	2080	174
II9	L	94	156	550	1050	145	LL27	L	300	403	1150	2100	160	TT16	L	280	390	1120	2480	172
II10	R	91	151	620	1120	153	LL28	R	300	400	1170	2250	167	TT17	R	271	384	1000	2160	171
II11	L	90	150	750	1100	172	LL29	L	290	403	1080	2220	162	TT18	L	290	392	1080	2030	174
II12	R	92	150	520	1220	176	LL30	R	300	442	1200	2230	160	TT19	R	260	384	930	2000	175
II13	L	91	153	630	1120	168	LL31	L	300	440	1000	2150	174	TT20	L	273	390	1010	1900	176
II14	R	90	151	580	1200	––	LL32	R	280	382	1150	2100	––	TT21	R	300	401	1150	2100	172
JJ1	L	320	560	––	––	––	MM1	L	100	130	––	––	––	TT22	L	300	408	1020	2110	169
JJ2	R	350	580	1380	––	154	MM2	R	80	130	650	––	176	TT23	R	303	410	1150	2220	168
JJ3	L	345	580	1370	2630	170	MM3	L	80	129	570	1200	177	TT24	L	301	409	1100	2180	170
JJ4	R	310	576	1400	2740	177	MM4	R	96	130	450	1050	175	TT25	R	300	387	1080	2130	154
JJ5	L	320	590	1490	2870	171	MM5	L	100	130	670	1100	176	TT26	L	298	411	1000	2070	176
JJ6	R	320	600	1550	2955	174	MM6	R	100	132	800	1500	178	TT27	R	300	430	1010	2000	168
JJ7	L	328	605	1350	2850	173	MM7	L	98	131	650	1450	179	TT28	L	295	427	1180	2200	177
JJ8	R	330	590	1570	2930	174	MM8	R	96	130	830	1500	175	TT29	R	297	415	1030	2180	164
JJ9	L	334	598	1497	3030	174	MM9	L	100	130	650	1450	176	TT30	L	290	418	1420	2350	177
JJ10	R	309	590	1350	2800	170	MM10	R	100	132	700	1300	172	TT31	R	280	390	1430	2800	169
JJ11	L	310	600	1270	2550	174	MM11	L	98	130	720	1350	175	TT32	L	290	416	1200	2670	175
JJ12	R	307	602	1480	2650	178	MM12	R	100	130	700	1330	––	TT33	R	300	420	1250	2500	174
JJ13	L	305	600	1430	2850	176	NN1	L	80	120	––	––	––	TT34	L	300	421	1210	2400	171
JJ14	R	304	600	1400	2730	175	NN2	R	78	120	600	––	176	TT35	R	294	402	1250	2430	177
JJ15	L	300	604	1360	2600	173	NN3	L	82	122	450	980	174	TT36	L	281	398	1400	2600	177
JJ16	R	300	602	1300	2650	176	NN4	R	80	124	550	950	177	TT37	R	290	398	1250	2580	178
JJ17	L	302	590	1400	2950	177	NN5	L	81	120	600	1050	168	TT38	L	287	397	1230	2440	172
JJ18	R	300	589	1550	3100	178	NN6	R	79	121	500	1000	174	TT39	R	300	401	850	2010	153
JJ19	L	302	600	1580	2850	174	NN7	L	80	120	453	900	172	TT40	L	304	421	1520	2250	167
JJ20	R	307	594	1350	2900	175	NN8	R	81	120	450	830	––	TT41	R	304	432	1200	2670	177
JJ21	L	310	601	1550	2970	175	OO1	R	90	127	––	––	––	TT42	L	291	390	1330	2490	178
JJ22	R	306	600	1551	3070	175	OO2	L	89	129	550	––	173	TT43	R	293	397	1300	2580	173
KK1	L	270	320	––	––	––	OO3	R	89	127	530	1050	163	TT44	L	296	415	1050	2340	163
KK2	R	268	320	1350	––	171	OO4	L	91	127	470	950	172	TT45	R	300	417	1250	2300	173
KK3	L	260	315	1200	2550	177	OO5	R	90	128	610	1100	177	TT46	L	301	420	1330	1900	167
KK4	R	260	318	1150	2320	173	OO6	L	86	126	400	1000	––	TT47	R	302	420	1050	2350	174
KK5	L	271	320	1100	2250	165	PP1	L	103	130	––	––	––	TT48	L	293	410	1230	2200	155
KK6	R	265	324	1250	2300	173	PP2	R	105	133	570	––	––	TT49	R	295	416	1180	2300	144
KK7	L	270	325	1300	2520	169	QQ1	R	108	132	––	––	––	TT50	L	300	420	1500	2500	177
KK8	R	260	314	1200	2450	171	QQ2	L	107	132	800	––	––	TT51	R	301	424	1190	2600	174
KK9	L	270	320	1450	2530	168	RR1	R	76	131	––	––	––	TT52	L	298	411	1430	2650	166
KK10	R	269	321	1350	2800	161	RR2	L	70	130	450	––	177	TT53	R	300	411	1050	2560	165
KK11	L	261	320	1180	2500	163	RR3	R	78	132	500	950	178	TT54	L	304	421	1180	2230	174
KK12	R	270	320	1220	2280	173	RR4	L	77	131	600	1070	176	TT55	R	296	415	1270	2420	178
KK13	L	268	316	1270	2470	170	RR5	R	70	130	450	1000	175	TT56	L	300	420	1360	2600	177
KK14	R	269	320	1420	2680	165	RR6	L	72	130	650	1050	173	TT57	R	300	421	1300	2650	176
KK15	L	274	321	1150	2520	177	RR7	R	72	131	550	1150	175	TT58	L	301	424	1200	2450	175
KK16	R	270	320	1230	2300	––	RR8	L	71	129	660	1130	176	TT59	R	300	419	1170	2480	178
LL1	L	280	380	––	––	––	RR9	R	70	130	450	1070	164	TT60	L	297	419	1320	2500	175
LL2	R	300	370	1300	––	175	RR10	L	70	130	650	1030	176	TT61	R	298	418	970	2200	––
LL3	L	305	350	1170	2420	164	RR11	R	73	131	600	1200	––	UU1	R	380	390	––	––	––
LL4	R	302	400	1150	2250	156	SS1	L	126	186	––	––	––	UU2	L	384	402	1070	––	177
LL5	L	300	390	1330	2350	167	SS2	R	129	187	800	––	167	UU3	R	382	400	1050	2100	172
LL6	R	303	402	1100	2330	163	SS3	L	130	190	750	1030	173	UU4	L	380	400	1200	2250	176
LL7	L	300	403	1150	2350	171	SS4	R	130	190	700	940	172	UU5	R	385	410	1400	2570	174
LL8	R	302	440	1120	2220	163	SS5	L	122	184	750	950	173	UU6	L	370	393	1200	2560	176
LL9	L	300	440	1070	2150	165	SS6	R	110	181	550	1270	174	UU7	R	360	396	1150	2300	177
LL10	R	300	442	1250	2200	173	SS7	L	106	180	600	1130	176	UU8	L	360	398	1350	2500	178
LL11	L	298	440	1100	2250	170	SS8	R	100	181	580	1100	––	UU9	R	378	400	1200	2580	177
LL12	R	303	445	1170	2200	170	TT1	R	250	380	––	––	––	UU10	L	380	402	1250	2450	178
LL13	L	302	445	1150	2250	166	TT2	L	261	384	700	––	175	UU11	R	381	410	1350	2530	177
LL14	R	320	443	1100	2170	173	TT3	R	266	385	1130	1300	178	UU12	L	380	410	1400	2700	––
LL15	L	301	440	1170	2230	169	TT4	L	262	385	1140	2160	173	VV1	R	290	340	––	––	––
LL16	R	302	447	1070	2180	175	TT5	R	250	380	1170	2200	173	VV2	L	289	340	1000	––	173
LL17	L	303	445	1200	2200	169	TT6	L	250	381	1100	2270	171	VV3	R	291	342	1170	2150	169
LL18	R	300	442	800	1980	157	TT7	R	294	386	1270	2360	167	VV4	L	290	340	1350	2460	165
LL19	L	304	443	1400	2100	171	TT8	L	290	382	850	2150	166	VV5	R	290	341	970	3150	156
LL20	R	300	440	930	2300	168	TT9	R	301	400	960	1800	163	VV6	L	292	344	960	1900	159
LL21	L	302	440	1200	2050	160	TT10	L	304	410	950	2000	172	VV7	R	288	340	1130	2050	167
LL22	R	300	443	1280	2350	162	TT11	R	297	395	1220	2230	168	VV8	L	290	341	1050	2100	––
LL23	L	300	450	1250	2480	171	TT12	L	290	390	900	2150	162							
LL24	R	290	390	1100	2350	174	TT13	R	300	400	1100	2080	171							

a single large pad under each toe. The second digit is 7.5 cm long and the fourth 7.8 cm. The narrow trackway (Fig. 4) illustrates that the animal had a relatively long stride, averaging 94 cm.

Footprint Type 4 (Fig. 5D) : Made by a larger ornithopod, the fourth type of footprint (S of Site III ; Fig. 4) is 30 cm long, with a second digit 21.5 cm in length, and a fourth digit of 25.5 cm length. As in the third footprint type, Type 4 has a broad (14.5 cm) "heel" pad impression and a single, broad pad under each toe (7.8, 9.0 and 8.5 cm wide for the second, third and fourth digits respectively). Unlike Type 3 footprints, in which the toes taper uniformly from the base to the bluntly pointed ungual impressions, digit impressions of Type 4 are narrow at the point where they separate from each other and become broadest near the mid-length of each toe. No trackways have been identified

TABLE 3. Distribution of left and right footprints and measurements of each from Site III, Ahrubulage.

#	R/L	FW	FL	P	S	SA
A1	?L	370	400	––	––	––
A2	?R	370	390	1280	––	––
B1	R	310	420	––	––	––
B2	L	310	380	1250	––	––
C1	?R	280	400	––	––	––
C2	?L	330	440	1390	––	––
D1	R	360	470	––	––	––
D2	L	310	450	1200	––	––
E1	L	330	350+	––	––	––
E2	R	340	370	1110	––	––
F1	?L	260	380	––	––	––
F2	?R	260	380	1260	––	––
F3	?L	260	360+	1300	2550	––
G1	R	370	480	––	––	––
G2	L	410	480	1410	––	––
G3	R	370	450	1300	2700	––
G4	L	280+	400+	––	––	––
H1	L	75	105	––	––	––
H2	R	80	130	350	––	––
H3	L	80	107	440	890	––
H4	R	80	110	500	940	––
H5	L	80	110	460	980	––
H6	R	850	110	440	920	––
I1	?	330	440	––	––	––
I2	?	320	370	1260	––	––
J1	?	390	410	––	––	––
J2	?	410	410	1230	––	––
K1	R	70	100	––	––	––
K2	L	80	100	410	––	––
K3	R	85	105	300	680	––
K4	L	70	110	280	540	––
K5	R	––	––	290	550	––
K6	L	80	110	300	600	––
L1	?R	70	100	––	––	––
L2	?L	70	100	340	––	––
M1	?L	150	210	––	––	––
M2	?R	150	210	980	––	––
M3	?L	130	210	860	1840	––
N1	?	140	200	––	––	––
N2	?	150	200	620	––	––
O	?	340	450	––	––	––
P	?	340	360	––	––	––
Q	?	310	400	––	––	––
R	?	290	390	––	––	––
S	?	260	300	––	––	––

for this footprint type, which was clearly made by either a hadrosaur or an iguanodont.

Footprint Type 5 (Fig. 5E) : Type 5 footprints were produced by a single, large theropod dinosaur, and are all part of a single trackway (JJ) at Site II (Fig. 3). The 22 footprints average 59 cm in length and 31 cm in width, and are aligned in a narrow trackway (step angle is 173 degrees) with an average stride length of 2.8 m. The major difference between these footprints and those of Types 1 and 2 is the posterior extension of each into a metatarsal impression with the hallux. The footprints are no more deeply impressed than any of the other theropod trackways at this site. However, it is possible that the animal sunk deep enough into the mud to leave its hallux and metatarsal impression and then the footprints filled with wet mud (see Gatesy et al., 1999). Average width of JJ tracks is 31.5 cm, which is intermediate between that of Types 1 and 2 footprints.

Footprint Type 6 (Fig. 5F) : The sixth type of footprint is from the Site II (F, K, L, Q, R, S, BB, DD, EE, FF, GG, NN, OO, RR ; Fig. 2) and is teardrop shaped, representing the

TABLE 4. Trackway orientations were taken from site maps, with the direction being determined by the first and last footprints in each series. The "Orientation" column records degrees from north (it is unknown whether the first author used true north or magnetic north in mapping Sites I and II). Unfortunately, the orientation of the cast prepared of the Site III slab is unknown, so compass orientation of the footprints cannot be determined.

Trackway	Identification	Orientation (°)
II–A		100
II–B		146
II–C		182
II–D		126
II–E		113
II–F	6	84
II–G		100
II–H		152
II–I		112
II–J		131
II–K	6	2
II–L	6	256
II–M		54
II–N		111
II–O		117
II–P		159
II–Q	6	348
II–R	6	147
II–S	6	339
II–T	1	187
II–U		64
II–V		275
II–W		243
II–X		280
II–Y		278
II–Z		77
II–AA		167
II–BB	6	322
II–CC		100
II–DD	6	120
II–EE	6	86
II–FF	6	267
II–GG	6	224
II–HH		213
II–II		57
II–JJ	5	97
II–KK		312
II–LL		60
II–MM		42
II–NN	6	188
II–OO	6	187
II–PP		267
II–QQ		89
II–RR	6	196
II–SS		32
II–TT	1	343
II–UU		166
II–VV		245
III–A	1	
III–B	1	
III–C	2	
III–D	2	
III–E	1	
III–F	2	
III–G	1	
III–H	3	
III–I	1	
III–J	1	
III–K	3	
III–L	3	
III–M	2	
III–N	2	
III–O	1	
III–P	1	
III–Q	2	
III–R	1	
III–S	4	

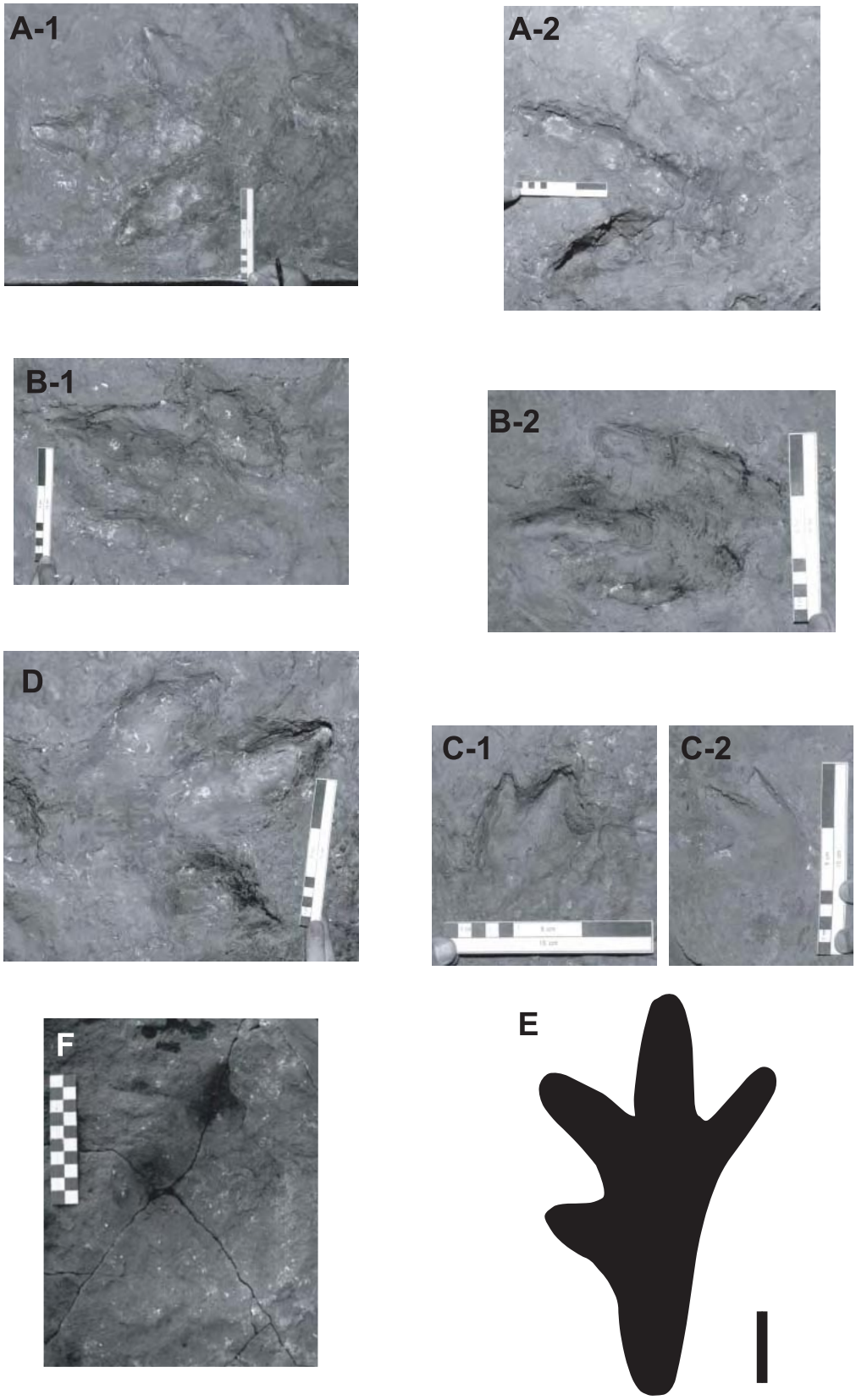

FIGURE 5. Examples of Type 1 to Type 6 footprints from the Lower Cretaceous rocks west of Chabu Sumu. **A**, Type 1 footprint ; **B**, Type 2 footprint ; **C**, Type 3 footprint ; **D**, Type 4 footprint ; **E**, Type 5 footprint ; **F**, Type 6 footprint. Scale bars equal 15 cm (**A–D**), 10 cm (**E–F**).

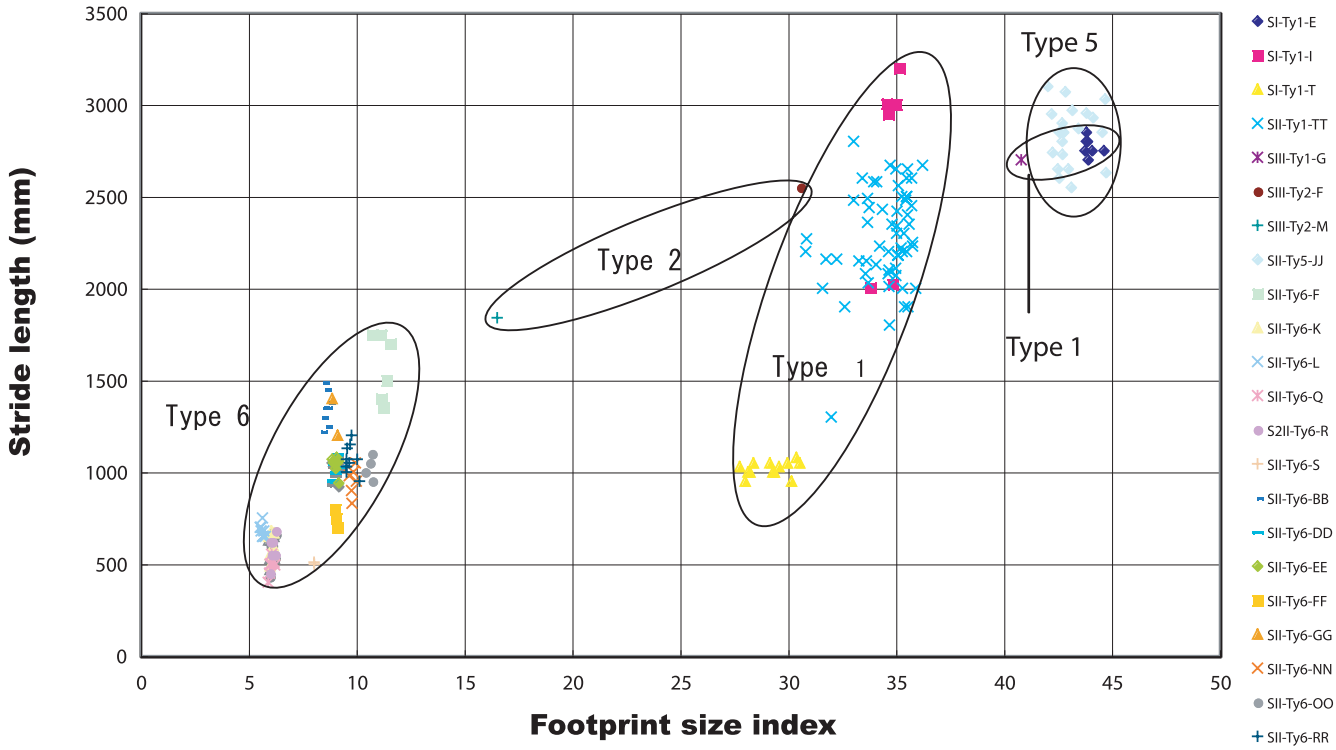

FIGURE 6. Scatter diagram showing the relationship of stride length to footprint size index for theropod pes footprints from the Ordos Basin. SI-Ty-E : Site number-Footprint type-Trackway number.

impressions left by animals walking through water-saturated mud. As they withdrew their feet from the mud, the mud simply flowed back into the footprint void. The supposed front of the footprint is the broad part of the teardrop. The impression tapers posteriorly, where it also curves towards the midline of the trackway. This suggests that the animal was rotating its body as it walked, swinging its legs inward to bring them under the body. Although infilling makes it impossible to determine size of animals making the footprints, the footprints themselves are small (from 10 to 13 cm long), the trackways narrow and in most cases pace and stride measurements are relatively short. This suggests that most of the trackmakers were themselves small individuals. As all animals were walking through the same mucky substrate, stride and pace measurements may be a better indication of the size of the trackmakers than the measurements of the footprints themselves. There is really no way of knowing just how much each footprint was infilled, but because all animals were probably restricted to a walk as they crossed the mud flats, a rough correlation between animal size and stride length can be assumed. Taller and more elongate animals might produce trackways of teardrop-shaped footprints with the longest strides (F, BB, GG), rather than the trackways with short strides (FF). In terms of identification, all have narrow trackways (step angles range between 156 and 178 degrees), suggesting that they were made by theropods.

DISCUSSION

All dinosaur footprint sites in this study are considered to have been under a fluvio-lacustrine regime, bordering a large lake in Early Cretaceous times.

Since Yabe et al. (1940) and Shikama (1942) reported *Grallator s-satoi* from the Early Cretaceous of Yangshan, Liaoning Province, no large dinosaur footprints were reported from northern China until the 1990's. Recently, however, several dinosaur footprint sites from China, such as at Luanping in Hebei Province, Yanguoxia in Gansu Province and the Ordos Basin, have been discovered (Li et al., 2002a, b ; Lockley et al., 2002 ; You and Azuma, 1995). Trackways of both large and small theropods, as well as bipedal and quadrupedal ornithopods occur at the Luanping site (You and Azuma, 1995). Luanping theropod footprints are similar to Type 1 or Type 2 ichnites in this paper, and bipedal ornithopod footprints are Type 4. Large and small theropod, sauropod, ornithopod, bird and pterosaur trackways have been preserved in Yanguoxia of Gansu Province (Li et al., 2002a, b). Theropod footprints at Yanguoxia are similar to Type 1 or Type 2 footprints of the Ordos Basin, but Type 3 and Type 4 ornithopod footprints have not been

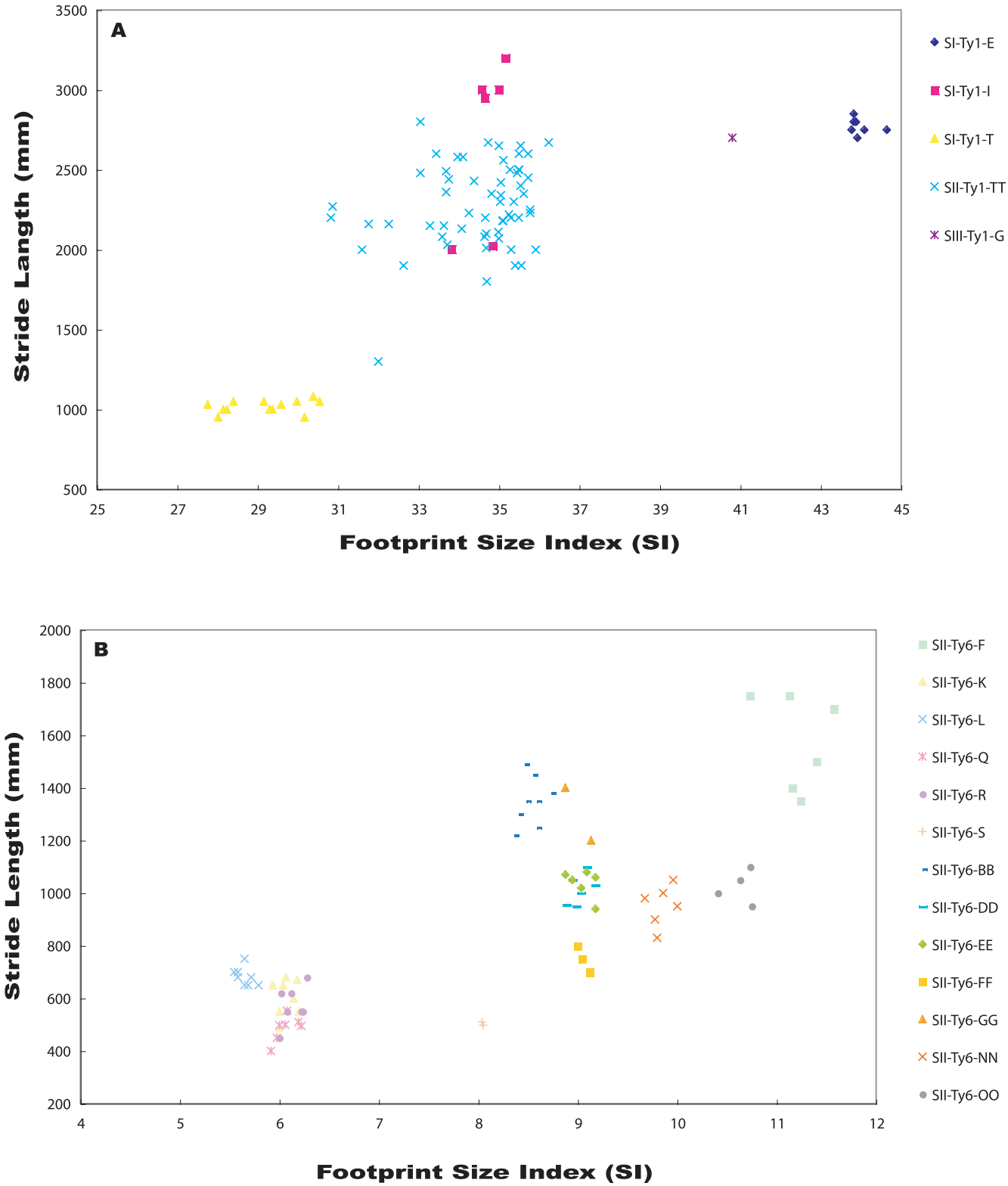

FIGURE 7. **A** and **B**, Scatter diagrams showing the relationship of stride length to footprint size index for Type 1 (A) and Type 6 (B) theropod pes prints from the Ordos Basin. S1-Ty-E : Site number-Footprint type-Trackway number.

recognized yet at these sites.

Early Cretaceous dinosaur footprints have been reported from the Tetori Group in Japan and the Gyeongsang Supergroup in South Korea. Various sorts of footprints - theropod, sauropod, ornithopod, thyrephoran and birds-have been recovered from the Tetori Group in Japan. Some of theropod footprints from the Tetori Group are similar to Type 1 or Type 2 footprints at the Ordos sites, and some of ornithopod footprints are similar to Type 4 Ordos footprints. Huh et al. (2003) reported at least 27 dinosaur footprint sites from Korea ; theropod footprints were found at 18 of those sites, sauropod footprints were reported from 25 sites and ornithopod prints at all sites. Theropod footprints from those sites range from small to large size and are similar to Type 1 and Type 2 Ordos footprints. Ornithopod footprints are of two sorts (*Iguanodon*-like and *Caririchnium*). An *Iguanodon*-like footprint is similar to the Type 4 footprints described in this paper.

Lower Cretaceous dinosaur sites from Canada, especially Grande Cache in Alberta (McCrea and Currie, 1998) have also produced the same variety of dinosaur footprint types. The most remarkable similarity comes from several records of Type 5 footprints from Grande Cache.

Body fossils of theropod and ornithopod are well known from the Early Cretaceous (Zhidan and Ejinhoro Groups) of the Ordos Basin and vicinity ; the Qinshan Formation in Shandong ; the Tugulu Group in Xinjiang ; the Dashuigou, Guying, Qaganner and Gong formations of Inner Mongolia ; the Xinminbao and Hekou Groups in Gansu ; and the Yixian Formation in Liaoning Province (Dong, 1992). Theropod skeletal materials that have been discovered at these sites include *Kelmayisaurus petrolicus, Phaedrolosaurus ilikensis* and *Tugulosaurus* faciles (Tugulu Group) ; "*Tyrannosaurus*" *lanpingensis* (Chingshong Formation) ; *Chilantaisaurus maortuensis* (Dashuigou Formation) ; *Predeinodon kwangshiensis* (Napan Formation) ; *Predeinodon* sp. (Zhidan Group) ; *Sinornithoides youngi* (Ejinhoro Formation) ; *Sinosauropteryx prima, Huaxiagnathus orientalis, Protarchaeopteryx robusta, Caudipteryx zoui, C. dongi, Beipiaosaurus inecpectus, Sinornithosaurus millenii* and *Microraptor zhaoianus* (Yixian Formation) (Dong, 1992 ; Hwang et al., 2004 ; Ji and Ji, 1996, 1997 ; Ji et al., 1998 ; Zhou and Wang, 2000 ; Xu et al., 1999 ; Xu et al., 2000a). Footprints of Type 1 in this paper may belong to a carnosaur, such as *Kelmayisaurus,* whereas Type 2 might belong to a coelurosaur such as *Sinosauropteryx* and *Huaxiagnathus,* and Type 6 might have been made by a large theropod, such as a tyrannosaurid or *Chilantaisaurus.*

Several kinds of ornithopod body fossils have also been found ; *Probactrosaurus gobiensis* and *P. alashanicus* (Dashuigou Formation) ; *Lanzhousaurus magnidens* (Hekou Group) ; *Jeholosaurus shangyuanensis* and *Jinzhousaurus yangi* (Yixian Formation) amongst others (Russell and Dong, 1993 ; You et al., 2005 ; Wang and Xu, 2001 ; Xu et al., 2000b). Taking these body fossils into consideration, Type 4 footprints could have been produced by iguanodontians, such as *Probactrosaurus, Lanzhousaurus, Jeholosaurus* or *Jinzhousaurus.* However, no ornithopod body fossils have been found in the vicinity yet that can be related to Type 3.

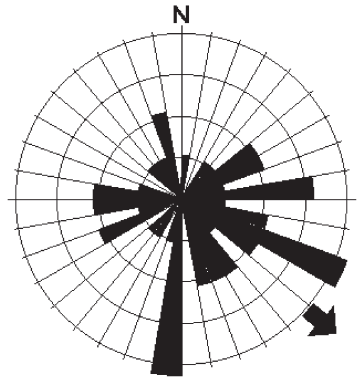

FIGURE 8. Rose diagram showing trends of theropod trackways from Site II.

A scatter diagram, based on data (footprint size index and stride length) from theropod trackways in Ordos Basin, clearly shows differences in trackmaker size-classes (Fig. 6). The distribution of Type 1 footprints is quite different from that of Type 6. Type 1 partially shares its area of distribution with Type 5, but these footprint morphologies are totally different from each other. Type 2 also differs in shape from Type 1, although there are fewer numbers of Type 2 footprints. Therefore, at least four kinds of trackmakers produced Types 1, 2, 5 and 6 footprints. Moreover, trackmakers of Type 1 and Type 6 footprints can be arranged into three different sizes, which might represent age-classes (Fig. 7A, B).

Trackways from Sites I and III do not exhibit any strong directional trends. At the northern end of Site II, the majority of animals were moving in an eastern direction. However, this trend is not as strong as at the southern end (Fig. 8). Accordingly, it is assumed that a water body such as a river or a lake may have prevented the trackmakers from moving across the northern part of Site II.

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