A probable crouching theropod dinosaur trace from the Tuchengzi Formation in Chicheng area, Hebei Province, China

河北赤城地区土城子组中一例极可能的兽脚类恐龙蹲伏迹

XING Li-da[1,2], Gerard D. GIERLIŃSKI[3,4], Jerald D. HARRIS[5], Julien D.DIVAY[1]
邢立达[1,2],杰勒德 D. 杰尔林斯基[3,4],杰瑞德 D. 哈里斯[5],朱利安 D. 迪维[1]

1. *Department of Biological Sciences, University of Alberta, 11455 Saskatchewan Drive, Edmonton, Alberta T6G 2E9, Canada*;
2. *Key Laboratory of Evolutionary Systematics of Vertebrates, Chinese Academy of Sciences, PO Box 643, 100044 Beijing, China*;
3. *JuraPark, ul. Sandomierska 4, 27-400 Ostrowiec Swietokrzyski, Poland*;
4. *Polish Geological Institute Rakowiecka 4, 00-975 Warszawa, Poland*;
5. *Physical Sciences Department, Dixie State College 225 South 700 East, St. George, Utah 84770, USA*
1. 阿尔伯塔大学生物科学系,埃德蒙顿 T6G 2E9, 加拿大;
2. 中国科学院脊椎动物进化系统学重点实验室,北京 100044;
3. 侏罗纪公园,奥斯特罗维茨 4, 27-400, 波兰;
4. 波兰地质研究所,华沙 4, 00-975, 波兰;
5. 美国迪克西州立学院自然科学系,犹他州 圣乔治 84770,美国

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Abstract: A probable theropod dinosaur crouching trace and associated tracks from the Tuchengzi (Houcheng) Formation of Siliang Mountain, Chicheng County, Hebei Province, China are the largest theropod tracks currently known from the formation. Although the crouching trace lacks manus and tail marks, the traces are interpreted as made by a crouching theropod because they include a left metatarsal impression and associated ischial, and possibly pubic, callosity traces. This represents the third known example of an asymmetric crouching position adopted by a theropod.

Key words: crouching theropod trace;*Therangospodus* isp.;cf. *Megalosauripus* isp.;Tuchengzi Formation;Jurassic-Cretaceous boundary

摘要:描述了河北省赤城县寺梁山土城子(后城)组一例极可能的兽脚类恐龙蹲伏迹及相关的足迹,该蹲伏迹也是该组地层目前发现的最大的兽脚类足迹。虽然缺乏前足迹和尾迹,但因保存了左跖骨印、关联的坐骨及可能的耻骨胼胝印被定为蹲伏迹。该蹲伏迹是世界上第三例非对称的兽脚类恐龙蹲伏迹。

关键词:兽脚类蹲伏迹;窄足龙足迹未定种;似巨齿龙足迹未定种;土城子组;侏罗系—白垩系界线
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Author:XING Li-da(1982-),male,presently specializes in the Mesozoic vertebrate paleontology and functional morphology.
E-mail:xinglida@gmail.com

1 Introduction

Dinosaur crouching (also called sitting or resting) traces are uncommon, but are important sources of information about the anatomies, postures, and behaviors of their track makers. All crouching traces thus far discovered were made by theropod and basal ornithischian dinosaurs. Some specimens made by theropods have even been examined in the contexts of "protofeather" origins and the evolutionary relationships between theropods and birds[1-4].

Only seven crouching traces made by theropods have been hitherto described[1-10]. Among these, the best known are specimens originally labeled as *Anomoepus major* (Fig. 1-A) and *Sauropus barratti*[11-13], which came from the Early Jurassic of the Connecticut Valley[14]. Subsequently, the ichnotaxonomic statuses of *A. major* and *S. barratti* have changed several times[13-15]. Gierliński (1994) attributed these specimens to *Grallator*[5] (*Eubrontes* and *Grallator sensu* Lockley[16], or *Anchisauripus sensu* Olsen et al.[17]), and this ichnotaxonomy has since become generally accepted[7,18]. A large theropod (*Eubrontes*-like) crouching traces was described from Sichuan, China[7]; another specimen, which includes manus traces, was found in Utah, USA[4]. The most recently discovered example is an exceptionally well-preserved specimen (Fig. 1-B) from the Early Jurassic of Poland[10] that pertains to either *Anchisauripus sensu* Olsen et al.[17] or *Eubrontes sensu* Lockley[16].

Here we describe an eighth crouching theropod trace (Fig. 1-C), from the Nijiagou track site on the southern slope of Siliang Mountain, Nijiagou Village, Yangtian Township, Chicheng County, Zhangjiakou City, Hebei Province, China. Xing et al. described didactyl *Menglongipus* (Dromaeopodidae) and *Grallator*-type tracks from the same site[19]. The Nijiagou track site and a second site(the Luofenggou site), which preserves *Therangospodus* isp. and *Megalosauripus* isp. tracks[20], lie on strata of the Tuchengzi Formation (also known as the Houcheng Formation). Sediments comprising this unit were deposited in the latest Jurassic and earliest Cretaceous: radiometric dating recovered a minimum age of 136-139 Ma[21-22] and a maximum age of 147 Ma[22]. The track-bearing stratum at the Nijiagou locality lies high in the Tuchengzi Formation, but it is not presently possible to determine whether the tracks are latest Jurassic or earliest Cretaceous in age. Theropod tracks, primarily those of the *Grallator* morphotype, are the most common track types in the Tuchengzi Formation[19,20, 23-28].

2 Institutional abbreviations

AC=Hitchcock Ichnology Collection, Pratt Museum of Natural History, Amherst College,. Amherst, Massachusetts, U.S.A; J=JuraPark, Solec Kujawski, Poland; LF=Luofenggou Field, Hebei, China; T.B=Track B, Nijiagou Field, Hebei, China; T.C=Track C, Nijiagou Field, Hebei, China.

3 *Therangospodus* morphotype in Nijiagou track site

Numerous theropod tracks, in several trackways (each assigned a letter-T.A, T.B, etc.), are preserved at the Nijiagou track site. Several tracks described by Xing et al. fig. 4b[19], are here re-interpreted based on new observations made during the 2010 field season. Specimens T.B.6, 7, 8, and 10(Fig. 2), the best preserved in the T.B. trackway, have an average length of 18.8 cm(range 18.2-19.6 cm), an average width of 12.4 cm(range 11.3-13.5 cm), average digit lengths of 8.3, 12.8, and 8.3 cm for digits Ⅱ, Ⅲ, and Ⅳ, respectively, and average divarication angles between digits Ⅱ-Ⅲ and Ⅲ-Ⅳ of 29.5° and 25.3°, respectively. The impressions of digits Ⅱ and Ⅲ widen distally. A preservationally and morphologically similar track (specimen LF2) is found at the Luofenggou (LF) track site.

The length:width ratios of the T.B tracks range from 1.4:1-1.7:1, which is slightly larger than the ratio of 1.3:1 of LF 1 and LF 2. Among the T.B tracks, specimen T.B.6 is unique in preserving an ovoid metatarsal region. The T.B. track maker probably sank into the substrate more deeply when making this track, creating a deeper impression in T.B.6. These

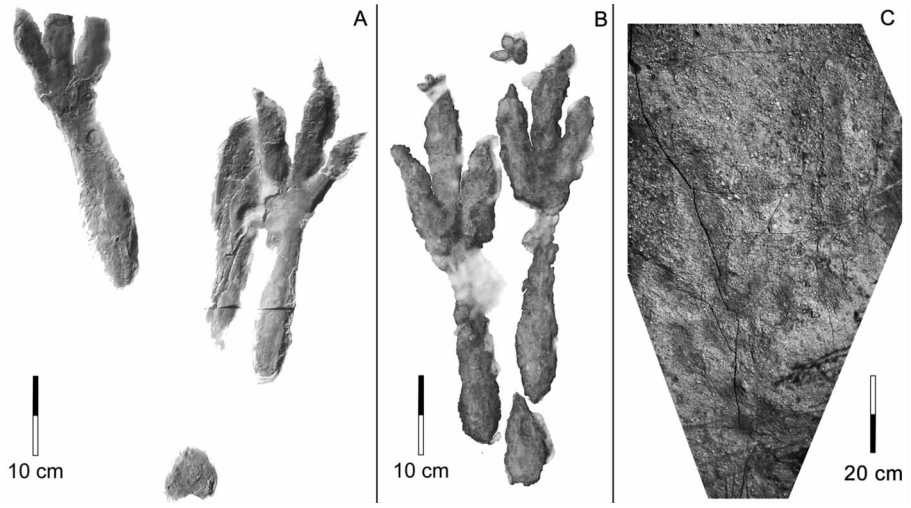

Fig. 1 Comparison of specimen T.C.1 with other asymmetrical crouching theropod impressions
A—specimen AC 1/7 from the Early Jurassic of Massachusetts, USA; B—specimen JuraPark J484 from the Early Jurassic of Poland; C—Resting theropod impression (T.C.1) from the Nijiagou track site, Chicheng County, Hebei Province, China

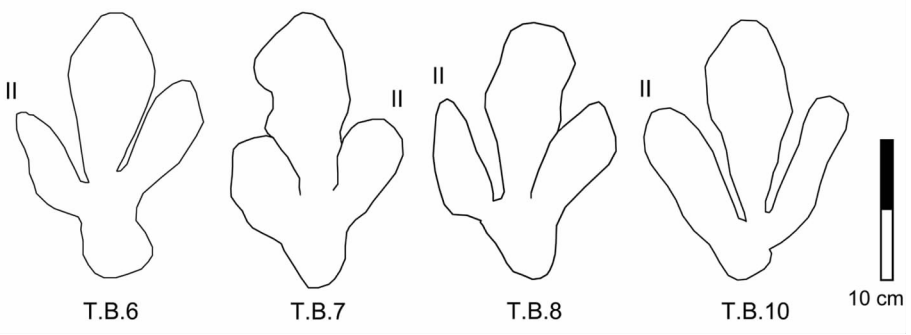

Fig. 2 Outline drawings of *Therangospodus* tracks T.B. 6, 7, 8, and 10 from the Nijiagou track site, Chicheng County, Hebei Province

characteristics are consistent with those of tracks at the Luofenggou site, which pertain to *Therangospodus* isp. [20], so we revise the ichnotaxonomy of the T.B tracks to *Therangospodus* isp.

4 Probable crouching theropod trace

Material: A pair of incomplete natural molds found at the Nijiagou track site is cataloged as T.C.1 (Fig.1−C, Fig.3; Table 1). The original tracks were not collected and are still in the field.

Holotype locality and horizon: Tuchengzi Formation, Upper Jurassic−Lower Cretaceous(Tithonian−Valanginian). Nijiagou track site, Chicheng, Hebei Province, China.

Description: A theropod resting impression comprising large, tridactyl, semiplantigrade footprints, an ischial callosity print, and a possible pubic callosity print, but lacking traces of the manus, belly, and tail. T.C.1(Fig.3−A) is preserved as a dark stain of extremely shallow depth on a conglomeratic substrate. The left footprint(T.C.1L) is the most complete and serves as the representative of pedal morphology; only the impression of the mesaxonic toe(digit Ⅲ) is well preserved in the right print(T.C.1R)(Fig. 3−B). Its length:width ratio is 1.49:1. Digit Ⅲ is directed cranially, and digit IV is longer than digit Ⅱ. The length of digit Ⅲ

Table 1　Measurements of crouching theropod trace T.C.1 from the Nijiagou track site, Chicheng County, Hebei Province

	ML	MW	Ⅱ	Ⅲ	Ⅳ	LM	WM	Ⅱ-Ⅲ	Ⅲ-Ⅳ
T.C.1L	58.7	33.6	19.1	42.8	24.4	23.3	18.7	31°	32°
T.C.1R	63.6	—	—	43.4	—	13.7	10	—	—

notes: L: left; R: right; LM: length of metatarsal impression(cm); ML: maximum length (not including the metatarsal impression)(cm); MW: maximum width, distance between the tips of digits Ⅱ and Ⅳ (cm); WM: width of metatarsal impression(cm); Ⅱ: length of digit Ⅱ(cm); Ⅲ: length of digit Ⅲ(cm); Ⅳ: length of digit Ⅳ(cm); Ⅱ-Ⅲ: angle between digits Ⅱ and Ⅲ(°); Ⅲ-Ⅳ: angle between digits Ⅲ and Ⅳ(°)

comprises about 73% of footprint length, differing markedly from the outer digits, which span only 33% -42% of the total footprint length. Digit Ⅱ has two digital pads; both digits Ⅲ and Ⅳ have at least three faint digital pads. The divarication angle between digits Ⅱ and Ⅳ is 63°. A metatarsal impression lies in line with the axis of digit Ⅲ; its caudal margin is slightly convex caudally. The metatarsal impression lies closer to the lateral side of the axis of footprint than the medial side; its terminal margin enlarges to exceed the width of the metatarsophalangeal region.

A sub-ovoid impression(12cm×7.4cm) located close to the caudomedial end of T.C.1L is an ischial callosity impression. A second sub-ovoid impression (10cm×9.2cm) between the left and right footprints might be the impression of a pubic callosity.

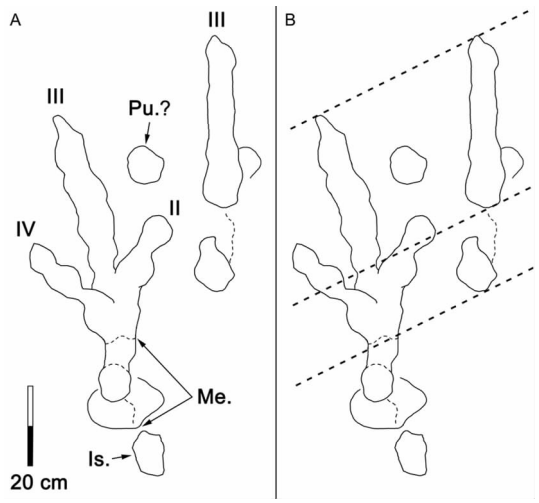

Fig. 3　Resting theropod impression (T.C.1) from the Nijiagou track site, Chicheng County, Hebei Province
A—outline drawing, Me.means metatarsal impression, Is.means ischial callosity impression, Pu.?means possible pubic impression, Ⅱ、Ⅲ、Ⅳ: digit Ⅱ、Ⅲ、Ⅳ; B—the dotted lines indicate consistent distances between the distal digit Ⅲ impression, proximal digit Ⅲ impression, and proximal metatarsophalangeal region

5　Discussion

The Siliang T.C.1 specimens are large, elongate, tridactyl theropod tracks readily compared with several well-known theropod ichnotaxa(e.g., *Grallator*, *Anchisauripus*, *Eubrontes*, *Kayentapus*, and *Gigandipus*). The T.C.1 tracks have less acute angles of divarication (63°) than those of the *Grallator-Anchisauripus-Eubrontes* plexus, but they are close to the angles described for *Kayentapus*(60-72°[29]), *Megalosauripus* (52°; Lockley et al. fig. 8[30]) and *Therangospodus*(56°; Lockley et al. Fig. 7[31]). The length of digit Ⅲ as a function of overall track length in the Siliang tracks (73%) is greater than the values for *Megalosauripus* (60%) and *Kayentapus*(69%), but close to the value for *Therangospodus*(74%). The T.C.1 tracks(58.7-63.6 cm in length) are longer than medium-sized *Therangospodus* tracks (averaging 28 cm long[31]) and *Kayentapus*(pes length ~35 cm[32]). Furthermore, the T.C.1 tracks lack cigar-shaped digits, unlike the *Therangospodus* morphotype described by Lockley et al.[31], but they are more robust than more gracile *Kayentapus* tracks[32]. Because the sample size of the Silian tracks is so small, coupled with the inability to discern systematic features, the T.C.1 tracks are impossible to attribute to a particular ichnotaxon.

As yet, no theropod body fossils have been recovered from the Tuchengzi Formation. The T.C.1

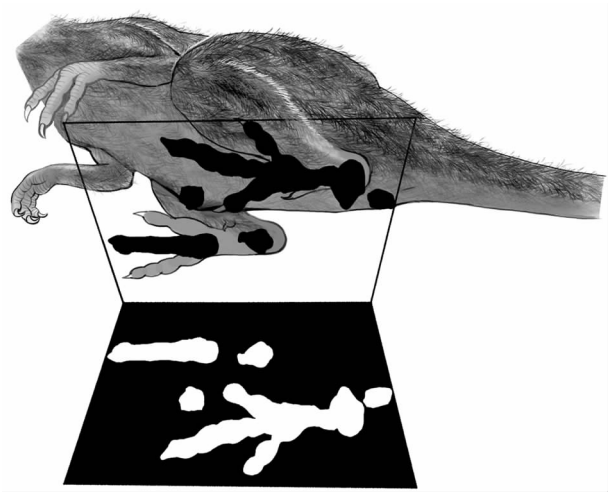

Fig. 4 Restoration of the resting theropod impression (T.C.1), made when the dinosaur placed its metatarsal impression and associated ischial, and pubic area in contact with the ground (by Xing Lida and Liu Yi(art assistant))

tracks, with total lengths of up to 82 cm including the metatarsal impression in T.C.6, are the largest theropod tracks from the Tuchengzi Formation and indicate that at least one large theropod taxon existed in the area during Tuchengzi time.

The classic Connecticut Valley crouching theropod traces(AC 1/7 and AC 1/1) include sub-crescentic or heart-shaped ischial callosity impressions and subparallel metatarsus impressions[1,2,7,18]. The *Eubrontes*-like Wumacun crouching track specimen also exhibits subparallel metatarsus impressions, a sub-triangular ischial impression, and a cranially situated pelvic (presumably pubic) impression[7]. The Coyote Buttes, Arizona specimen, which is more poorly preserved than other specimens, includes subparallel metatarsus im pressions and a subcircular ischial impression[9]. The crouching *Eubrontes* specimen from St. George, Utah possesses nearly symmetrical, elongate metatarsus impressions and circular ischial impressions[4]. It is unclear whether symmetrical vs. asymmetrical crouching traces reflect taxonomic or morphofunctional differences in the track makers, different behaviors in different conditions at the moments of track making on the parts of the track makers, or simply an ability of theropods to comfortably alternate between symmetrical and asymmetrical resting poses with no internal or external etiological origin.

The areas immediately cranial and caudal to the T.C.1 tracks were, at the time the tracks were discovered and studied, buried by overlying mudstone strata, so the presence of manus or associated tail prints is impossible to assess at present, which limits comparison of T.C.1 to other theropod crouching traces that preserve these features[4,9]. Specimen T.C.1 resembles AC 1/7 and JuraPark J484 in possessing an ischial callosity impression located asymmetrically, closer to the caudomedial end of the left footprint. This indicates that the track maker rested in an asymmetric crouched or semi-crouched position (Fig. 4).

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References

[1]Gierliński G. Feather-like impressions in a theropod resting trace from the Lower Jurassic of Massachusetts[J]. Morales M. The Continental Jurassic. Museum of Northern Arizona Bulletin, 1996, 60: 179-184.

[2]Gierliński G. What type of feathers could nonavian dinosaurs have, according to an Early Jurassic ichnological evidence from Massachusetts? [J]. Przeglad Geologiczny, 1997, 45: 419-422.

[3]Sabath K, Gierliński G. The Hitchcock enigma: first feathers or artifacts? [J]. Tracking Dinosaur Origins, the terrestrial Triassic/Jurassic Transition, Abstracts Volume, 2005: 21-22.

[4]Milner ARC, Harris J D, Lockley M G, et al. Bird-Like Anatomy, Posture, and Behavior Revealed by an Early Jurassic Theropod Dinosaur Resting Trace[J]. PLoS ONE, 2009, 4(3): e4591 (1-14).

[5]Gierliński G. Early Jurassic theropod tracks with the metatarsal impressions[J]. Przegląd Geologiczny, 1994, 42: 280-284.

[6]Farlow J O, Galton P M. Dinosaur trackways of Dinosaur State Park, Rocky Hill, Connecticut[C]//Letourneau P M, Olsen P E. The Great Rift Valleys of Pangea in Eastern North America Volume 2: Sedimentology, Stratigraphy, and Paleontology. New York: Columbia University Press, 2003:248-263.

[7]Lockley M G, Matsukawa M, Li J J. Crouching theropods in taxonomic jungles: ichnological and ichnotaxonomic investigations of footprints with metatarsal and ischial impressions[J]. Ichnos, 2003, 10: 169-177.

[8]Weems R E. The manus print of *Kayentapus minor*; its bearing on the biomechanics and ichnotaxonomy of Early Mesozoic saurischian dinosaurs[J]. New Mexico Museum of Natural History and Science Bull., 2006, 37: 369-378.

[9]Milàn J, Loope D B, Bromley R G. Crouching theropod and *Navahopus* sauropodomorph tracks from the Early Jurassic Navajo Sandstone of USA[J]. Acta Palaeontologica Polonica, 2008, 53: 197-205.

[10]Gierliński G D, Lockley M G, Niedzwiedzki G. A distinctive crouching theropod trace from the Lower Jurassic of Poland [J]. Pieńkowski G, Martin A J, Meyer C A. Second International Congress on Ichnology (Ichnia 2008). Geological Quarterly, 2009, 53:471-476.

[11]Hitchcock E. Fossil footsteps in sandstone and graywacke[J]. American Journal of Science, 1st ser., 1837, 32:174-176.

[12]Hitchcock E. Final Report on the Geology of Massachusetts [M]. Amherst, MA, Commonwealth of Massachusetts, 1841:1-831.

[13]Hitchcock E. Ichnology of New England: a Report on the Sandstone of the Connecticut Valley, Especially its Fossil Footmarks[M]. Boston: William White, 1858:1-199.

[14]Lull R S. Triassic life of the Connecticut Valley[M]. State of Connecticut, State Geological and Natural History Survey Bulletin, 1915, 81: 1-336.

[15]Olsen P E, Baird D. The ichnogenus *Atreipus* and its significance for Triassic biostratigraphy[C]//Padian K. The Beginning of the Age of Dinosaurs. Cambridge: Cambridge University Press,1986:61-87.

[16]Lockley M G. Philosophical perspectives on theropod track morphology: blending qualities and quantities in the science of ichnology[J]. Gaia, 2000, 15:279-300.

[17]Olsen P E, Smith J B, McDonald N G. Type material of the type species of the classic theropod footprint genera *Eubrontes*, *Anchisauripus*, and *Grallator* (Early Jurassic, Hartford and Deerfield basins, Connecticut and Massachusetts, U.S.A.)[J]. Journal of Vertebrate Paleontology, 1998, 18(3):586-601.

[18]Olsen P E, Rainforth E C. The Early Jurassic ornithischian dinosaurian ichnogenus *Anomoepus*[C]//Letourneau P M, Olsen P E. The Great Rift Valley of Pangea in eastern North America, volume two. New York: Columbia University Press, 2003:314-353.

[19]Xing L D, Harris J D, Sun D H ,et al. The Earliest Known Deinonychosaur Tracks from the Jurassic-Cretaceous boundary in Hebei, China[J]. Acta Palaeontologica Sinica, 2009, 48(4): 662-671.

[20]Xing L D, Harris J D, Gierliński G D. *Therangospodus* and *Megalosauripus* track assemblage from the Upper Jurassic-Lower Cretaceous Tuchengzi Formation of Chicheng County, Hebei Province, China and Their Paleoecological Implications[J]. Vertebrata PalAsiatica, 2011, In press.

[21]Swisher III C C, Wang X L, Zhou Z H, et al. Further support for a Cretaceous age for the feathered dinosaur beds of Liaoning, China: New $^{40}Ar/^{39}Ar$ dating of the Yixian and Tuchengzi Formations[J]. Chinese Science Bulletin, 2002, 47: 135-138.

[22]Zhang H, Wei Z L, Liu X M, et al. Constraints on the age of the Tuchengzi Formation by LA-ICP-MS dating in northern Hebei-western Liaoning, China[J]. Science in China (D), 2009, 52:461-470.

[23]Yabe H, Inai Y, Shikama T. Discovery of dinosaurian footprints from the Cretaceous? of Yangshan, Chinchou: preliminary note[J]. Proceedings of the Imperial Academy, Japan preliminary, 1940, 16: 560-563.

[24]Shikama T. Footprints from Chinchou, Manchoukuo, of Jeholosauripus, the Eo-Mesozoic Dinosaur[J]. Central National Museum of Manchoukuo, 1942, 3: 21-31.

[25]Young C C. Fossil footprints in China[J]. Vertebrata PalAsiatica, 1960, 4: 53-66.

[26]Matsukawa M, Lockley M G, Li J J. Cretaceous terrestrial biotas of East Asia, with special reference to dinosaur-dominated ichnofaunas: towards a synthesis[J]. Cretaceous Research, 2006,27:3-21.

[27]Fujita M, Azuma Y, Lee Y N, et al. New theropod tracksite from the Upper Jurassic Tuchengzi Formation of Liaoning Province, northeastern China[J]. Memoir of the Fukui Prefectural Dinosaur Museum, 2007, 6: 17-25.

[28]Zhang Y Z, Zhang J P, Wu P ,et al. Discovery of dinosaur tracks from the Middle -Late Jurassic Tuchengzi Formation in the Chaoyang area, Liaoning Province[J]. Geological Review, 2004, 50: 561-566.

[29]Welles S P. Dinosaur footprints from the Kayenta Formation of northern Arizona Plateau[J]. Quarterly of the Museum of Northern Arizona, 1971, 44:27-38.

[30]Lockley M G, Meyer C A, Santos V F. dos. *Megalosauripus* and the problematic concept of megalosaur footprints[J]. Gaia,1998, 15:313-337.

[31]Lockley M G, Meyer C A, Moratalla J J. *Therangospodus*: trackway evidence for the widespread distribution of a Late Jurassic theropod dinosaur with well-padded feet[J]. Gaia, 1998, 15: 339-353.

[32]Lockley M G, Gierliński G D, Lucas S G. *Kayentapus* revisited: Notes on the type material and the importance of this theropod footprint ichnogenus[J]. New Mexico Museum of Natural History and Science Bulletin, 2011, 53: 330-336.