Sullivan, R.M. and Lucas, S.G., eds., 2016, Fossil Record 5. New Mexico Museum of Natural History and Science Bulletin 74.

EARLY JURASSIC *ANOMOEPUS* TRACK FROM THE FENGJIAHE FORMATION OF NORTHERN CENTRAL YUNNAN, CHINA

LIDA XING[1], MARTIN G. LOCKLEY[2], SHAOJIN HU[3], QINFEN LI[4] and W. SCOTT PERSONS IV[5]

[1]School of the Earth Sciences and Resources, China University of Geosciences Beijing 100083, China; -email: xinglida@gmail.com; [2]Peace Region Palaeontology Research Centre, Tumbler Ridge, British Columbia, Canada; [3]Dinosaur Tracks Museum, University of Colorado Denver, P.O. Box 173364, Denver; [4]School of Resources and Environmental Engineering, Southwest Petroleum University, Chengdu, Sichuan, China; [5]Department of Biology, Jacksonville State University, 700 Pelham Rd, Jacksonville, Alabama 36265;

Abstract—Photographs, newspaper reports and other unpublished documentation indicate the presence of hitherto undocumented tridactyl tracks from the Lower Jurassic Fengjiahe Formation at Dianwen Village in Yunnan Province China. Our analyses of these records allow us to assign some of the better preserved tracks to *Anomoepus* isp. indet. This report adds to the growing number of reports of ichnogenus *Anomoepus* from the Lower and Middle Jurassic rocks of southern China. These occurrences indicate that small ornithischian dinosaurs were a significant component of these Early and Middle Jurassic faunas.

INTRODUCTION

In 1986, researchers from the Beijing Natural History Museum and the Kunming Management Committee of Cultural Relics described the first dinosaur tracks in Yunnan Province from a locality in Xiyang Yi Autonomous Township, Jinning County (Zhen et al., 1986). This site is located in the Lower Jurassic Fengjiahe Formation and includes a rich assemblage of theropod tracks.

Most other Yunnan Province tracks are concentrated in the Chuxiong area, and include Lower Jurassic ornithischian (*Shenmuichnus wangi*) and theropod (*Changpeipus carbonicus*) footprint assemblages from the Lufeng Formation (Xing et al., 2009, 2015a, in press a), a small number of Middle Jurassic theropod (*Eubrontes* isp.) and sauropod tracks (*Brontopodus* isp.) from the Chuanjie Formation (Xing et al., 2014), an assemblage of ?Middle–Upper Jurassic theropod–sauropod tracks of various sizes from the Shedian Formation (Xing et al., 2016a), and possible theropod swim traces from the Jurassic–Cretaceous boundary in the Anning Formation (Xing et al., in press b). Additionally, in the course of establishing a national geological park in conjunction with the Lufeng Land Resources Bureau, the lead author has, over the past two years, discovered a wealth of ornithischian tracksites at a rate that far outstrips that at which the sites can be scientifically described; see, as an example, the discovery of *Anomoepus* (Xing et al., in press c).

In 1990, archaeologists from the Kunming Bureau of Cultural Relics (currently Kunming Museum) and the Culture Museum of Luquan County found a group of dinosaur tracks on five fallen rocks, at Eagle Cliff, Dianwen Village, Luquan County, north Kunming City (Fig. 1), and took photographs and collected some specimens. However, these finds were only reported in newspapers (e.g., On 9 June 1990, the third page of *People's Daily*, title: Yunnan discovered dinosaur footprints), and were never formally described. In 2016, two of the present authors (QL, LX) visited this tracksite. However, no new tracks were discovered, probably due to erosion of the original material. Herein, we offer a detailed description, based on the original 1990 findings.

Abbreviations: **DW** = Dianwen site, Luquan County, Yunnan, China; **LQ** = Luquan Yi and Miao Autonomous County Bureau of Culture, Multimedia, Press & Sport Tourism, Yunnan, China

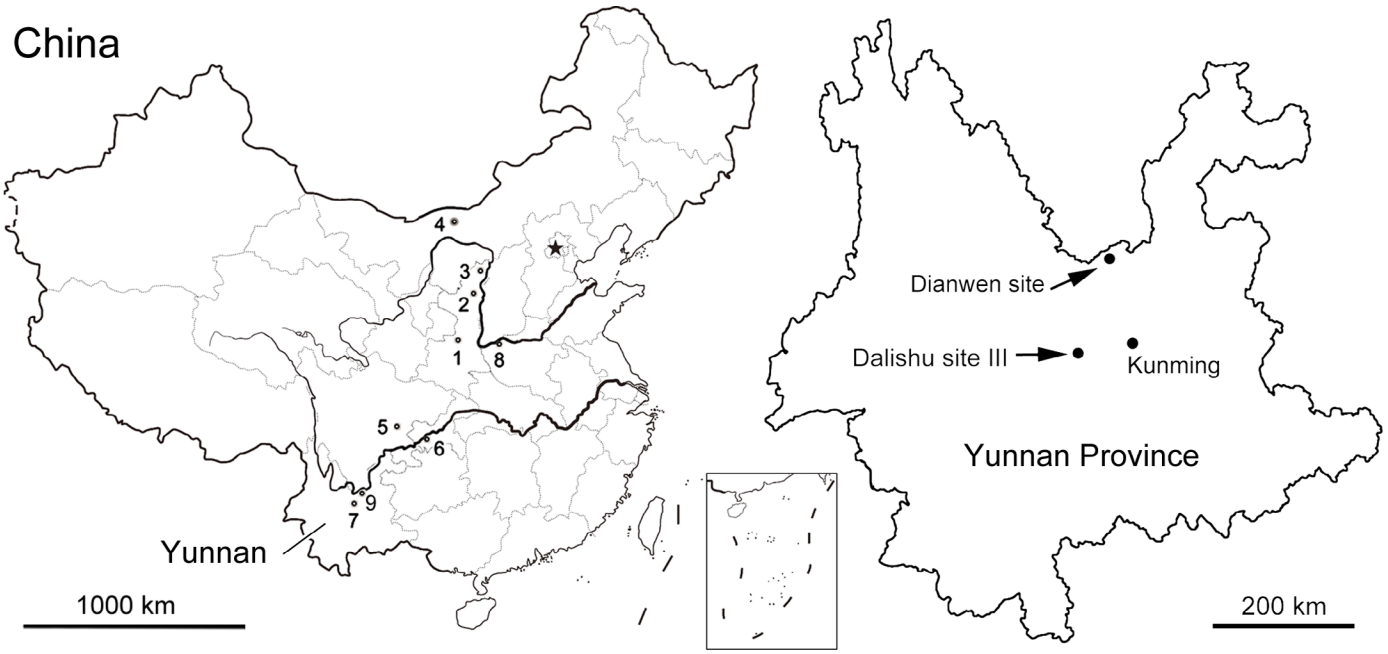

FIGURE 1. Locality map showing location of the Dianwen site, China and the distribution of *Anomoepusm* tracks from China: **1**, Middle Jurassic Jiaoping Coal Mine site, Shaanxi Province (Xing et al., 2015b); **2**, Middle Jurassic Huo and Wang sites from Shaanxi Province (Xing et al., 2015b); **3**, Lower Jurassic Lijiananwa site from Shaanxi Province (Li et al., 2012); **4**, Lower Jurassic Wulatezhongqi site from Inner Mongolia (Li et al., 2010); **5**, Middle Jurassic Jinlijing site, Sichuan Province (Lockley and Matsukawa, 2009); **6**, Upper Jurassic Nan'an site from Chongqing municipality (Xing et al. 2013); **7**, Lower Jurassic Dalishu tracksite III from Yunnan Province (Xing et al. in press a); **8**, Middle Jurassic Yima Northern Open-pit Coal Mine site from Henan Province (Xing et al., 2016b).

GEOLOGICAL SETTING

As part of the Kangdian (West Sichuan-Central Yunnan) paleoland the Mesozoic depression in central Yunnan had been a geological uplift until the development of a fault subsidence zone at the end of Triassic Period. The Fengjiahe Formation is the oldest Lower Jurassic red bed unit in the region and varies in thickness throughout (Zhang, 1996). The Formation is over 1500 m thick and lies in conformable contact with the Upper Triassic Shezi Formation below and the Middle Jurassic Zhanghe Formation above (Zhang, 1996). The Fengjiahe Formation is characterized by purple-red mudstone and argillaceous siltstone interbedded with gray-green and yellow-green quartz sandstone and feldspathic quartz sandstone, and contains the track-bearing horizon. The formation is rich in vertebrate fossils and famous for its *Lufengosaurus* fauna, which contains typical dinosaurs like the basal sauropodomorphs, such as *Lufengosaurus* and *Yunnanosaurus* (Fang and Li, 2008).

DESCRIPTION OF TRACKS

All tracks from the Eagle Cliff tracksite were natural tridactyl casts, with the largest spanning about 20 cm and the smallest about 3-4 cm in length. There were over 50 tracks on a 1.7 x 1.2m fallen rock (according to personal observation by Wu Shaojin).

DW-T1 was the best preserved tridactyl track, but was only photographed, not collected (Fig. 2). Using the coin included in one of the photographs of the track as a scale, the track is approximately 5.7 cm long. The width of DW-T1 is nearly equal to its length (length/width ratio is approximately 1.0). The pads of three digits are indistinctly impressed. The claw marks of digits II and III are sharper than that of digit IV. The proximal region of digits II and IV form a sub-symmetric bilobed heel that lies in line with the axis of digit III. DW-T1 shows a relatively wide digit divarication angle (II–IV = 64°) and weak mesaxony, with an anterior triangle length/width ratio of 0.28.

LQ-T1 and LQ-T2 were isolated tracks on the same slab and were collected in 1990 by WU Shaojin. However, they are poorly preserved. Q-T1 lacks digit IV, while digit II shows two clear digital pads. LQ-T2 is 6.4 cm in length with a length/width ratio of 1.0. Its digit III is relatively well preserved, with three clear digital pads, while the two lateral digitals are obscure, with unrecognizable digital pads. LQ-T2 shows relatively wide digit divarication angle (II–IV = 78°) and weak mesaxony, with an anterior triangle length/width ratio of 0.31. The lateral margin of the digit IV impression of LQ-T2 is relatively indistinct: i.e., with low relief (Fig. 3, indicated by gray region). This indistinct digit IV impression may indicate slippage or sliding by the trackmaker, or some other influence on preservation. Digit IV reveals an indistinct, shallow outer margin to the trace parallel to the main, deeper part of the trace. The shallow trace diverges laterally by about 10°. Similar features can be seen in some tridactyl tracks such as C*hongqingpus* V1394-5, from the Upper Jurassic Nan'an site, Chongqing (Xing et al., 2013).

INTERPRETATION

Anomoepus is well known from Lower-Jurassic strata of North America (Olsen and Rainforth, 2003; Lockley and Gierlinski, 2006). In China, *Anomoepus* tracks are primarily found in Lower-Middle Jurassic formations (Xing et al., 2016b) and also usually co-occur with *Grallator-Eubrontes-Kayentapus* and *Deltapodus* (Xing et al., 2015b). This stratigraphic occurrence is consistent with the occurrence of the ichnogenus in the globally widespread Lower Jurassic biochron of Lucas (2007).

In China, the first report of *Anomoepus* came from the southwest of Sichuan Province (Lockley and Matsukawa, 2009) (Fig. 4). *Anomoepus* has also been found in the Ordos Basin, including Jiaoping (Young, 1966; Xing et al., 2015b), Shenmu (Li et al. 2012), and Zizhou (Xing et al., 2015b). Additional tracks are now also known from the Hailiutu Basin, near the Ordos Basin (Li et al. 2010), and from the Upper Jurassic Nan'an site, from the Chongqing municipality, southwestern China (Xing et al., 2013). Xing et al described two new groups of *Anomoepus* tracks from Yunnan Province (Xing et al., in press c) and Henan Province (Xing et al., 2016b).

The morphology of the small tridactyl tracks from Dianwen strongly resemble that of the ichnogenus *Anomoepus*, being similar in size and having relatively wide divarication angles (64°–78°) and weak mesaxony (0.28–0.31). But limitations on sample size and preservation make the Dianwen specimens difficult to confidently refer to any particular ichnospecies of *Anomoepus,* and, thus, here the Dianwen tracks are tentatively assigned to *Anomoepus* isp.

The sub-symmetric bilobed heel of DW-T1 is a relatively unusual manifestation, and may reflect an unusual shape of the trackmaker's feet. The trait is seen in some other tridactyl tracks, such as the archosaur

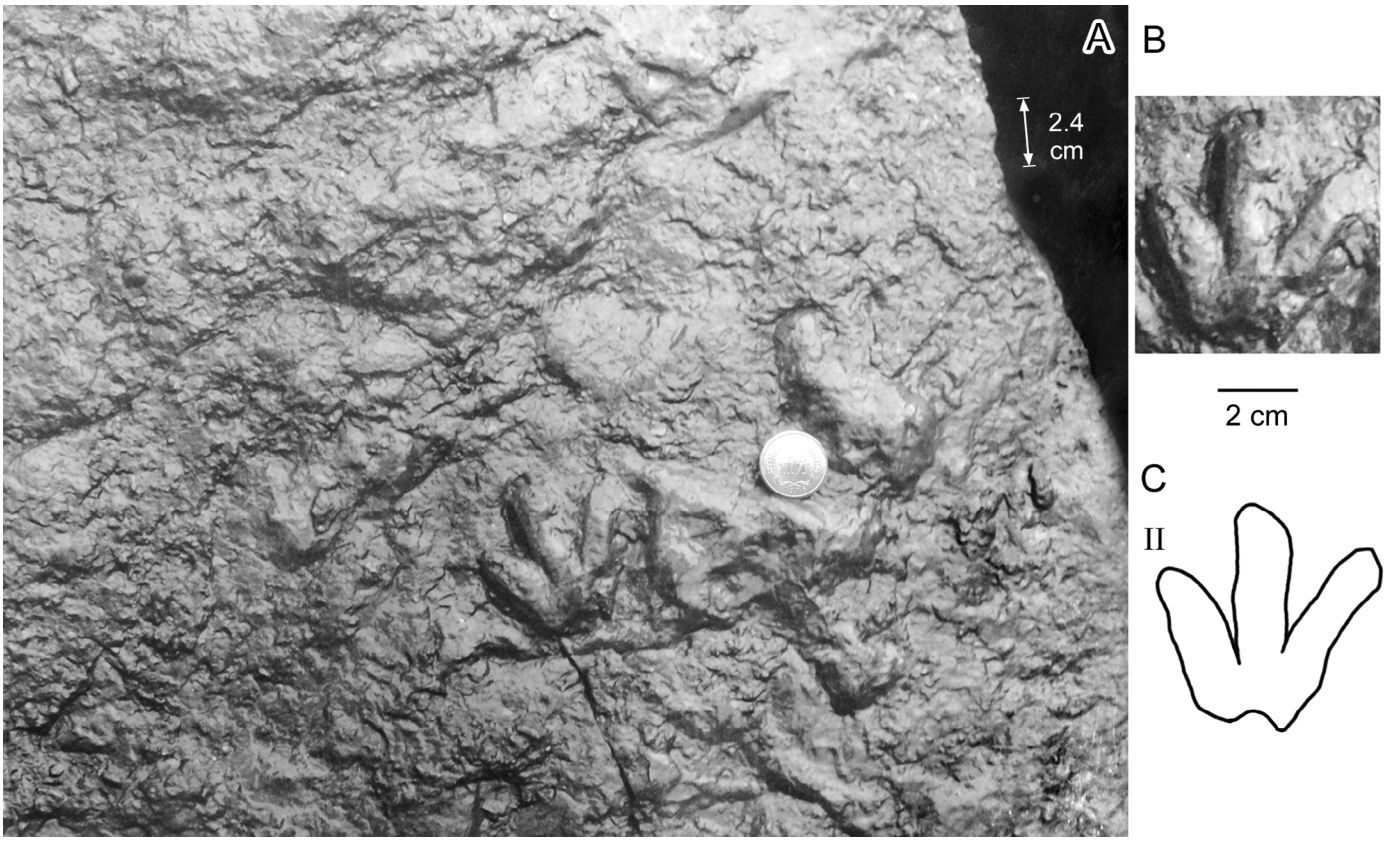

FIGURE 2. Photograph (By SHAOJIN HU) and interpretative outline drawing of *Anomoepus* track DW-T1 at Dianwen tracksite.

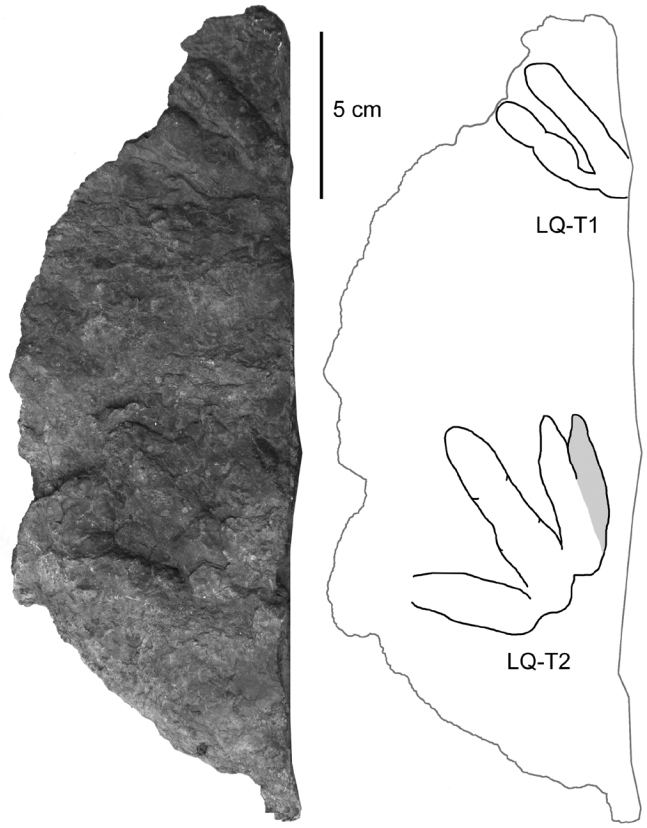

FIGURE 3. Photograph (By QINFEN LI) and interpretive outline drawing of *Anomoepus* tracks LQ-T1–2 at Dianwen tracksite.

Atreipus, from the Late Triassic of North America and Europe (Olsen and Baird, 1986); the theropod *Siamopodus khaoyaiensis*, from the Cretaceous of Thailand (Lockley et al., 2006); and the Cretaceous ornithopod *Caririchnium kyoungsookimi* (Lim et al., 2012). The trait could also easily be caused in an isolated specimen by some irregular property of the substrate.

The Dianwen *Anomoepus* isp. is the ninth *Anomoepus* record in China and the second in Yunnan Province. The other *Anomoepus* isp. in Yunnan Province comes from the Lower Jurassic Lufeng Formation in the Dalishu area, Lufeng County (Xing et al., in press a) and a few examples of Dalishu *Anomoepus* show a diagnostic tetradactyl morphology. Moreover, compared with the new Dianwen specimens, the Dalishu *Anomoepus* is larger and wider in divarication angles (77°–115°) but with a smaller in anterior triangle length/width ratio (0.28–0.31 vs. 0.41). The mesaxony (0.28) of DW-T1 is possibly the weakest among China's *Anomoepus* records thus far. Such differences may indicate a diversity of ornithopod taxa in the Lower Jurassic of Yunnan. However, at present such a tentative inference cannot be supported without detailed analysis of all *Anomoepus* in order to determine the extent ichnological of variation, and its possible significance.

DISCUSSION AND CONCLUSIONS

Recent discoveries have revealed that tracksites are more common that previously supposed, not only in the Lower and Middle Jurassic of southern China, but also in other parts of the Chinese stratigraphic column and globally in many other regions. The Dianmen tracksite is a good example of a small site that is representative of the track record in the fluvio-lacustrine clastic facies of the Fengjiaahe Formation which is mostly known for skeletal remains of large sauropodomorphs, and theropods indicative of a saurischian-dominated fauna. Hitherto the track record has yielded only theropod tracks. Thus the recognition of *Anomoepus* tracks is the first indication of the presence of ornithischians in this formation. This is perhaps not surprising for two reasons. First, tracks were not considered as important as skeletal remains, and so were overlooked or not described. Second, earlier studies of tridactyl tracks tended to confuse theropod tracks (*Grallator* morphotype) with ornithischian tracks (*Anomoepus* type). So, *Anomoepus* was not recognized in China until the decade of the 2000s (Lockley and Matsukawa, 2009), despite being relatively widespread and representative of a global biochron (Lucas, 2007); see Xing et al.,

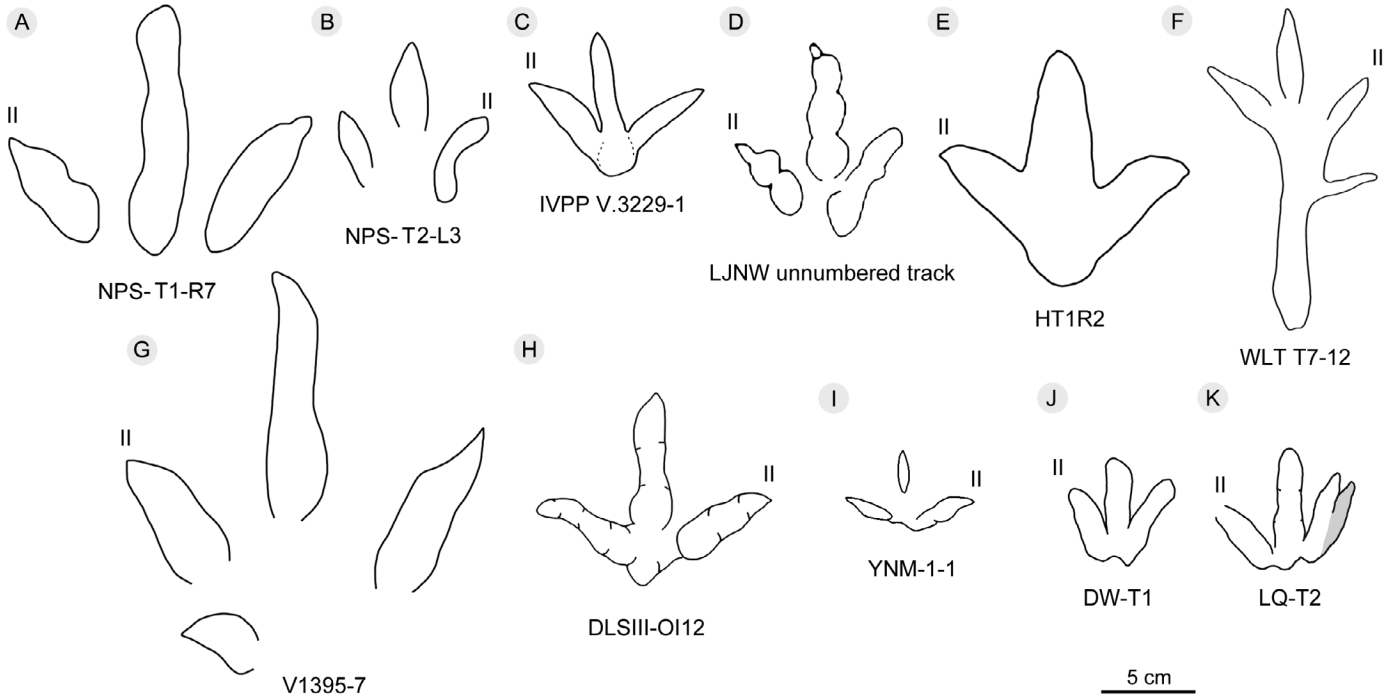

FIGURE 4. Schematic diagrams of *Anomoepus* ichnotaxa to the same scale. **A** and **B,** from Middle Jurassic Jinlijing site, Sichuan Province; **C,** from from Middle Jurassic Jiaoping Coal Mine site, Shaanxi Province (Xing et al., 2015b); **D,** from Lower Jurassic Lijiananwa site from Shaanxi Province (Li et al. 2012); **E,** from Middle Jurassic Huo and Wang sites from Shaanxi Province (Xing et al., 2015b); **F,** from Lower Jurassic Wulatezhongqi site from Inner Mongolia (Li et al. 2010); **G,** from Upper Jurassic Nan'an site from Chongqing municipality (Xing et al., 2013); **H,** from Lower Jurassic Dalishu tracksite III from Yunnan Province (Xing et al., in press a); **I,** from Middle Jurassic Yima tracksite from Henan Province (Xing et al., 2016); **J** and **K,** (this paper).

TABLE 1. Measurements (in cm) of the dinosaur tracks from Dianwen tracksite, Yunnan Province, China.

Number	ML	MW	II-IV	L/W	AT
DW-T1	5.7	5.5	64°	1.0	0.28
LQ-T1	4.9	—	—	—	—
LQ-T2	6.4	6.6	78°	1.0	0.31

Abbreviations: **ML**: Maximum length; **MW**: Maximum width (measured as the distance between the tips of digits II and IV); **II-IV**: angle between digits II and IV; **L/W** is dimensionless; **AT**: anterior triangle length-width ratio.

(2013, 2015b, 2016b, in press c) for other reports of *Anomoepus* from the Early and Middle Jurassic of China.

Recently it has become evident that tracks may change our view of the composition of faunas in a given formation. Thus, studies of Cretaceous fluvio-lacustrine deposits from China have shown they are track rich, but lack significant skeletal remains. They are therefore Type 1 and Type 2 deposits (Lockley 1991; Lockley and Hunt, 1995; Lockley et al., 2015a, b; Xing and Lockley 2016). Due to the preponderance of skeletal remains in the Fengjiahe Formation it would be regarded as a Type 4 formation in which skeletal remains dominate over tracks. Based on previous documentation it could also be placed in the 4a category in which the skeletal remains (saurischian) and tracks (theropodan) are consistent. However, the discovery of presumed ornithischian tracks changes the balance of evidence, so that the Fengjiahe Formation might be considered as Type 4b deposit in which the bone and track evidence is not consistent. The obvious conclusion is that faunas in any given deposit can only be characterized by reporting all skeletal and track evidence.

ACKNOWLEDGMENTS

We thank Yong Ye (Zigong Dinosaur Museum, China) for their suggestions on an earlier version of the manuscript. This research project was supported by the 2013 and 2015 support fund for graduate student's science and technology innovation from China University of Geosciences (Beijing), China.

REFERENCES

Fang, X.S. and Li, P.X., 2008, Jurassic red bed in the central Yunnan of China. Geological Publishing House, Beijing, 111 p.

Li, J.J., Bai, Z.Q., Lockley, M.G., Zhou, B., Liu, J. and Song, Y., 2010, Dinosaur tracks in Wulatezhongqi, Inner Mongolia: Acta Geologica Sinica, v. 84, p. 723–742.

Li, J.J., Lockley, M.G., Zhang, Y.G., Hu, S.M., Matsukawa, M. and Bai, Z.Q., 2012, An important ornithischian tracksite in the Early Jurassic of the Shenmu Region, Shaanxi, China: Acta Geologica Sinica, v. 86, p. 1–10.

Lim, J.D., Lockley, M.G. and Kong, D.Y., 2012, The trackway of a quadrupedal ornithopod from the Jindong Formation (Cretaceous) of Korea: Ichnos, v. 19, p. 101–104.

Lockley, M.G., 1991, Tracking Dinosaurs: a New Look at an Ancient World. Cambridge, Cambridge University Press, 238 p.

Lockley, M.G. and Gierlinski, G., 2006, Diverse vertebrate ichnofaunas containing *Anomoepus* and other unusual trace fossils from the Lower Jurassic of the western United States: implications for paleoecology and palichnostratigraphy: New Mexico Museum of Natural History and Science, Bulletin 37, p. 175-191.

Lockley, M.G. and Hunt, A.P., 1995, Dinosaur tracks and other fossil footprints of the western United States. New York, Columbia University Press, 360 p.

Lockley, M.G. and Matsukawa, M., 2009, A review of vertebrate track distributions in East and Southeast Asia: Journal Paleontological Society of Korea, v. 25, p. 17-42.

Lockley, M.G., Matsukawa, M., Sato, Y., Polahan, M. and Daorerk, V., 2006, A distinctive new theropod dinosaur track from the Cretaceous of Thailand: implications for theropod track diversity: Cretaceous Research, v. 27, p. 139-145.

Lockley, M.G., Xing, L.D., Matsukawa, M., Li, J.J. and Li, R.H., 2015a, The utility of tracks in paleoecological census studies: case studies from the Cretaceous of China; *in* Zhang, Y., Wu, S. Z. and Sun G., eds., The 12th Symposium on Mesozoic Terrestrial Ecosystems, Abstracts Volume, Shenyang China, Aug, 16-20th 2015, p. 175-177.

Lockley, M.G., Xing, L.D, Li, R.H. Li, J.J., and Matsukawa, M., 2015b. The value of tetrapod tracks in paleoecological census studies: Examples from the Cretaceous of China. Society of Vertebrate Paleontology, Abstracts of 75th Meeting, p. 166.

Lucas, S.G., 2007, Tetrapod footprint biostratigraphy and biochronology: Ichnos, v. 14, p. 4-38.

Olsen, P. and Baird, D., 1986. The ichnogenus *Atreipus* and its significance for Triassic biostratigraphy; *in* Padian, K., ed., The Beginning of the Age of Dinosaurs: Cambridge, Cambridge University Press, p. 61-87.

Olsen, P.E. and Rainforth, E.C., 2003, The Early Jurassic ornithischian dinosaurian ichnogenus *Anomoepus*; *in* Letourneau, P.M. and Olsen, P.E., eds., The great rift valleys of Pangea in eastern North America, Volume 2: Sedimentology, stratigraphy, and paleontology: New York, Columbia University Press, p. 314-368.

Xing, L.D. and Lockley, M.G., 2016, Tracking Early Cretaceous dinosaurs in southwestern China: Track based census methods for describing animal communities; *in* Kim, K.S Kim, D H. and Lim J.D., eds., Spring Meeting of the Korean Earth Sceince Society and Gyeongnam Goseong International Symposium, Gyeongnam Educational Welfare Center April 7-8th 2016, p. 32-36.

Xing, L.D., Harris, J.D., Toru, S., Masato, F. and Dong, Z.M., 2009, Discovery of dinosaur footprints from the Lower Jurassic Lufeng Formation of Yunnan Province, China and New Observations on Changpeipus: Geological Bulletin of China, v. 28, p. 16-29.

Xing, L.D., Lockley, M.G., Chen, W., Gierliński, G.D., Li, J.J., Persons, W.S.IV., Matsukawa, M., Ye, Y., Gingras, M.K. and Wang, C.W., 2013, Two theropod track assemblages from the Jurassic of Chongqing, China, and the Jurassic stratigraphy of Sichuan Basin: Vertebrata PalAsiatica, v. 51, p. 107-130.

Xing, L.D., Lockley, M.G., Miyashita, T., Klein, H., Wang, T., Persons, W.S.IV., Pan, S.G., Zhang, J.P. and Dong, Z.M., 2014, Large sauropod and theropod tracks from the Middle Jurassic Chuanjie Formation of Lufeng County, Yunnan Province and palaeobiogeography of the Middle Jurassic sauropod tracks from southwestern China: Palaeoworld, v. 23, p. 294-303

Xing, L.D., Lockley, M.G., Zhang, J.P., You, H.L., Klein, H., Persons, W.S.IV., Dai, H. and Dong, Z.M., 2015a, First Early Jurassic ornithischian and theropod footprint assemblage and a new ichnotaxon *Shenmuichnus wangi* ichnosp. nov. from Yunnan Province, southwestern China: Historical Biology DOI: 10.1080/08912963.2015.1020424

Xing, L.D., Lockley, M.G., Tang, Y.G., Klein, H., Zhang, J.P., Persons, W.S.IV., Dai, H. and Ye, Y., 2015b, Theropod and ornithischian footprints from the Middle Jurassic Yanan Formation of Zizhou County, Shaanxi, China: Ichnos, v. 22, p. 1-11

Xing, L.D., Lockley, M.G., Zhang, J.P., Klein, H., Wang, T, Kümmell, S.B. and Burns, M.E., 2016a, A theropod–sauropod track assemblage from the ?Middle–Upper Jurassic Shedian Formation at Shuangbai, Yunnan Province, China, reflecting different sizes of trackmakers: Review and new observations: Palaeoworld, v. 25, p. 84-94

Xing, L.D., Abbassi, N., Lockley, M.G., Klein, H., Jia, S.H., McCrea, R.T. and Persons, W.S.IV., 2016b, The first record of *Anomoepus* tracks from the Middle Jurassic of Henan Province, Central China: Historical Biology DOI: 10.1080/08912963.2016.1149480

Xing, L.D., Lockley, M.G., Klein, H., Zhang, J.P. and Persons, W.S.IV., in press a, A new ornithischian–dominated and theropod footprint assemblage from the Lower Jurassic Lufeng Formation of China: New Mexico Museum of Natural History and Science, Bulletin 74.

Xing, L.D., Lockley, M.G., Klein, H., Zhang, J.P., Wang, T., Persons, W.S.IV. and Dong, Z.M., in press b, A tetrapod footprint assemblage with possible swim traces from the Jurassic–Cretaceous boundary, Anning Formation, Konglongshan, Yunnan, China. Palaeoworld.

Xing, L.D., Lockley, M.G., Klein, H., Falkingham, P.L., Kim, J.Y., McCrea, R.T., Zhang, J.P., Persons, W.S.IV., Wang, T. and Wang, Z.Z., in press c, First Early Jurassic small ornithischian tracks from Yunnan Province, southwestern China: PALAIOS.

Young, C.C., 1966, Two footprints from the Jiaoping Coal Mine of Tungchuan, Shensi: Vertebrata PalAsiatica, v. 10, p. 68-71

Zhen, S., Li, J., and Rao, C., 1986, Dinosaur footprints of Jinning, Yunnan: Memoirs of the Beijing Natural History Museum, v. 33, p. 1-19.

Zhang, Z.Y., 1996. Stratigraphy (lithostratic) of Yunnan Province. Wuhan, China University of Geosciences Press, 366 p.