Ornithopod (Dinosauria: Ornithischia) tracks from the Upper Cretaceous Zhutian Formation in the Nanxiong basin, Guangdong, China and general observations on large Chinese ornithopod footprints

记广东南雄盆地上白垩统主田组鸟脚类足迹及中国已命名的大型鸟脚类足迹的属级新观察

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Abstract: Herein we describe three trackways that pertain to *Hadrosauropodus nanxiongensis* ichnosp. nov. from the Yangmeikeng track site in the Nanxiong Basin, Guangdong Province, China. The tracks occur in the Upper Cretaceous Zhutian Formation. The nearby Gushi track site preserves trackways attributable to *Hadrosauropodus* isp. These represent the first occurrences of hadrosaur footprints in China. These discoveries expand the known distribution of hadrosaur tracks from North America to China, and provide evidence for the existence of large hadrosaurs in the Cretaceous of the Nanxiong Basin. Other previously-described, large, ostensible ornithopod track occurrences in China are discussed: *Sinoichnites* is represented only by an informal "plastotype," *Yangtzepus* is attributable to a theropod, and *Iguanodonopus* is considered a *nomen nudum* and its specimens attributable to *Iguanodontipus*. New specimens of *Jiayinosauropus* allow some redescription of the ichnotaxon, and the unnamed Neixiang footprint is redescribed.

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Key words: Nanxiong basin in Guangdong; Upper Cretaceous Zhutian Formation; *Hadrosauropodus nanxiongensis; Yangtzepus; Iguanodonopus; Jiayinosauropus*; Neixiang footprint

摘要:记述了广东省南雄盆地上白垩统主田组3组恐龙行迹,由杨梅坑足迹点的足迹命名了南雄鸭嘴龙足迹(*Hadrosauropodus nanxiongensis* ichnosp. nov.)一新种;古市足迹点的足迹归入鸭嘴龙足迹一未定种(*Hadrosauropodus* isp.)。这是中国鸭嘴龙足迹属的首次描述,将该足迹的分布从北美拓展至中国,并为南雄盆地存在大型的鸭嘴龙提供了新的化石证据。还整理了中国已描述的大型鸟脚类足迹:中国足迹(*Sinoichnites*)被定为非正式的塑模标本;扬子足印(*Yangtzepus*)被归入兽脚类足迹;禽龙足迹(*Iguanodonopus*)被认为是裸名,归入禽龙足迹(*Iguanodontipus*);嘉荫足迹(*Jiayinosauropus*)增加了新材料并得以具体描述;内乡足迹(Neixiang footprint)得以重新描述。

关键词:广东南雄盆地;晚白垩世主田组;南雄鸭嘴龙足迹;扬子足迹;禽龙足迹;嘉荫足迹;内乡足迹

中图分类号:P534.53;Q915.86 **文献标志码**:A **文章编号**:1671-2552(2009)07-0829-15

1 Introduction

Outcrops in the Nanxiong Basin, near Shaoguan City, northern Guangdong Province, expose Cretaceous-Paleogene red beds of the Nanxiong Group. Recently, abundant Late Cretaceous dinosaur body [1] and trace fossils, including dinosaur eggs[2] and footprints[3], have been discovered in the basin.

In early 1980s, local geologists found some small theropod dinosaur tracks in the Nanxiong Group[4]. In 1983 and 1984, a Sino-German (joint Chinese Academy of Sciences-University of Bonn) scientific expedition discovered more than twenty dinosaur footprints, including two possible sauropod tracks, at the Yangmeikeng track site near the town of Youshan (formerly Datang) [3]. Later, a University of Notre Dame expedition discovered more than fifty dinosaur footprints, also at the Yangmeikeng track site in 1993. Fang Xiaosi and Zhang Xianqiu discovered fourteen similar dinosaur footprints at south of the town of Gushi in 2004.

Late in March, 2008, at the invitation of the Nanxiong County Bureau of Land and Resources, the senior author examined these dinosaur footprints. Some of the Yangmeikeng site tracks have been substantially weathered; the majority have been backfilled. The two best-preserved footprints were cast, and the casts are housed in the Nanxiong Dinosaur Museum. Here we describe the tracks from both the Yanmeikeng and Gushi sites, as well as review other, similar tracks attributable to large ornithopods from China.

2 Institutional abbreviation

CFEC=Chongqing Museum of Natural History, Chongqing, China. IVPP=Institute of Vertebrate Paleontology and Paleoanthropology, Beijing, China. J=Shenzhou Dinosaur Museum, Jiayin Dinosaur National Geological Park, Heilongjiang, China. NCBLR = Nanxiong County Bureau of Land and Resources, Shaoguan, China. NDM=Nanxiong Dinosaur Museum, Shaoguan, China. QJGM=Dinosaur Track Site of Geological Museum of Qijiang Municipality´s Bureau of Land Resources and Housing Management, Chongqing, China. TMP=Royal Tyrrell Museum of Palaeontology, Drumheller, Alberta, Canada. YMK=Yangmeikeng tracksite, Shaoguan, China.

3 Geological setting

Most Upper Cretaceous strata in the Nanxiong Basin are placed in the Nanxiong Group. Since the 1960s, many geological prospecting parties have surveyed the basin. However, controversy remains over Nanxiong Group subdivision[5]. Here we follow the stratigraphic scheme of Li et al. that divides Nanxiong Basin Cretaceous-Paleogene strata, in ascending order, into the basal Songshan Formation of unspecified but Cretaceous age, the overlying, Upper Cretaceous Nanxiong Group (consisting of the Yuanpu, Zhutian, and Zhenshui formations), and the capping Paleogene Luofozhai Group (consisting of the Shanghu, Nongshan, and Guchengcun formations). The tracks described herein and previously are in the Zhutian Formation.

Zhao et al. divided the Nanxiong Group into the Yuanpu and Pingling formations[6]; their "Yuanpu Formation" corresponds to the Yuanpu and Zhutian formations of Li et al.[5], and the "Pingling Formation" corresponds to the Zhenshui Formation. Magnetostratigraphy and K/Ar dates[2,6] indicate Maastrichtian ages for the "Pingling" and upper part of the "Yuanpu" formations. Therefore, the age of the Zhutian ("upper Yuanpu") Formation is Maastrichtian (latest Late Cretaceous).

The tracks at the Yangmeikeng track site (see Fig. 1) occur in the "7th layer" of the Zhutian Formation[7], which is comprised of red-brown, pelitic siltstone mixed with laminate (thin-layered), fine-grained sandstone. The tracks at the newer Gushi track site (114°14′48″E,25°02′51″N) are also in the Zhutian Formation, though they occur in a sage-green, pelitic siltstone that is stratigraphically slightly lower than Yangmeikeng track site horizon (Zhang, personal communication, Dec., 2008). The track-bearing unit at the Gushi site weathers red-brown. Zhutian Formation sediments were deposited in fluvio-lacustrine facies[7].

4 Systematic ichnology

4.1 General observations on previously-described, large ornithopod tracks in China

Large (≥20 cm in length) ornithopod tracks have half a century of discovery and research in China. However, all existing descriptions are relatively simple and devoid of systematic comparison, resulting in unclear affiliations. Some holotypes have even been lost. When discussing hadrosaur track occurrences worldwide, Lockley et al. did not mention Chinese discoveries[8]. Therefore, it is necessary to reexamine the evidence and reassess previous conclusions concerning these ornithopod tracks.

4.1.1 Brief introductions to *Sinoichnites, Yunnanpus, Caririchnium*, and *Laoyingshanpus*

Sinoichnites. Kuhn originally named and described this ornithopod track from the lower Upper Jurassic Anding Formation in Shenmu County, Shanxi Province, China[9]. *Sinoichnites* was assigned to Iguanodontidae by Young, Kuhn, and Zhen et al.[9-11]. Unfortunately this track, which was the first reported from China, has been lost. Based on pictures of the original specimen, the *S. youngi* specimen currently housed at Beijing Natural History Museum is a cast of the holotype. According to the International Code of Zoological Nomenclature[12], for a taxon (or ichnotaxon) to persist, a lost holotype needs to be replaced by a neotype, a condition difficult to satisfy until another specimen, preferably from the same locality and same track sequence, can be found. Until that time, the cast at the Beijing Natural History Museum can be regarded as an informal "plastotype."

Yunnanpus. Chen and Huang originally de-

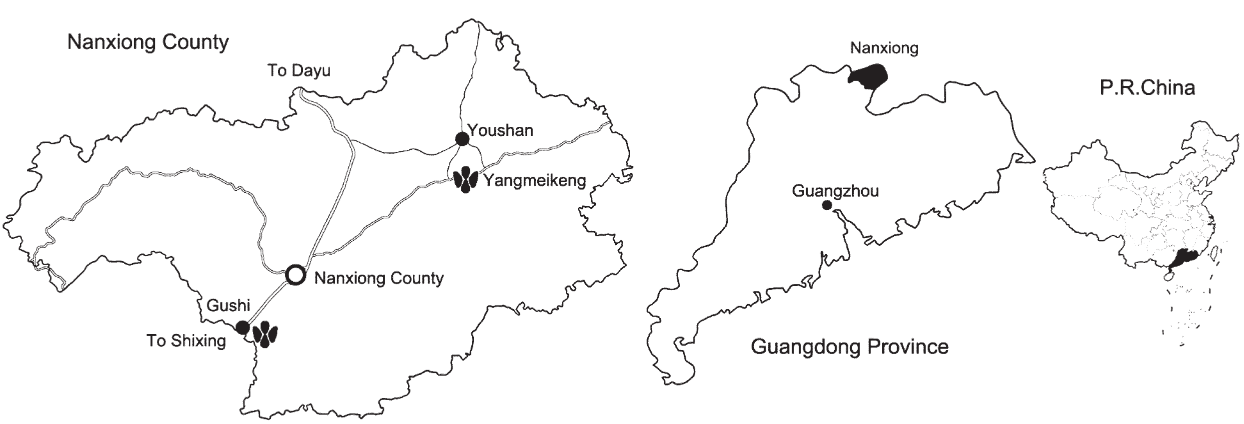


Fig. 1　Geographic map of the two new dinosaur footprint localities
(Gushi and Yangmeikeng, indicated by the footprint icons)

scribed this ichnotaxon (as "ichnofamily indet.") from the Upper Cretaceous Jiangdihe Formation from Yuanjitun village in Changling town, Yunnan Province, China[13]. *Yunnanpus* was assigned to Theropoda by Chen and Huang[13], but it was assigned to Ornithopoda by Zhen et al. [14]. Lockley et al. considered the holotype trackway too poorly preserved and insufficient for detailed comparisons with other tracks. Therefore, the ichnotaxon is best regarded as a *nomen dubium*[15].

Caririchnium. Leonardi erected this ichnotaxon based on Early Cretaceous tracks from Brazil[16]; the first Chinese occurrence, from the ?Middle Cretaceous Jiaguan Formation of Qijiang County, Chongqing Municipality, China, was given ichnospecies distinction as *C. lotus*[17]. *Caririchnium* ispp. have also been reported in Texas, Colorado, Oklahoma, New Mexico, Korea, and Japan. The justification for inferring that the track maker was a hadrosaur seems to be based on the age of the tracks[8].

Laoyingshanpus. Xing et al. originally named and described these ornithopod tracks from the? Middle Cretaceous Jiaguan Formation of Qijiang County, Chongqing Municipality, China[17]. *Laoyingshanpus* was co-discovered with *Caririchnium lotus*. Detailed descriptions and comparisons of the Qijiang tracksite will appear elsewhere.

4.1.2 New observations on *Yangtzepus, Iguanodonopus, Jiayinosauropus,* and the Neixiang footprint

***Yangtzepus* Young, 1960**

Type ichnospecies.

Yangtzepus yipingensis Young, 1960[10]

(Fig. 2-A、B、C, Table 1, Plate Ⅰ-D)

Holotype: IVPP V2473, three natural molds on three slabs from the ?Upper Jurassic or ?Cretaceous of the Lower Chiating Series (Jiading Group), Guanyingchong tracksite of Gaijin village in Yibin City, Sichuan Province, China.

Diagnosis: Medium-sized, tridactyl theropod (originally attributed to an ornithopod) tracks that lack manus and tail traces. The divarication angle between digits Ⅱ and Ⅲ is wider than that between digits Ⅲ and Ⅳ. Digit Ⅲ is directed forward, and digit Ⅳ is similar to digit Ⅱ in length. The long axis of each digit is parallel to the track axis. A metatarsophalangeal pad is oval in shape.

Description: The length:width ratio of IVPP V2473.1 (the holotype) is 1.52. Digit Ⅲ is the longest and digit Ⅳ is the shortest. All digits are similar in width. The digital pad formula is x-2-3-3-x. The divarication angle between digits Ⅱ and Ⅲ is 22° and between Ⅲ-Ⅳ is 17°. Claw marks are discernible and most pronounced on digit Ⅱ; the claw mark of digit Ⅲ is small and directed inward, and that of digit Ⅳ is the smallest. An oval metatarsophalangeal pad impression sits at the caudal end of digit Ⅲ. The pad impression is separated from digit Ⅲ by a distinct line, but for other two digits, such demarcation lines are not well-defined.

IVPP V2473.2 is somewhat smaller than V2473.1 but it has a higher length:width ratio (1.88). The divarication angle between digits Ⅱ and Ⅲ, at 20°, is subequal to the 19° angle between digits Ⅲ and Ⅳ. Claw marks are indistinct, entirely absent on digit Ⅲ and only the base is preserved on digit Ⅳ. Skin im pressions were observed both in the Metatarsophalangeal pad and the caudal end of digit Ⅲ[10]. Incomplete IVPP V2473.3 is devoid of the tips of all digits.

Discussion: The interpretation of the third track, IVPP V2473.3, as a manus impression has been widely cited. However, Young did not provide sufficient support for this assertion, only that (a) it is much smaller than the other two specimens, (b) the outer digits are distinctly divergent, (c) the middle toe is well separated from the heel, and (d) it is difficult to discern the segmentation of the pad[10]. Of these ostensible criteria,(a) is not valid because of potential ontogenetic differences in track makers, (b) and (c) are also present in IVPP V2473.1 and 2, and (d) is only the result of the nature of specimen preservation. Subsequently, he incorrectly distinguished the manus from the pes based on "the lateral digits of manus are apparently disconnected, whereas the lateral digits of pes are long."[18] The fragment of IVPP V2473.3 is extremely similar to V2473.2. Therefore V2473.3, in all probability, is merely an incomplete *Y. yipingensis* pes print.

In a similar case, Young provided insufficient evidence to assign *Y. yipingensis* to Ornithopoda [10]. Later, it was assigned to Iguanodontidae by Kuhn[9] and to Ornithopoda by Zhen et al.[11]. Morphologically, the most similar tracks to *Y. yipingensis* include unnamed footprint G46 (Fort Terrett Formation, Middle Copperas Creek, Albian, Texas[19−20]) and unnamed "round−toed" footprint (Morrison Formation, Kimmeridgian−Tithonian, Garden Park, Colorado[21]). The former is considered to pertain to the large theropod *Acrocanthosaurus*; the latter was attributed to a camptosaurid ornithopod. The proportions, digital pad formula, and claw impressions of *Y. yipingensis* suggest a theropod track maker rather than an ornithischian. Similar criteria were cited in assigning *Ornithopodichnites*[22], *Orcauichnites*[22], and *Minisauripus*[23] to theropods[24, 25].

Young touted the "primitiveness" of *Y. yipingensis* as the justification for modifying the known age of the Chiating Series (Jiading Group) to the Late Jurassic[10], instead of Cretaceous, which is insufficient evidence. Ye concluded a late Early Cretaceous age for the unit based on ostracods[26], which is therefore a better supported age for *Y. yipingensis*. Incidentally, this age is very close to that of the unnamed footprint G46 mentioned above.

***Iguanodonopus* Zhen et al., 1996**

=*Iguanodon* Zhen et al., 1994

Type ichnospecies.

Iguanodonopus xingfuensis Zhen et al., 1996[14]

(Fig. 2−D, Table 1)

Holotype:CFEC−E−1 a and b, both positive and negative impression footprints from the ?Lower Cretaceous of Sichuan, China.

Description:Tridactyl ornithopod tracks that lack manus and tail traces. The length:width ratio of CFEC−E−1 is 1.38. Digit Ⅱ is isosceles triangular in shape and is of similar length to digit Ⅳ. The forward −pointing, similarly −shaped digit Ⅲ is the longest. Digit Ⅳ is also of the same shape but is the shortest in the track. Digits Ⅱ and Ⅳ are similar in width, each somewhat narrower than digit Ⅲ. Digits Ⅱ and Ⅲ are deeply impressed, whereas digit Ⅳ is shallowly (lightly) impressed. The apices of the claws are well defined, with parabolic shapes, particularly on digit Ⅲ. A large, arcuate metatarsophalangeal pad impression is present at the caudal end of the track. The pad impression is contiguous with all three digits but is not well demarcated from any of them. The divarication angle between digits Ⅱ and Ⅲ is 18°, which is narrower than the angle of 31° between digits Ⅲ and Ⅳ.

Discussion: Zhen et al. described tracks they called *Iguanodon* (FEC−E−1) from Emei County, Sichuan Province, China [23] that they perceived as exhibiting the diagnostic characteristics of the ichnotaxon *Iguanodon* from Dorset, United Kingdom[27−28]. Zhen et al. emended the Emei *Iguanodon* as *Iguanodonopus* and maintained their previous assertion of similarity with the UK specimens with the exception of size[14]. The size of a footprint varies with ontogeny as well as both individual and species differences, so size is therefore not a sufficient criterion upon which to diagnose an ichnospecies.

Sarjeant et al. discussed the history of *Iguanodon* footprints and, to alleviate confusion with the taxon *Iguanodon*, erected the ichnotaxon *Iguanodontipus* to accommodate the Dorset footprints [29]. Sarjeant et al. assigned CFEC−E−1 to *Iguanodontipus burreyi*, which has the following diagnostic characteristics: tridactyl, digit Ⅲ directed forward and approximating an equilateral triangle in shape; digits Ⅱ and Ⅳ directed almost laterally, somewhat narrower than digit Ⅲ, and have the shapes of isosceles triangles with rounded to sub−acute distal ends; and caudal end of the sole smoothly curved or very slightly flattened. Although the divarication angles in CFEC−E−1 are narrower than those of the *Iguanodontipus burreyi* type, this trait alone is not sufficient for distinguishing different ichnotaxa. In addition, CFEC−E−1 is distinguished from *Iguanodontipus billsarjeanti*[30] most readily by its lack of manus prints.

Sarjeant et al. though not using the name *Iguanodonopus*, perceived that "the *Iguanodon* footprints reported from Sichuan, China, by Zhen Shuonan et al. (1994) appear too elongate to be correctly attributed to that genus."[29]. Nomenclaturally, *Iguanodonopus* was erected earlier than *Iguanodontipus*, but the description of the former was devoid of detailed description and discussion, rendering it a *nomen nudum*. In addition, it has hardly been cited. The senior author suggests that it is attributable to *Iguanodontipus*, making the Emei specimens *Iguanodontipus xingfuensis*.

Jiayinosauropus **Dong et al., 2003**

Type ichnospecies.

Jiayinosauropus johnsoni Dong et al., 2003[31]

(Fig. 2–E, Table 1, Plate Ⅰ – E,F)

Holotype:J F1 (= JDGP V.01, Jiayin Dinosaur National Geological Park), one natural mold on a slab from the Upper Cretaceous Yong'ancun Formation of Jiayin County in Changling town, Heilongjiang Province, China.

Referred material:J F2, half one natural mold on a slab from the Upper Cretaceous of Heilongjiang, China.

Description:Tridactyl ornithopod track that lacks manus and tail traces. The length:width ratio of J F1 is 0.84. Digit Ⅲ is the shortest, whereas digit Ⅳ is the longest. All digits are in oval shape, with claw marks at the tips of digit Ⅲ and Ⅳ; the latter is extremely pronounced. The 46° divarication angle between digits Ⅱ and Ⅲ is wider than the 31° angle between digits Ⅲ and Ⅳ. The caudal end of the metatarsophalangeal pad impression is incomplete, with smoothly curved margins.

Both J F2 and J F1 are from the same site, but

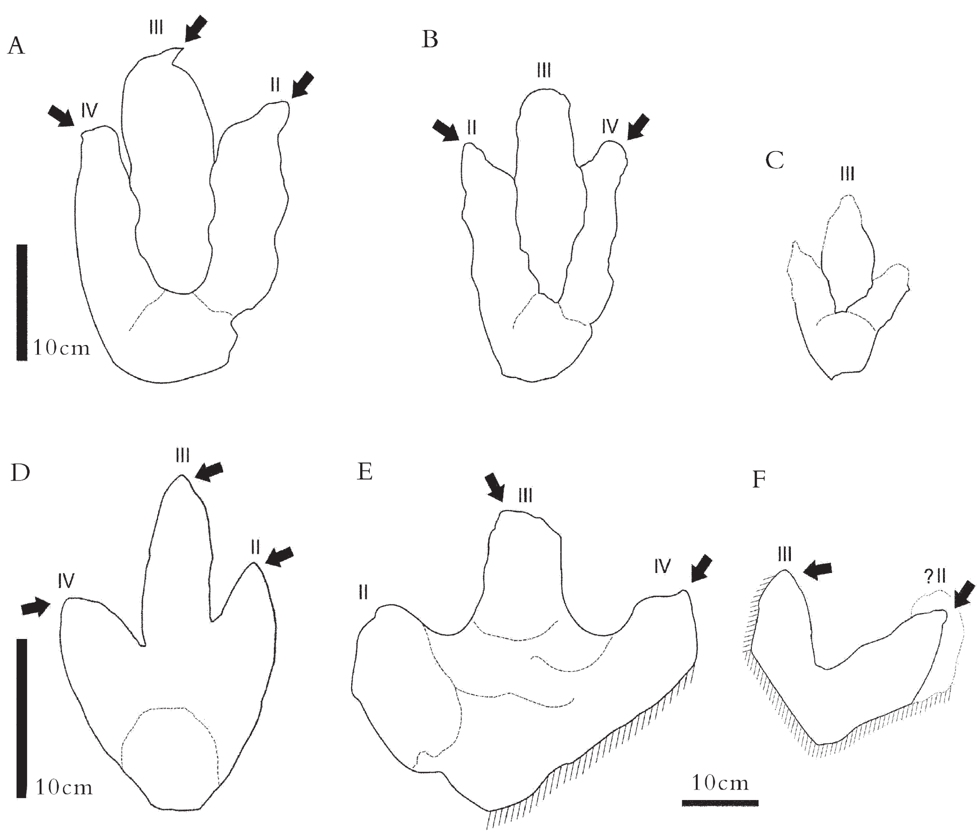


Fig. 2 Outline drawings of *Yangtzepus yipingensis* IVPP V2473.1 (A), V2473.2 (B), V2473.3 (C), *Iguanodonopus xingfuensis*. CFEC–E–1 (D), *Jiayinosauropus johnsoni*. J F1 (E) and J F2 (F)

arrows indicate claw marks

the former is distinctly smaller than the latter. Only two digits are preserved in J F2; the high divarication angle (49°) between them suggests that they are digits Ⅱ and Ⅲ. The tips of digits Ⅱ and Ⅲ in J F2 are upside-down V shaped, which differs from the smooth, parabolic curves in J F1. A claw-drag mark is visible at the cranial end of digit Ⅱ.

Discussion:Many of the characteristics that *Jiayinosauropus* exhibits are similar to those of *Hadrosauropodus*[8], such as rough symmetry, the greater width than length of the footprint, and the maximum width located at the caudal metatarsophalangeal pad region. J F1 is devoid of tear drop-shaped pads on all digits. No real boundaries divide the metatarsophalangeal pad region from the three digits, especially for digits Ⅱ and Ⅳ. However, due to the absence of the caudal end of the metatarsophalangeal region, diagnostic characteristics of the fossil are difficult to ascertain. Therefore, *J. johnsoni* is considered provisionally valid.

Although the newly discovered J F2 has not been described to date, the specimen is labeled as *Jiayinosauropus* in a display at the Jiayin Dinosaur National Geological Park. The apices of the two digits(a claw-drag mark of digit Ⅱ excluded) preserved in J F2 are both in upside-down V-shaped, which is more typical of narrow, pointed, claw-bearing theropod footprints. However, the substantial divarication angle between digits indicates affiliation with J F1. Thus, the assignment of J F2 to *J. johnsoni* is provisionally accepted here. Possible emendation of the ichnotaxon will depend on newly discovered material in the future.

Neixiang Footprint. [32]
(Fig. 3)

Material:IVPP V5783, one natural mold on a slab from the Cretaceous of Xiaguan Basin, Henan Province, China.

Description: As interpreted, tridactyl ornithopod track that lacks manus and tail traces. The length: width ratio of IVPP V5783 is 1.39. The impressions of the digits are deformed due to the track maker walking over uneven ground, but they are approximately oval. A metatarsophalangeal region with a length of 4.83 cm and width of 9.48 cm is apparent; its maximum width is along the cranial margin. In the central area of the track, surrounded by the digit and metatarsophalangeal regions, is a deep concavity that would, since the specimen is a natural cast, have been a marked elevated region in the actual track. The footprint is most deeply impressed at the distal of digit Ⅲ where the depth reaches roughly 5.5 cm.

Discussion:IVPP V5783 represents a very unusual instance of a dinosaur stepping on, breaking, and

Fig. 3　Photograph of nest of eggs IVPP V5783(A), close-up of area in box in A, containing the Neixiang footprint and trampled eggs(B) and outline drawing of the Neixiang track, IVPP V5783 (C)
?Ⅲ=probable dligit Ⅲ impression; arrow indicates inferred direction of motion

Table 1 **Measurements of *Yangtzepus yipingensis*** (IVPP V2473.1~3), ***Iguanodonopus xingfuensis*** (CFEC−E−1), ***Jiayinosauropus johnsoni*** (J F1, J F2), **and the Neixiang footprint** (IVPP V5783)

Measurement	IVPP V2473.1	IVPP V2473.2	IVPP V2473.3	CFEC-E-1	J F1	J F2	IVPP V5783
Maximum length/cm	29	21	13.4**	21.2	35.94	-	14.14
Maximum width/cm (distance between the tips of digits II and IV)	19.02	11.17	12.3**	13.21	42.81	-	10.17
Length of digit II*/cm	17.39	11	6.5**	10.1	18.21	?17.06	-
Length of digit III*/cm	21.47	14.4	7.68**	14.75	17.44	11.13	?7.07
Length of digit IV*/cm	16.58	11.6	7.15**	9.21	21.54	-	-
Angle between digits II and III	22°	20°	-	18°	46°	?49°	-
Angle between digits III and IV	17°	19°	-	31°	31°	-	-
Angle between digits II and IV	39°	39°	-	49°	77°	-	-

notes: *measured to the rear margin of the caudalmost digital node; **incomplete

distorting dinosaur eggs in an ostensible nest. Ornithopods trampling eggs in nests has been hypothesized as an explanation for nests containing abundant eggshell fragments; such trampling presumably was performed by juveniles remaining in the nest to be cared for by parents[33], but this is the first instance of an actual track atop more or less intact eggs. The track is too large to have been made by a recent hatchling from the same kinds of eggs and therefore does not represent an instance of altricial young remaining nest−bound.

The nest contains 16 dinosaur eggs. In one corner of the nest, an unusual concavity is present between an incomplete egg and three adjacent eggs. The concavity overlaps and deforms these eggs; the deformation is most pronounced toward the center of the concavity. Zhao believed that the concavity was probably the result of an accident, in which the dinosaur was hastily attempting to cover the nest after giving birth to the eggs[32]. Because the track was not made in readily deformable sediment and therefore did not have a clean outline that would describe the general pedal morphology of the track maker, the footprint is difficult to assign to any particular ichnogenus or ichnospecies. This "tridactyl footprint"[32] was attributed to an ornithopod[34]. Based on its description, it is similar to *Iguanodontipus*[29].

Zhao believed that the track maker of Neixiang footprint probably also laid the *Youngoolithus* eggs found in the vicinity and on which the track occurs[32]. *Youngoolithus* belongs to the oofamily Faveoloolithidae, and faveoolithid eggs have been considered sauropodan, not ornithopod[35]. In a similar case, Mohabey described a tridactyl footprint from the Upper Cretaceous Lameta Formation of the Kheda District, India[36] that looks something like an ornithopod pes print, but was attributed to the manus of a sauropod dinosaur on account of its association with three sauropod eggs[37]. The new observations and interpretations of the Neixiang footprint indicate that it probably belongs to an ornithopod instead of a sauropod. Occasionally, ichnofossils do not necessarily correspond simply with nearby body fossils (e.g., eggs with bones; for example, Granger[38] vs. Norell et al.[39]).

Zhao did not specify from which formation the nest of *Youngoolithus* eggs (IVPP V5783) came, but the specimen was assigned a Cretaceous age because it produced faveoloolithid eggs[32]. *Youngoolithus* has been discovered in the Zoumagang and Sangping formations of the Sangping−Xiaguan basin[40]. The iguanodontian ornithopod *Nanyangosaurus zhugeii*[41] was also discovered in the Sangping Formation. The possibility that the Neixiang footprint was made by an ornithopod, perhaps even *Nanyangosaurus*, is therefore plausible and supported by the body fossil record in this region.

4.2 **Yangmeikeng tracksite**

Dinosauria

Hadrosauridae

Hadrosauropodus Lockley et al., 2003

Type ichnospecies.

Hadrosauropodus langstoni Lockley et al., 2003[8]

Diagnosis: Trackway of a large, three-toed biped. Tracks as wide or wider than long. Each toe impression consists of an oval pad with its long axis parallel to the track axis. Track axis rotated inward (about 20°) relative to trackway midline. Step short, about 2× foot length. Heel rounded, transversely or caudally concave, with bilobed caudal margins. May be associated with small manus tracks (Lockley et al., 2003).

Hadrosauropodus nanxiongensis ichnosp. nov.

(Fig. 4-A, B, Table 2, Plate Ⅰ-A, C, Plate Ⅱ)

Etymology: The ichnospecies name "*nanxiongensis*" from the Chinese "Nanxiong" Basin indicates the fossil site.

Holotype: All specimens occur in three trackways (YMK.A-YMK.C) of natural pes print casts; YMK.A consists of three tracks (YMK.A.1-3), YMK.B of five tracks (YMK.B.1-5), and YMK.C of four tracks (YMK.C.1-4). Of these, the best preserved (YMK.A.2, of which NDM.F1 is a cast) is here designated as the holotype.

Referred material: All the remaining tracks in trackways YMK.A-C. Additionally, a second cast stored in the Nanxiong Dinosaur Museum, NDM.F2, is of uncertain provenance (see below).

Type locality and horizon: Zhutian Formation (Upper Cretaceous), Yangmeikeng tracksite, Shaoguan, Guangdong Province, China.

Diagnosis: Mid-sized *Hadrosauropodus*. Tridactyl tracks that are longer than wide and that lack manus and tail traces; angles between digits Ⅱ and Ⅳ range from 51° to 95°; round convexity on the caudolateral margin of digit Ⅱ; maximum width of digit Ⅳ is roughly twice that of digit Ⅱ.

Description: The specimens are natural casts of

Table 2 Measurements of Nanxiong footprints

Measurement	NDM.F1	NDM.F2	NCBLR.F.M1
Maximum length/cm	40.38	37.86	36.22
Maximum width/cm (distance between the tips of digits II and IV)	51.32	27.38	25.95
Length of digit II*/cm	16.6	20	11.08
Length of digit III*/cm	18.87	17.14	14.86
Length of digit IV*/cm	16.42	17.38	11.89
Angle between digits II and III	45°	21°	22°
Angle between digits III and IV	50°	30°	25°
Angle between digits II and IV	95°	51°	45°

notes: *measured to the rear margin of the caudalmost digital node

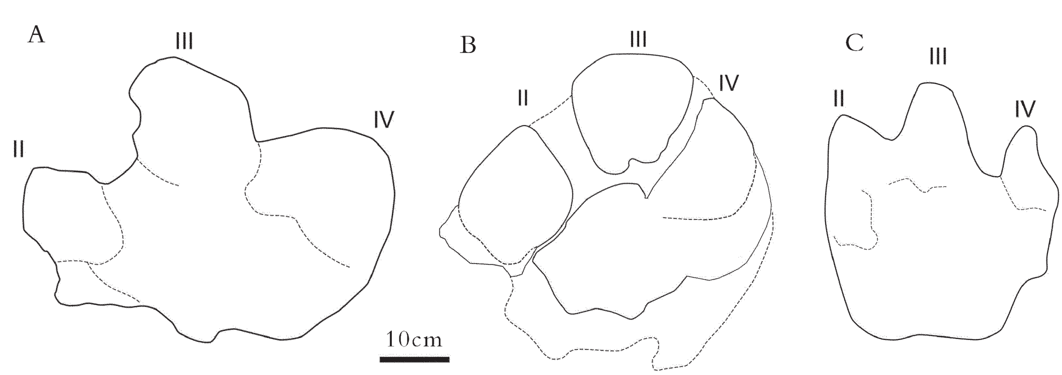


Fig. 4 Outline drawings of NDM.F1 (A), NDM.F2 (B), and NCBLR.F.M1 (C)

tridactyl ornithopod pes tracks; the trackways lack manus and tail traces. The length:width ratio of NDM.F1 is 0.79. Digit Ⅱ is short and the narrowest of the three digits. Digit Ⅲ is the longest, and its claw mark is broadly parabolic. The claw mark is directed craniolaterally. Digit Ⅳ, the shortest, is similar to digit Ⅱ in length but twice its width. The divarication angle between digits Ⅱ and Ⅲ (45°) is somewhat narrower than that between digits Ⅲ and Ⅳ (50°). The step lengths in tracks from the YMK.A series are short, about 2× foot length. The axes of the YMK.A tracks are rotated inward relative to trackway midline. In each track, the caudal margin of the metatarsophalangeal region is concave. A round convexity at the caudolateral margin of the holotype is also present in other tracks from the YMK.A series.

NDM.F2 is also a tridactyl ornithopod pes print. The length:width ratio is 0.79. Digit Ⅱ is the longest and diamond-shaped, with a round convexity at the caudolateral margin. Digit Ⅲ is the shortest, similar in width to digit Ⅱ. The claw mark at the tip has an parabolic shape. Digit Ⅳ is intermediate in length between Ⅱ and Ⅲ but is the narrowest. A large metatarsophalangeal pad with a slightly concave caudal end was observed. The 21° divarication angle between digits Ⅱ and Ⅲ is somewhat narrower than the 30° angle between digits Ⅲ and Ⅳ.

4.3 **Gushi tracksite**

Hadrosauropodus isp.

(Fig. 4-C, Fig. 5, Table 2, Plate Ⅰ-B)

Material: Fourteen complete natural casts housed at Gushi tracksite. The tracks are cataloged individually as NCBLR.F.1-12. A cast of the best one (Fig. 4) is stored in the Nanxiong County Bureau of Land and Resources, where it is cataloged as NCBLR.F.M1.

Locality and horizon: Zhutian Formation (Upper Cretaceous), Yangmeikeng tracksite, Shaoguan, Guangdong Province, China.

Description: Tridactyl ornithopod tracks that lack manus and tail traces. The length:width ratio for NCBLR.F.M1 is 1.4. Digit Ⅱ is the shortest and isosceles triangular in shape. The forward-directed digit Ⅲ is the longest, similar in width with digit Ⅱ. Digit Ⅳ is shorter than digit Ⅱ, the narrowest of all the digits, and generally isosceles triangular in shape. The claw marks of all digits have parabolic shapes, especially digit Ⅲ. The metatarsophalangeal region is large but lacks any indication of distinct pads; the caudal margin of the track is smoothly curved and slightly concave. The divarication angle (22°) between digits Ⅱ and Ⅲ is somewhat narrower than that between digit Ⅲ and Ⅳ (25°).

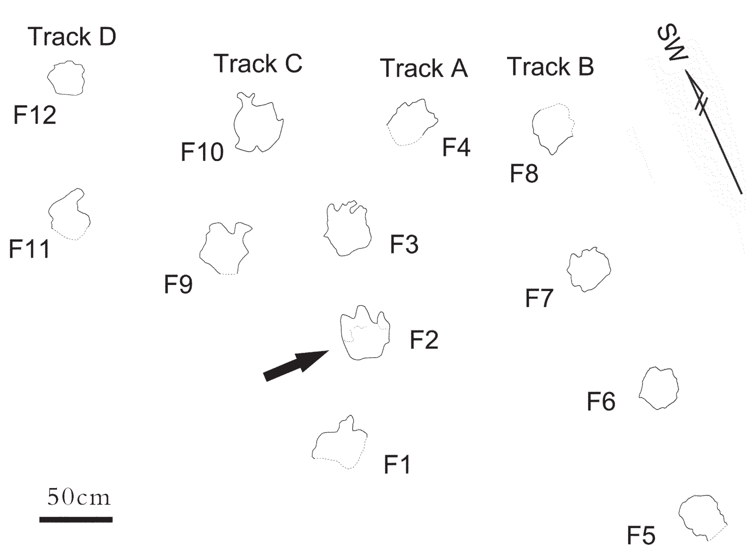
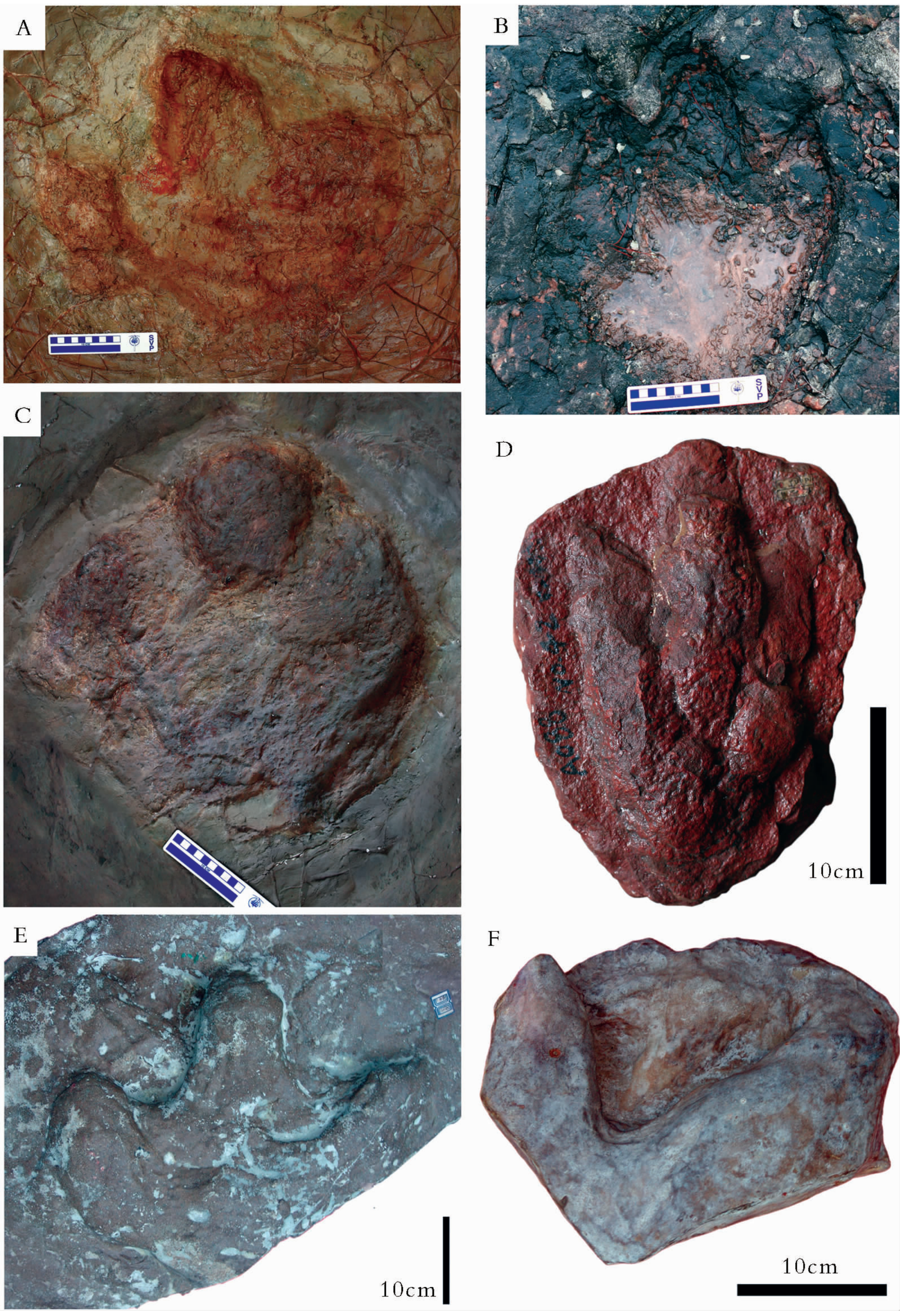


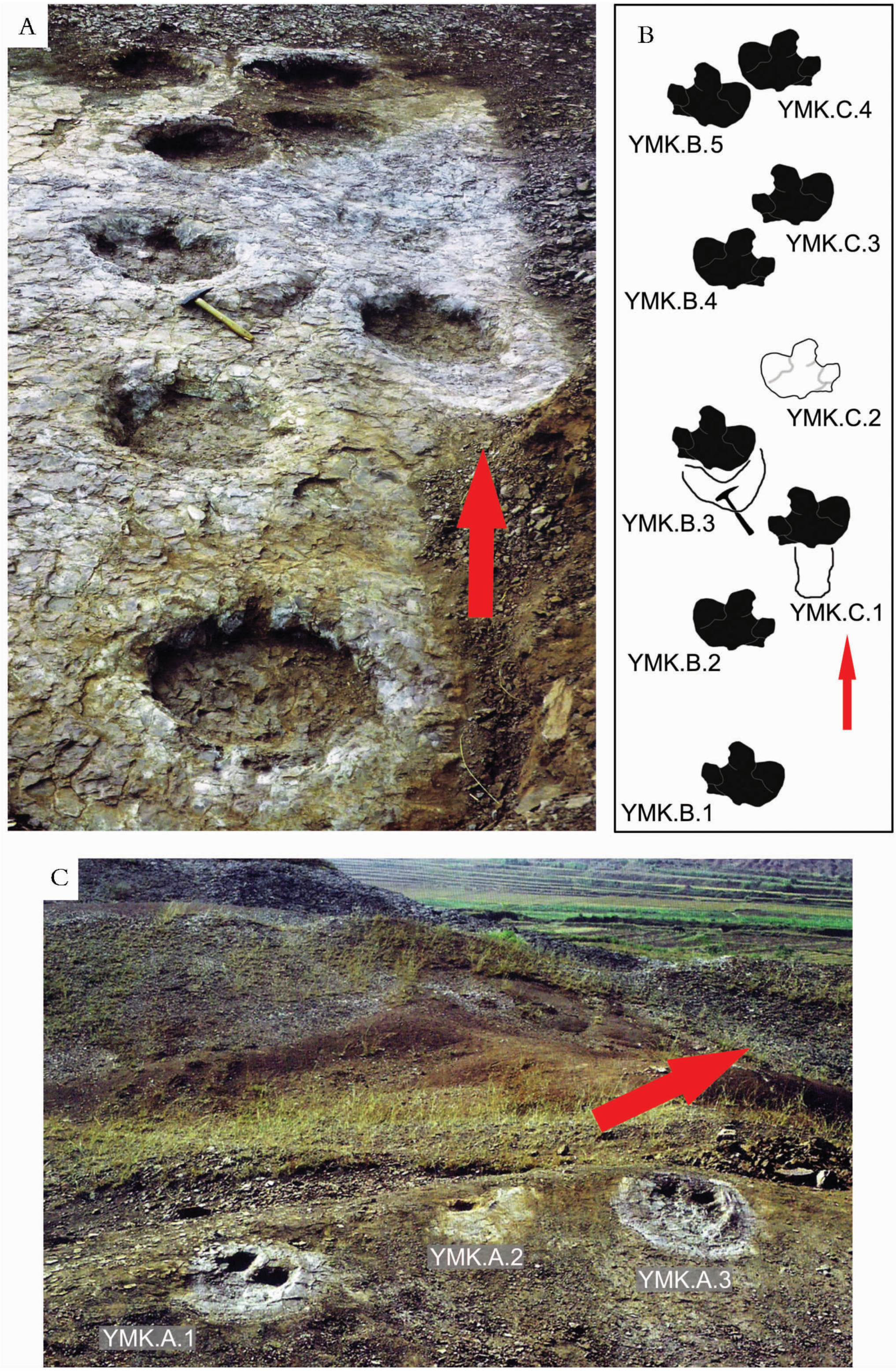
Fig. 5 Distribution of the footprints at the Gushi tracksite
arrow indicates NCBLR. F. MI

图版 I　Plate I



A. *Hadrosauropodus nanxiongensis* ichnosp. nov. (NDM.F1); B. *Hadrosauropodus* isp. (NCBLR.F.M1); C. *Hadrosauropodus nanxiongensis* ichnosp. nov. (NDM.F2); D. *Yangtzepus yipingensis* (IVPP V2473.2); E. *Jiayinosauropus johnsoni* (J F1); F. *Jiayinosauropus johnsoni* (J F2)

图版Ⅱ Plate Ⅱ



A. Tracks of *Hadrosauropodus nanxiongensis* ichnosp. nov. (YMK.B.1–5 and YMK.C.1–4);
B. Schematic diagram of (A), drawn from a photograph taken at another angle, among which YMK.C.2 has been collected or damaged; C. Tracks of *Hadrosauropodus nanxiongensis* ichnosp. nov. (YMK.A.1–3) red arrows indicate the direction of motion

Twelve of the fourteen tracks are arranged in four trackways (Fig. 5), among which Trackway A, consisting of NCBLR.F1–F4, is the best preserved. The step lengths are: F1–F2: 77.2 cm; F2–F3: 73 cm, F3–F4: 81 cm. Pace angulations are: F1–F2–F3: 165°, F2–F3–F4: 149°. The stride lengths are: F1–F3: 149 cm; F2–F4: 148.5 cm. Trackway B consists of NCBLR.F5–F8, of which F8 is indistinct. Two poorly-preserved footprints were observed in Trackways C and D, respectively.

4.4 Discussion of footprints from Yangmeikeng and Gushi tracksites

Lockley et al.[8] reviewed hadrosaur track occurrences worldwide, validating the ichnotaxa *Amblydactylus*, *Caririchnium*, *Iguanodontipus*, and *Hadrosauropodus*. Per the new observations and reexamination made for this paper (see section 4.1, above), valid large ornithopod tracks in China include *Iguanodontipus*, *Caririchnium lotus*, *Laoyingshanpus*, and, provisionally, *Jiayinosauropus*. The differences exhibited by the Yangmaikeng tracks outlined below from other *Hadrosauropodus* ichnospecies justifies placing them in a distinct ichnospecies, *H. nanxiongensis*.

Tracks from the Yangmeikeng and Gushi tracksites are attributable to *Hadrosauropodus* by: tracks as wide or wider than long; each toe impression consists of an oval pad; track axis rotated inward relative to trackway midline; step short, about 2× foot length; and metatarsophalangeal region rounded, transverse or caudally concave with bilobed caudal margin. Unfortunately, further comparison is unavailable because of the lack of manus impressions in these tracks. Other partial and poorly-preserved footprints at the Yangmeikeng tracksite appear simply as pits, which led Erben et al. to consider them sauropod tracks[3].

Three characteristics distinguish NDM.F1 from *H. langstoni*: (1) the 95° divarication angle between digits Ⅱ and Ⅳ is greater than the 70° of angle of *H. langstoni* (TMP 87.76.6); (2) the round convexity on the caudolateral margin of digit Ⅱ is only present in Yangmeikeng tracks, but not for other *Hadrosauropodus*; and (3) the maximum width of digit Ⅳ is roughly twice that of digit Ⅱ. Of these, the latter is most prominent and unknown in any other large ornithopod track; its consistency across several sequential tracks indicates that it is not an extramorphological artifact. Therefore, it and the other differences support placing these tracks in a new ichnospecies.

The track of which NDM.F2 is a cast is unknown. The only information about it is that the fossil is from the Yangmeikeng tracksite. However, the information from the Nanxiong Dinosaur Museum suggests that its source tracksite has been weathered. NDM.F2 and NDM.F1 both possess similar length: width ratios. In NDM.F2, the divarication angle between digits II and IV is narrower than in NDM.F1; variable lengths of each digit between the two tracks may be due to different sediment consistencies or individual differences of the track makers. The reason for assigning NDM.F2 to *Hadrosauropodus nanxiongensis* is that these footprints possess the diagnostic characteristics mentioned above (2 and 3). NDM.F2 contributes information lacking in NDM.F1: its metatarsophalangeal pad is more discernible than in NDM.F1. More footprints are still being discovered at this site that will help determine whether or not this attribution is correct.

No well-defined lines were detected between the caudal ends of digits and the metatarsophalangeal regions of the Gushi tracks, including NCBLR.F.M1. Therefore they cannot be attributed to *H. langstoni* or any other ichnospecies with certainty, and are better referred to merely as *Hadrosauropodus* isp.

The occurrence of *Hadrosauropodus* has now been established in the Upper Cretaceous of the Nanxiong Basin in Guangdong Province. Together with *H. langstoni* from the Lance Formation (late Maastrichtian) of Wyoming, USA, the Chinese occurrences constitute a new, broader distribution of *Hadrosauropodus*.

Though tracks attributed to hadrosaurs are now known in the Maastrichtian of Guangdong, this attribution would be strengthened by body fossils. *Microhadrosaurus*[42] was discovered in the "Yuanpu Formation" of the Nanxiong Basin. Dong regarded this genus as much like *Edmontosaurus*[42]. Brett-Surman in contrast, regarded the material as possessing no characteristics that would allow it to be differentiated from other hadrosaur, rendering it a *nomen dubium*[43] (see also Horner et al.[44]). Nevertheless, the material appears to pertain to a hadrosaur, affirming the presence of this clade in the region and bolstering a hadrosaur affiliation for the *Hadrosauropodus* tracks. Maastrichtian hadrosaurs are also known from elsewhere in China (*Sahaliyania, Wulagasaurus*[45]) and adjoining areas of Mongolia and Russia[44, 46], so even if *Microhadrosaurus* does not pertain to a hadrosaur, the presence of hadrosaurs in Guangdong in the Maastrichtian is not precluded on either paleobiogeography or biochronologic grounds. *Hadrosauropodus nanxiongensis* and *H.* isp. therefore provide new fossil evidence for the presence of a large hadrosaur in the Nanxiong Basin.

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