山东诸城地区下白垩统一新类型鸟类足迹

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内容提要:1931 年,Mehl 报道的来自 Dakota Group 的 *Ignotornis mcconnelli* 是第一个被广泛接受的中生代鸟类足迹。目前,亚洲、北美洲、欧洲、非洲和南美洲都有白垩纪鸟类足迹的报道,尤其以东亚地区最为丰富。山东诸城张祝河湾恐龙足迹点保存了一枚完整的鸟类足迹,本文对该鸟类足迹进行了详细描述与对比。研究认为,该鸟类足迹区别于以往发现的鸟类足迹,根据其形态建立了新种:玲珑诸城鸟足迹 *Zhuchengornipes exquisitus*。玲珑诸城鸟足迹造迹者可能为滨鸟类,形成于干旱气候下的滨浅湖环境。

关键词:诸城;下白垩统;鸟类足迹;滨鸟类

鸟类足迹化石是鸟类在沉积物表面行走留下的足迹化石记录。鸟类足迹化石在晚中生代的地层,特别是白垩系中是比较常见的,是比哺乳动物或两栖动物足迹更为广泛的一类遗迹。东亚地区早白垩世鸟类足迹的分异度和丰度,为了解鸟类的足部解剖学特征、生存环境、生活习性、行为学方面提供了重要信息(Lockley et al. ,1992),特别是为鸟类起源与早期演化方面的研究提供了新思路。国际上第一个被广泛接受的中生代鸟类足迹是来自 Dakota Group 的 *Ignotornis mcconnelli*(Mehl,1931)。目前,已有大量来自亚洲、北美洲、欧洲、非洲和南美洲白垩纪鸟类足迹的报道(lockley et al. ,2010;李建军等,2011),东亚地区也有更丰富的鸟类足迹被研究(Lockley et al. ,1992,2002a;Lim et al. ,2000,2002;Li Daqing et al. ,2002;Azuma et al. ,2002,2006;李日辉等,2005a;Kim et al. ,2006;Matsukawa et al. ,2006;Zhang Jianping et al. ,2006)。近年来,我国白垩系中发现了大量新的鸟类足迹化石,其中包括一些待描述的鸟类足迹(Li Daqing et al. ,2002,2006;李日辉等,2005a,2005b;Lockley et al. ,2006a,2012,2013;Lü Junchang et al. ,2010;Xing Lida et al. ,2010,2011)。Xing Lida 等(2010)及王宝红等(2013)曾报道山东诸城张祝河湾化石点下白垩统发现的足迹组合,其中 Xing Lida 等(2010)在其中识别出一保存较为完整的鸟类足迹化石(编号 ZDRC. F3)。通过对该鸟类足迹的简单描述和研究认为,其可能与韩国的镇东鸟足迹(*Jindongornipes*)相似,但比镇东鸟足迹略小。李建军(2015)则将其归为镇东鸟未定种(*Jindongornipes* sp.)。作者近期对这一鸟类足迹进行了详细描述和对比研究,并认为其区别于以往发现的鸟类足迹,是一种新类型的鸟类足迹化石,并将其建立一新属新种,即:玲珑诸城鸟足迹(*Zhuchengornipes exquisitus* gen. et sp. nov.)。

1 系统古生物学

鸟纲 Class Aves Linnaeus,1758

遗迹科未定 Family Ichnofamily indet

玲珑诸城鸟足迹(新遗迹属)*Zhuchengornipes exquisitus* gen. et sp. nov.

词源:“Zhucheng”为“诸城”的汉语拼音,地名,指化石标本产地所在城市。“exquisitus”形容足迹标本的小巧,精致。

正型标本:标本编号 ZDRC. F3,保存较为完整的鸟类足迹,现保存于诸城市恐龙文化研究中心。

层位与产地:足迹化石产于山东省诸城市张祝河湾村下白垩统大盛群田家楼组砂岩中(王宝红等,2013;Xing Lida et al. ,2015)。该化石点除保存有此鸟类足迹化石外,还保存有中小型蜥脚类恐龙

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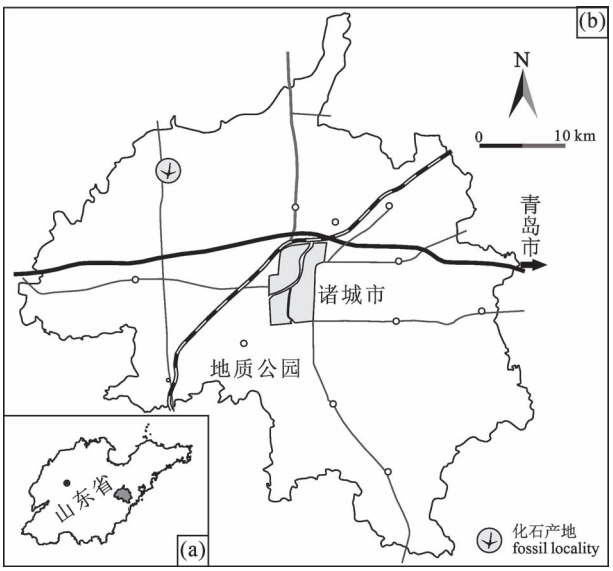

图 1 山东诸城张祝河湾化石产地地理位置图
(据 Xing Lida et al. ,2010, 略改)
Fig. 1 Map of Zhangzhuhewan site showing the fossil locality (Modified from Xing Lida et al. ,2010)

足迹与疑似鸟脚类恐龙足迹化石(Xing Lida et al. , 2015)。

鉴别特征:小型的四趾型鸟类足迹,长略大于宽(长 3. 1 cm,宽 2. 9 cm),趾行式,四趾由跖趾垫连接。Ⅱ、Ⅲ、Ⅳ三趾向前,Ⅱ趾略长于Ⅳ趾,拇指印迹小,伸向后方,拇指与Ⅲ趾的夹角为 180°。长宽比值近于 1,趾迹纤细,跟部印迹明显较小,缺少蹼迹。Ⅱ、Ⅲ趾之间的夹角略大于Ⅲ、Ⅳ趾之间的夹角,Ⅱ、Ⅲ、Ⅳ趾迹的形状呈长锥形。爪迹、趾垫印迹不清晰。

2 标本描述

正型标本 ZDRC. F3 为一孤立保存的右足足迹,保存在一蜥脚类恐龙足迹附近,为凹型足迹,趾行式,足迹较小,长 3. 1 cm,宽 2. 9 cm(长度略大于宽度),长宽比值为 1. 07,趾迹纤细,跟部印迹明显较小,缺少蹼迹。

ZDRC. F3 具有清晰的四趾,为常态足,亦称不等趾足(anisodacty1)(李建军,2015)(Ⅱ、Ⅲ、Ⅳ三趾向前,拇指印迹伸向后方),拇指与Ⅲ趾的夹角为 180°。四趾印迹清晰,Ⅱ、Ⅲ、Ⅳ趾迹的形状由近端向远端逐渐变细,整个趾迹呈长锥形;拇趾较小。四趾由跖趾垫连接,跟部(跖趾垫)印迹明显较小。其中,拇指最短(长 0. 7 cm),略微向内侧弯曲,Ⅱ趾略长于Ⅳ趾(Ⅱ趾长 1. 6 cm,Ⅳ趾长 1. 3 cm),Ⅲ趾最长(长 2. 0 cm),约为拇指长度的 3 倍。Ⅱ、Ⅲ趾之间的夹角(66°)略大于Ⅲ、Ⅳ之间的夹角(60°),Ⅱ、Ⅳ趾趾间角为 126°,爪迹不清晰,趾垫印迹无法清晰分辨。

3 分析与讨论

3.1 鸟足迹鉴别特征与种属

鸟类足迹化石广泛分布并保存于白垩纪地层,常与白垩纪小型兽脚类恐龙足迹造成混淆(李建军,2015)。Lockley 等(1992,2012)提出了古鸟类足迹区别于兽脚类足迹的标准,即:① 足迹较小;② 趾迹纤细;③ 趾垫印痕不清晰;④ Ⅱ~Ⅳ趾间角大,鸟类足迹Ⅱ~Ⅳ趾间角一般为 110~120°或者更大;⑤ 拇趾(Ⅰ趾)印迹伸向后方;⑥ 爪迹纤细;⑦ 时间分布:鸟类足迹几乎都保存在后侏罗纪沉积中。McCrea 等(2001)指出,足迹的长/宽比值对于区分鸟类足迹和恐龙足迹非常有用,认为鸟类足迹的比值一般比恐龙类的小,约为 1. 0 甚至更小。玲珑诸城鸟足迹特征符合上述鸟类足迹标准的①~⑦,同时,玲珑诸城鸟足迹的长宽比为 1. 07,符合鸟类足迹长/宽比值约为 1. 0 这一标准。因此,玲珑诸城鸟足迹为鸟类足迹。

Xing Lida 等(2010)认为 ZDRC. F3 与我国其他地区的中生代鸟类不同,但与韩国下白垩统镇东组的滨鸟类足迹 *Jindongornipes* 相似。两者都缺少蹼迹,拇趾较短且后向。然而,*Jindongornipes* 的拇趾有两个末端趾垫,第Ⅱ趾至第Ⅳ趾之间的角度大于玲珑诸城鸟足迹。据此,作者认为该足迹有别于镇东鸟足迹。李建军(2015)指出 ZDRC. F3 的Ⅱ、Ⅳ趾

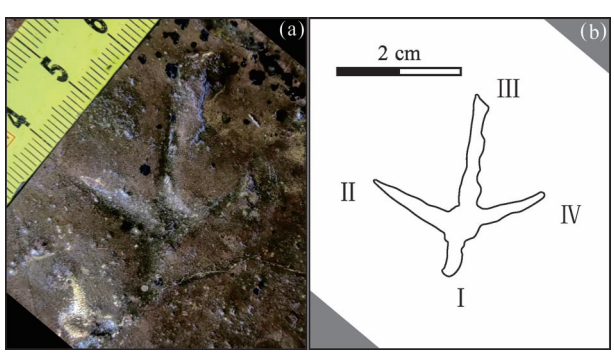

图 2 玲珑诸城鸟足迹 *Zhuchengornipes exquisitus* 正模标本(ZDRC. F3)照片(a)和足迹轮廓图(b)
Fig. 2 The photograph (a) and outline (b) of the footprint *Zhuchengornipes exquisitus* gen. et sp. nov. (the fossil number is ZDRC. F3)

夹角为 126°,在镇东鸟足迹(*Jindongornipes*)的Ⅰ、Ⅳ趾夹角(125 ~ 150°)的范围;另外,Lockley 等(1992)在描述镇东鸟足迹时,仅仅根据其拇趾的印迹特征推测镇东鸟足迹的拇趾有两个趾节着地,但其没有描述拇趾趾垫特征。因此,李建军等(2015)认为 ZDRC. F3 与镇东鸟足迹的两点区别并不明显,只是 ZDRC. F3 的个体小于镇东鸟足迹的模式种(*J. kimi*),不应将其归入 *J. kimi*,而是归为了镇东鸟足迹属未定种。但镇东鸟足迹属(*Jindongornipes*)为镇东鸟足迹科(Jindongornipodidae)下的一属,Lockley 等(2006)在建立镇东鸟足迹科(Jindongornipodidae)时,给定该科的鉴别特征包括:中等大小(6. 5 ~ 7. 5 cm 宽)的四趾型足迹,趾迹纤细,Ⅱ、Ⅳ趾趾间角大(125 ~ 160°),Ⅱ趾短于Ⅳ趾;拇趾长度中等,指向后方,与Ⅲ趾的夹角为 180°。Ⅱ、Ⅲ、Ⅳ趾趾垫式为 2-3(4)-4,但一般不清晰;Ⅲ趾基本平行于行迹中轴线(Lockley et al. ,2006b)。本研究认为,ZDRC. F3 虽然与镇东鸟足迹科的足迹有相似之处,但是也存在明显的区别,如:①ZDRC. F3 为小型足迹,宽度为 2. 9 cm,不到镇东鸟科足迹的一半,不在 6. 5 ~ 7. 5 cm 宽度范围内;②Ⅱ趾略长于Ⅳ趾,不符合镇东鸟科Ⅱ趾短于Ⅳ趾这一特征。因此,不应将 ZDRC. F3 归为镇东鸟科镇东鸟属的未定种,应将其从镇东鸟足迹科中移出,建立新属新种。由于其特征不符合现有已知各科的特征,暂将其归为未定科处理。

3. 2　造迹者栖息古地理环境

山东省诸城地区白垩系自下而上划分为莱阳群、青山群、大盛群和王氏群。大盛群自下而上进一步划分为马郎沟组、田家楼组、寺前村组和孟疃组。其中,田家楼组与孟疃组以滨浅湖相砂岩、粉砂岩及泥岩为主(王宝红等,2013)。早白垩世晚期胶莱盆地为一巨大湖盆(张岳桥,2008),化石点处于胶莱盆地边缘的滨浅湖环境(李金良等,2007)。前人在该组中发现了丰富的孢粉类、叶肢介、腹足类等生物化石(李庆平等,1992;司双印,2002),说明大盛群沉积时化石点的沉积环境为湖泊相。此外,诸城鸟足迹(*Zhuchengornipes*)具有典型的滨鸟类(shorebirds)足迹(滨鸟是一类在各种水体附近活动和觅食的中小型鸟类)形态特征:足迹很小,趾间角很大(Lockley et al. ,2012)。对比现生的岸边鸟类均属于常态足鸟类(李建军,2015),诸城鸟足迹为常态足,符合岸边鸟类的足迹特征,推测造迹者为滨鸟类。据前人地质研究和鸟类足迹的产出状况推测,在白垩纪早期化石点产地为大型湖泊的边缘,属滨浅湖环境,而并非 Xing Lida 等(2010)所认为的河流相环境。

诸城鸟足迹(*Zhuchengornipes exquisitus*)保存于一蜥脚类足迹附近。鸟类足迹与蜥脚类足迹的组合是亚洲东部足迹化石群的一种地域特色,蜥脚类足迹和鸟类足迹保存在一起的现象只在中国和韩国发现(Lockley et al. ,2002b)。诸城鸟类足迹组合符合东亚鸟类足迹组合的特点。其中,诸城鸟足迹 ZDRC. F3 的保存状况最好,相对来说,较大的蜥脚类足迹则保存不太理想。影响足迹形成(形态)和保存的最重要因素是基底的含水量(Allen,1997;Manning,2004),Xing Lida 等(2010)认为张祝河湾化石点的基底可能是浸水环境,蜥脚类足迹形成时,因体重等原因在踩进基底并拔出的过程中破坏了足迹的细节,小型的鸟类足迹受这样的影响则较少(Xing Lida et al. ,2010)。因此,作者认为是基底的含水量较大造成了小型的鸟类足迹比大型足迹的保存状况要好一些。

Lockley(1991)描述了高质量足迹的保存环境:恐龙踩踏了湖滨滩地之后,滩地慢慢变干燥了,形成的足迹长时期暴露在空气中,变得十分坚硬。在足迹硬化过程中没有降水,使足迹得以充分固结。后来的洪水携带的泥沙把已经坚硬的足迹掩盖了起来,使其得以保存成化石。足迹化石在湿度适中的海滨、湖滨和河滨等地有可能形成。李建军等(2011)指出干旱性湖泊周围特别容易形成并保存足迹化石,蜥脚类足迹一般都发现在蒸发量超过降雨量的环境中(Lockley et al. ,1994),代表干旱环境,鸟类足迹附近伴生有泥裂(Xing Lida et al. ,2010)也证实了这一点。张祝河湾发现足迹化石,说明在足迹形成时,该地区处于干旱的气候,才使得足迹得到充分的阳光照射。

蜥脚类足迹的边缘都有明显的挤压脊,幻迹周围不形成挤压脊(李建军,2015),说明足迹化石均保存在足迹形成的原始层面上,这表明早白垩世时期鸟类、蜥脚类恐龙都出没于这一区域。除张祝河湾外,在诸城的棠棣戈庄及皇龙沟地区也发现了恐龙足迹(Xing Lida et al. ,2010,2015;Li Rihui et al. ,2011;王宝红等,2013;许欢等,2013;张艳霞等,2017)。虽然诸城地区下白垩统中赋存较为丰富的恐龙、龟类及鸟类足迹化石(Xing Lida et al. ,2010,2015;Li Rihui et al. ,2011;王宝红等,2013;许欢等,2013;lockley et al. ,2015;张艳霞等,2023),但在保

存足迹化石的岩层中却几乎没有植物化石的发现，推测早白垩世时期该区域植被稀少。恐龙及其他生物并不生活在这里，可能是生活在周围植被茂盛的区域，这里的巨型湖泊仅是周围动物赖以生存的重要水源地。

研究认为，张祝河湾足迹化石点为一巨型湖盆的边缘地带，湖边缘坡度小，而且湖水很浅，在干旱的季节，湖水蒸发量大于降水量，湖泊边缘发生间歇性干旱，导致大片的湖滨滩地露出水面暴露在空气中，此时生活在附近的鸟类、蜥脚类恐龙到湖边进行捕食、饮水等活动，在潮湿松软的湖岸边留下了足迹。由于太阳的持续暴晒，留有足迹的湖边滩地进一步的干燥，出现了泥裂，足迹也随之硬化、固结、成型。随着后期降水携带的泥沙把已坚硬的足迹掩埋并保存，之后进入成岩阶段形成化石。

4 结论

通过对山东诸城地区张祝河湾下白垩统一完整鸟类足迹形态及其埋藏特征的研究，得出以下结论：

(1)通过形态特征对比，显示玲珑诸城鸟足迹 *Zhuchengornipes exquisitus* gen. et sp. nov. 是区别于之前发现的鸟类足迹，为一新类型。

(2)玲珑诸城鸟足迹产于滨浅湖环境，足迹很小且趾间角很大，推测造迹者为早白垩世滨鸟类。

(3)玲珑诸城鸟足迹赋存于下白垩统大盛群田家楼组，前人地质研究及鸟类足迹的产出层位伴生的蜥脚类足迹和泥裂，显示该足迹形成于干旱气候下的滨浅湖环境。

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A new avian footprint from the Lower Cretaceous in Zhucheng, Shandong Province

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Objectives: There is a complete avian footprint (ZDRC. F3) preserved in the Lower Cretaceous at the Zhangzhuhewan dinosaur footprint site in Zhucheng, Shandong Province. It had been briefly described and classified as the *Jindongornipes* sp. This article conducts a detailed systematic paleontological study of the footprint, and preliminary reconstruct the paleoenvironment and paleogeography of the Zhangzhuhewan dinosaur footprint site.

Methods: A detailed feature description of the avian footprint in Zhangzhuhewan dinosaur footprint site was conducted using observation and measurement methods, and their morphological characteristics and related parameters were compared with the footprint of the Jindongornipodidae, analyzing the similarities and differences between the two. Based on regional geology, preservation characteristics of dinosaur and avian footprints, and layer structures, the paleogeography and paleoclimate of their survival period are reconstructed, and the formation environment and process of the avian footprint are speculated.

Results: There are significant differences in the footprints between ZDRC. F3 and Jindongornipodidae: ① ZDRC. F3 is a small footprint with a width of 2. 9 cm, less than half of the bird family footprint in Jindongornipodidae, and not within the range of 6. 5 ~ 7. 5 cm in width; ② The digit Ⅱ is slightly longer than the digit Ⅳ, which does not conform to the characteristic of the Jindongornipodidae that the digit Ⅱ is shorter than the digit Ⅳ. ZDRC. F3 was removed from Jindongornipodidae and a new genus and species of *Zhuchengornipes exquisitus* gen. et sp. nov was established. The regional geology and characteristics of dinosaur and avian footprints and mud cracks indicate that Zhangzhuhewan dinosaur footprint site is located at the edge of a giant lake basin. The slope of the lake edge is small, and the lake water is shallow at Zhangzhuhewan site. During the dry season, the evaporation of the lake water exceeds the precipitation. Intermittent droughts occur at the edge of the lake, resulting in large areas of lakeside beaches exposed to the air. At that time, bird living nearby left footprints on the lakeside.

Conclusions: *Zhuchengonipes inquisitus* gen. et sp. nov. is a new type of avian footprint that differs from the avian footprints previously discovered and may have been created by shorebirds. The avian footprint was formed in the coastal and shallow lake environment of arid climate in the Early Cretaceous.

Keywords: Zhucheng; Lower Cretaceous; avian footprint; shorebirds

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