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First Record of Cenozoic Bird Footprints from East Asia (Tibet, China)

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Cenozoic bird tracks are known largely from North America, Europe, and the Middle East. There have been no reports of Cenozoic bird tracks from East Asia. This paper describes a series of two trackways produced by a galliform-like or gruiform-like bird from the Oligocene to Early Miocene of Tibet. The tracks are represented by tracings collected from a coal mine in Shigatse, Tibet, during the late 1970s. The tracks are comparable to *Ornithoformipes* and *Pavoformipes* and likely represent a medium-sized to large cursorial or flightless bird. In relation to modern bird tracks, the tracks bear a striking resemblance to those produced by the North American Wild Turkey (*Meleagris gallopavo*) except that *M. gallopavo* tracks often possess a small, elevated hallux impression. Due to the fact that these are tracings, however, a hallux may have been present and simply have been overlooked. The Shigatse trackways were, unfortunately, lost when the mine was closed and then backfilled during the 1980s, and there is little to no likelihood of recovery. Casts can be catalogued as holotype specimens but tracings cannot; however, all the original tracings have been donated to a public institution by their discoverer, Yimin Wu.

Keywords Bird footprints, Oligocene to Early Miocene, Shigatse, Tibet

INTRODUCTION

The known fossil record of Cenozoic bird tracks on the Asian continent has previously been limited to Iran (Lambrecht, 1938; Ataabadi and Khazee, 2004; Lockley and Harris, 2010). In 2011, the first Chinese Cenozoic bird tracks were discovered in the Sanshui Basin. These Sanshui bird footprints, which include numerous distinctive track morphologies, are currently under investigation by the authors of this paper but have yet to be formally described. We here report the recognition of several Cenozoic bird footprints from Shigatse (also Xigazê or Rikaze), Tibet. These tracks have been previously described but were misidentified as nonavian theropod dinosaur tracks (Wu, 1979). This confusion was the result of an uncertain geologic age, which subsequent stratigraphic work has resolved as Oligocene–early Miocene (Li, 2004). The morphology of the tracks is consistent with that of birds (see below), thus the Shigatse "dinosaur" tracks are actually the first known Cenozoic bird tracks from China.

HISTORY OF RESEARCH

In summer 1972, paleobotanist Yimin Wu and geologists Huang Diangui and Zhu Guangsui from the Tibet Geology Bureau's Third Geological Brigade discovered a series of fossil tracks at the Dongga coal mine. These tracks were found in the gray medium-grained sandstone of the Qiuwu Formation. Yimin Wu believed the tracks to be the footprints of juvenile dinosaurs (Wu, 1979). In a geological survey report, Wei Zhensheng and Tan Yueyan noted the discovery of the "juvenile dinosaur" tracks along with abundant Late Cretaceous plant fossils (Wei and Tan, 1979). Qian Dingyu reported that "huge waterfowl tracks (?)" were present in the upper sandstone of the Qiuwu coal measures (Qian, 1985). Yimin Wu sent line drawings of the tracks to Zhao Xijin, Dong Zhiming (Institute of Vertebrate Paleontology and Paleoanthropology, Chinese Academy of Sciences, China), and Zhen Shuonan (Beijing Natural History Museum, Beijing, China). Zhao Xijin and Dong Zhiming considered the tracks as those of theropod dinosaurs. Based on the documents provided by Zhen Shuonan or Li Jianjun, Matsukawa et al. (2006) remarked on the "Late Cretaceous slender-toed theropod from Shigatse."

Unfortunately, the Dongga tracksite was destroyed by road construction in 1984. In addition, the Dongga coal mine has been backfilled, and further excavation has been prohibited. No track specimens were ever collected. Representative examples of well-preserved tracks were measured and traced, using thin paper film overlays, but no photographs were taken and no latex molds were made (Yimin Wu, personal communication,

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February 13, 2012). Given that field excavation is now impossible, Wu's tracings are the sole remaining information on the Dongga tracks.

GEOLOGICAL SETTING

Shigatse is located in the southwest of the Tibet-Qinghai plateau (Fig. 1). The stratum containing coal lies in the west of Shigatse and is named for the Qiuwu coal measures. The deposits with coal are distributed along the Yarlung Zangbo suture zone. The coal stratum is more than 200 km long and 4.5 km wide. The Dongga coal mine, located in Dongga Township, 41 km west from downtown Shigatse, was established in 1971 and closed in 1987.

The Qiuwu Formation is a set of intercalated sandstones and mudstones, mixed with conglomerate (Yin et al., 1988) (Fig. 2). There is an unconformity between the Qiuwu and the upper Gangdise granite (Yin et al., 1988). Various suggestions have been made regarding the geological age of the Qiuwu Formation. Based on phytoliths, Wu (1979) and Guo (1975) considered the Qiuwu Formation to be Late Cretaceous. Geng and Tao (1982) argued that the Qiuwu Formation straddled the Late Cretaceous and the Eocene. Later, Tao (1988) suggested that the formation was exclusively Eocene. Qian (1985) regarded it as Late Paleocene to Middle Eocene. The age estimations of Geng and Tao (1982), Tao (1988), and Qian (1985) were all based primarily on plant megafossils. Recently, using palynomorph data from the coal-containing deposits of the Qiuwu Formation, Li (2004) determined the age of the formation was younger—Oligocene to Early Miocene—which is the age adopted herein.

DESCRIPTION OF MATERIAL

Materials

Based on the initial albeit informal survey of Wu (1979), there were seven tridactyl tracks at the Dongga site. Today, only two illustrations are preserved (Figs. 3–4). These illustrations are cataloged together as HDT.211P (HDT = Huaxia Dinosaur Tracks Research and Development Center, Gansu, China).

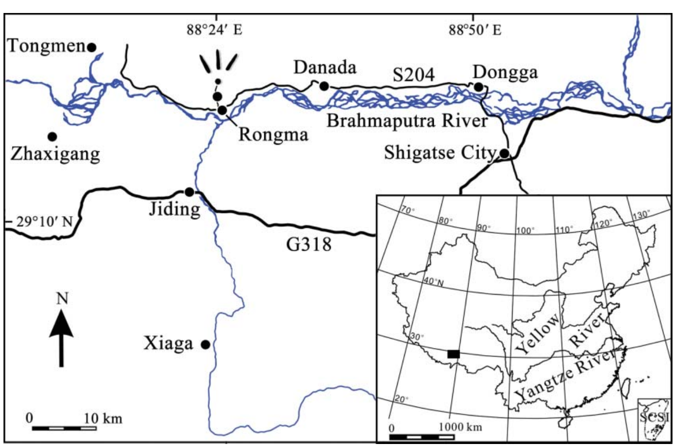

FIG. 1. Geographic position of the bird footprint locality (indicated by the footprint icon). (Color figure available online.)

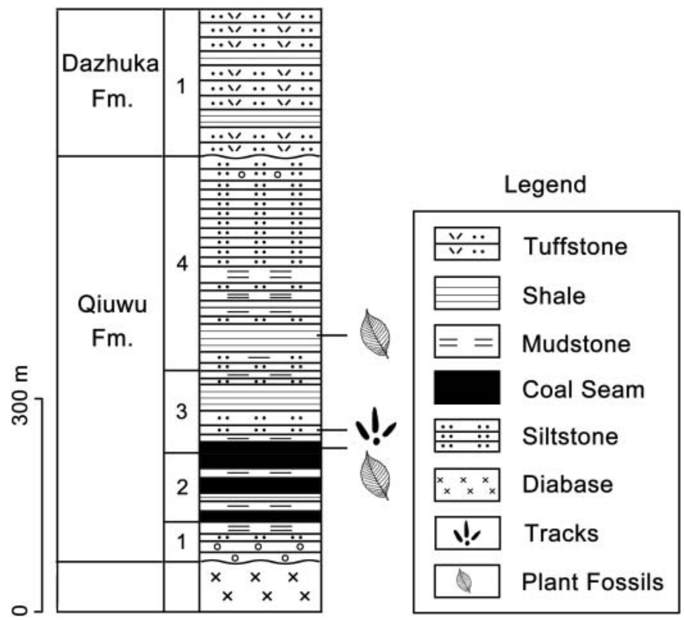

FIG. 2. Stratigraphic section of the Qiuwu Formation at the Dongga track locality (modified from Qian, 1985).

Locality and Horizon

Qiuwu Formation, Oligocene to early Miocene. Dongga tracksite, Shigatse City, Tibet, China.

Description

According to the field records of Yimin Wu the sandstone outcrop containing the Dongga tracks is 1.8 m across. Two trackways are present on the slab, one with three footprints and the other with four footprints (Fig. 3). Among them, HDT.211P.b2 is the most distinct (Fig. 4). This footprint is roughly equal in width and length (approximately 12 cm). All of the digits are approximately 4–6 cm long. According to the original data, the divarication angles between the lateral digits and digit III are 45– 50° (original record, II–III: 45°, III–IV: 50°, or II–III: 50°, III–IV: 45°. It is difficult to confirm exactly which toe is which, as the original method of measuring the angle is unknown; therefore, the data are for reference only). The depth of the track is approximately 2 mm. The metatarsal pad is round, diameter approximately 1.5 cm, depth approximately 3 mm, distance to proximal digit III approximately 2 cm (Fig. 4A, each square represents 1 × 1 cm).

It is worth noting that the Wu's original records seem to indicate that there was a large degree of uncertainty about the identification of digits II and IV. In the majority of anisodactyl bird tracks, however, the divarication between digits II and III is less than the divarication between digits III and IV, such as *Koreanaornis*, *Goseongornipes*, *Aquatilavipes*, and

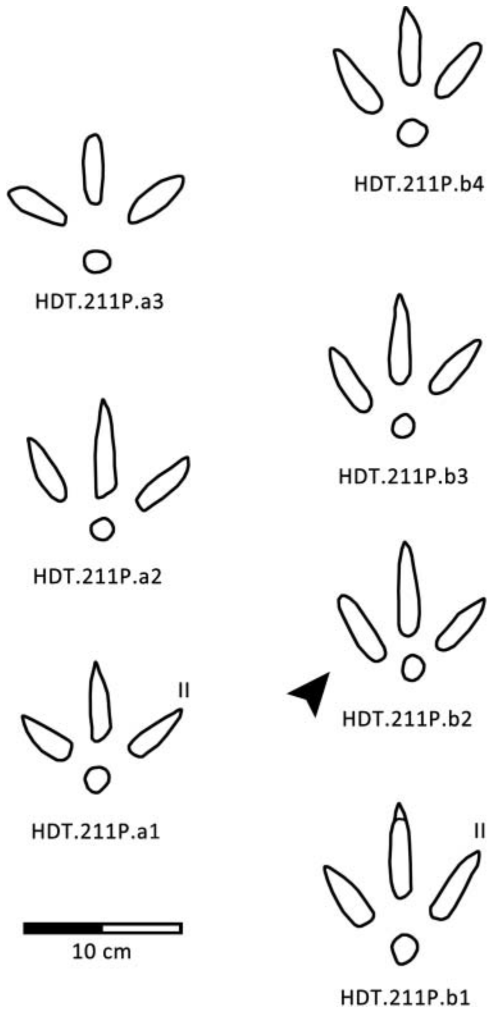

FIG. 3. Dongga bird trackways emended from Yimin Wu's drawing. The arrows indicated the most distinct one, HDT.211P.b2.

Moguiornipes (Xing et al., 2011). The Dongga tracks also follow this trend (see below), but this is not the case with *Barrosopus* from Argentina (Coria et al., 2002) or unnamed avian tracks from western Canada (Buckley and McCrea, 2011). On the other hand, the HDT.211P.b1 to HDT.211P.b3 and other tracks show the left-right-left gait as indicated by the pace angulation

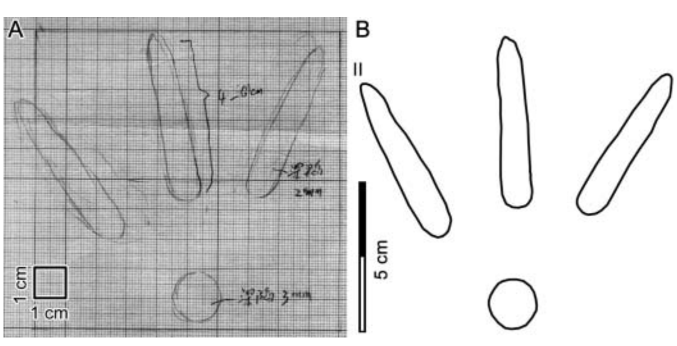

FIG. 4. Dongga bird track HDT.211P.b2. **A:** Drawing by Yimin Wu; **B:** Our drawing of the same specimen.

(see below). Thus, we followed that digit II–IV were identifiable from the original records.

The tracing of the well-preserved track HDT.211P.b2 is a medium-sized, tridactyl bid track. The length-to-width ratio is 0.94 (9.8 in length, 10.4 in width). The length of digits II–IV is 5.7, 5.8, and 5.5 cm, respectively. Digit III is directed cranially. Digit IV is slightly shorter than digit II and III. Total digit divarication, as measured using modern methodology, is 65° (i.e., 34° between III and IV and 31° between II and III). A circular metatarsophalangeal pad (diameter 1.7 cm) lies nearly in line with the axis of digit III, at a distance of 2.4 cm from the proximal digit III.

Based on Wu's tracings, the estimated pace length of HDT.211P.a1– 3 averaged 16.6 cm (range from 16.5 to 16.7 cm), stride length was 33.2 cm, pace angulation was approximately 177° (range 176° to 178°). The pace length of HDT.211P.b1– 4 averaged 17.1 cm (range from 16.2 to 18.0 cm), stride length averaged 34.1 cm (range from 33.2 to 35 cm), and the pace angulation was approximately 180° (the same as HDT.211P.a1– 3).

DISCUSSION

The Dongga tracks are medium-sized (12 cm long), robust, and lack both hallux and web impressions. These characteristics differ from Cenozoic web-footed bird tracks, that is, *Presbyornithiformipes* (Yang et al., 1995). They are also dissimilar to other known Cenozoic bird tracks by their toe thickness and lack of a hallux, separating them from *Ardeipeda* and *Gruipeda,* both of which possess a hallux (Scrivner and Bottjer, 1986; Sarjeant and Langston, 1994), although recent descriptions of *Gruipeda* show that these tracks may lack a hallux impression (Diaz-Martinez et al., 2012). Their large size and relatively lower angle of divarication separates them from Cenozoic shorebird-like tracks including *Charadriipeda* (Sarjeant and Langston, 1994). They differ from Mesozoic tracks based on their size and other features: they are much larger than *Koreanaornis* (Kim, 1969) and are more robust than *Aquatilavipes* (Currie, 1981), which also lacks the isolated metatarsal pad. *Jindongornipes* is large but possesses a hallux (Kim et al., 2012), and *Ignotornis*, *Hwangsanipes*, and *Goseongornipes* all possess webbing (Kim et al., 2012).

The Dongga tracks are similar in size to *Pavoformipes* (Fig 5B), a turkey-like track from the Miocene of Mexico (Lockley and Delgado, 2007). However, the Dongga tracks lack a hallux; the divarication angles between digits II and IV are less than the 80° of *Pavoformipes*, the metatarsophalangeal pad is separated from the digit pads in the Dongga tracks, and the overall track size is smaller than *Pavoformipes*. The Dongga tracks are also smaller than *Ornithoformipes* (Fig. 5C) (Patterson and Lockley, 2004), a very large (FL = 33 cm) Eocene footprint from Washington State. The divarication angles between digits II and IV of the tracks are similar (54° in *Ornithoformipes*), both lack hallux impressions, both have digit impressions that are subequal in length, and both have a metatarsophalangeal pad that is separated from the digit pads.

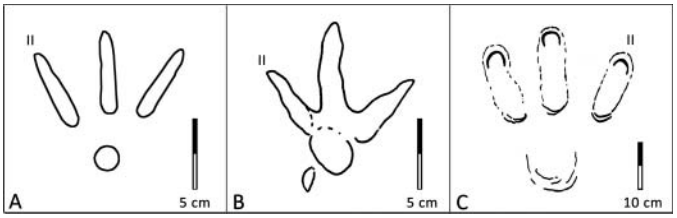

FIG. 5. Comparison of specimen HDT.211P.b2 with other cursorial fossil bird tracks. **A:** HDT.211P.b2 from the Oligocene to Early Miocene, Tibet, China. **B:** *Pavoformipes pintasotoi* CU 230.104 from the Miocene, Durango, Mexico (Lockley and Delgado, 2007). **C**: *Ornithoformipes controversus* CU 230.78 from Eocene, Washington, USA (Patterson and Lockley, 2004).

Unlike the Dongga tracks, however, *Ornithoformipes* possesses crescentic, subcircular ungual impressions, has a robust heel, and is subsymmetrical. Based on the comparison between the Dongga tracks, *Pavoformipes,* and *Ornithoformipes*, the Dongga tracks may have been produced by cursorial or flightless birds. This interpretation is supported by the morphology of modern cursorial bird tracks. Many ground-dwelling or ground-foraging birds have relatively low angles of divarication (see Falk et al., 2011); however, the divarication angles are not as low as those possessed by Passeriform and other arboreal anisodactyl birds. Cursorial birds may possess a relatively robust hallux impression (i.e. Ruffed Grouse *Bonasa umbellus*), a much smaller, clearly elevated hallux impression (i.e., Northern Bobwhite *Colinus virginianus* and wild Turkey *Meleagris gallopavo*) or may lack generally a hallux impression entirely (i.e., Sandhill Crane *Grus canadensis*) (Elbroch and Marks, 2001). Many of these cursorial birds often lack hallux impressions due to the elevated nature of toe I. Many anisodactyl cursorial birds have significantly more robust toes than arboreal or shorebirds (Elbroch and Marks, 2001). Based on the Dongga tracks' angle of divarication, robustness of toes, and presence of a small, elevated hallux impression, these tracks likely belonged to a cursorial, ground-foraging bird.

Cenozoic fossils of large ground birds are known from China. Among them, *Zhongyuanus xichuanensis* (Hou, 1980) is the only one known from the Early Eocene. The only specimen of *Z. xichuanensis* is fragmentary and its geological age does not coincide with the Dongga tracks. Fossil Chinese Struthioniformes include the Late Miocene *Struthio linxiaensis* (Hou et al., 2005), the Late Pleistocene *Struthio anderssoni* (Yang and Sun, 1960), and the Early Pliocene *Struthio wimani* (Lowe, 1931). However, the didactyl feet of *Struthio*—a basic morphologic trait for the genus (Mourer-Chauviré et al., 1996)—do not coincide with the morphological characteristics of the Dongga tracks and their stratigraphic age does not overlap.

Modern anisodactyl bird tracks show correlation between the morphology of the feet and behavior and ecology (Falk et al., 2011). In general, the greater the angle of divarication between toes II and IV, the less arboreal and more cursorial. Shorebirds—Charadriiformes—possess the widest angle of divarication in anisodactyl birds (100–120º). This high angle of divarication has been hypothesized to act as a snowshoe to keep the bird from sinking in soft mud (Falk et al., 2011). Arboreal birds, including the Passeriformes, have extremely narrow angles of divarication, the better to facilitate the grasping of branches. Ground-foraging birds possess an angle of divarication less than shorebirds but greater than perching birds (usually 70–90º) (Falk et al., 2011).

In comparison to modern bird tracks, the Dongga tracks are similar in size and morphology to the tracks left by the North American wild turkey (*Meleagris gallopavo*). *M. gallopavo* tracks are different from the Dongga tracks in that they often will have a small, elevated, reflexed hallux impression present, but this is not always the case (see Elbroch and Marks, 2001, p. 136). The presence or absence of a hallux is, therefore, a poor diagnostic tool in this type of track. *M. gallopavo* spends much of its time foraging on the ground in woodlands or open field and will often roost in trees (Boeker and Scott, 1969); therefore, the interpretation of the Dongga bird—or birds—as cursorial is supported by this evidence.

The Dongga tracks are associated with coal-bearing facies (Wu, 1979). According to the palynomorph assemblages, dominant plants at the Dongga tracksite include broad-leaved plants such as Fagaceae, Ulmaceae, and Moraceae (?), whereas conifers are considerably rare and ferns exhibit a lack of abundance and diversity. The presence of broad-leaved plants and a general scarcity of conifers indicate that the environment was warm, subtropical, and very wet (Li, 2004).

REASONS FOR REPORT

Due to the difficulty inherent in collecting fossil tracks, artificial casts can serve as holotypes. However, photographs and line drawings are excluded. The Dongga tracks are an example of the latter. *Sinoichnites*, an ornithopod track from Shanxi Province, China (Kuhn, 1958), is an example of the former. Unfortunately these tracks have been lost. Based on pictures of the original specimen, the *Sinoichnites* specimen currently housed at Beijing Natural History Museum is a sculpture of the holotype (Xing et al., 2009). For the foreseeable future, the Dongga tracksite will remain inaccessible to excavation. The first author of this paper found no hint of tracks during a personal visit to the site in 2011. This tracksite has been buried for 30 years, and there is little to no chance of recovering any specimens for collection and research. (All of the original illustrations have already been donated to the Huaxia Dinosaur Tracks Research and Development Center by Yimin Wu.) The Dongga tracks constitute the first record of Cenozoic birds in Tibet and contribute to our understanding Tibetan Cenozoic biodiversity.

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