Cretaceous Research 52 (2015) 138–152

Contents lists available at ScienceDirect

Cretaceous Research

journal homepage: www.elsevier.com/locate/CretRes

Re-description of the partially collapsed Early Cretaceous Zhaojue dinosaur tracksite (Sichuan Province, China) by using previously registered video coverage

Lida Xing [a, *], Martin G. Lockley [b], Daniel Marty [c], Laura Piñuela [d], Hendrik Klein [e], Jianping Zhang [a], W. Scott Persons [f]

[a] School of the Earth Sciences and Resources, China University of Geosciences, Beijing 100083, China
[b] Dinosaur Tracks Museum, University of Colorado Denver, PO Box 173364, Denver, CO 80217, USA
[c] Naturhistorisches Museum Basel, Augustinergasse 2, CH-4001 Basel, Switzerland
[d] Museo del Jurásico de Asturias MUJA (Jurassic Museum of Asturias), Colunga E-33328, Spain
[e] Saurierwelt Paläontologisches Museum, Alte Richt 7, D-92318 Neumarkt, Germany
[f] Department of Biological Sciences, University of Alberta, 11455 Saskatchewan Drive, Edmonton, Alberta T6G 2E9, Canada

ARTICLE INFO

Article history:
Received 13 June 2014
Accepted in revised form 19 September 2014
Available online 10 October 2014

Keywords:
Dinosaur footprint
Sauropoda
Theropoda
Ornithopoda
Locomotion
Turning trackway
Brontopodus
Eubrontes
Grallator
Pteraichnus

ABSTRACT

A re-description of the Early Cretaceous Zhaojue dinosaur tracksite (Sichuan Province, China) is the major focus of the present work. The tracksite is located in an active copper mine, and a dinosaur track-bearing surface of about 1500 m^2 (named tracksite I) initially discovered in 1991, has since almost completely collapsed due to ongoing quarry activities. Only about 5% of the initial surface still remains in place (named "remaining tracksite"), while due to the collapse a few new but rather poorly-preserved tracks were unearthed on an underlying level. While the tracks still in place were studied using common field techniques, a schematic tracksite map of the collapsed surface was drawn based on a "corrected orthophotograph" that was generated from overview photographs and from video frames. Fortunately, the resolution of some of the close-up video frames is sufficiently high to observe general track morphology, and to re-interpret previously wrongly identified trackways. Here, we report a quite diverse ichnocoenosis consisting of sauropod, ornithopod, theropod, and pterosaur trackways and isolated tracks. The sauropod trackways belong to the *Brontopodus*-type and were possibly left by medium-sized titanosaurs. One of the sauropod trackways turns around and makes an astonishingly narrow turn of more than 180° with very pronounced "off-tracking" of the manus with respect to the pes. Such unusual trackways are important for the reconstruction of sauropod locomotion. The theropod trackways were left by small and medium-sized animals with the imprint morphology being similar to that of the ichnogenera *Grallator* and *Eubrontes*. Large tridactyl tracks with blunt toes are tentatively identified as ornithopod tracks and may be described as *Caririchnium*-type *tracks*. Pterosaur tracks can be assigned to *Pteraichnus*. The association of pterosaur with small theropod tracks is rather unusual, and this tracksite further corroborates the frequent presence of large ornithopods in inland environmental settings.

1. Introduction

The Sichuan Basin is famous for its rich Jurassic dinosaur faunas, whereas those from the Cretaceous are scarcely known. Thus, Early Cretaceous dinosaur tracksites are important to fill this faunal gap (Zhen et al., 1994; Xing et al., 2007, 2011a, 2013), and among the Sichuan tracks, those from the Zhaojue region are exceptional.

In September 1991, while mining copper, in Sanbiluoga Village (Sanchahe Township, Zhaojue County) in Sichuan Province (Fig. 1), a very large surface with various dinosaur trackways (here designated as "tracksite I" or "original tracksite") was exposed in the Lower Cretaceous Feitianshan Formation. However, it was only in December 2004 that Jiefang Ebi from the Zhaojue County Bureau of Culture, Multimedia, Press, Sport and Tourism investigated these tracks. The track-bearing surface spans approximately 1500 m^2 and displays at least twelve discrete trackways (Figs. 2A, 3). In February 2006, Kui Li and Jian Liu from the Museum of Chengdu University of Technology re-studied the tracksite and published two abstracts

* Corresponding author.
E-mail address: xinglida@gmail.com (L. Xing).

http://dx.doi.org/10.1016/j.cretres.2014.09.010
0195-6671/

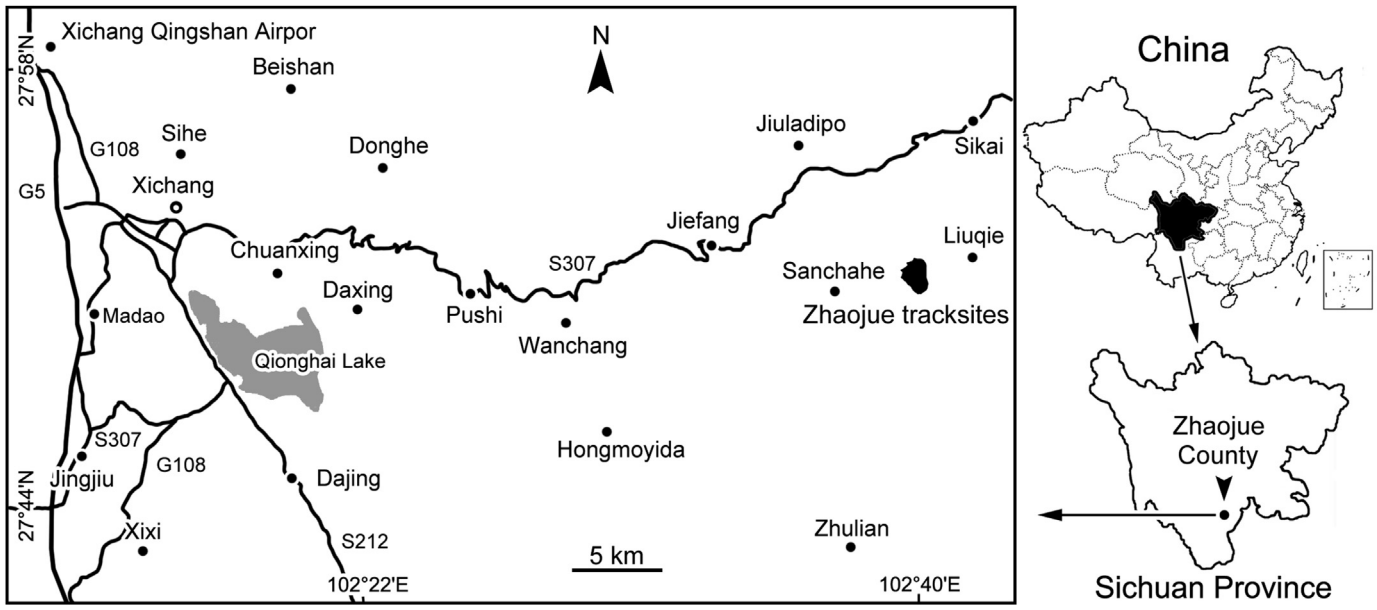

Fig. 1. Geographical setting of the Zhaojue tracksite (footprint icon) within Sichuan Province, China.

indicating that there were more than 1000 vertebrate tracks at tracksite I, including tracks of sauropods, theropods, and pterosaurs (Liu et al., 2009, 2010).

Unfortunately, between 2006 and 2009, the largest part of tracksite I collapsed due to ongoing mining operations and resulting landslides (Fig. 2B). The collapsed track-bearing bed was approximately one meter in thickness, and included several layers with tracks. The first author of the present paper investigated the tracksite in 2012 and 2013, and by that time, 95% of tracksite I had collapsed. The remaining part (here designated as "remaining tracksite"), and representing about 5% of the original tracksite is located in the southernmost extremity of the location (Fig. 2B), exhibiting around 100 tracks (Fig. 4). Underneath the collapsed strata, ten tracks were newly exposed. These are mainly sauropod and theropod undertracks. A new tracksite, named tracksite II was discovered on the slope opposite tracksite I in the same quarry, and it belongs to the same Feitianshan Formation. Xing et al. (2013) described the dinosaur track assemblage of tracksite II, including the first definitive non-avian theropod swim trackway from China. Herein we re-evaluate the fauna of tracksite I based on the scant remaining material, photographs and on analysis of video material shot in 2006 prior to the collapse of tracksite I.

2. Material and methods

2.1. The remaining tracksite

Due to the steepness of the bedding planes (40–50°) at both the remaining southern part of tracksite I and tracksite II (Xing et al., 2013), it was necessary to use climbing ropes during the study of track-bearing surfaces.

In order to make accurate maps, essential for areas scheduled for destruction by ongoing quarry operations, tracks were photographed, outlined in chalk, and traced on large transparent plastic sheets. In addition a representative area with well-preserved tracks was mapped by hand using a chalk grid. Several natural casts were collected, and latex moulds of the best-preserved tracks were made. Additionally, detailed tracings of selected tracks were made on transparent acetate film. Latex moulds, plaster replicas, and tracings are deposited in the collections of the Huaxia Dinosaur Tracks Research and Development Center (HDT) and the University of Colorado Museum of Natural History (UCM).

For the trackways of quadrupeds, gauge (trackway width) was quantified for pes and manus tracks using the ratio between the width of the angulation pattern of the pes (WAP) or manus (WAM) and the pes length (PL) or manus width (MW), respectively (according to Marty, 2008; Marty et al., 2010). The (WAP/PL)-ratio and (WAM/MW)-ratio were calculated from pace and stride length, assuming that the width of the angulation pattern intersects the stride under a right angle and at the approximate midpoint of the stride (Marty, 2008). If the (WAP/PL)-ratio equals 1.0, the pes tracks are likely to touch the trackway midline. If the ratio is smaller than 1.0, tracks intersect the trackway midline, and are considered to be narrow-gauge trackways (*sensu* Farlow, 1992; see also Romano et al., 2007). Accordingly, a value of 1.0 separates narrow-gauge from medium-gauge trackways, whereas the value 1.2 was arbitrarily fixed between medium-gauge and wide-gauge trackways, and trackways with a value higher than 2.0 are considered to be very wide-gauge (Marty, 2008; Marty et al., 2010).

Track rotation was measured with respect to the stride length between two consecutive pes/manus tracks, with positive values indicating an outward rotation (see also Marty, 2008: Fig. 2.11).

Photogrammetric images were produced from three photographs (taken by film camera in 2006) which were converted into scaled, highly accurate 3D textured mesh models using Agisoft Photoscan (http://www.agisoft.ru/) (Falkingham, 2012). The mesh models were then imported into Cloud compare (http://www.danielgm.net/cc/) where the models were rendered with accurately scaled colour topographic profiles (Falkingham, 2012).

2.2. Photo and video documentary of tracksite I

Prior to the collapse of tracksite I, overview photos were taken and kindly provided by Sichuan Daily (initially figured in January 14, 2005), Liangshan Daily (initially figured in June 19, 2012), Mr Jiefang Ebi, and Prof. Kui Li. However, they lack a scale and more