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Tracking a Legend: An Early Cretaceous Sauropod Trackway from Zhaojue County, Sichuan Province, Southwestern China

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Cretaceous tetrapod (dinosaur and pterosaur) tracks from Zhaojue County in Sichuan Province are locally very abundant. Large scale quarrying operations at the Sanbiluoga Copper Mine site have produced extensive exposures, and track material for detailed study. However, natural track-bearing outcrops also occur at a site in Jiefang Township. The traditions of the local Yi people, indigenous to the area, attribute such tracks to Zhigealu, a central creator hero-ancestor, who made the footprints while riding his heavenly steed through the area. Through seeing tracks exposed by quarrying the local people offered these legend-based interpretations, and reported the Jiefang site which was previously unknown to scientists from outside the area. Thus, it is important to pay attention to local legends about track makers since they may lead directly to significant fossil footprint discoveries. Thereby paleontology and ichnological research can benefit largely from archeological sciences as well as from oral narratives from the local people. The recently discovered sauropod trackway from Jiefang is an excellent example. It comprises 16 pes-manus sets arranged in a narrow-gauge pattern. A peculiarity is the combination of this feature with morphological characteristics known from typical wide-gauge *Brontopodus* trackways suggesting a tentative assignment to cf. *Brontopodus*. The discovery enlarges the distribution and diversity of *Brontopodus*-like trackways and their producers in the Cretaceous Sichuan Basin.

Keywords Yi people, Zhigealu, Dinosaur tracks, *Brontopodus*

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INTRODUCTION

The fossil footprints of a dinosaur were first scientifically described in 1836 (Hitchcock, 1836). However, dinosaur tracks had been noticed centuries, even millennia, earlier by many cultures around the world, and dinosaur prints and trackways have been the inspiration behind ancient legends, art, dances, songs, and religious ceremonies. Examples include dinosaur footprints in Italy identified as those of the hero Heracles and the giant cattle of the monster Geryon by the ancient Greeks (Baucon et al., 2012); theropod tracks identified as the tracks of a giant feathered "Emu-man" creature from "Dream Time" by Australian Aborigines (Mayor and Sarjeant, 2001); rock art by Bushmen related to observations of dinosaur tracks in Lesotho, Africa (Ellenberger et al., 2005; Helm, 2012); sauropod footprints assigned to a deity of the mountains, Shan Shen, in Changdu County, Tibet (Xing, et al., 2011a); the Hopi Snake Dance of Native American Hopi people in Arizona (Look, 1981; Mayor, 2005), and Native American oral traditions and rock art associated with dinosaur tracks in the American Southwest including petroglyphs of the Fremont Culture Paleo-Indians (Mayor, 2005; Lockley et al., 2006).

Chinese history is generally considered to have begun in 3000 B.C. at the beginning of the Xia Dynasty and the Shang Dynasty, during a period referred to in subsequent legends as the "Yellow Emperor Period." The first reliable historical recordings begin in the first year of the Western Zhou Dynasty Republic, 841 B.C. (Twitchett and Fairbank, 1978; Bai, 1999). Outcrops of Mesozoic rocks are abundant throughout China and over thousands of years native Chinese people have frequently discovered dinosaur tracks and attempted to explain

them. In a survey of the cultural significance of Chinese fossil tracks, Xing et al. (2011a) demonstrated that dinosaur footprints have been variously interpreted as tracks made by divine birds (such as the Phoenix or Golden Chicken), as tracks left by unusually large mammals (such as a legendary rhinoceros), as mystically implanted stone lotus blossoms, and as hand impressions made by mythical deities and legendary heroes (such as the local mountain deity King Gesar).

Zhigealu (pronunciation: Zhi-ge A-lu) (Fig. 1) is a central creator hero-ancestor in the legends of the Yi culture, and is among the most revered figures in Yi mythology (Feng, 1986; Aluoxingde, 1994). Herein we describe a successful instance of discovering a new scientifically significant dinosaur track site by interpreting local Zhigealu legends.

DISCOVERY AND CULTURAL INFLUENCE

In September 1991, a copper mining operation exposed a stretch of dinosaur tracks in Sanbiluoga, Zhaojue County, Sichuan Province (Fig. 2). This tracksite included abundant footprints of sauropod and ornithopod dinosaurs and also rarer tracks of theropod dinosaurs and pterosaurs. After the tracks were exposed, local Yi people considered the tracks to be footprints left by Zhigealu while riding Simudydian (the hero's "heavenly steed") (Fig. 1). The sauropod manus tracks at the Sanbiluoga tracksite are pea-shaped and the pes tracks are sub-circular. The large ornithopod tracks include poorly preserved round pes impressions. Both the sauropod and ornithopod tracks roughly resemble horse's hoof prints.

In December 2004, one of us (Jiefang Ebi) investigated these tracks. The outcrop spanned approximately 1,500 square meters and included 12 individual trackways. Unfortunately, the tracksite gradually collapsed between 2006 and 2009, and more than 95% of the tracks have been severely damaged.

The interpretation of the Yi people was not unique to the Sanbiluoga tracksite. Further communication with the local Yi people revealed that similar "Simudydian hoof prints" had been observed elsewhere and that these tales had been passed down through many generations. In July 2013, the lead author encountered a legend of the hero Zhigealu riding his heavenly horse in an area named Alumuju, west of Erjiede Village, Jiefang Township, Zhaojue County (Fig. 2). According to the local legend, Zhigealu frequently rode in this region when returning from visitations in heaven and it was said that the descent back to earth caused Simudydian to step deeply into the ground, leaving impressions of his hooves in the bedrock. Based on this legend, a fossil hunting expedition was organized to search the Alumuju region for dinosaur tracksites.

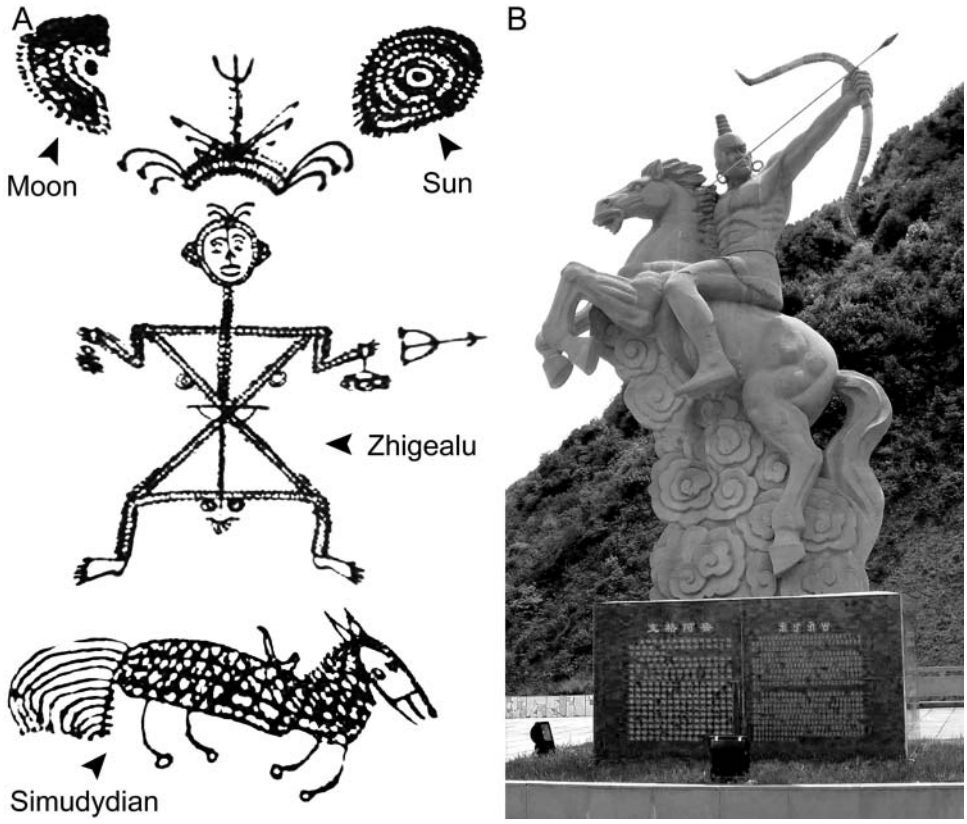

FIG. 1. **A**. Zhigealu and Simudydian in the legends (llustrated by Qubisuomo Bimo, modified from Aluoxingde, 1994); **B**. Zhigealu statue at Luojishan Mountain of Liangshan Yi Nationality Autonomous Prefecture, Sichuan Province.

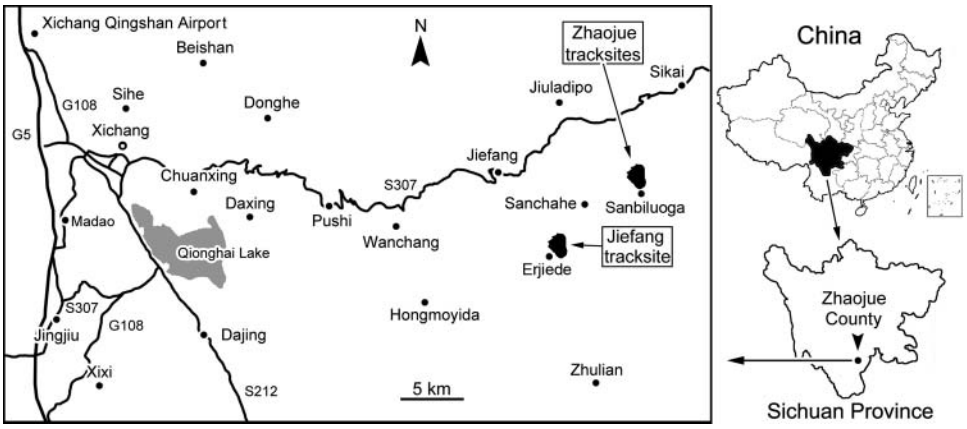

FIG. 2. Location of the Jiefang and Zhaojue track localities (indicated by the sauropod track icon) in Sichuan Province, China.

Finally, a large sauropod tracksite was discovered there by the explorers (Figs. 3 and 4). The tracks run north along an exposed surface approximately 50 m above the banks of the Laqing River. The tracks were not severely weathered, indicating that they had been exposed for a relatively short period of time. It is likely that the rise and fall of the Laqing River and the gradual erosion of the rivers' banks periodically exposes many such trackways throughout the ages, which would account for the local legend. The track-rich exposures are located above a natural route across the area's rocky terrain.

The name "Alumuju" is derived from the word "Alu," which refers to Zhigealu; "mu," which means horse; and "ju," which means footprint. Thus the name means "the footprints left by Zhigealu's horse." Repeated ancient discoveries of dinosaur footprint exposures here appear to have influenced local oral traditions. The tracks were interpreted as physical evidence confirming religious beliefs and they reveal the origin of the geographic name. The Zhaojue region is the major birthplace of the culture of the Liangshan Yi Nationality. The oral traditions that arose here in antiquity likely spread and caused dinosaur trackways discovered in other regions to be interpreted similarly. This tracking of a Chinese legend suggests that other heretofore unstudied dinosaur track sites could be discovered by gathering local folklore referring to footprints in stone left by legendary beings.

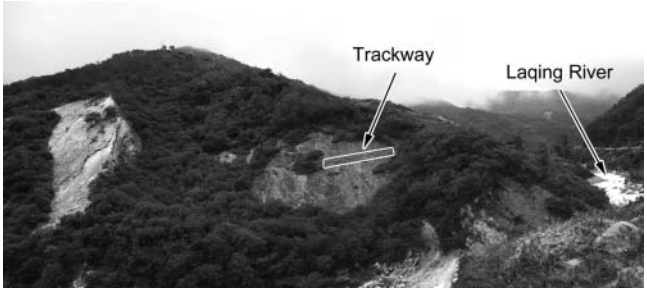

FIG. 3. Overview of the Jiefang tracksite.

GEOLOGICAL SETTING

The Jiefang tracksite is located in Erjiede Village, Jiefang Township, Zhaojue County, Liangshan Yi Autonomous Prefecture, Sichuan Province, China (102°36′24.40″E, 27°48′37.00″N) (Fig. 2). Based on the regional geological investigation report (1:200,000) of the Xichuan area (SPGB-FRGST and SPMGB-PRGT, 1965), the Jiefang tracksite is part of an exposure of the Feitianshan Formation.

The Cretaceous-Paleogene strata in the Liangshan Region are divided into the Lower Cretaceous Feitianshan Formation, the Upper Cretaceous Xiaoba Formation, and the Paleocene Leidashu Formation (CMSPSC, 1982; Gu and Liu, 1997). The Feitianshan Formation is a 302–1090 m thick unit of fluvial facies comprised of red clastic sediments. It was first assigned to the Late Jurassic, but has since been identified as Early Cretaceous in age (Wei and Xie, 1987).

METHODOLOGY

Fortunately, weathering and prolonged exposure has not yet significantly damaged the Jiefang tracksite. To better observe the morphology of the tracks, it was necessary to climb in order to take measurements from the trackways, such as length and width of each track as well as pace and stride length. All tracks were traced on transparent plastic and acetate sheets. The whole trackway outline drawing was then photographed to produce the illustration shown in Figure 4.

For 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

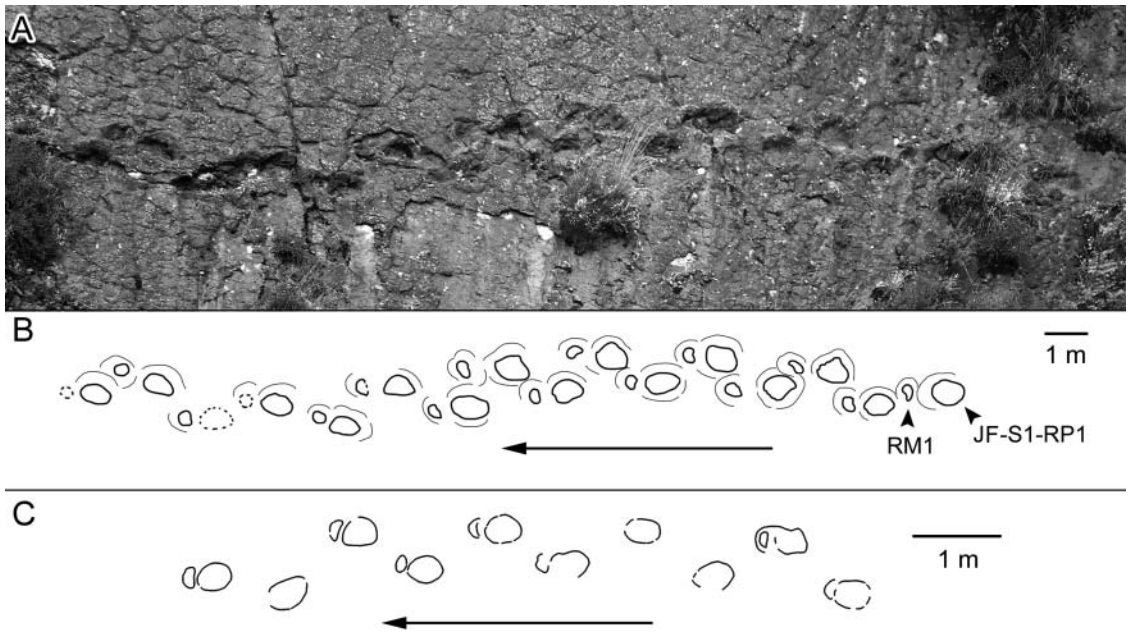

FIG. 4. Photograph (**A**) and outline drawing (**B**) of the Jiefang sauropod trackway. **C** outline drawing of sauropod trackway from the Zhaojue tracksite for comparison.

the trackway midline. If the ratio is smaller than 1.0, pes tracks intersect the trackway midline, which corresponds to the definition of narrow-gauge (see Farlow, 1992). Accordingly, a value of 1.0 separates narrow-gauge from medium-gauge trackways, whereas the value 1.2 is 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).

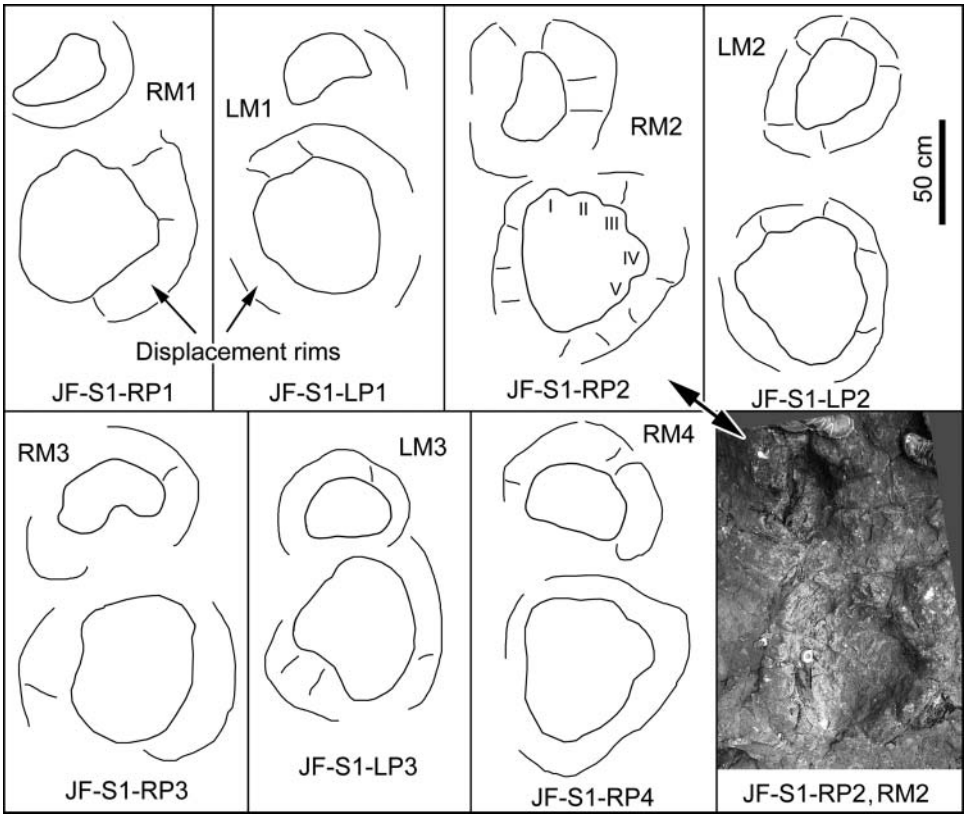

FIG. 5. Sauropod tracks from the Jiefang tracksite.

SYSTEMATIC ICHNOLOGY

Material. 16 complete pes–manus track pairs from a single trackway at the Jiefang tracksite, are cataloged as JF-S1-RP1–LP6, RM1–LM6 (JF, Jiefang tracksite; S, sauropod; R, right; L, left, P, pes, M, manus) (Figs. 4 and 5; Table 1). All tracks remain in the field.

Locality and horizon. Feitianshan Formation, Lower Cretaceous. Jiefang tracksite, Jiefang Township, Zhaojue County, Sichuan Province, China.

Description. Each of the JF-S1 tracks consist of two distinct parts: (1) the internal portion which is the true track *sensu stricto*, (2) the external portion marked by sediment displacement rims around the internal portion. In JF-S1, the manus tracks average length is 23.5 cm and the average width is 41.1 cm, while the pes track average length is 72.8 cm and the average width is 52.9 cm. The pes track JF-S1-RP2 and the manus track RM2 are the best-preserved.

The manus track JF-S1-RM2 is U-shaped with a length: width ratio of 0.6. It lacks discernible claw marks. The width of the sediment displacement rim is approximately 24 cm. The metacarpophalangeal region is concave. The manus tracks significantly diverge outward relative to the midline by a maximum value of 145° (51° on average). This value is larger than the outward rotation of the pes tracks (35° on average). The pes track JF-S1-RP2 is oval, with a length:width ratio of 1.2. The distance from RP2 to RM2 is 26 cm. The lateral sediment displacement rims are substantially wider than the median displacement rims (34 cm and 19 cm, respectively). Digits I, II, and III have identifiable claw marks, digit IV has a depression made by a small ungual or foot callosity. Digit V is indicated by a small lateral lobe. The metatarsophalangeal pad region is smoothly curved. The pace angulation is 113° for the manus and 122° for the pes tracks.

DISCUSSION

Most sauropod trackways in China are referred to *Brontopodus*, and are wide- or medium- gauge (Lockley et al., 2002). The pes and manus morphology and trackway configuration of

TABLE 1

Measurements (in cm, except PA in degrees) of sauropod tracks from the Jiefang tracksite, Sichuan Province, China. Abbreviations: PL: Pes length; PW: Pes width; PA: Pace angulation; PL: Pace length; SL: Stride length; L/W: Maximum length/ Maximum width; WAP: Width of the angulation pattern of the pes (calculated value); WAM: Width of the angulation pattern of the manus (calculated value); WAP/PL and WAM/MW are dimensionless

Number.	PL	PW	SL	PL	PA	L/W	WAP	WAM	WAP/PL	WAM/MW
JF-S1-RM1	22	42	230	137	119°	0.6	—	68	—	1.8
JF-S1-RP1	69	57	233	133	132°	1.2	52	—	0.8	—
JF-S1-LM1	20	41	229	130	115°	0.6	—	73	—	2.0
JF-S1-LP1	76	52	221	122	123°	1.5	59	—	0.8	—
JF-S1-RM2	24	42	229	142	118°	0.6	—	74	—	2.0
JF-S1-RP2	67	57	230	129	126°	1.2	58	—	0.9	—
JF-S1-LM2	34	44	212	125	106°	0.8	—	79	—	1.8
JF-S1-LP2	70	53	230	129	135°	1.3	48	—	0.7	—
JF-S1-RM3	21	47	217	140	112°	0.5	—	73	—	1.9
JF-S1-RP3	73	48	215	120	132°	1.7	47	—	0.6	—
JF-S1-LM3	26	42	200	122	105°	0.6	—	77	—	2.5
JF-S1-LP3	76	48	191	115	107°	1.6	70	—	0.9	—
JF-S1-RM4	28	43	220	130	114°	0.7	—	71	—	2.0
JF-S1-RP4	67	54	193	122	106°	1.2	73	—	1.1	—
JF-S1-LM4	21	39	195	132	103°	0.6	—	74	—	2.2
JF-S1-LP4	69	54	198	120	108°	1.3	72	—	1.0	—
JF-S1-RM5	25	41	203	117	105°	0.7	—	77	—	2.1
JF-S1-RP5	71	52	228	125	124°	1.4	60	—	0.8	—
JF-S1-LM5	21	38	228	138	133°	0.7	—	48	—	1.5
JF-S1-LP5	77	54	245	133	122°	1.4	68	—	0.9	—
JF-S1-RM6	20	37	—	110	—	0.6	—	—	—	—
JF-S1-RP6	75	50	—	147	—	1.5	—	—	—	—
JF-S1-LM6	20	37	—	—	—	0.6	—	—	—	—
JF-S1-LP6	77	56	—	—	—	1.4	—	—	—	—
Mean	—	—	—	—	—	—	61	71	0.9	2.0

the JF-S1 trackway is typical for sauropod trackways (Lockley, 1999, 2001). This trackway is clearly narrow-gauge, based on the (WAP/PL)-ratio of 0.9, close to 1.0. This is unusual for Cretaceous trackways which are usually wide gauge (Lockley et al., 1994).

Santos et al. (2009) defined the characteristics of *Brontopodus*−like tracks as 1) wide-gauge trackway; 2) pes prints longer than broad, with large, outwardly directed claw marks representing digits I–III, a small claw trace marking digit IV and a small callosity or pad mark representing digit V; 3) U-shaped manus prints with rounded marks of digits I and V; and 4) high heteropody. However, *Brontopodus* trackways show a relatively large manus and therefore rather low heteropody, contrary to the definition of Santos et al. (2009). Most of the characteristics of the Jiefang sauropod trackway are similar those of *Brontopodus*−like tracks. However, the Jiefang sauropod trackway is narrow-gauge, not wide gauge. This is a further example for variation in the pattern of *Brontopodus*-like sauropod trackways. The heteropody (a ratio of manus to pes size) of the Jiefang sauropod tracks is 1:3.1—close to *Brontopodus birdi* (1:3) but less than in *Breviparopus* (1:3.6) and significantly less than in *Parabrontopodus mcintoshi* (1:4 or 1:5).

The dinosaur track record from the Cretaceous Sichuan Basin is dominated by theropods and ornithopods (Xing et al., 2011b). Rare bird tracks (Zhen et al., 1995) have also been discovered. The discovery of sauropod footprints (ichnogenus *Brontopodus*) at the Zhaojue tracksites is the first record of sauropod tracks from the Cretaceous of Sichuan (Xing et al., 2013) (Fig. 4C). The wide-gauge stance of the Zhaojue *Brontopodus*-type trackways suggests that the tracks were those of more basal Titanosauriformes such as brachiosaurids (Wilson and Carrano, 1999; Lockley et al., 2002), and scattered titanosaur fossils have been unearthed in Qianjiang District, Chongqing (Wang, 1976). The narrow-gauge sauropod trackway from the Jiefang tracksite is here tentatively referred to cf. *Brontopodus* based on morphological similarities of the tracks and the relatively low heteropody similar to typical *Brontopodus* as well as the difference from the latter by the narrow-gauge trackway pattern. This new record indicates that the producers of *Brontopodus*-like trackways had a wider distribution in the Cretaceous Sichuan Basin. These may have been sauropods other than titanosaurs with a narrower gait but with similar feet.

CONCLUSIONS

Paleontology and research on dinosaurs and their footprints can benefit from archeological sciences by reviewing the literature and noting historical legends from native people and ancient tribes. However, this is only helpful if there are independent indications from fossil remains in the area as well. The recently discovered dinosaur tracks from Early Cretaceous deposits at the Jiefang tracksite in Zhaojue County of Sichuan Province are an excellent example. Decisive hints came from local people and folktales mentioning the footprints of the horse of the ancient hero Zhigealu in the surroundings.

The trackway belongs to a sauropod and is important inasmuch as it displays a rare combination of a narrow-gauge pattern with features typically known from wide-gauge forms such as the relatively low heteropody.

The discovery increases the distribution and morphological diversity of *Brontopodus*-like trackways and their producers in the Cretaceous Sichuan Basin.

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