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Giant sauropod tracks from the Middle-Late Jurassic of Zimbabwe in close association with theropod tracks

ALI AIT-KACI AHMED, THEAGARTEN LINGHAM-SOLIAR AND TIM J. BRODERICK

Recently four new sites of dinosaur footprints were discovered in the Ntumbe area in Zimbabwe (Broderick 1985; Munyikwa 1996; Lingham-Soliar & Broderick 2000; Ait-Kaci Ahmed & Mukandi 2001). Significantly, in one of the sites are the first giant sauropod footprints found in sub-Saharan Africa (Fig 1). The location is ca. 400–500 m NW of the first theropod trackway found (Broderick 1985) and falls on the Kachowe 1/50,000 scale toposheet (1629 B2), 30°00 E and 16°10 S. In the other sites we found 88 footprints of large theropod dinosaurs tracks (an ichnogenus similar to that recorded previously; see Broderick 1985; Munyikwa 1996), the largest number recorded in a single site in Zimbabwe to date. Forty-three of these are on the same horizon as the sauropod tracks and located close to them (ca. 140 m). The other 45, also close by, are in a marginally older horizon. A striking feature of this small exposure is the presence of five closely associated theropod trackways heading in the same direction.

The present paper gives a description of the sauropod footprints, their geology and sedimentary sub-environment. The association in time and space of sauropod and theropod dinosaurs in the region have implications for group predatory interactions (Lingham-Soliar *et al.*, 2003). Evidence for a polytypic dinosaur fauna of the region is presented.

Geology

The Ntumbe trackway locality lies within strata of the post-Karoo Dande Sandstone Formation (for detailed geology see Oesterlen 1998; Lingham-Soliar & Broderick 2000, fig 1 (map), table 1; Lingham-Soliar et al. 2003, fig 2d) and which beds are correlative to those of the Kadzi area. The red bed sediments in the latter area overlie tholeiitic basalt flows of the Jerama Hills that have provided K-Ar isotopic age determinations of 170 ± 9 and 167 ± 8 Ma (Barber 1994) and are Mid-Jurassic. About 50 km east of the Ntumbe River in the Kadzi Valley remains of the four sauropod genera *Barosaurus, Brachiosaurus, Dicraeosaurus* and *Torniera* have been identified and the presence of *Camarasaurus* and arguably *Allosaurus* (the latter based on a single bone), have been tentatively indicated. Raath & McIntosh (1987) assigned an Upper Jurassic (Tithonian) age to the Kadzi bone assemblage. The unbroken total thickness in the Dande Formation sedimentation indicates that the age of this unit could range from the Mid-Jurassic into the Middle Cretaceous. A recent study (Ait-Kaci Ahmed & Mukandi 2001) indicates the Ntumbe strata have a more reasonably Middle to Upper Jurassic affinity rather than Early Jurassic as suggested previously (Lingham-Soliar & Broderick 2000).

Sedimentary sub-environment of the Ntumbe footprints

Oesterlen and Millsteed (1994) note the development of bituminous mudstones that indicate a shallow-water lake (or quiet over bank) sub-environment where crusts of gypsum and possibly halite reflect periodic aridity. They recorded palaeocurrent directions in the southern outcrop area as being dominantly towards the northwest, away from the present-day Escarpment. Linguoid and linear ripples in the vicinity of the footprint locality indicate a similar current direction. Ripple marks and desiccation features on alternate beds, and sometimes on the same bed, show that periodic precipitation occurred in this semi-arid environment. It indicates that the dinosaur footprints were preserved in an overbank adjacent to the river channel in which sediment accumulated during flooding. Choncostracans (see Lingham-Soliar & Broderick 2000) are preserved from presumably stagnating flood waters (Tasch 1984). The footprints are preserved in a rapidly drying silty sand (indicated by desiccation cracks and ripples) and infilled by a softer, more erodible muddy sediment. Footprints are found on different adjacent bedding planes and extensively elsewhere in the Ntumbe environment, indicating the presence of predaceous dinosaurs over a period of several thousand years.

Description

Sauropod tracks

Of the six sauropod footprints the best represents the left pes; it is 94 cm long by 56 cm wide, and 20 cm deep anteriorly (Fig 2). The elongated shape of the foot is typical of some giant sauropods (Brenchley & Harper 1998, figs. 5.18, 5.19). Digit I is strongly curved, first inward toward the animal and then out, with a hint of the claw. Digits II and III show marked claw impressions. Digit III is apparently larger than I and II; this coincides with the claw sizes and pes shape in a foot of *Brachiosaurus* at Tübingen University (TL-S personal observation; Farlow 1992). These claw impressions appear rugose (figure 2, inset), possibly occurring as the tip of the claw made the first contact with the sediment and cut downward, creating furrows (as a plough), before the digit came to rest. Digits IV and V show possible nail impressions rather than claws.

A circumferential sandstone ridge surrounds the track imprint. At its widest it is 35 cm and the deepest point above the pavement is 15 cm. Two deep anterior radial fractures and a third less distinct posterior radial fracture probably indicate circumferential stress as a consequence of sediment displacement (Prof. John R.L. Allen, Reading University, UK, personal communication, 2002; Lockley *et al.* 1989; Allen 1997; Lingham-Soliar 2003). The remaining five sauropod tracks were found close by (Fig 1); the nearest is 6 m to the east of the above track, is severely eroded and shallow (ca. 90 cm long by 55 cm wide) and lacks a surrounding raised ridge. It shows little detail other than four pits representing the toe impressions. Four prints occur 2–5 m north of this track. The first three do not show details of the claws. However, two have the elongated shape of track 1 and are identified tentatively as pes. The others are sub-circular and are tentatively identified as the manus. All four (Fig 1) exhibit a well-formed raised sandstone ridge around them. In track 6, in addition to the raised sandstone ridge, three toe impressions are evident. The track (nos. in brackets) lengths are 87 (3), 60 (4), 80 (5), and 73 (6) cm. The tracks, in an area ca. 3 m long by 2 m wide, may represent all four limbs of a smaller, standing individual.

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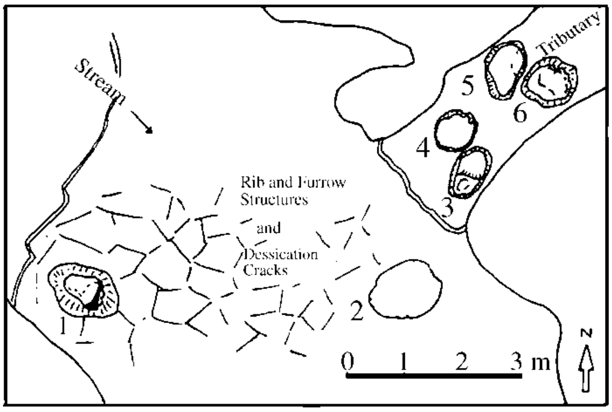

Fig 1. Sketch map of the location of six sauropod footprints within the Ntumbe area.

Fig 3. A well preserved theropod footprint from a site of similar age to that of the sauropod tracks close by. Scale = 25 cm.

Theropod tracks

Eighty-eight tracks of large theropods were found, all apparently of the same ichnogenus (probably of an allosaurid-type dinosaur; Fig 3). Forty-three of the theropod footprints are of identical age to that of the sauropod tracks. The other 45 are marginally older, but of particular interest because among them five trackways are identified. There are a number of instances of overprinting of tracks and the overall signs and implications are of group theropod behavior, possibly connected with predation (Lingham-Soliar *et al.* 2003; Farlow *et al.* 1989).

Discussion

Isolated bones of *Brachiosaurus* were previously identified from the Dande Formation of northern Zimbabwe about 50 km away (Raath & McIntosh 1987). This information together with the large size of the six sauropod tracks described here makes a tentative proposal of a brachiosaurid-type trackmaker reasonable.

Brachiosaurus was first discovered in Africa in Tendaguru, Tanzania (e.g. see Fastovsky & Weishampel 1996). Other records of sauropod footprints are from north Africa (e.g. Taquet 1977; Dutoit & Ouazzou 1980; Jenny & Jossen 1982; Ishigaki 1989; Monbaron *et al.* 1999). Important associations have been made with the Late Jurassic dinosaur faunas of Tendaguru and of the Morrison Formation in the USA (Lockley *et al.* 1986), in which *Brachiosaurus* was also found. Footprints of giant sauropods, however, were not found in Tendaguru despite the deposits being marginally marine to deltaic. Occurrence of giant sauropod footprints in Zimbabwe, the first in sub-Saharan Africa, put in this context, is significant.

The Morrison and Tendaguru *Brachiosaurus* are Late Jurassic in age. The geological data for the Zambezi Valley at present suggests a Middle to Late Jurassic affinity. A Late Jurassic age makes a connection with *Brachiosaurus* feasible. On the other hand a Mid-Jurassic age may suggest a closer correlation with a brachiosaurid-like sauropod such as *Atlasaurus imelakei* from the Middle Jurassic of Morocco (Monbaron *et al.* 1999). The only other sub-Saharan records of sauropod dinosaur footprints to my knowledge are of smaller sauropod tracks recorded by Ellenberger and Ginsberg (1966) and Ellenberger (1972) from earlier Triassic and Triassic/

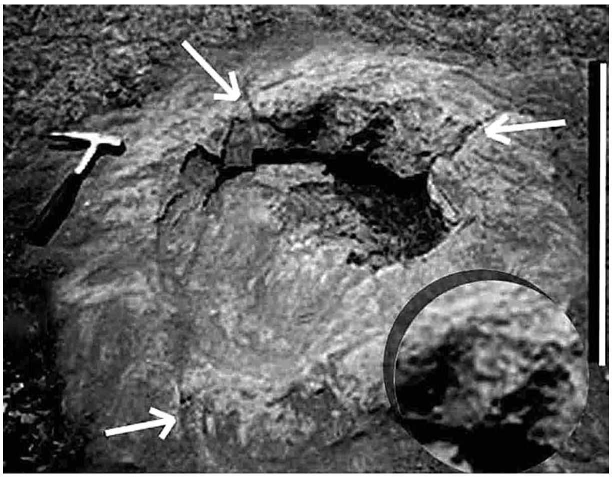

Fig 2. A well-preserved sauropod track of the left pes found in the Ntumbe area. A distinctive ridge surrounds the track and arrows show radial fractures. Scale = 100 cm. Inset shows two claw impressions.

Fig 4. The present state of the sauropod track in Figure 2 after being trampled by elephants. The rectangle shows what is left of the track (three toes). The unique mound surrounding it is completely destroyed. Note the smooth banks (see text).

Jurassic horizons of Lesotho, with implications of sauropod origins.

A notable difference concerning the dinosaur faunas of the Morrison and Tendaguru formations is the absence of data, either skeletal or footprint, of large theropod dinosaurs in the latter formation comparable to *Allosaurus* from the Morrison Formation. The evidence of large theropod and giant sauropod associations from closely associated tracks is the first in sub-Saharan Africa. The numerous skeletal specimens of *Allosaurus* found at the Cleveland-Lloyd Quarry in Utah is considered to denote a group of animals attracted to the site for the common purpose of feeding. Here, footprint evidence of predator/prey interactions (Lingham-Soliar *et al.* 2003) is equally, if not more, compelling since there can be no doubt about the proximity of the two groups, the theropods and sauropods. Skeletal remains, on the other hand, may be dispersed over considerable distances and associations and aggregations may be biased.

Taken together these records of sauropods, large theropods (Lingham-Soliar *et al.* 2003) and of small theropods of reasonably similar age (Lingham-Soliar & Broderick 2000) indicate a polytypic dinosaur fauna within a relatively small area of Zimbabwe, which broadens our knowledge of the dinosaur fauna of southern Africa and places it in a broader context globally (Lockley *et al.* 1994).

Postscript: unique hazards in the survival of ichnotraces in Africa

Recently (August 2003) one of the authors (AAA) revisited the site of the best preserved sauropod track (Fig 2). Unfortunately, the track and surrounding sandstone bed was severely damaged (Fig 4). The sandstone bed is both fractured and broken with some displacement close to the damaged track. All that remains of the track are three toes with the surrounding mound eroded. Trampling by a herd of elephants of the sandstone bed is reasonably proposed (TB) as the most likely cause of the destruction. The adjacent smoothly rubbed and rounded banks (Fig 4) are strong telltale signs of elephant behavior. Further support comes from the presence of water, in the normally seasonally dry river beds, suggesting that this was probably a drinking point at the time of the destruction. Water may also explain the severity of the damage to the sandstone bed since the bed sits on a semi-fluid base of mud and water, which is both plastic and pliable. The ephemeral nature of the mound surrounding the track (most vulnerable to e.g. physical trampling, natural erosion etc.) is highlighted and points to why it may be so rarely preserved around the world. The four less well preserved tracks close by (Fig 1), thought to be possibly of a single sauropod, were unharmed. The agent of destruction of the dinosaur fossil track described here must rank as unique in the annals of ichnology and is also ironic given that the track of the largest extinct land animal should be destroyed by the largest extant counterpart.

We believe that these tracks, as well as the theropod tracks mentioned above (Lingham-Soliar *et al.* 2003), were first exposed after very heavy floods in northern Zimbabwe about ten years prior to our discovery. Hence their timely discovery in this volatile region and the present record are fortuitous. Unfortunately, the remoteness and wildness of the Chewore Area make protection of dinosaur tracks very difficult, certainly against for instance herds of elephants and changing river courses.

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**Theagarten Lingham-Soliar [linghamst@ukzn.ac.za], Department of Zoology, University of KwaZulu-Natal (Westville Campus), Private Bag X54001, Durban 4000, Kwazulu-Natal, South Africa; Ali Ait-Kaci Ahmed, Geological Survey of Zimbabwe, P.O. Box CY210, Causeway, Harare, Zimbabwe; Tim J. Broderick, Makari, 19 Jenkinson Road, Chisipite, Harare, Zimbabwe.*

**Joint first and corresponding author.*