

First perissodactyl footprints from Flysch deposits of the Barail Group (Lower Oligocene) of Manipur, India

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Two pes imprints of a perissodactyl mammal constituting a single step of a trackway have recently been discovered in Oligocene Flysch deposits of the Barail Group in Manipur, India. The tridactyl, mesaxonic imprints (~7 cm in length) show strong similarities to footprints known from the Paleogene of China and can be attributed to a tapiroid, rhinocerotoid or equoid trackmaker. This is the first record of perissodactyl footprints from the Lower Oligocene of India and the first evidence of mammals in the Barail Group of the age. Remarkable is the occurrence in a marginal marine setting, whereas other known perissodactyl footprints from the Eocene–Oligocene in particular from North America, Europe and China come from fluvio-lacustrine strata.

1. Introduction

Compared with the footprints of Mesozoic dinosaurs, Cenozoic vertebrate traces are still less studied and often do not attract the same attention of ichnological research. However, in recent years, their potential for paleobiogeography, paleoecology, and biostratigraphy was recognized, and a growing number of papers that focus especially on mammal tracks from the Tertiary and Pleistocene (Vialov 1965, 1966; Demathieu *et al.* 1984; Kordos 1985; McCrea *et al.* 2004; Hunt and Lucas 2007; Lucas 2007; McDonald *et al.* 2007) have been published. From the Tertiary, most records come from the Neogene, whereas Paleogene localities are less abundant (McDonald *et al.* 2007). Important surfaces with footprints of brontotheres, tapirs, rhinoceroses, ancient horses and other ungulates as well as bird tracks from the Eocene–Oligocene are known from North America, South America, Europe and China (Lockley and Hunt 1995; Lockley *et al.* 1999; Lockley and Meyer 1999;

Xing *et al.* 2013). Some trackbearing units of South America and China were originally mistaken for Mesozoic deposits, but their stratigraphic age is now identified as Cenozoic (Lockley *et al.* 1999; Melchor *et al.* 2002, 2013; DeValais and Melchor 2008). Thus far, the Cenozoic footprint record from India is scarce. From the Siwaliks of India, footprints of Miocene artiodactyls have been described by West *et al.* (1983). Here we describe the first mammal (perissodactyl) footprints from Lower Oligocene Flysch deposits of the Barail Group in Manipur, India. The ichnofossils supplement the skeletal record of perissodactyls from the Paleogene of South Asia that comprises numerous tapiromorph forms (Antoine *et al.* 2003; Holroyd *et al.* 2006; Missiaen and Gingerich 2012).

2. Geological setting

The Indo–Myanmar Ranges (IMR) is thought to be the northern elongation of the Indonesian island

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arc. It is an arcuate shaped tectonic belt having a convexity towards west. Brunschweiler (1966) described the region in terms of three major lithostratigraphic units: the Naga Metamorphic Complex, the Naga Hills Flysch and the Upper Chindwin Molásse. The Naga Hills is the northernmost segment of the IMR and trending nearly NE–SW. The segment mainly consists of the Naga-Patkoi Hills of Nagaland and the northern part of the Manipur Hills. Acharyya *et al.* (1986) described the geological and tectonic setting of the Naga Hills in terms of two distinct longitudinal belts; the Central Naga Hills Palaeogene Flysch sediments and the Naga-Chin Hills Ophiolite Belt. The Central Naga Hill Palaeogene Flysch sediments, which can simply be referred to as the Flysch Belt are principally made up of sediments of Disang and Barail groups, constituting the western part of the Naga Hills segment. Most of the lithostratigraphic units in the region occur in the form of an imbricate thrust system where older lithostratigraphic units lie above the younger ones (Soibam 2000; Soibam and Pradipchandra 2006). The principal lithostratigraphic units of the Flysch Belt in the state of Manipur are composed of turbidite sediments of the Disang and Barail groups and molásse sediments of the Surma and Tipam groups, respectively (table 1). The Disang Group (Upper Cretaceous to Upper Eocene) consists of a monotonous sequence of dark grey to black splintery shales, and occasional rhythmites of shales and siltstones/fine-grained sandstones, forming the principal lithostratigraphic units of the eastern half of the state of Manipur (23°50′–25°55′N latitudes and 093°00′–094°45′E longitudes). The Barail Group, mainly Oligocene in age, with a possible range to the Upper Eocene, consists of ~3000 m thick arenaceous beds intercalated with shales and carbonaceous shales, silty shales and siltstones intercalated with thin shale beds and sandstones that rest on the Disang Group. The occurrence of Barail sediments in the state mainly starts from the western foothill regions of the Imphal Valley (figure 1). The basal part of the Barail Group has a gradational (with local tectonic) contact with the Disang Group (Soibam 2000). This gradational contact is related with a gradual change from dominantly argillaceous deep marine to a mainly arenaceous shallow marine depositional environment (Guleria *et al.* 2005). The Barail Group has been divided into three formations namely the Laisong, Jenam, and Renji (Evans 1932). The Laisong Formation, about 1200 m thick, is characterized by alternations of shale, silty shale, siltstone and fine to medium grained sandstones, giving rise to a typical turbidite sequence (figure 2). This formation contains abundant and varied sedimentary structures such as ripple marks, undulating

bedding, cross-stratification, hummocky cross-stratifications, herringbone structures, etc., indicating wave and current influence, and deposition above storm wave base. The studied section reflects a transition zone and could represent a large fluctuation in the sedimentation rate. Therefore, sedimentary facies deposited above storm wave-base comprises large sedimentary structures, otherwise they are characteristic of sediments formed below the storm wave-base level. The footprints described herein come from a silty shale near the base of the Laisong Formation at the Gelmon locality (23°44′19.9″N – 092°40′16.5″E, elevation of 905 m). The Laisong Formation section at Gelmon locality may be considered to be of Lower Oligocene age taking reference to earlier studies carried out in the state in sections that belong to Upper Disang (Middle to Upper Eocene) and Lower Barail (Upper Eocene to Oligocene) transition sections. For example, Kachhara *et al.* (2000) treated the Biozone B at Thoubal (Kabrang Hill, 24°39′67″N–094°00′57″E; Kaina Hill, 24°41′20″N–094°01′31″E) as the lowermost lithological contact of the Barail Group (Laisong Formation) with the Upper Disang Formation based on bivalves such as *Cardium*, *Chlamys*, *Lucina*, *Ostrea*, *Trigonia*, *Pinna*, *Spondylus*, *Tellina*, *Pecten* and *Turritella*. However, a proper age to this formation may only be assigned after proper dating of the sediments, which has not been done so far.

3. Tetrapod footprints

3.1 Material

Two successive footprints of a trackway catalogued as MSM-1 and displayed in the Manipur State Museum (figure 3). A cast of the specimen has been made using modelling clay and is kept at the Geological Museum, United College, Manipur.

3.2 Locality and horizon

Silty shale beds with lingoid ripples and scour marks, about 30 mm thick, at Gelmon locality (Manipur, India). Track-bearing layer close to the base of the Lower Laisong Formation of the Barail Group.

3.3 Description

Two tridactyl imprints, probably those of the pes, representing a single step (right–left) of a trackway (pace length = 18.6 cm) (figure 3A). They have been preserved as moderately impressed concave epireliefs. Their overall shape is mesaxonic

Table 1. *Stratigraphic succession of Manipur (modified after Soibam 2000).*

Group	Formation	Age	Lithology
Alluviums	Younger	Recent	Dark grey to black clay, silt and sandy deposits.
	Older	Pleistocene	Clay, sand, gravel, pebble and boulder deposits.
----- Unconformity -----			
Tipam	Tipam sandstone	Late Miocene	Greenish to blue, moderate to coarse ferruginous sandstone with sandy shale, clay. Molásse deposits.
Surma	BokaBil (~ 1400m)	Late Miocene to	Shale, sandy shale, siltstone, ferruginous sandstone massive to false-bedded ferruginous sandstone.
	Bhuban (~ 1400 m)	Late Oligocene	Alternations of sandstone and shale with more argillaceous horizons in the middle and minor conglomerate. Transitional characters from Flysch to molásse sediments.
----- Unconformity -----			
Barail	Renji (800 m) sediments	Late Oligocene to	Massive to thickly bedded sandstone. Flysch.
	Jenam (~ 1200 m)	Late Eocene	Massive to thickly bedded sandstone with carbonaceous shale horizons. Flysch sediments.
	Laisong (~ 1200 m)		Intercalation of bedded sandstone with relatively thin siltstone and shale. Conglomerate horizon in upper part. Characterised by abundant trace fossils and less invertebrate/plant/leaf fossils. Flysch sediments.
Disang	Upper Disang (~ 2000 m)	Late Eocene to	Intercalations of shale with relatively thin siltstone and sandstone showing rhythmites. Characterised by presence of certain pelecypods, gastropods, microfossils and few trace fossils. Flysch sediments.
	Lower Disang (~ 2000 m)	Late Cretaceous	Dark grey to black, splintery shale with virtually no vertebrate and trace fossil evidence. Flysch sediments.
----- Unconformity -----			
	Ukhrul limestone	Late Cretaceous	Limestone, chert, conglomerate characterised by abundant microfossils – foraminifers and radiolarians.
----- Unconformity -----			
Ophiolite Mélange Zone		Cretaceous/older	Basic and ultrabasic rocks
----- Unconformity -----			
Metamorphic Complex		Pre-Mesozoic	
----- Unconformity -----			
Basement Complex		Pre-Mesozoic/older	

with digit trace III being longest and projecting more anteriorly compared with lateral digits. The first imprint (figure 3A-ii) is 6.3 cm in length and 8.2 cm in width (length/width = 0.8), the better preserved second imprint (figure 3A-i), 7 cm in length and 7.7 cm in width (length/width = 0.9). The digit traces are moderately spread. Their divarication was measured in the well-preserved second imprint with 41° (II–III), 18° (III–IV) and 58° (II–IV). They terminate in broad rounded, hoof-like impressions. In particular, the digit trace III of the second imprint shows three distinct circular to oval impressions of the digital pads and the distal hoof. The digit traces are embedded in a broad oval, faint impression of the

sole that shows a posteriorly concave embayment forming a bilobate posterior margin. The embayment is positioned in line with digit trace III. There is no indication of the presence of manus imprints.

4. Discussion

The tridactyl, mesaxonic shape and the hoof impressions indicate a perissodactyl mammal as the trackmaker. Footprints of perissodactyls are known, for example, from Upper Eocene deposits of Trans-Pecos, Texas, USA and have been assigned to tapiroid, rhinocerotoid and brontotheroid group

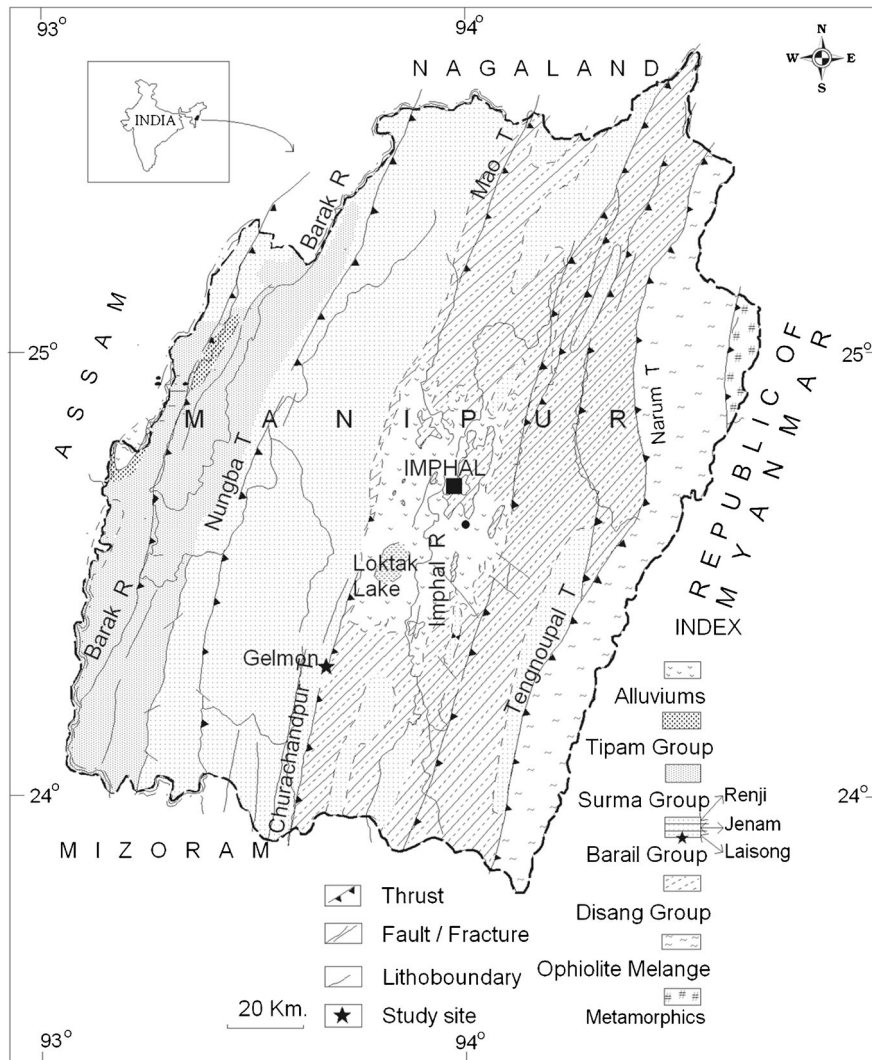


Figure 1. Geological map of Manipur (northeast India) indicating study (track) site.

trackmakers (Sarjeant and Langston 1994). Important surfaces with perissodactyl footprints come from the Eocene Chuckanut Formation and the Pudget Group of Washington (USA) (Mustoe 2002; Mustoe and Hopkins 2013). These tracks have been attributed to *Hyracotherium*-like equids and/or tapiroids, known also by a rich skeletal record from the North American west. Famous localities with perissodactyl and other ungulate footprints are in the Duchesne, Uinta, Green River and Debeque formations of Utah and Colorado (USA) as well as in Paleogene (Eocene–Oligocene) deposits of France, Spain and Peru (Demathieu *et al.* 1984; Lockley and Hunt 1995; Hamblin *et al.* 1998, 1999; Lockley and Meyer 1999; see Lockley *et al.* 1999 for overview). The locality in the Apt Basin of southeastern France which is in Lower Oligocene calcareous lake deposits, shows trackways with typical pes and manus imprints of a rhinocerotoid and was named *Rhonzootherichnus* (Demathieu *et al.*

1984). However, the imprints are much larger compared with those from Manipur and the middle digit trace is more broad with a sharp distal edge of the hoof. One of the best localities with Cenozoic tracks, that also contains perissodactyl footprints, is in the lower Miocene of Hungary (Kordos 1985; Szarvas 2007). The well-preserved tracks of rhinocerotoids are also larger than those of the Manipur specimen and the middle digit has a broad-oval shape. From Asia, perissodactyl footprints are known from Eocene and Miocene deposits of Iran (Ataabadi 2007) and especially from the Xinjiang Province of China (Lockley *et al.* 1999). The tridactyl footprints from Iran show a more extended heel portion with a posteriorly convex margin and are over 20 cm in size. By their shape and size, the imprints described herein resemble the footprints from China. Both are mesaxonic tridactyl with a bilobate posterior margin. The latter are 6 cm

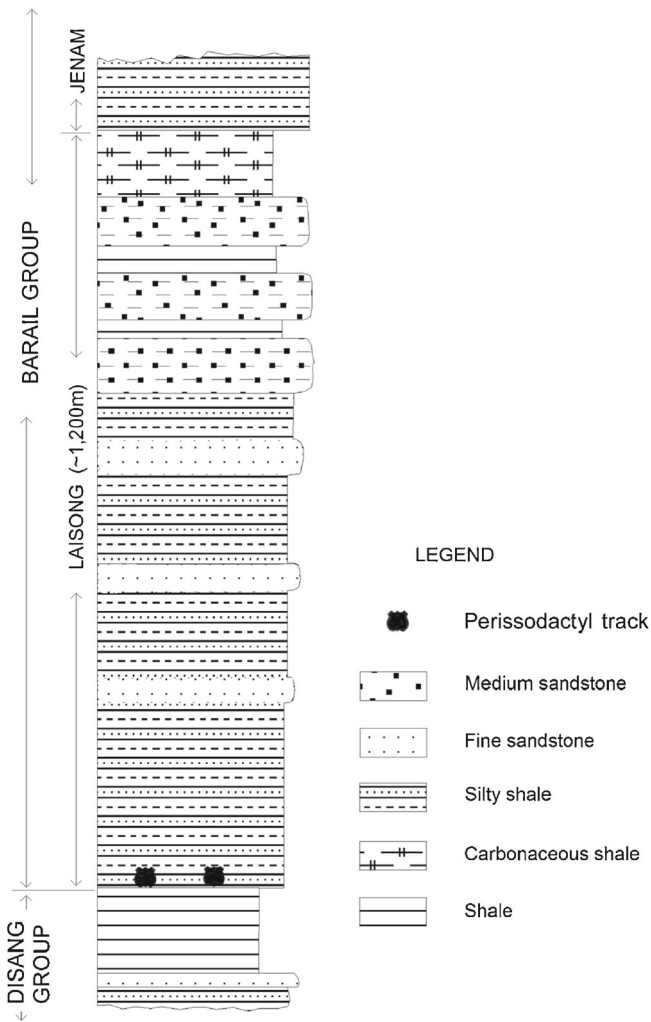


Figure 2. Lithostratigraphic section showing the position of the perissodactyl track horizon.

in length and 8 cm in width, which matches the measurements given for the Barail specimen above. On the contrary, perissodactyl footprints described from North America and Europe mostly show a posteriorly convex and continuous margin (Lockley *et al.* 1999; Mustoe 2002). Small tridactyl imprints of perissodactyls have been described from the Oligocene of Spain by Murelaga *et al.* (2000) and Astibia *et al.* (2007), but all have an elongate ‘heel’ and a convex posterior margin, whereas the imprints from the Barail Group are relatively short, broad and concave posteriorly. The lack of a manus imprint in the Barail specimen may be due to overstep by the pes which is a common feature in mammal tracks (Mustoe 2002). Costeur *et al.* (2009) figure footprints of larger rhinocerotoids from the Oligocene of southeastern France, but these have a mediolaterally extended hoof impression on the third digit which is characteristic of rhinoceros tracks. By their overall shape, the perissodactyl footprints from the Barail Group can rather be assigned to small equids or

tapiroids, even if basal rhinocerotoids cannot be excluded. Ichnotaxonomically, perissodactyl footprints have been assigned to different ichnogenera such as *Apoxyopus*, *Rhinoceripeda*, *Plagiolophus*, *Plagiolophustipus*, *Lophiopus* or *Palaeotheripus*. In most cases, a differentiation is difficult to make and the ichnotaxonomy will certainly need revision. Also, further prospection at the Gelson footprint locality and nearby areas might yield larger samples that permit a more detailed determination. Therefore, the footprints from the Barail Group are not assigned here to a distinct ichnotaxon.

5. Conclusions

The footprints from the Laisong Formation of the Barail Group are the first record of Lower Oligocene perissodactyl tracks from India, strongly resembling those previously described from Xinjiang Province of China. Remarkable is the paleoenvironment which is considered as marginal marine. Singh *et al.* (2012) indicated a tropical to sub-tropical climate for the depositional basin of Laisong sediments. The depositional setting/environment of the Upper Disang–Lower Barail transition sediments was considered as moist tropical with high humidity by Guleria *et al.* (2005) based on morphologies of Paleogene monocot and dicot plant leaves from Manipur such as *Dicotylophyllum kainai* sp. nov., *Phoenicites indica* sp. nov., *Amesoneuron manipurensis* sp. nov., *Dicotylophyllum asymmetricum* sp. nov., etc. These taxa differ from any known fossil dicotyledonous floras from various parts of India (Guleria and Mehrotra 1999; Mehrotra and Mandaokar 2000). It is likely that the source material of plant fossils came from the Myanmar landmass rather than from the Indian subcontinent. The similarities between the Laisong tracks and those from Xinjiang Province of China could be correlated to a continuous landmass connection between China and Myanmar during Lower Oligocene time, favouring a likely migration and dispersal of different vertebrates. However, this is only a speculative observation and based on a small sample of footprints, this cannot be proved presently. Interestingly, skeletal remains of middle Eocene perissodactyls (rhinocerotoids) from Myanmar show a relationship with coeval forms from North America and Asia (Holroyd *et al.* 2006). Vertebrate body fossils from the Indian subcontinent indicate a faunal exchange with other parts of Asia as well as with Europe (Antoine *et al.* 2003; Rose *et al.* 2006; Missiaen and Gingerich 2012). Further material and study is needed to explain this conclusively. It has to be noted that the deposition of plant fossils was prior to the subduction of the Indian plate beneath the Myanmar

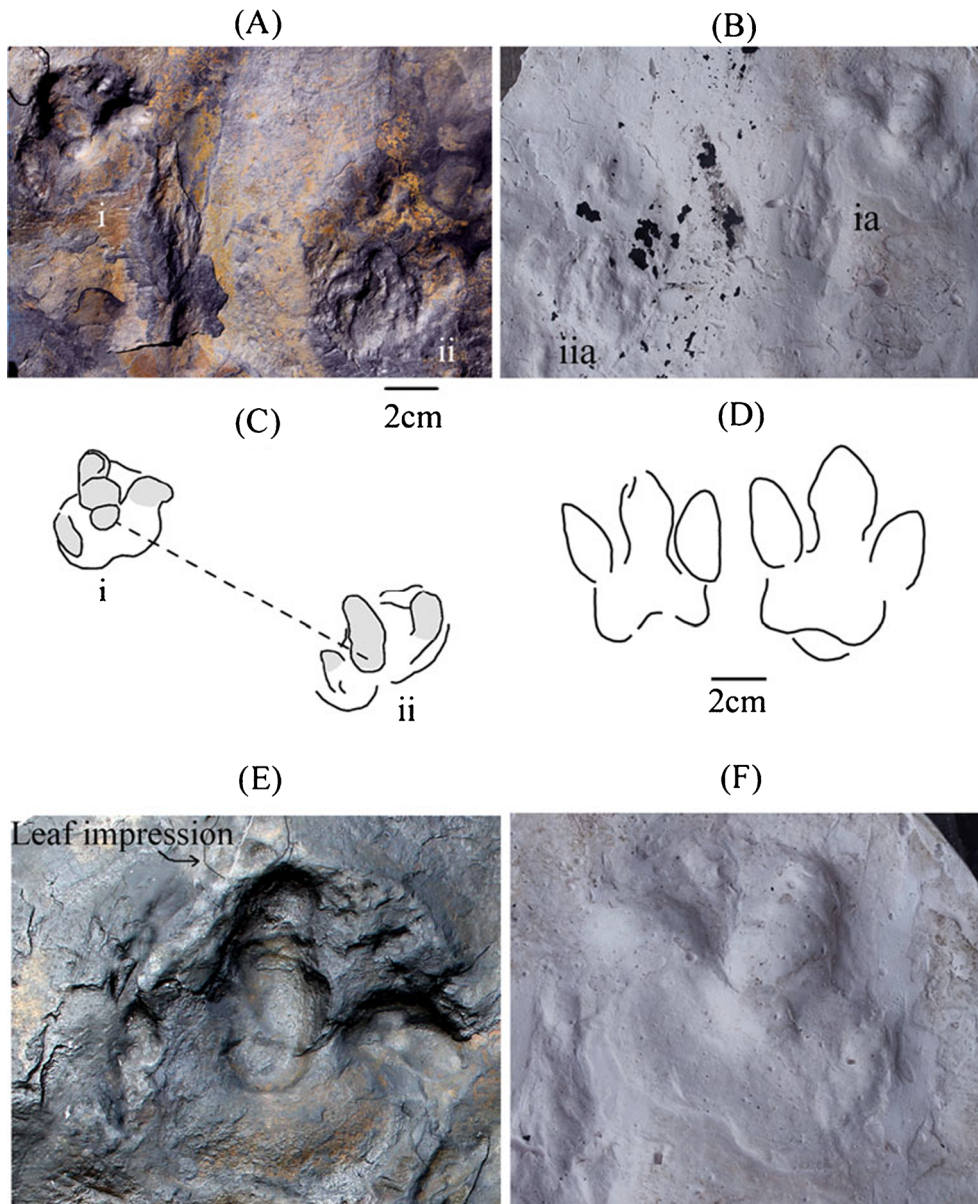


Figure 3. Pes tracks of a perissodactyl mammal (MSM-1) from the base of the Laisong Formation (Barail Group, Lower Oligocene) of Manipur (northeast India) preserved as concave epireliefs. (A) Photograph of footprints (i) left and (ii) right from partial trackway. (B) Cast of (A) where ia and iia are respectively the corresponding casts of tracks i and ii in (A). (C) Sketch of the partial trackway. (D) Perissodactyl pes imprints from the Paleogene of Xinjiang Province, China for comparison (after Lockley *et al.* 1999). (E) Close-up of pes i in (A); notice the leaf impression on the top left corner of (E). (F) Cast of (E).

micro-plate (cf. Soibam and Khuman 2008). Therefore, the exchange of terrestrial faunas between the Indian landmass and the Myanmar continental margin was very unlikely at that time. With respect to the palaeoenvironment, Rajkumar *et al.* (2008, 2012) reported a marginal marine depositional setting for the Laisong sediments and the trackbearing unit based on various invertebrate-ichnofossils. On the other hand, perissodactyl footprints from North America, Europe and China all come from fluviolacustrine deposits. The

new discovery from Manipur indicates the wide distribution of the trackmakers that may have been early equoids, tapiroids or rhinocerotoids frequenting the subtropical to tropical Lower Oligocene coasts of the western Myanmar continental margin.

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