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Large Tetrapod Burrows from the Permian Naobaogou Formation of the Daqingshan Area, Nei Mongol, China

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Abstract: Two new tetrapod burrow casts from the Naobaogou Formation (Middle or Late Permian) of Nei Mongol, China are described. It marks the first pre-Cenozoic tetrapod burrow from China, and one of the earliest records of tetrapod burrows. Comparison to other Permian and Triassic burrows suggests that these burrows were created by tetrapod slightly smaller than *Lystrosaurus*. Deduced from the morphology and sizes of two burrows and known tetrapods of the Naobaogou Formation, the burrow should be the production of a therapsid, most likely a dicynodon. These burrows indicate a seasonal climate and this area was semiarid or arid during that time.

Key words: burrow, Naobaogou Formation, dicynodon, therocephalian

1 Introduction

Pre-Cenozoic terrestrial tetrapod burrows have received much attention after Smith (1987) described the first complex burrow casts from the Upper Permian Teekloof Formation of the Beaufort Group. Their distribution has extended to Antarctica (Miller et al., 2001; Sidor et al., 2008), North America (Hasiotis et al., 2004), Morocco (Voigt et al., 2011), and Poland (Tałanda et al., 2011). Most burrows come from the Lower Triassic (Bordy et al., 2011; Groenewald, 1991; Groenewald et al., 2001; Miller et al., 2001; Sidor et al., 2008; Modesto and Botha-Brink, 2010), whereas they are also discovered from the Middle Triassic (Sidor et al., 2008; Voigt et al., 2011), the Upper Triassic (Hasiotis et al., 2004; Tałanda et al., 2011), the Lower Jurassic (Riese et al., 2011), the Middle Jurassic (Loope, 2006), the Upper Jurassic (Hasiotis et al., 2004), and Mid-Cretaceous (Varricchio et al., 2007). These burrows are identified as the production of dicynodonts (Smith, 1987; Groenewald, 1991; Bordy et al., 2011), cynodonts (Groenewald et al., 2001; Damiani et al., 2003), therocephalians (Modesto and Botha-Brink, 2010), therapsid or mammals (Hasiotis et al., 2004; Riese et al., 2011), procolophon (Groenewald, 1991), archosaurs or turtles (Hasiotis et al., 2004); although only some of them are based on direct evidence. Meanwhile, some other Permian therapsids may have fossorial behavior based on osteological evidence (Cox, 1972; Cluver, 1978; Botha, 2003), although no direct burrowing evidence is available for them.

Pre-Cenozoic tetrapod burrow has never been reported in China. Here we report two large burrows from the Naobaogou Formation of Tumd Right Banner, Nei Mongol (Inner Mongolia), China. Comparing to the Permian and Triassic burrows from South Africa and Antarctic, we argue that therapsids likely made the described burrows here. It marks the first evidence of pre-Cenozoic tetrapod burrows from China, and one of the oldest terrestrial tetrapod burrows all over the world. Finally, we discuss the paleoenvironmental implications for these assignments.

Institutional Abbreviations—BP, Bernard Price Institute for Palaeontological Research, Johannesburg; SAM, South African Museum, Cape Town; **IVPP**, Institute of Vertebrate Paleontology and Paleoanthropology, Chinese Academy of Sciences, Beijing; **UWBM**, Burke Museum of Natural History and Culture, Seattle.

2 Geological Setting

The Permian rocks in the Daqingshan area, Nei Mongol were fluvial and lacustrine deposits within intermountain basin. They comprise of the Shuanmazhuang, Zahuaigou, Shiyewan, Naobaogou and possible Laowopu formations (Bureau of Geology and Mineral Resources of Nei Mongol Autonomous Region, 1991; Jin et al., 2000). Deposits of

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the Naobaogou Formation consist of fine to coarse-grained sandstone, laminated siltstone, mudstone, and occasional marlite and are almost purple or dark purple in color. These deposits, more than 1000 m in thickness, can be divided into three sedimentary cycles (Zhu, 1989). These rocks were mostly deposited under conditions of braided streams, floodplains, and floodplain lakes.

Age of the Naobaogou Formation was generally viewed as the Late Permian, mainly based on the dicynodont *Daqingshanodon* which came from the lower part of the formation (Zhu, 1989; Bureau of Geology and Mineral Resources of Nei Mongol Autonomous Region, 1991). Recent years, the Naobaogou Formation was correlated with the Sunjiagou Formation of the Ordos Basin, the Guodikeng Formation of Xinjiang, and the *Dicynodon* Assemblage Zone of South Africa, because *Daqingshanodon* is referred to family Dicynodontidae (Li et al., 2008) or a junior synonym of *Dicynodon* (Lucas, 2001). However, *Daqingshanodon* shows to be a basal member of Cryptodontia (Kammerer et al., 2011), and this indicates that the age of *Daqingshanodon* possibly ranges from the *Tropidostoma* to *Dicynodon* Assemblage Zones of South Africa. A captorhinid from the first member of the Naobaogou Formation (Li and Cheng, 1997) was referred to *Gansurhinus qingtoushanensis*, which also occurred in the Dashankou Fauna from the Qingtoushan Formation (former Xidagou Formation) (Reisz et al., 2011; Liu et al., 2012). Age of the Dashankou Fauna was suggested as Wordian or even Roadian (Rubidge, 2005; Liu et al., 2009). Based on new evidence, the age of the Naobaogou Formation could be earlier than previous assignment. Two burrows were collected from the base of the third member of the Naobaogou Formation, so the age of burrows could be the Late Permian or late Middle Permian; more precise age will be approached after more comprehensive understanding of the fossils from this formation.

3 Materials

Similar to burrow casts discussed by Sidor (2008), the general shape of the casts probably has not been significantly altered. As previous works on tetrapod burrows (Smith, 1987; Miller et al., 2001; Hasiotis et al., 2004; Sidor et al., 2008; Bordy et al., 2011; Riese et al., 2011; Tałanda et al., 2011; Voigt et al., 2011), we do not intent to assign these materials to a specific ichnogenera but focus on describing the morphology and interpreting the producer.

Two burrow casts described here are exposed on one locality at Tumed Right Banner, Nei Mongol (N 40°43′12″, E110°42′04″). They have been collected in 2011 and accessioned into collections of IVPP as V 18605 and V 18606. The host rock is thinly laminated red mudstone, and the burrow infilling consists of fine to medium sand mixed with silt.

IVPP V 18605 The burrow is curved and seems to be helical in shape (Figs. 1, 2), with a ramp angle of around 15°. Its widths are little varied from the proximal to distal ends. The maximum measurements of burrow cast are approximately 160 cm long, 23 cm wide, and 10 cm tall for the preserved cast.

The burrow cast has broken into several pieces. The

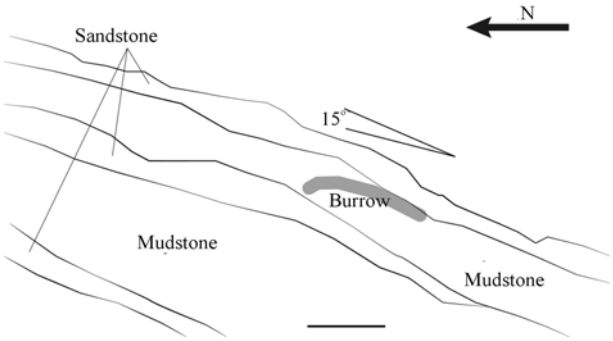

Fig. 2. Sketch of burrow cast IVPP V18605 as found in the field.

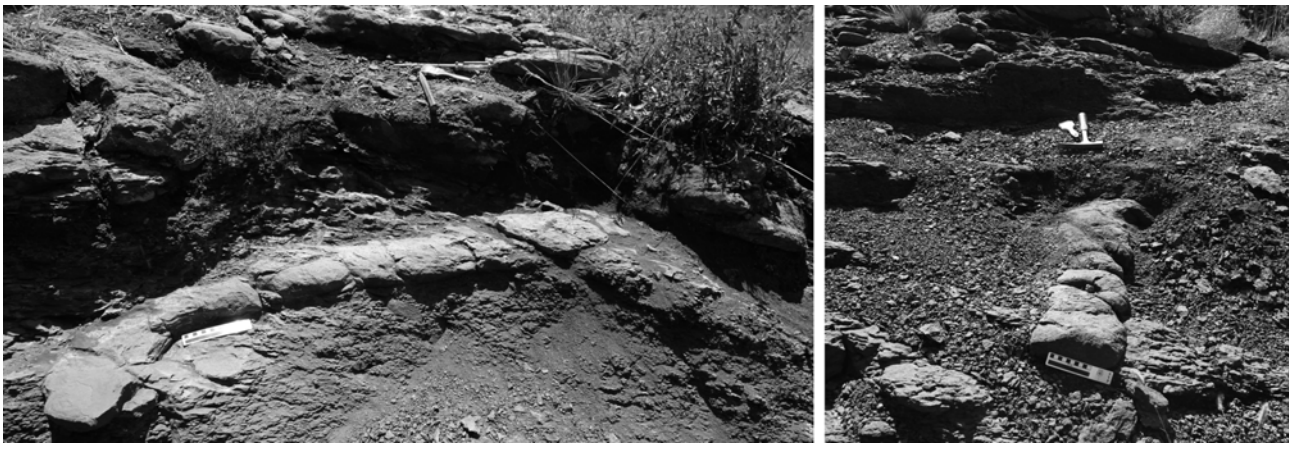

Fig. 1. Two burrow casts in the field. Left: IVPP V18605; Right: IVPP V 18606. Scale bars equal 10 cm.

proximal end is close to the sandstone layer and should close to the entrance (Fig. 3). It has a squared-off appearance; this shape could be formed by the incomplete filling of burrow with sand and the original shape of the burrow is not completely preserved. The burrow floor is fairly uniform and flat, without preserved scratches (e.g., Figs. 3, 4). The distal end is an inclined surface with rounded appearance, and is slightly enlarged in diameter. This part possibly was not too far away from the living chamber, which was lost to erosion before the specimen was collected.

In dorsal view, the burrow cast has nearly parallel lateral sides. The dorsal surface of the burrow cast (i.e., the 'roof' of the burrow) is domed from side to side and has a relatively smooth surface (Figs. 4, 5). The sides of the burrow chamber lack an appreciable vertical component; instead they bend inwards immediately to begin forming the roof. In ventral view, the surface is dominated by two longitudinal lobes separated by a median trough which is a ridge formed by muddy matrix in burrow. The cross-section of burrow shows that the central ridge is smooth, low and wide (Fig. 4). In lateral

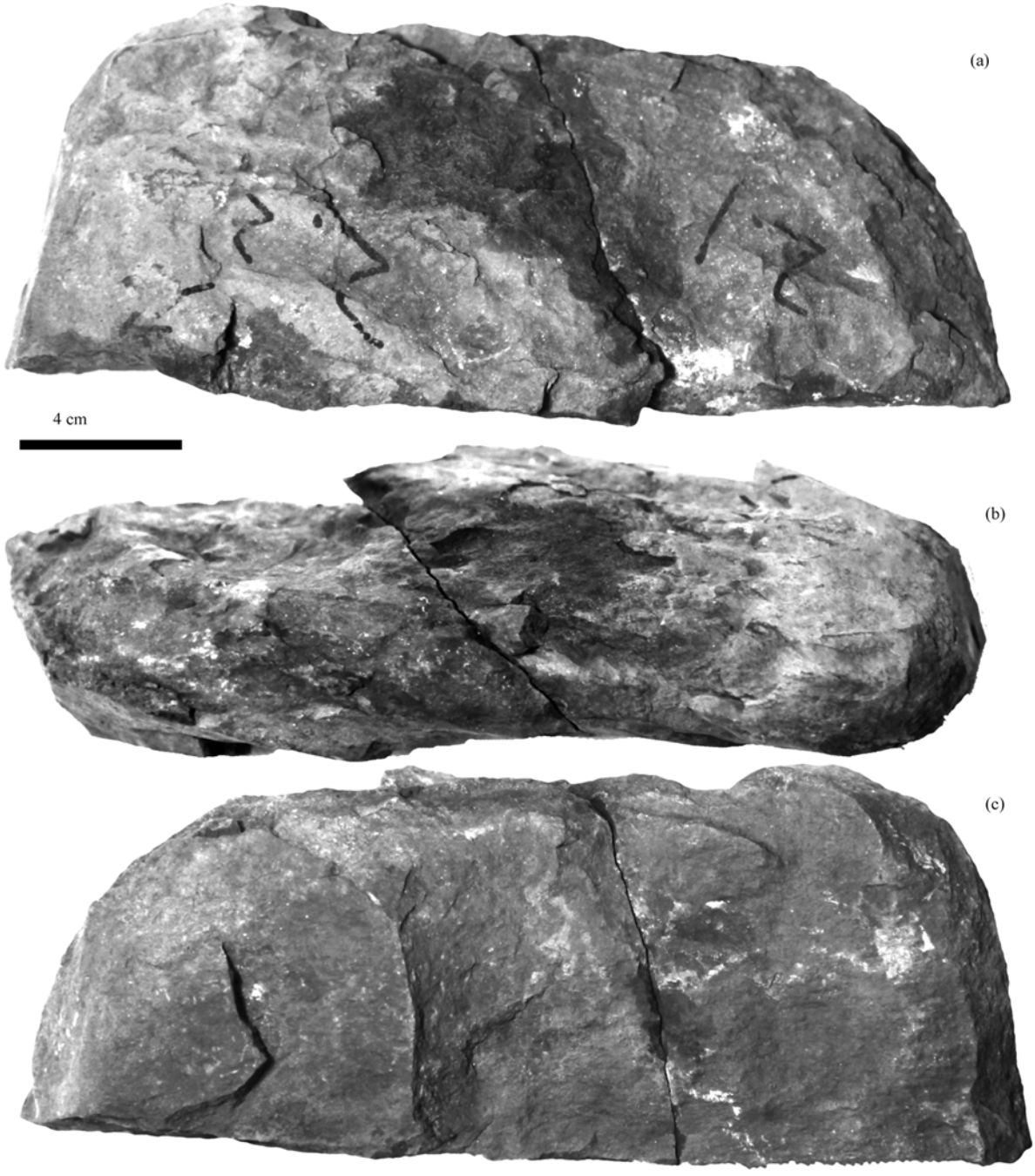

Fig. 3. The proximal end (IVPP V18605-1) in a, dorsal, b, proximal, and c, ventral views.

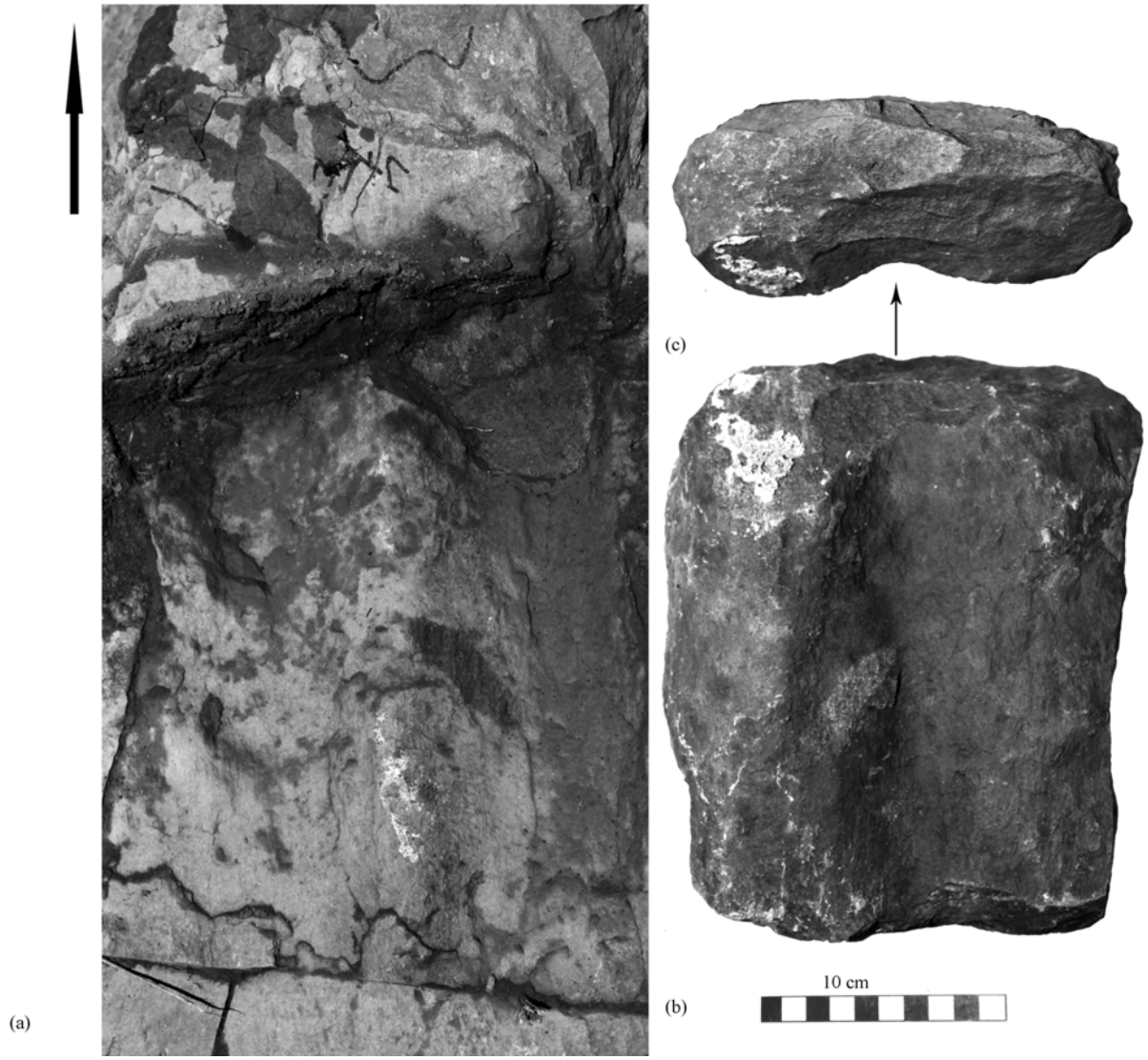

Fig. 4. One proximal block (IVPP V18605-2), ventral surface of burrow (a) and corresponding cast (b); c, distal view of the cast, showing the cross-section.

view, the dorsal and ventral surfaces of the burrow cast are roughly parallel.

Ridges and furrows, which we interpret as scratch marks, are clearly visible on the distal side of the cast and mostly distribute on the ventrolateral and lateral sides of the cast (Fig. 5). The lateral scratch marks mostly run nearly parallel with the long axis of the cast. The ridges are crudely developed, projecting a few millimeters above the burrow cast, and are separated by around 1 cm wide furrows.

IVPP V 18606 The maximum measurements are approximately 100 cm long, 25 cm wide, and 11 cm tall for the preserved burrow cast (Fig. 1). It lies on the same layer as the previous burrow and is only separated from it for approximately 10 m. This burrow is similar to the previous burrow except no clearly ridges and furrows.

4 Discussion

The large size and the scratch marks of the burrow casts indicate the excavator as a tetrapod. Possible excavators of the burrows, based on the fossils known from the Naobaogou Formation, include dicynodont (Zhu, 1989), captorhnid (Reisz et al., 2011), and therocephalian. General evaluation of the excavator is based on body size and burrow morphology.

The diameter of most tunnels very closely matches the body diameter of its excavator (Martin and Bennett, 1977; Voorhies, 1975). Accepted this assumption, the excavator should be slightly smaller than the size of adult *Lystrosaur*, for their burrows are slightly smaller than the latter (Groenewald, 1991). Captorhinid is not likely the excavator because *Gansurhinus* is too small. Furthermore, no fossorial behavior is known for this group.

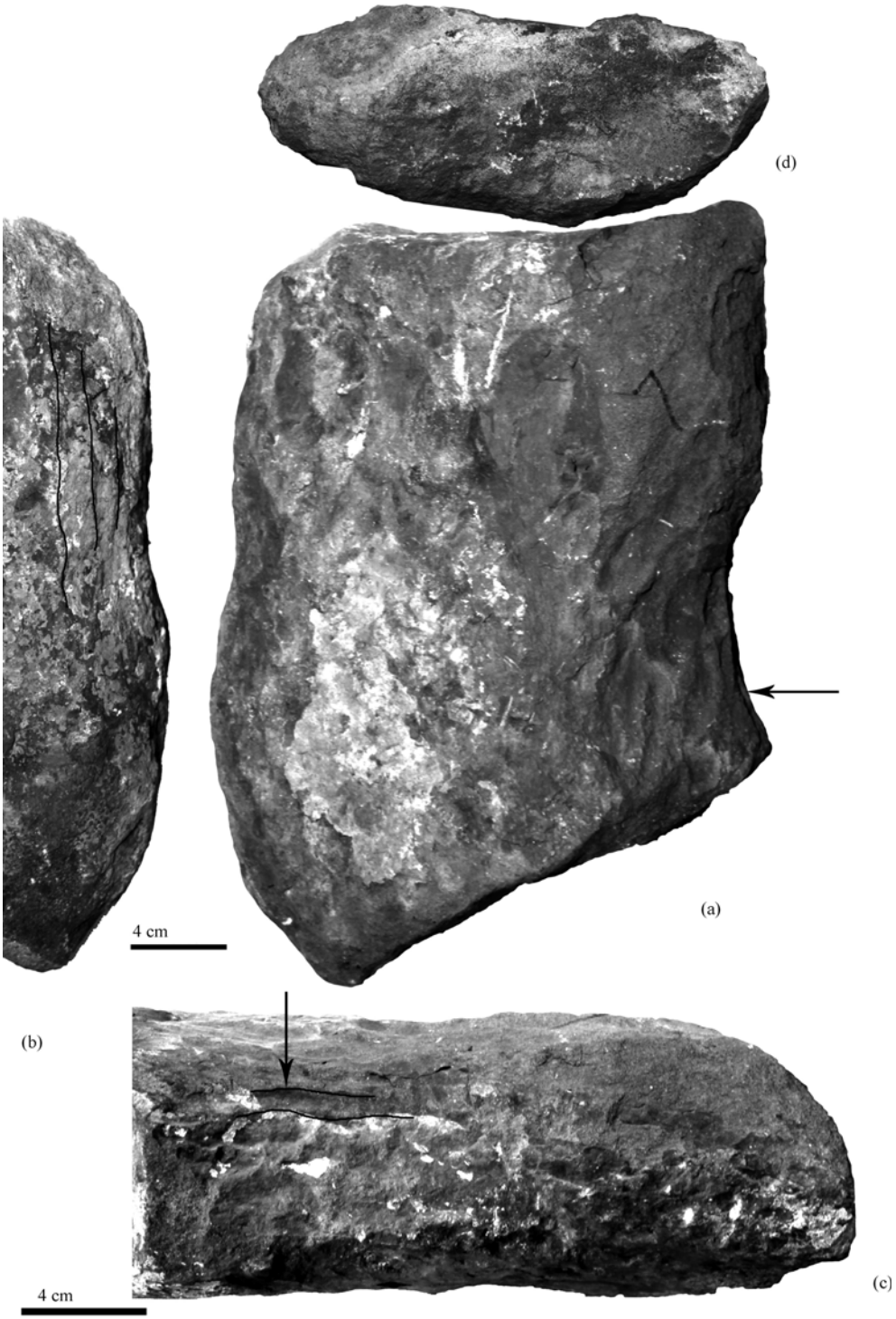

Fig. 5. One distal block (IVPP V18605-7) in a, dorsal, b, ventral, c, lateral, and d, proximal views, arrows point the scratches.

New Chinese burrow casts are similar to *Gyrolithes* and *Daimonelix* type burrow casts in table 2 of Groenewald (1991) in size and general shape. They have both following characteristics: single burrow, helical, loosely coiled, sandstone fill in mudstone host rock, grooves and ridges on sides. The cross-section shape of Chinese burrow casts is similar to UWBM 88617 from Antarctica, both with rounded upper surface, bilobate ventral surface separated by a gentle ridge. The Chinese burrows are larger and flatter than the UWBM 88617, with the width larger than double of the height (Sidor et al., 2008). However, these burrow casts cannot be compared directly,

because UWBM 88617 is a terminal chamber, while IVPP V 18605 and V 18606 are not.

Carnivores are not likely the excavator of coiled burrow. In generally, carnivores construct relatively straight burrows (Hembree and Hasiotis, 2008; Voorhies, 1975). Therocephalians have not evolved as herbivores until the Triassic, and they are carnivores in the Permian. Because of IVPP V 18605 is coiled, it seems that therocephalians are not the excavator. *Lystrosaurus* was attributed as the excavator of coiled, large-scale *Daimonelix*-like burrow casts from *Lystrosaurus* Assemblage Zone by Groenewald (1991). So the excavator of the Naobaogou burrows possibly is a dicynodont. This attribution accords well with the bilobate ventral surface of cast. A bilobate ventral surface is known in cynodont and dicynodont burrows (Damiani et al., 2003; Groenewald et al., 2001; Sidor et al., 2008), while the situation is unclear in therocephalian.

These burrows are the only reported terrestrial tetrapod of Permian other than those of *Diictodon* in South Africa described by Smith (1987). It shows the fossorial behavior is not limited in small tetrapods in Permian. These burrows also indicate that the surface conditions are harsh or severely fluctuating and this area was semiarid or arid regions during that time.

5 Conclusions

The excavator of burrows from Naobaogou Formation should be a therapsid, mostly like a dicynodont, which is slightly smaller than *Lystrosaurus* in size. These burrows represent the oldest burrow record for large tetrapod. They also indicate a seasonal and semiarid or arid climate.

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