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LATE EARLY CRETACEOUS CROCODYLIFORM TRACKWAYS FROM NORTHEASTERN THAILAND

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Abstract—The Aptian-Albian locality of Huai Dan Chum in northeastern Thailand has yielded several trackways of crocodylians, together with ornithopod and theropod trackways. The crocodyliform trackways are described and some are referred to the ichnofamily Batrachopodidae.

INTRODUCTION

Mesozoic vertebrate footprints have been recognized from 12 localities in Thailand and Laos, ranging in age from the Late Triassic to the late Early Cretaceous (see Le Loeuff et al., 2006, 2009 for a review of the Southeast Asian ichnological record). Most tracks and trackways have been referred to various dinosaur groups (i.e., theropods, sauropods and ornithopods), only Triassic footprints from the Carnian-Norian Huai Hin Lat Formation being referred to other archosaurs, possibly phytosaurs (Le Loeuff et al., 2009). Lockley et al. (2009) have also mentioned an isolated large crocodile footprint from the Early Cretaceous (?Neocomian) Phra Wihan Formation (see below).

The crocodile trackways described in this paper are thus the third occurrence of non-dinosaurian ichnites in the Mesozoic of Southeast Asia. They were discovered at the most important ichnological locality of Thailand, both in terms of number of footprints excavated and quality of their preservation. It is situated in northeastern Thailand in the Changwat (province) Nakhon Phanom. The Huai Dan Chum locality is more precisely located in the district of Tha Uthen, on the road between Nakhon Phanom and Ban Pang, close to the confluence of the Si Songkhram and Mekong Rivers, 29 km northwest of the town of Tha Uthen (Fig. 1). Discovered in 2002 by geologists from the Department of Mineral Resources of Thailand (DMR), it has been briefly reported in several recent papers (Le Loeuff et al., 2003, 2005, 2009; Matsukawa et al., 2006). Matsukawa et al. (2006) call the locality "Lao Nat." The proper toponym is Huai Dan Chum, not Huai Dam Chum as improperly transliterated by Le Loeuff et al. (2009). Following our first papers, which emphasized the importance of the locality, the quarry was acquired by the Department of Mineral Resources of Thailand and important work was undertaken in 2007 and 2008 to excavate new tracks, and protect the site with the building of a roof above the outcrops and the creation of interpretive posters with dinosaur reconstructions.

GEOLOGICAL AND PALEONTOLOGICAL CONTEXT

The Huai Dan Chum locality is a now abandoned quarry where large blocks of sandstones were extracted to consolidate the banks of the Mekong River and its effluents. These sandstones belong to the Khok Kruat Formation of the Khorat Group, a thick sequence of Mesozoic continental red bed sediments deposited over much of NE Thailand and neighboring parts of Laos and Cambodia (Racey, 2009). The Khok Kruat Formation itself is a unit considered of Aptian-Albian age on palynological and paleontological grounds (Racey and Goodall, 2009). A latest Aptian age was suggested by Sattayarak et al. (1991) on the basis of palynomorphs found in the upper part of the Khok Kruat Formation, although no floral lists were provided. Its vertebrate osteological record includes sharks (including the hybodont *Thaiodus*, otherwise known from the Aptian-Albian Takena Formation of Tibet; according to Cuny et al. (2008), other hybodontiformes genera present in the Khok Kruat Formation are *Hybodus*, *Heteroptychodus*, *Khoratodus* and *Acrorhizodus*), and bony fishes (Sinamiidae indet., Semionotidae indet.: cf. Cavin et al., 2009). Tetrapods include cryptodiran chelonians of the families Carettochelyidae and Adocidae (Tong et al., 2009), various dinosaurs (Spinosauridae, Titanosauriformes, Psittacosauridae, Iguanodontidae: cf. Buffetaut et al., 2005 for a recent review) and crocodiles. The latter consist of *Khoratosuchus jintasakuli*, the most advanced non-eusuchian crocodile from Southeast Asia (Lauprasert et al., 2009). A dwarf atoposaurid and a possible goniopholid are also represented by skulls, teeth, jaws, osteoderms, etc. (Lauprasert, 2006; Lauprasert et al., in press).

FIGURE 1. Location map. **1**, Huai Dan Chum; **2**, Muong Phalane (Laos); **3**, Hin Lat Pa Chad. Scale bar = 100 km.

The Khok Kruat Formation comprises sandstone, siltstone, conglomerate, shale and paleosols deposited in a dominantly fluvial environment with some possible paralic or even marine influences according to Racey and Goodall (2009), although the last assertion seems unlikely as its fauna is entirely continental or freshwater. At Huai Dan Chum Quarry, the 10 m thick section comprises medium to fine sandstone with mudstone intercalations. The main footprint surfaces are associated with ripple marks and mud cracks.

The Huai Dan Chum quarry is the single ichnological locality of the Khok Kruat Formation, although its lateral equivalent in Laos (Champon Formation, also known as Grès supérieurs Formation) has yielded an ichnoassemblage in the Savannakhet Basin (Allain et al., 1997; fig 1: 2). Huai Dan Chum has mainly yielded hundreds of theropod footprints referred to *Asianopodus* by Matsukawa et al. (2006) with a single ornithopod (cf. *Caririchnium*) trackway (Le Loeuff et al., 2009). We have also recognized at least 15 crocodile trackways during a recent survey of the site (December 2009). The Lao site of Muong Phalane (Allain et al., 1997) comprises a sauropod trackway, together with ornithopod and theropod trackways (see Matsukawa et al., 2006; Le Loeuff et al., 2009 for recent reviews).

DESCRIPTION OF THE TRACKWAYS

The Huai Dan Chum Quarry comprises several track-bearing slabs on its northern edge. The tracks are preserved as concave epireliefs. The main track-bearing slab at the western edge of the quarry is an exposure about 24 m long and 3 to 5 m wide with some ripple marks on its northern side. The surface reveals more than 450 recognizable tracks, belonging to more than 50 theropod trackways, which will be described in detail elsewhere, and one ornithopod trackway of six footprints comprising five consecutive steps. We have located seven crocodile trackways on this slab. A second slab 50 m to the east includes more crocodile (eight) and theropod trackways. We describe and illustrate here some of the best preserved morphotypes of these crocodile tracks.

Morphotype 1

The occidental slab bears essentially the trackways of very small animals. Two of them (C2 and C3) cross each other on the westernmost part of the track-bearing slab (Fig. 2). The trackways are wider than usual batrachopodid trackways (trackway width = 2.61 FW for C2; 3.27 FW for C3). In this rather large trackway the pes pace angulation is rather low at about 135–145°. There is a pronounced heteropody. When preserved, the manus is placed immediately in front of the pes. No tail marks were observable in 2009, although during a previous survey in January 2006 we noticed some possible tail marks between the footprints. The footprint length is less than 40 mm (C3: FL = 35mm; C2: FL = 29 mm). The manus is pentadactyl and digitigrade. Digit 1 of the manus is posteriorly directed. The tetradactyl pes (Fig. 3) is digitigrade to plantigrade. Pes digits III and IV are subequal in length and longer than digit II; digit I is the shortest. When preserved, the four digits are parallel (no divarication).

Morphotype 2

The oriental slab shows much larger tracks (Fig. 4). The trackway is rather wide (trackway width = 2.84 FW) with a low pace angulation (135-140°). C1 has a footprint length varying from 95 to 120 mm (mean FL = 108 mm). Step is 1.67 FL. There are neither manus prints nor tail marks observable. The footprints are not very well preserved, and some of them are covered by theropod footprints. They are apparently tetradactyl and plantigrade with a large heel impression.

COMPARISONS

Few Mesozoic crocodile footprints have been reported from Asia. Young (1943) described the ichnospecies *Kuanyuangpus szechuanensis* from the "Middle Jurassic" of Sichuan (China), which was later referred by Zhen et al. (1989) to the ichnogenus *Batrachopus*, although this label is rejected by Lockley et al. (2010). These footprints are poorly preserved and seem quite different from the Thai specimens. Lockley et al. (2009) have briefly mentioned a very large, isolated footprint from the site of Hin Lat Pa Chad (Fig.1). This locality belongs to the (?)Neocomian Phra Wihan Formation of northeastern Thailand. This tetradactyl footprint is remarkable by its very large size (20 cm wide) and might be related to the contemporaneous giant crocodile *Sunosuchus thailandicus*

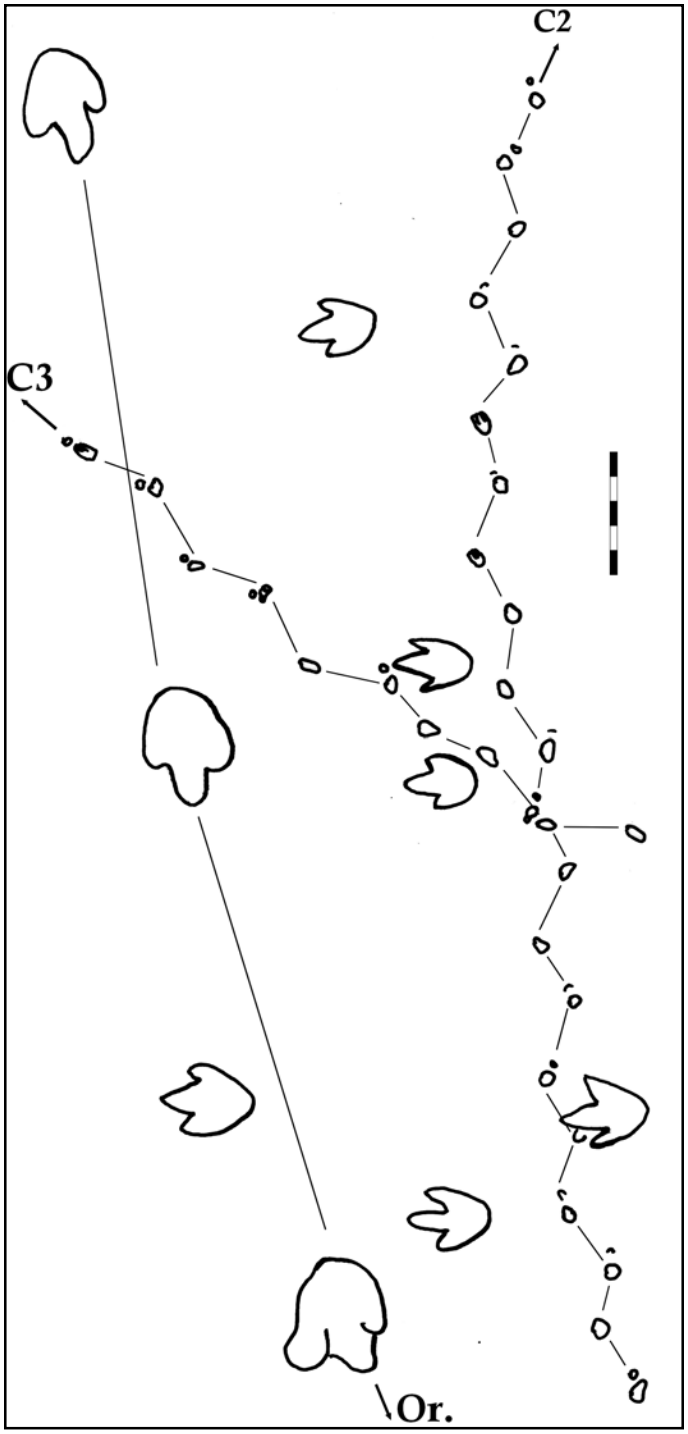

FIGURE 2. Map of western slab with trackways C2 and C3 (morphotype 1) crossing an ornithopod trackway (Or.). Scale bar = 20 cm.

described by Buffetaut and Ingavat (1980, 1984) from the underlying Phu Kradung Formation.

Morphotype 1

The main characters observable on the trackways of Huai Dam Chum are those summarized by Lockley and Meyer (2004) in their emendation of the diagnosis of the ichnofamily Batrachopodidae: trackway of a quadruped with pronounced heteropody; manus pentadactyl, digitigrade and much smaller than the pes. Pes tetradactyl, semi-plantigrade with four digits. Inner margin of pes tracks falls on or near track-

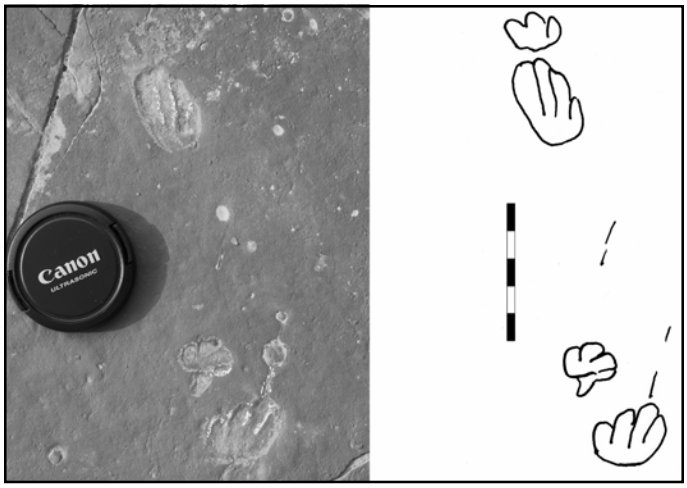

FIGURE 3. Enlargement of two manus-pes couples (C3). Scale bar = 5 cm.

way axis: outward pes rotation 15–30° based on alignment of digit III (foot axis) in relation to trackway axis. Placement of manus also close to trackway axis and typically immediately in front of the pes. One difference with this familial diagnosis is the width of the trackway: it is about twice pes width for Batrachopodidae according to Lockley and Meyer (2004) but between 2.6 and 3.2 for morphotype 1 in Huai Dam Chum. Accordingly, pace angulation is lower than expected for Batrachopodidae (150-160°) as it falls between 135 and 145°. A second difference is that the step is between 3.6 and 3.9 FL (2-3 FL for batrachopodids). Despite these small differences we refer the morphotype 1 footprints to the ichnofamily Batrachopodidae as *Batrachopus* sp.

Morphotype 2

Again, the main characteristics of morphotype 2 are batrachopodid features. However, given their imperfect preservation we do not refer them to the family Batrachopodidae and rather consider them as indeterminate crocodyliform footprints. Although we cannot reject the hypothesis of pterosaurian footprints, it seems more likely that this trackway was made by a crocodile as not a single pterosaur manus print, which are usually deeper than pes prints, was found at the site (Mazin et al., 2003).

CONCLUSIONS

Morphotype 1 represents the first well-preserved fossil crocodile trackways from Southeast Asia that can be referred to the ichnofamily Batrachopodidae (ichnogenus *Batrachopus*). We are aware that referring Aptian-Albian crocodyliform tracks to an Early Jurassic ichnofamily is surprising, as this ichnogenus has not previously been reported from the Cretaceous. However, pending a complete revision of crocodile ichnosystematics this conservative approach is preferred. It is clear that the generalized pattern of crocodile pes and manus since the early Mesozoic does not allow an easy systematic discrimination and this conservative ichnotaxonomy does not reflect the radiation of Jurassic and Cretaceous crocodyliforms. A detailed revision of *Batrachopus* trackways is needed.

Although many crocodile skeletal remains are known from the Khok Kruat Formation, most of them (i.e., isolated teeth, osteoderms) do not allow a precise systematic assignment. Two species have been described from this formation, *Khoratosuchus jintasakuli*, an advanced non-eusuchian neosuchian crocodyliform of moderate size with a preserved skull length of 191mm. Its anterior part being broken, its real length is difficult to estimate; as it was not a longirostrine form according to Lauprasert et al. (2009), and it was in all likelihood shorter than 300 mm. A second species of atoposaurid from the underlying Sao Khua Formation (Lauprasert et al., in press) is considered as a dwarf

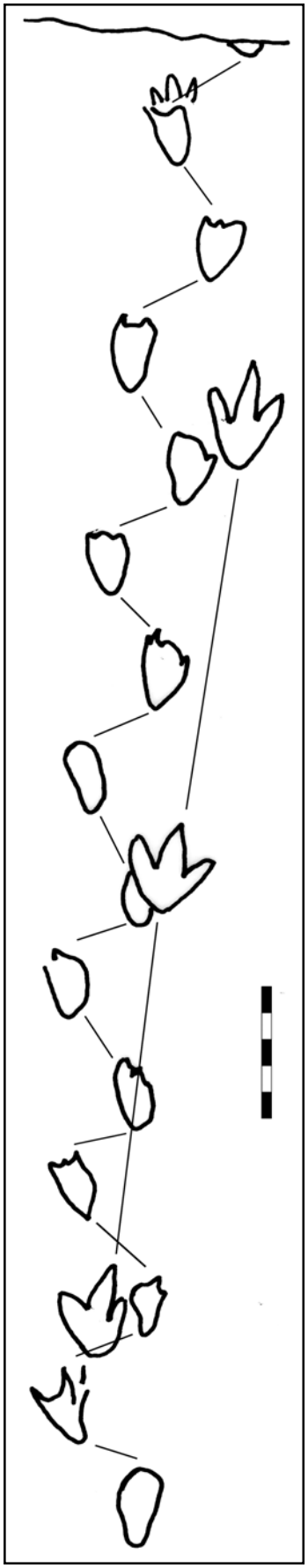

FIGURE 4. Map of eastern slab (C1; morphotype 2). Scale bar = 20 cm.

crocodyliform (adult skull length: 63 mm). Teeth of similar dwarf crocodiles are known from the Khok Kruat Formation (Lauprasert et al., in press), and such a dwarf atoposaurid might be the maker of the very small footprints of Huai Dan Chum. The ichnological record of crocodiles in Thailand thus reflects the biodiversity known from the skeletal record with a mixture of dwarf, normal-sized and even giant crocodiles, as the isolated footprint described by Lockley et al. (2009) strongly evokes the contemporaneous giant species *Sunosuchus thailandicus*.

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