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Dinosaur footprints from the Phra Wihan Formation (Early Cretaceous of Thailand)

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Abstract – The ichnological assemblage of the Phra Wihan Formation (early Early Cretaceous of northeastern Thailand) includes the first sauropod tracks ever found in Thailand. It is reminiscent of the fauna of the underlying Jurassic Phu Kradung Formation with theropods, small ornithischians of uncertain affinities (possibly *Hypsilophodon*-like ornithopods) and sauropods. It suggests that, in southeastern Asia, an important faunal change occurred in the Early Cretaceous among continental vertebrates, whereas little happened at the Jurassic–Cretaceous boundary. ***To cite this article: J. Le Lœuff et al., C. R. Palevol 1 (2002) 287–292.***

Dinosauria / footprints / Early Cretaceous / Thailand

Résumé – Les empreintes de pas de dinosaures de la formation Phra Wihan (Crétacé inférieur de Thaïlande). L'assemblage ichnologique de la formation Phra Wihan (Crétacé basal de Thaïlande) comprend les premières traces de sauropode découvertes en Thaïlande. Il rappelle la faune de la formation sous-jacente, la formation Phu Kradung avec des théropodes, des sauropodes et de petits ornithischiens aux affinités incertaines (peut-être des ornithopodes de type *Hypsilophodon*). Cette composition faunique suggère qu'un remplacement de faune important est survenu en Thaïlande au début du Crétacé, plutôt qu'à la limite Jurassique–Crétacé. ***Pour citer cet article : J. Le Lœuff et al., C. R. Palevol 1 (2002) 287–292.***

Dinosauria / empreintes de pas / Crétacé inférieur / Thaïlande

Version abrégée

1. Introduction

Datée du Crétacé basal [11, 12], la formation Phra Wihan est exposée sur le plateau de Khorat, dans le Nord-Est de la Thaïlande. Si plusieurs formations du groupe de Khorat (les formations Phu Kradung, Sao Khua et Khok Kruat) ont livré des ossements rapportés à différents groupes de vertébrés [3], la formation Phra Wihan (située entre les formations Phu Kradung et Sao Khua) ne contient que des empreintes de pas de dinosaures [1, 7]. Deux gisements sont évoqués ici : Phu Faek, dans la province de Kalasin et Hin Lat Pa Chad, dans la province de Khon Kaen (Fig. 1).

2. Phu Faek

Plusieurs pistes de théropodes et deux empreintes de pieds de sauropodes (Fig. 3) ont été identifiées sur ce site. La principale piste (Fig. 2) a été laissée par un grand théropode (hauteur estimée au bassin : 205 cm) se déplaçant au pas (environ 4 km h^{-1}).

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3. Hin Lat Pa Chad

Cette localité est située dans les collines de Phu Wiang, à l'est de la ville de Khon Kaen.

À côté d'empreintes de théropodes, plusieurs pistes de ce gisement peuvent être rapportées à de petits dinosaures ornithischiens. La plus longue d'entre elles a été laissée par un petit dinosaure quadrupède ; elle comprend 25 empreintes de pied et 15 empreintes de mains. Le pied était fonctionnellement tridactyle et la main apparemment tétradactyle (Fig. 4). Le doigt interne du pied (II) est le plus petit, le doigt III étant le plus long. La longueur moyenne des empreintes de pied est de 109,5 mm, pour une largeur moyenne de 83 mm. Une des caractéristiques les plus remarquables de cette piste est la position très latérale des empreintes de mains par rapport aux empreintes de pieds.

La piste présente un mélange de caractères communs chez les théropodes (présence de griffes relativement pointues), les ornithopodes (main en forme d'étoile, largeur des doigts) et même les marginocéphales (empreintes de mains situées latéralement par rapport aux empreintes de pieds : [9]).

Il paraît raisonnable de rapporter ces traces à un petit dinosaure ornithopode de type *Hypsilophodon*. Les empreintes de mains sont très semblables à celles d'*Anomoepus intermedius* et d'*Anomoepus scambius* (Jurassique inférieur du Connecticut : [16]), qui sont interprétées comme des empreintes d'ornithopode. La formule phalangienne d'un animal comme *Hypsilophodon* (main : 2–3–4–3?–1? ; pied : 2–3–4–5–0 [14]), au pied fonctionnellement tridactyle et aux griffes modérément acérées, est compatible avec les empreintes d'Hin Lat Pa Chad. La position très latérale des mains suggère une posture semi-érigée dans la démarche quadrupède. La hauteur de l'animal, au niveau du bassin, peut être estimée aux environs de 53 cm [16], ce qui est très proche d'un petit ornithopode, connu par un fémur provenant de la formation sous-jacente, la formation Phu Kradung [2].

4. Conclusions

L'assemblage faunique déduit des empreintes de la formation Phra Wihan (sauropodes, théropodes, petits ornithopodes) paraît finalement plus proche de celui de la formation Phu Kradung (théropodes, sauropodes euhelopodidés, petits ornithopodes, stégosaures : [6–8]) que de l'assemblage plus récent de la formation Sao Khua (théropodes tyrannosauridés, ornithomimidés et ?spinosauridés, sauropodes nemegtosauridés [5, 10]), qui n'a livré aucun reste d'ornithopode à ce jour.

Les modifications de la faune continentale du Sud-Est asiatique se seraient donc produites au début du Crétacé (entre le dépôt de la formation Phra Wihan et celui de la formation Sao Khua), plutôt qu'à la limite Jurassique–Crétacé.

1. Introduction

The Early Cretaceous continental formations of the Khorat Group of Northeastern Thailand [2–4] fill a gap in our knowledge of Asian continental vertebrates, between the Chinese Late Jurassic Upper Shaximiao Formation and Barremian Yixian Formation [15]. They are therefore of considerable importance for our understanding of the evolution of Asian non-marine faunas across the Jurassic–Cretaceous boundary. While several formations of the Khorat Group (namely, the Phu Kradung, Sao Khua and Khok Kruat formations) have yielded abundant bones and teeth belonging to various groups of vertebrates (see [3] for a recent review), other formations have yielded footprints only. Although theropod footprints have been reported from the possibly Barremian Phu Phan Formation [5], the main track-bearing formation of the Khorat Group is the older Phra Wihan Formation. So far, only preliminary reports of the dinosaur footprints from the Phra Wihan Formation, which is referred to the early Early Cretaceous on the basis of palynomorphs [11, 12] have been given [1, 7]. Two main localities are described below: the Phu Faek site in Kalasin province and the Hin Lat Pa Chat site in the Phu Wiang hills, in Khon Kaen province (Fig. 1).

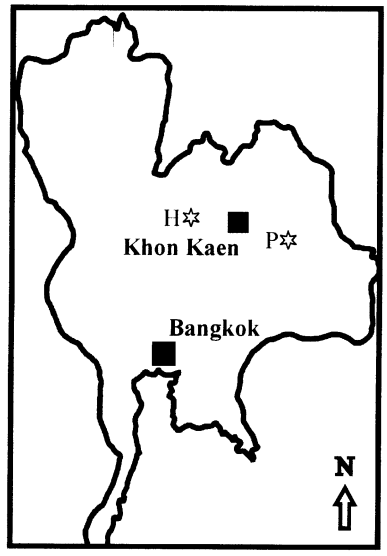

Fig. 1. Location map of the Phu Faek (P) and Hin Lat Pa Chad (H) localities.

Fig. 1. Carte de situation des gisements de Phu Faek (P) et Hin Lat Pa Chad (H).

2. Phu Faek

The dinosaur footprints were discovered in 1996 by two schoolgirls in a dry riverbed. The site is an outcrop

of the Phra Wihan formation. Tracks are preserved as impressions on the upper surface of a sandstone bar. A preliminary account of this discovery was given by Buffetaut et al. [7]. Casts of some footprints are available for study at the Dinosaur Museum in Sahatsakhan (Kalasin Province). At least 25 dinosaur footprints form seven trackways. Large and small theropods are present, as well as a sauropod.

2.1. Theropods

The main trackway at Phu Faek includes seven tridactyl prints of a theropod (Fig. 2). The length of the pes varies from 38 to 43 cm and its width from 34 to 40 cm. Digit III is by far the longest (23 to 26 cm). Large claw marks are observable on the best-preserved prints. This trackway was left by a fairly large theropod (calculated height at the hip using Thulborn (1990) formula: 205 cm). The ratio *SL*/*h* (where *SL* represents stride length and *h* the height at the hip) is quite low (1.08), indicating a walking gait (about 4 km h^{-1}). Other theropod tracks at Phu Faek are less complete. They were made by smaller animals.

2.2. Sauropod

Two large elongated pes prints (length: 52 cm; width: 40 cm) are preserved in an overlying bed, just above the main track-bearing slab. They can be referred to a sauropod (Fig. 3). Poorly preserved prints in front of the two pes prints might represent manus prints. The two large footprints are probably successive pes prints. The track-bearing slab being broken, nothing else is preserved of this track. This very partial track constitutes the first sauropod track discovered in Thailand. It is far too incomplete to allow any tentative assessment to a sauropod family. Other isolated tracks in Phu Faek might represent sauropod manus prints.

3. Hin Lat Pa Chad

The Hin Lat Pa Chad site is located in the hills of Phu Wiang. This locality is also situated in a riverbed, and tracks are preserved as impressions on the upper surface of a sandstone layer. A preliminary account of this discovery was given by Buffetaut and Suteethorn [1]. The locality shows eight different trackways of small theropods, a large theropod, and several small ornithischians described below. Other very small footprints at Hin Lat Pa Chad are of indeterminate origin.

Ornithischians

The longest trackway at Hin Lat Pa Chad (trackway 1; Fig. 4) was left by a small quadrupedal animal. It comprises 25 pes prints and 15 manus prints. Casts of the best-preserved footprints are available for study at the Phu Kum Kao Dinosaur Museum (Thailand) and at the 'Musée des Dinosaures' in Espéraza (France; MDE-D.247).

4. Description

Pes impressions indicate a functionally tridactyl and mesaxonic foot, with the inner digit II smaller than the others. Digit III is the longest. Distinctive claw marks can be observed at the tip of the toes, in the form of 'retro-scratches' indicating sharp claws rather than rounded hooves. Total length of pes prints (*FL*) varies from 80 to 130 mm (mean *FL*: 109.5 mm) and total width (*FW*) from 70 to 95 mm (mean *FW*: 83 mm). *FW/FL* = 0.76, which fits the range in theropods and some small ornithopods [16]. Stride length varies

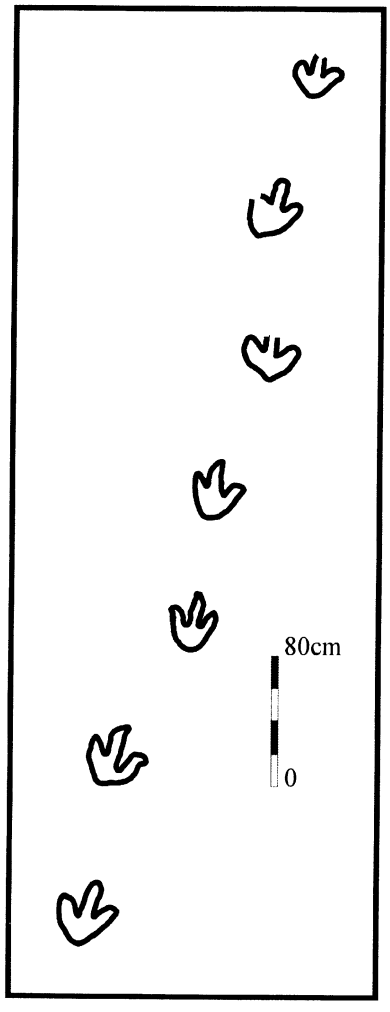

Fig. 2. Theropod trackway in Phu Faek.

Fig. 2. Piste de théropodes à Phu Faek.

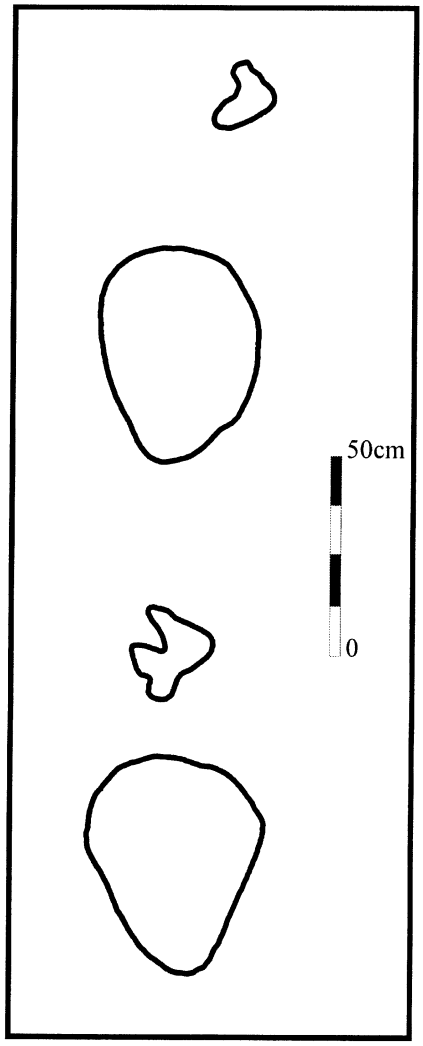

Fig. 3. Sauropod tracks in Phu Faek.

Fig. 3. Empreintes de sauropodes à Phu Faek.

between 48 and 68 cm (mean *SL*: 55.8 cm). Pace length varies from 25 to 31 cm (mean *PL*: 28.7 cm). Pace angulation is rather high (152.8°).

Manus prints are apparently tetradactyl, with the external digit pointing outwards (considering that this feature is not linked to the preservation of the manus prints). The manus prints are situated laterally to the pes prints. They also show claw marks at the extremity of the toes. Total length of manus varies from 40 to 70 mm (mean manus length: 57 mm).

Stride length varies between and 52 and 60 cm (mean *SL*: 56.4 cm); pace length varies from 28.5 to 38 cm (mean *PL* : 34.1 cm). Pace angulation is 111.6°.

A remarkable characteristic of the Hin Lat Pa Chad trackway is that the manus trackway width is much larger than the pes trackway width.

5. Discussion

The foot was functionally tridactyl and the manus apparently tetradactyl. The trackway presents a puzzling mixture of features common in theropods (claws, low divarication), ornithopods (star-shaped manus, pace angulation, broad toes), and even marginocephalians (manus trackway width larger than pes trackway width).

The distinct claw marks are reminiscent of theropods; the pace angulation (152.8°) is rather low for small theropods (usual range between 160° and 170°,

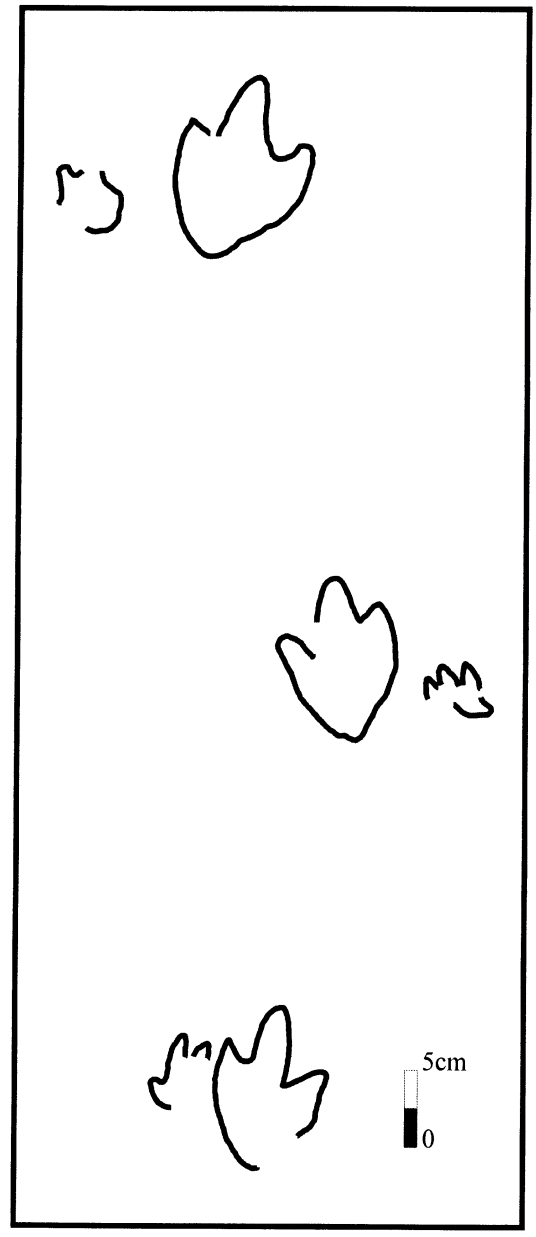

Fig. 4. Ornithopod tracks in Hin Lat Pa Chad.

Fig. 4. Traces d'ornithopodes à Hin Lat Pa Chad.

occasionally as low as 150° or as high as 180°; cf. [16]). The ratio *SL*/*FL* is also rather low (5.1) for small theropods (usual range 7 to 8, but it can vary between 4 and 16, according to Thulborn [16]). The ratio *FW*/*FL* is rather low (0.76) and consistent with the usual pattern of theropod footprints. The total divarication is very low (footprints longer than wide), which is typical for theropods. The rather broad toes are nevertheless different from usual narrow toes of theropods. Anyhow, the tetradactyl manus would indicate very primitive theropods (ceratosaurs); such trackways attributed to quadrupedal theropod have been referred to the ichnogenus *Atreipus*. However, these tracks consistently show manus prints anterior to pes prints, or slightly antero-medially or antero-laterally placed, and the fingers are roughly parallel. The lateral position of the manus prints, suggesting a sprawling posture, and the very divergent digit IV are hardly consistent with a theropod origin.

An alternative explanation is an ornithischian origin of the tracks; some small ornithischians had relatively sharp claws (e.g., *Hypsilophodon*, *Psittacosaurus*, *Microceratops*). The pace angulation (151.8)° of our tracks and the *SL/FL* ratio are in the range for quadrupedal small ornithopods (pace angulation varies from 120 to 150° with a *SL*/*FL* ratio about 5:1). Total divarication is low, but fits within the range of variation observed in ornithopods ($62° \pm 9°$, cf. [16]). Star-shaped or fan-shaped manus prints are characteristic of small ornithopods and the manus of *Anomoepus intermedius* is very similar to the manus described above. In their general morphology, the manus prints from Hin Lat Pa Chad are reminiscent of *Anomoepus intermedius* and *Anomoepus scambus* (Lower Jurassic of Connecticut, figs 6.28d and 6.28h in [16]), which are interpreted as ornithopod tracks. Pace angulation of manus trackway is usually about 100° for small ornithopods. However, the laterally positioned manus prints suggesting semi-erect, sprawling front limbs, are different from *Anomoepus* manus prints, which are situated anteromedially to the footprints. The inferred semi-erect posture of the track maker casts some doubt on its ornithopod affinities. Nevertheless, several trackways with laterally positioned manus prints have been interpreted as ornithopod trackways.

A sprawling posture seems to have been widespread among marginocephalians [9]. Among this group, the strong development of the lateral digit of the manus does not fit psittacosaurs, which have a very reduced digit IV [13]. A neoceratopsian origin cannot be completely excluded: the Late Cretaceous *Microceratops* has a very reduced pes digit I and its foot may have been functionally tridactyl; the hand of *Leptoceratops gracilis* was functionally tetradactyl. Therefore, an Early Cretaceous ancestral neoceratopsian would likely produce tracks similar to those from Hin Lat Pa Chad.

However, the phalangeal formulae of the small ornithopod *Hypsilophodon foxii* (manus: 2–3–4–3?–1+?; pes: 2–3–4–5–0; see [14]) would also fit our tracks. Because of their unusual nature, we suggest that the Hin Lat Pa Chad trackways described above should be referred to small ornithischians, considering that all their characters, including the moderately sharp claws, are consistent with small ornithopods.

Their height at hip (*h*) can be estimated from the foot length (*FL*) using Thulborn's equation ($h = 4.8 \times FL$). This gives a height of 53 cm for an estimated speed of 0.68 m s^{-1}. Such a small dinosaur is very close (at least in size) to a small ornithopod described on the basis of a femur from the underlying Phu Kradung Formation [4].

6. Conclusions

The Phra Wihan Formation has, so far, yielded no fossil bones. Footprints are thus the only way to approach the biodiversity of the corresponding time interval. The dinosaur assemblage is diverse, with large and small theropods (Phu Faek and Hin Lat Pa Chat), sauropods (Phu Faek), and small ornithischians (Hin Lat Pa Chat). The presence of large sauropods is not surprising, as both the underlying Phu Kradung Formation and the overlying Sao Khua Formation have a good skeletal record of these dinosaurs (euhelopodids in the Phu Kradung Formation versus nemegtosaurids and possible euhelopodids in the Sao Khua Formation: [4, 10]). Theropods are also known from both formations.

On the basis of the presence of small ornithischians, the Phra Wihan track assemblage seems closer to the fauna of the underlying Phu Kradung Formation, which includes small and large theropods, euhelopodid sauropods, small ornithopods, and stegosaurs [8]; this assemblage, which also includes temnospondyl amphibians [6] and tritylodonts, is reminiscent of that from Late Jurassic formations in China. The overlying Sao Khua Formation has yielded tyrannosaurid, ornithomimid and ?spinosaurid theropods, and nemegtosaurid sauropods [2] but, so far, no ornithischian among thousands of bones from many localities.

The ichnological record of the Phra Wihan Formation would thus be closer to the dinosaur assemblage of the Phu Kradung Formation than to that of the Sao Khua Formation. It should be noted that many of the Phu Kradung vertebrate sites are located at the top of that thick formation, not far below the footprint levels of the

Phra Wihan Formation. The resemblance in the vertebrate assemblages may suggest that the Phu Kradung Formation is basal Cretaceous rather than Late Jurassic in age, a possibility already suggested by palynological evidence. This would mean that Jurassic vertebrates are still unknown in Thailand. However that may be, a notable change within Southeast Asian dinosaur assemblages seems to have occurred during the Early Cretaceous, posterior to the deposition of the Phra Wihan Formation and before the deposition of the Sao Khua Formation, rather than at the Jurassic–Cretaceous boundary.

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