# EARLY CRETACEOUS VERTEBRATE FOOTPRINTS FROM HAUI DAN CHUM SITE, THA U-THANE DISTRICT, NAKHON PHANOM PROVINCE

BY

TIDA SAENYAMOON

Presented in partial fulfillment of the requirements for
the Master of Science degree in Biology
at Mahasarakham University
May 2006



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Tida Saenyamoon

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# Chapter 1

# Introduction

## Background and Rationale

The fossil record contains two sources of information about organisms. First are body fossils such as bones, teeth and scales. The second are trace fossils such as footprints, teeth-marks, claw-marks, nests, eggs, gastroliths and coprolites (Thulborn. 1990). Trace fossils record the active movement and behavior of ancient organisms, while an ancient organism was still alive. Track features and trackway patterns are important to identify the track-maker. Dinosaur tracks provide information about foot anatomy (size, shape and number of toes), biomechanics, locomotion, behavior, ecology, biostratigraphy, palaeoenvironment and geographic distribution (Thulborn. 1990 ; Kuban. 1994). Trackways can indicate that the animals were walking, trotting or running, and whether the animals were traveling in a bipedal (two-legged) or quadrupedal (four-legged) gait. In addition, we can estimate the speed of the track-maker and discuss other behavior (Anthony. 2001). Footprints provide data on the size, shape and number of toes of the track-maker (Thulborn. 1990). Dinosaur footprints have been extensively used as biostratigraphic makers, environmental indicators, measures of faunal diversity and evidence of group behaviors. Trackways have also been used to estimate locomotor posture, gait and speed (Stephen and others. 1999).

Fossil vertebrates are abundant in the Mesozoic sediments of the Khorat Plateau forming the Khorat Group, Northeastern Thailand (Figure 11) (Buffetaut and Suteethorn. 1993). The Khorat Group consists of 5 Formations (Figure 12), in ascending order the Phu Kradung, Phra Wihan, Sao Khua, Phu Phan, and Khok Kruat Formations, ranging in age from Late Jurassic to Early Cretaceous (Carter and Bristow. 2003 : 271-285). Fossil dinosaurs and other vertebrates (including fresh water sharks, fish, turtles and crocodiles) have been found from the Phu Kradung (Late Jurassic to Early Cretaceous) Sao Khua, and Khok Kruat Formations (Early Cretaceous). Dinosaur footprints have been found from the Phra Wihan, Phu Phan, and Khok Kruat Formations (Buffetaut and others. 1985b; Buffetaut and Suteethorn. 1993; Buffetaut and others. 1997; Le Loeuff and others. 2002).

Although the Khok Kruat Formation has found a lot of bones from many site but trackways are quite rare. The first reported footprints from this formation were referred to a small theropod dinosaur and a possible Deinonychosaur (two-toed footprints) by Le Loeuff and others (2003).

In January and February, 2004, the last survey at Huai Dan Chum (Phanom sub-district, Tha U-Thane district, Nakhon Phanom province) has yielded a large number of footprints from a large slab of sandstone. They were probably made by theropods and ornithopods as well as non-dinosaurian small reptiles. The study of this material emphasizes on morphology of trackways and footprints to understand vertebrate biodiversity and ecology in Northeastern Thailand during the Late Early Cretaceous period (100 million years ago). In addition, this study will encourage people to be aware of the value of their natural resources.

**Research Objectives**

1. To study the morphology and systematics of vertebrate footprints.
2. To study the locomotion and ecology of the track-makers.
3. To study the taphonomy and sedimentology of the locality.
4. To find efficient measures for protection and valorization of the site.

**Scope of Research**

This study is on morphology, systematics and palaeoecology of vertebrate footprints, which were found in the outcrop of Khok Kruat Formation at Huai Dan Chum (Phanom subdistrict, Tha U-Thane district, Nakhon Phanom province) and about valorization of fossil resources. Both field and laboratory study are involved. In the field study, artificial casts, and replicate moulds have been made, and photographs were taken. The footprints were drawn on plastic film and measurement of footprints and trackways were taken. In the laboratory, these materials were drawn on millimeter paper, measured, described and compared with other material.

**Benefits of Research**

1. To know who make the footprints.
2. To improve our knowledge about the palaeobiology of track-makers.
3. To know the relation of the fossils within their environment.
4. To protect the locality from vandalism, weathering, and valorize the site.

**Definition of Terms**

1. Footprint: The impression made by any foot (front or back) in soft sediment. It subsequently becomes a fossil footprint when the sediment turns to rock.

2. Trackway: Two or more consecutive footprints (steps) belonging to a particular animal progressing in a given direction.

3. Mesaxonic: Footprint with digits II and IV sub-equal in length, while digit III is longer than the others.

4. Epirelief: The original imprint or natural mould.

5. Hyporelief: The footprint filling or natural cast.

6. Theropod: Bipedal, carnivorous saurischians; includes gracile coelurosaurs and robust carnosaurs.

7. Ornithopod: Means "bird foot"; includes bipedal to quadrupedal ornithischians like the iguanodontids and hadrosaurs.

8. Taphonomy: The study of the processes involved in the fossilization.

9. Sedimentology: The study of sedimentary rocks and the processes by which they are formed.

10. Systematics: The study of similarities and differences in organisms and their relations; includes taxonomy and classification.

11. Palaeoecology: The study of the environments, interactions, trophic relationships, and behavior of extinct organisms.

12. Manus prints: The impression of the fore foot of the track-maker.

13. Pes prints: The impression of the hind foot of the track-maker.

# Chapter 2

## Review of Literature

Review of literature in this chapter is arranged as follows;

1. The discovery of vertebrate footprints in Southeast Asia
2. Geology of Khorat Platau
3. The discovery of Tha U-Thane footprint site
4. Geological Overview
5. Conservation and Preservation

### The discovery of vertebrate footprints in Southeast Asia: a historical review

Fossil footprints in Thailand had been mentioned in 1868 by the French explorer Henri Mouhot, who traveled in Siam in the 1860s. He mentioned footprints of "antediluvian" animals at Phrabat in Central Thailand but did not describe or illustrate them (Buffetaut and others. 1985b citing Mouhot. 1868). On 7th of March 2005, author visit these footprints in Phra Bhuddhabat temple, Phrabat district, Saraburi province. In fact, they are corals not footprints (Figure 13) (Le Loeuff and others. In press).

Real fossil vertebrate footprints were first reported in 1985 by Buffetaut and others, who described footprints from the Phu Phan Formation (Early Cretaceous) in Phu Luang Wildlife Sanctuary, Loei province on the Khorat Plateau in Northeastern Thailand. The 15 footprints are scattered on a 8 $m^2$ in area sandstone slab. The footprints are tridactyl, without any impression of the hallux. The middle toe (digit III) is longer than the side toes (digits II and IV); the tips of digits show sharp claw impressions. The footprints are longer than wide; the best preserved one is 36 cm long and 31 cm wide. According to McNeill Alexander's formula (Alexander. 1976), the height at the hip is estimated to be 1.78 m, the stride length is estimated to be 2.80 m long. This study indicates that the track-makers are bipedal meat-eater dinosaurs (carnosaur). The speed of the track-makers was estimated at 8 km/hour. The pattern of footprints suggests a small group of adult carnosaurs walking together in the same direction to hunt in packs (Buffetaut and others. 1985 a ; Buffetaut and others. 1985b) (Figure 14).

In 1989, new dinosaur footprints were found on a sandstone slab referred to the Phra Wihan Formation at Hin Lat Pa Chad in the hills of Phu Wiang (Khon Kaen province). This locality is situated in a riverbed and shows 8 different trackways of small theropods (Figure 16), a large theropod (Figure 15), and several small ornithischians (Figure 17). Other very small footprints are of indeterminate origin (Buffetaut and Suteethorn. 1993 ; Le Loeuff and others. 2002).

In 1992, dinosaur footprints were found on a large block of reddish brown sandstone in Khao Yai National Park by a member of a Naturalist Club who informed geologists at Chulalongkorn University. The footprints are on the bank of Mae Nam Sai Yai in the northeastern part of Khao Yai National Park, Northeastern Thailand. They are on a white sandstone cliff of the Phra Wihan Formation. The footprints comprise 2 sizes, both are identified as bipedal carnivores (theropod). The large one is represented by a single tridactyl (three-toes) footprint with 26 cm wide 31 cm long. The small one is known by 7-8 tridactyl footprints, 13.7 cm long, 14 cm wide on average. All of them are theropod footprints. The large footprints were made by adult carnivores while the small ones were made by juveniles of the same species (Polachan and Daorerk. 1993 ; Lockley and others. 2002) (Figure 18). The artificial mould and replicate cast of these footprints are at the Petrified wood Museum in Nakhon Ratchasima province and in Phu Kum Khao Dinosaur Research Center in Kalasin province.

In 1993, a Lao-French team found dinosaur footprints in Muong Phalane, Savannakhet province (Laos). The three levels with dinosaur footprints are visible on the bank of the Sang Soy River on a tabular bedded sandstone belonging to the top of the "Grès supérieurs" Formation, dated by the occurrence of fresh water pelecypods (Trigonioidacea) from the end of the Lower Cretaceous. It is also the age proposed for the Khok Kruat Formation of the Khorat Group in Thailand (Mouret. 1994) and the "Grès supérieurs" Formation is in all likelihood a lateral equivalent of the Khok Kruat Formation. The lower slab has 13 theropod footprints, with a hip-height estimated at 170 cm. The speed is estimated at 5 km/h. The medium slab has 8 footprints of an ornithopod and 38 of sauropods. The hip-height of ornithopod is 210 cm and the speed is estimated to be 6 km/h. The upper slab has 2 theropod footprints similar to those of the lower slab. The facies of the sediment collected in Muong Phalane and the occurrence of ripple-marks on the slab seem to be related to a flood plain (Allain and others. 1997). On 27th of February 2005 we visited this locality. On the right bank of the Sang Soy river many footprints that were assigned by Allain and others to sauropod (1997) are in fact ornithopod. Furthermore, the tridactyl footprints(MP20 to MP27) that they assigned to an ornithopod, look like theropod footprints (Buffetaut and others. 1997 ; Le Loeuff and others. 2002) (Figure 19).

In 1996, dinosaur footprints were discovered by two schoolgirls, in a dry riverbed. The site is an outcrop of the Phra Wihan Formation at Phu Faek, between Na Khu and Huai Phung district (Kalasin province, Northeastern Thailand). At least 25 footprints belong to 7 trackways of large and small theropod as well as a sauropod. The main theropod trackway comprises 7 footprints. Footprints are tridactyl (Figure 21), 38 to 43 cm long and 34 to 40 cm wide. Digit III is longer than digits II and IV (23 to 26 cm). Large claw-marks are observable on the best preserved footprints. The height at the hip is estimated to be 205 cm. The ratio stride length (SL)/height at the hip (h) is 1.08, indicating that this trackway was left by a large theropod walking about 4 km/h (Thulborn. 1990). Other theropod tracks are less complete. They were made by smaller animals. The sauropod trackway has 2 large elongated pes prints 52 cm long, 40 cm wide (Figure 20). There are poorly preserved prints in front of the two pes prints which might be manus prints. This very partial trackway constitutes the first sauropod trackway discovered in Thailand. It is far too incomplete to allow any tentative assessment to a sauropod family (Buffetaut and others. 1997 ; Le Loeuff and others. 2002).

In February 2000, theropod trackways were found on a sandstone slab of the Phra Wihan Formation. The locality is near a stream in Phu Kao (Nong Bua Lam Phu province, Northeastern Thailand). There are several trackways in different directions and more than 20 footprints. These trackways have not been described in detail (Figure 22).

In March 2000, footprints have been found on the surface of a sandstone slab of the Phu Thok Formation at Nam Tok Chattrakan National Park (Northeast of the City of Phitsanulok, Central Thailand). These footprints are currently under study. In all likelihood they were not made by dinosaurs but more possibly by some Tertiary mammals (Setoguchi and Matsuoka. 2004).

In October 2003, footprints were found on the surface of the sandstone of Huai Hin Lat Formation at Tad Huai Nam Yai, Nam Naow district, Petchaboon province. 3 trackways were made by quadrupedal animals (Figure 23). Two of them are closed to each other and one of them is 40 m from the others. The trackways are impressed on a cliff. The study of these footprints is in process. They were made by archosaurs (probably non dinosaurian archosaurs) cf. (Le Loeuff and othes. 2005).

**Geology of Khorat Plateau**

Non-marine Mesozoic sediments are widespread on the Khorat Plateau and part of adjacent Laos, Cambodia through Southwestern China (Heggmann and others. 1994; Racey and others. 1994). Carter and Bristow (2003) mentioned that the Khorat Group consists of 5 Formations, only (in ascending order the Phu Kradung, Phra Wihan, Sao Khua, Phu Phan, and Khok Kruat Formations). The main lithologies of these rocks are reddish brown to light gray sandstones, conglomeratic sandstone, siltstones, claystones and conglomerates. Calcrete nodules and siltstones are also present in claystones but salt and gypsum are found only in the Khorat Plateau. The rocks are interpreted as having been deposited by meandering and braided rivers in semiarid to arid conditions (Meesook. 2000).

The Mesozoic sediments from the Khorat Plateau have yielded abundant vertebrate assemblages ranging in age from Late Triassic to Early Cretaceous. Dinosaurs are quite abundant; they mainly occur in the Lower Cretaceous Formation (especially the Sao Khua Formation), but also in the Late Jurassic (Phu Kradung Formation) and the Late Triassic (Nam Phong Formation). Vertebrates other than dinosaurs are less diversified than dinosaurs; these vertebrates comprise different kinds of fish, temnospondyle amphibians, pterosaurs, phytosaurs, crocodiles and turtles. All are preserved as isolated teeth and bones (Buffetaut and Suteethorn. 1998), only dinosaurs were known by both bones, footprints and eggs (Buffetaut and others. 2003 : 69-82).

There is a gap between the Nam Phong Formation (Norian to Rhaetian) and the overlying Phu Kradung Formation (Late Jurassic/Early Cretaceous), which suggests that the Huai Hin Lat and Nam Phong Formations do not belong to the Khorat Group. The Late Jurassic/Early Cretaceous for the Phu Kradung Formation is interred on the basis of

Berriasian-Barremian age for the overlying Phra Wihan Formation because Phu Kradung Formation lacks suitable age diagnostic material. The assigned age is not unreasonable as most outcrops, including the type locality at Khao Phu Kradung, are confined to the uppermost parts of the Formation where it is clearly conformable with the overlying Phra Wihan Formation.

Racey and others (1994) and Carter and others (1995) suggested a Lower Cretaceous age for the Phra Wihan Formation by using palynomorphs and Fission Track Analysis. Sao Khua and Phu Phan Formations are dated as Early Cretaceous. Khok Kruat Formation is dated as Aptian to Albian according to the vertebrate fauna (Buffetaut and others. 1993) and palynoflora (Sattayarak and others. 1991). The Mahasarakham salt, which overlies the Khorat Group has yielded Albian-Cenomanian palynomorphs in its lower part.

**The discovery of Tha U-Thane footprint site**

In July 2001, a team of geologists from the Department of Mineral Resources inspected a quarry at Huai Dan Chum (Tha U-Thane district, Nakhon Phanom province). The quarry is on the road between Nakhon Phanom and Ban Paeng, 27 km from Tha U-Thane, the coordinates for the site 1958217 (Figure 1). The quarry is 20 m deep, 200 m wide, 500 m long (Figure 2). Large blocks are extracted to consolidate the banks of the rivers in Nakhon Phanom province. The Department of Mineral Resources team found dinosaur footprints on displaced slabs of sandstone. On July 8 2001, the Department of Mineral Resources came to Huai Dan Chum, where they found more dinosaur footprints on displaced slabs with ripple-marks and mud-cracks. In February 2003, the Department of Mineral Resources came back for another survey, and they found for the first time in situ dinosaur footprints on a large slab 2 to 3 m wide and 30 m long. They made casts and replicate mould. The first footprints from Huai Dan Chum were found on displaced slabs with ripple-marks and mud-cracks; they were referred to small theropod dinosaurs and a possible Deinonychosaur (two-toed footprints) by Le Loeuff and others (2003). In January 2004, students of Mahasarakham University and J. Claude discovered a new slab with dinosaur footprints (a large 39 m2 slab with ripple-marks and mud-cracks). The Thai-French team mapped this slab in February, 2004 and found more than 200 footprints belonging to 32 vertebrate trackways (Figure 3).

**Geological Overview**

The Khok Kruat Formation is assigned by some geologists to the top of the Khorat Group because the overlying Maha Sarakham Formation is separated from the Khok Kruat Formation by an unconformity (Sattayarak and others. 1991 a,b ; Racey and others. 1996) but this not clear that this unconformity is local or regional. The sharp contact with the basal anhydrite of the overlying Maha Sarakham Formation was observed and was reported in seismic studies (Sattayarak and others. 1991 a). The Formation is well-distributed in the outer parts of Phu Phan Range bounded along the outer rim of the Phu Phan Formation with presumably conformable contacts. Generally, the formation consists of reddish-brown, fine-to medium-grained sandstones and siltstones and mudstones; conglomerates are also present. Total thickness of this formation is 430-700 m (Meesook. 2000) and the total stratigraphic column cannot be measured due to rarity of outcrops and lack of subsurface data.

This formation in the northern part of its range is widespread in the vicinities of Muang, Phang Khon, Phanna Nikhom, Tao Ngoi, and Kut Bark districts. At Nam Phung Dam and Phu Phan districts, in Sakon Nakhon province it is composed of reddish-brown, fine-to medium-grained arkosic sandstones and mudstones with occasional conglomerates. Plant remains, bivalve and vertebrate fragments have been found.

The formation in the middle part of its geographical range is similar to that of the northern portion consisting of reddish-brown sandstones with siltstones and mudstones but less well-exposed than in the north.

The formation in the southern part is widespread throughout the areas covering the vicinities of Muang, Phrathum Ratchawongsa, and Phanna districts in Amnatcharoen province; Trakanputphon, Kutkhaopun, and Sri Muang Mai districts in Ubon Ratchathani province; and part of Phatiu district in Yasothon province. The rocks are conformably underlain by the Phu Phan Formation, which consists of maroon to reddish-brown carbonate nodules, siltstones and light-grey caliches. Depositional environment of these rocks is interpreted as having been formed by meandering rivers but less mature than those of the Sao Khua Formation.

Dinosaur remains are known from the Khok Kruat Formation for a relatively long time (Table 1), (Buffetaut and Suteethorn. 1993); The first remains to be found were teeth and bone fragments which could only be assigned to indeterminate theropods. At Ban Dong Bang Noi, Chaiyaphum province, jaws of the small ceratopsian Psittacosaurus were described as a new species, *P. sattayaraki* (Buffetaut and Suteethorn. 1992). This new species is indicative of faunal relationships with Northern Asia (Buffetaut and others. 1989).

In the vicinity of Ban Thung Bun and Sri Muang Mai district, Ubon Ratchathani province, dinosaur fragments, turtle plates and Lepidotes fish scales have been found in rocks consisting of reddish-brown mudstones, siltstones and conglomerate lenses. Most of the fossils are confined to lenses of conglomerates. As a result of a recent study, teeth found in this location are clearly identifiable as belonging to iguanodontids and are the first firm evidence of ornithopod dinosaurs from Thailand (Buffetaut and others. 1997). Hadrosaurids were previously described in dinosaur-bearing red beds at Muang Phalane in the Donghen Basin near Savannakhet, in Laos (Hoffet. 1944). These Hadrosaurids were redescribed as ornithopods (Buffetaut. 1991 ; Taquet and others. 1995) which can be correlated with those in the red beds of the Khok Kruat Formation. Stratigraphically, the Muang Phalane dinosaur-bearing red beds are overlain by a salt formation which is very probably equivalent to the Maha Sarakham Formation of Thailand.

Based on the hybodont shark Thaiodus, an Aptian to Albian age (Early Cretaceous) is given to the Khok Kruat Formation (Cappetta and others. 1990).

TABLE 1 Vertebrate fossil record from Khok Kruat Formation

| Vertebrate recorded | Species | Fossil found | Reference |
|---|---|---|---|
| Sauropod: at least one species | -*Phuwiangosaurus sirindhornae* | Bone, teeth | Buffetaut and Suteethorn, 1993; Buffetaut and others, 2002c |
| Theropod: at least three species | -Deinonychosauria<br>-Ornithomimosauria<br>-*Siamosaurus suteethornii* | Bone, teeth, and footprints* | Buffetaut, 1983; Buffetaut and Suteethorn, 1993; Buffetaut and others, 2003; Le Loeuff and others, 2003 |
| Ornithopod: at least two species | -Iguanodontid<br>-Hardrosaurid | Bone, teeth, and footprints* | Buffetaut and Suteethorn, 1993; Buffetaut and Suteethorn, 1998; |
| Ceratopsian: at least one species | -*Psittacosaurus Sattayaraki* | Dentary, maxilla fragment, pos-carnial | Buffetaut and others, 1989; Buffetaut and Suteethorn, 1992; Buffetaut and Suteethorn, 2002 |
| Crocodile: at least three species | -Atoposaurid like crocodile<br>-Goniopholid<br>-undescribed specimen | Bone, teeth, incomplete skull and footprints* | Buffetaut and Suteethorn, 1993; |
| Turtle: at least two species | - *Kizylkumemys khoratensis* n. sp.<br>- *Shashemys sp.*<br>- ?Trionychidae | Carapace and plastral fragments | Buffetaut and Suteethorn, 1993; Tong and others, 2005; Claude com. Pres. |
| Hybodont shark: at least six species | -*Hybodus sp.*A<br>-*Thaiodus*<br>-New genus and sp.#1 | Teeth | Cappetta and others, 1990; Buffetaut and Suteethorn, 1993; Cuny and others, |

TABLE 1 (continue)

| Vertebrate recorded | Species | Fossil found | Reference |
|---|---|---|---|
| | -*Heteroptychodus steinmanni*<br>-New genus and sp.#2<br>-New genus and sp.#3 | | 2003 |
| Fish: at least one species | Semionotiformes | Scale, dermal bone, and teeth | Buffetaut and Suteethorn, 1993; Cavin and others, 2003 |

Remark: *In this study

**Conservation and Preservation**

Footprints are a valuable and nonrenewable natural resource. This means that in many cases discoveries still *in-situ* need to be fully documented, replicated, or, if in danger of imminent natural or human-induced destruction, collected to preserve their current scientific value and potential.

There are three main approaches to preserving a permanent record of tracks or any other fossil. First, one can provide scientific documentation in the from of written descriptions, maps, photographs, and other illustrations. The second is to make replicas of the specimens; the third is to actually collect the specimens and reposit them in a museum (Lockley and Hunt. 1995)

The following list, including field and museum exhibits scattered around the world, is by no means exhaustive. All sites have been selected because they include some form of professional interpretation (Lockley. 1991).

1. Alameda Parkway

The situate is west of Denver near the site of the famous 1877 discovery of

Jurassic dinosaur bones in Morrison Formation, the younger Cretaceous Dakota Group beds of Alameda Parkway exhibit several hundred footprints of iguanodontid and coelurosaurian dinosaurs. The site is fenced off, interpretative brochures and a "Field Guide to Dinosaur Ridge" are available. As the guide explains, the Alameda ("promenade") site really was a dinosaur promenade 100 million years ago. It is part of a megatracksite that has been dubbed the Dinosaur Freeway.

2. The American Museum of Natural History

Although not best known for its fossil footprints, the American Museum of Natural History in New York boasts a spectacular dinosaur tracks exhibit prepared by Roland T. Bird, showing a Jurassic diplodocus mounted above Cretaceous the exhibit is unauthentic for a number of reasons; however it does include the best brontosaur trackway segment on display anywhere in the world.

3. Dinosaur State Park, Connecticut

An on-site exhibit of Lower Jurassic tracks similar to those studied by Edward Hitchcock can be found at Rocky Hill, Connecticut. The track bearing layers were uncovered by highway construction activities in 1966, and authorities moved with admirable dispatch to preserve the site as Dinosaur State Park and interpret it for the benefit of the public. Dinosaur tracks at this site include Anchisauripus, Eubronte, and Grallator.

4. Dinosaur State Park, Texas

Situated on the banks of the Paluxy River near Glen Rose, this is the track site made famous by Roland T. Bird when he first uncovered and described spectacular Cretaceous brontosaur tracks, some of which were excavated and taken to the American Museum. Much of the track-bearing layer is under water and river valley alluvium, but replicas are on display at the park entrance, and rangers are available to advise visitors as to what can be observed.

5. Lark Quarry

The Middle Cretaceous Lark Quarry dinosaur tracksite is situated in a remote region of Queensland, Australia. Despite this fact, it has been extensively documented, and considerable efforts have been mad to protect and preserve the site. It is famous for the large number of small dinosaur tracks that have been interpreted as evidence of a dinosaur stampede. Explanatory signs have been posted at the site, and replicas of tracks are on sale at the Queensland Museum in Brisbane.

6. Münchehagen

Situated near Hannover, Germany, the Münchehagen site features a spectacular exposure about the size of a football field, with seven sauropod trackways and a carnivore trackway. One of the sauropod trackway is protected by a permanent shelter. The site is Lower Cretaceous in age. Brochures are available at the site, and the tracks are documented in detail in the German literature.

7. Ribadessella

Recently the Spanish Institute of Geology and Mineralogy published an impressive color booklet on the dinosaur footprints of the Ribadessella area in northern Spain, describing, among other things, the variety and significance of Late Jurassic herbivore and carnivore trackways exposed in the spectacular cliffs and coastal exposures. The area is designated a point of geological interest.

8. La Rioja

The somewhat younger (Early Cretaceous) group of tracksites and found in the La Rioja region of north-central Spain has been described in a number of technical publications as well as in the La Rioja sites yield a variety of herbivore and carnivore trackway types. They are also accessible to the public and marked and protected with signs, fences, and shelters.

# Chapter 3

## Methodology

This chapter is arranged as follows;

1. Materials
2. Methods
   2.1 Field work
   2.2 Laboratory work

### Material

Vertebrate footprints are 202 individual footprints preserved as hyporeliefs organized in 32 trackways. They are on a slab of reddish-brown sandstone in the Khok Kruat Formation, member of Khorat Group of northeastern Thailand. These strata consist of reddish sandstone and siltstone. The tracks are associated with mud-cracks and ripple-marks. Although the footprints are diverse structurally, almost all appear to be made by theropod dinosaurs. Some footprints are clearly preserved ornithopod footprints and others are croccodile footprints. These footprints are described in the next chapter.

### Methods

1. Field work

1.1 Excavation

Fossil footprints were mechanically by opening the outcrop and cleaning the slab.

1.2 Photographs

Photos have been taken after the tracks were cleaned. The footprints were highlighted with water or gel. Some photos consist of close-ups of individual clear specimens, and high overhead photos show multiple tracks in succession (Kuban. 1994).

1.3 Mapping and Drawing

Drawing is done by putting plastic film (2.60 m x 15 m) on the slab to cover all footprints. Then, footprint's outline are drawn on the plastic film using a permanent pen (Lockley. 1991). The geographical position of the locality and the North was determined by using GPS. The direction of the trackway were determined by using compass.

1.4 Artificial cast (Obata and others. 1989).

1.4.1 Any dust or debris should be swept from the footprints.

1.4.2 The surface of the footprints and the surrounding track should then be lightly smeared with Polyvinyl Acetate (PVA).

1.4.3 Cut a strip of plasticine to form a wall surrounding the footprints and its inner surface should also be smeared with PVA.

1.4.4 The silicone rubber should be mixed with a catalyst to achieve a smooth consistency similar to cream.

1.4.5 Coating the cliff surface with mixed silicone rubber, using a brush.

1.4.6 Covering silicone rubber with fiberglass for reinforcing.

1.4.7 Coating with polyester resin to dry.

1.4.8 Remove the mould.

1.5 Replicate mould (Obata and others. 1989).

1.5.1 Cut a strip of plasticine to from a wall surrounding the moulding.

1.5.2 Mixing resins with talc powder and Polyester color paste.

1.5.3 Coating the surface of the artificial mould with resin, using a brush.

1.5.4 Covering the resin with fiberglass, using brush and coating with resin again.

1.5.5 Covering with fiberglass and coating with resin again for reinforcement.

1.5.6 Repair the surface with talc powder.

1.5.7 Let it dry, then replicate cast.

2 Laboratory work

2.1 Mapping and Drawing

The pictures from the plastic film are reproduced on paper by plotting block (10 x 10 cm) on the plastic film. Then, the 1/10 copy is made on millimeter paper. (Lockley. 1991).

2.2 Measurements

The footprints size (Figure 4), interdigital angles, total divarication (Figure 5), pace and stride lengths (Figure 5) were measured on the field and on the plastic film (Thulborn. 1990).

2.3 Estimate size and speed (Thulborn. 1990)

2.3.1 Estimate height hip (h) is made using Thulborn's formula (1989) (Figure 7).

Small Theropods (FL < 25 cm) h = 4.5 FL

Small Ornithopods (FL < 25 cm) h = 4.8 FL

(h is hip height, FL is footprint length).

2.3.2 Estimate the speed (V) is made using Alexander's formula (1976).

$$V = 0.25\ g^{0.5}\ SL^{1.67}\ h^{-1.17}$$

(V is the speed, g is the gravitational constant, SL is the stride length and h is the hip height).

2.4 The Pace Angulation (ANG) was calculated using Thulborn's formula (1990) (Figure 6).

$$\cos ANG = \frac{(PL_a)^2 + (PL_b)^2 - (SL)^2}{2 \times (PL_a) \times (PL_b)}$$

(PL is Pace Length, SL is Stride Length).

Behavior can be investigated from the detail of stride length (walk SL < 2.0 m; trot SL = 2.0-2.9 m; run SL > 2.9 m), trackway directions and their morphology.

2.5 Systematic Study

Characteristics of footprints and trackways were collected for considering the taxonomic position of the footprints in this study (Thulborn. 1990; Lockley. 1991).

2.6 Palaeoecological Study

Palaeoecological interpretation is done by using the information of trackways and other sedimentological features (mud-cracks and ripple-marks).

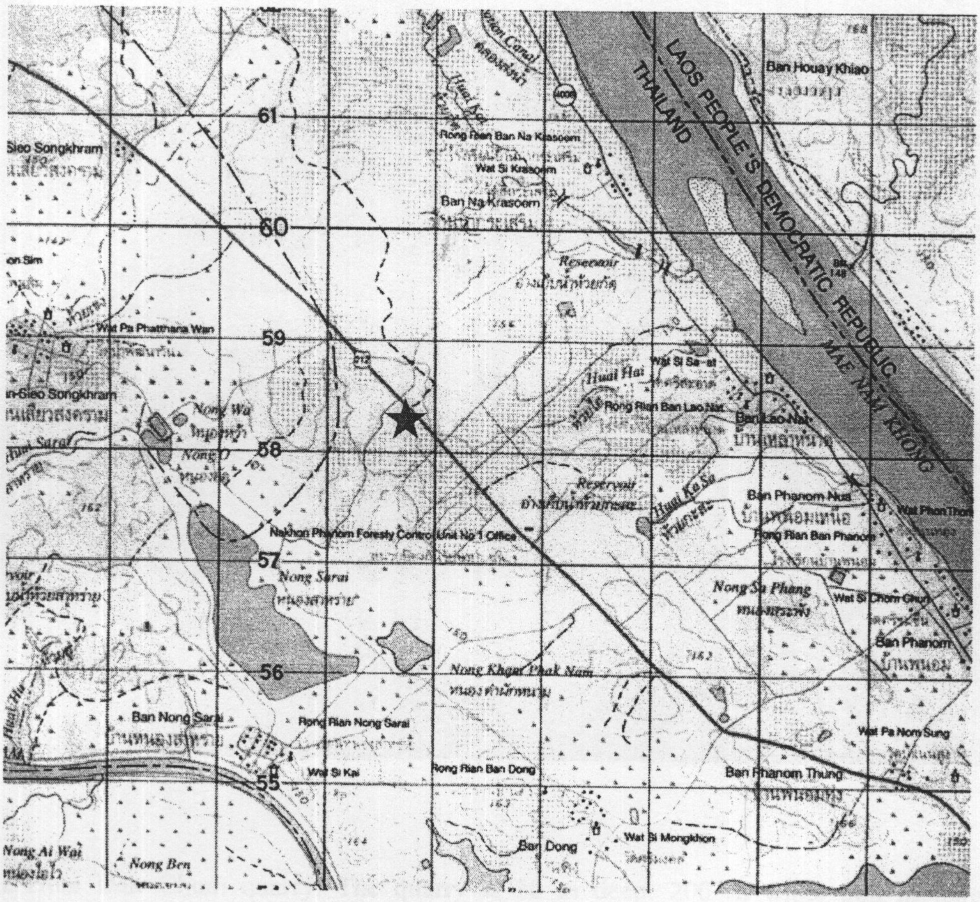



FIGURE 1 Locality map. The star indicate Huai Dan Chum Site. The quarry is roadside of the Route 212 from Nakhonphanom to Ban Paeng, 27 km from Tha U-Thane city.

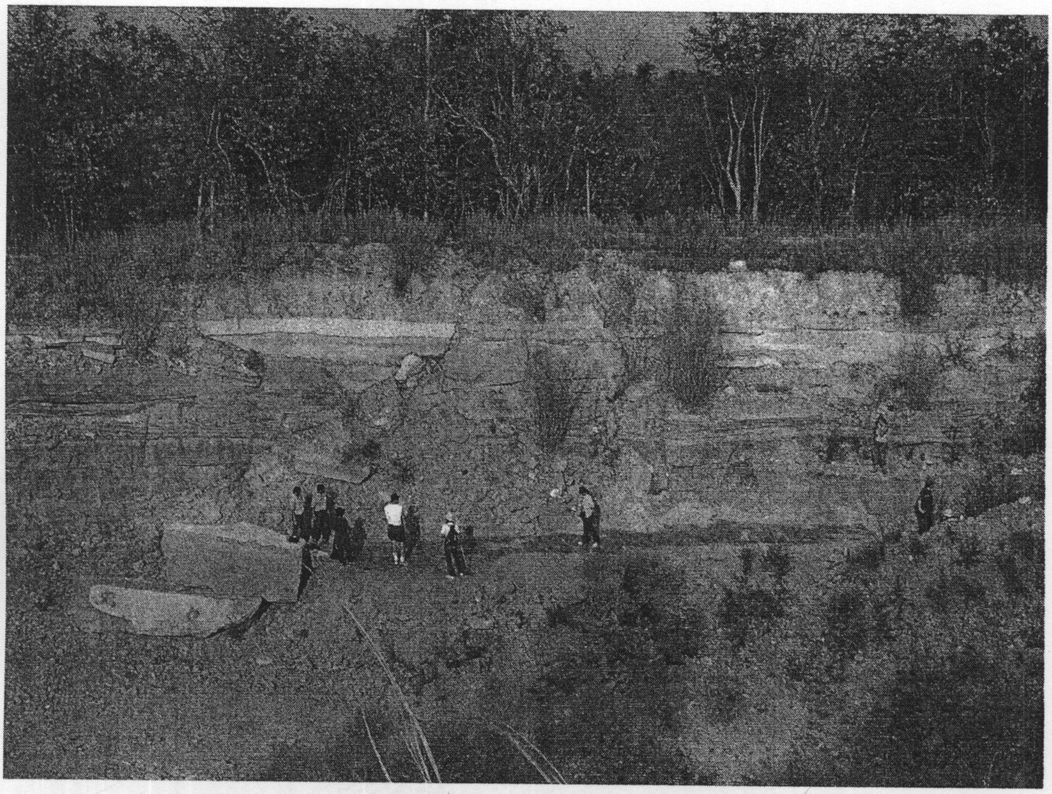


FIGURE 2 Huai Dan Chum quarry. The quarry is 20 m deep, 200 m wide, 500 m long. The slab is 39 $m^2$.

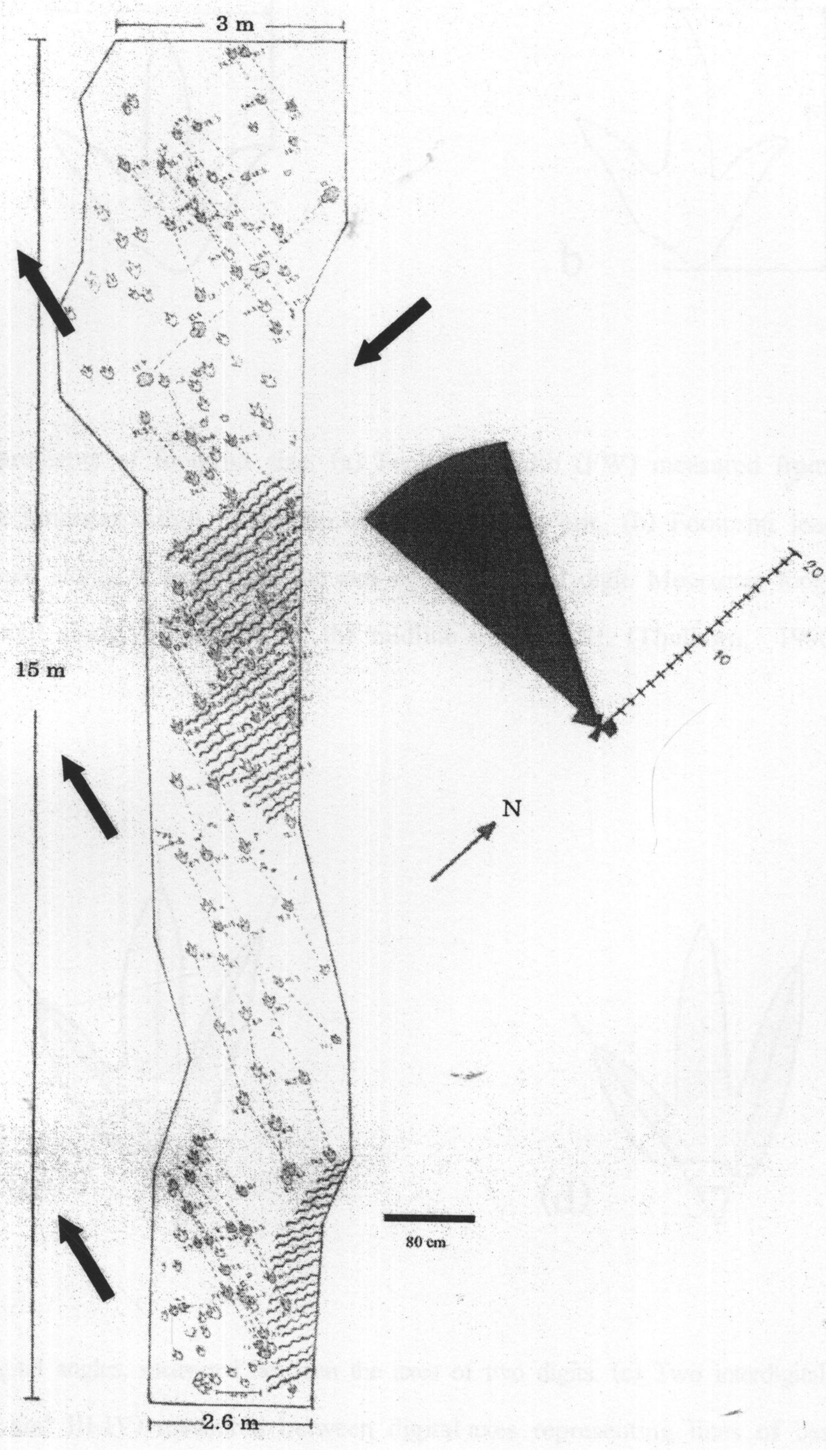



FIGURE 3 Distribution map of vertebrate footprints, showing the direction and orientation.

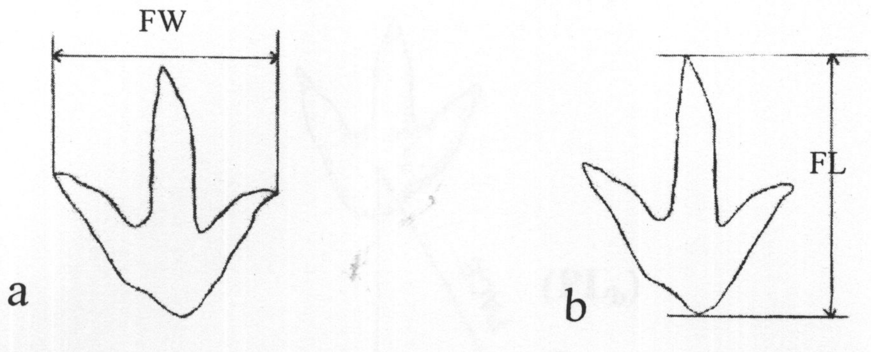



FIGURE 4 Measurements of footprint size. (a) Footprint width (FW) measured from the tip of the innermost digit to the tip of the outermost one. (b) Footprint length (FL) measured along, or parallel to, the axis of the principal digit. Mesaxonic footprint measured along, or parallel to, the midline of digit III. (Thulborn, 1990).

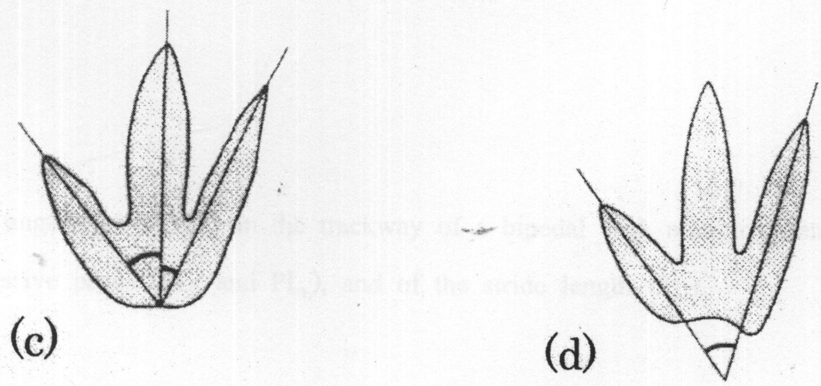



FIGURE 5 Interdigital angles, measured between the axes of two digits. (c) Two interdigital angles (II-III and III-IV) measured between digital axes representing lines of best fit. (d) Total divarication, measured between axes of the innermost digits.

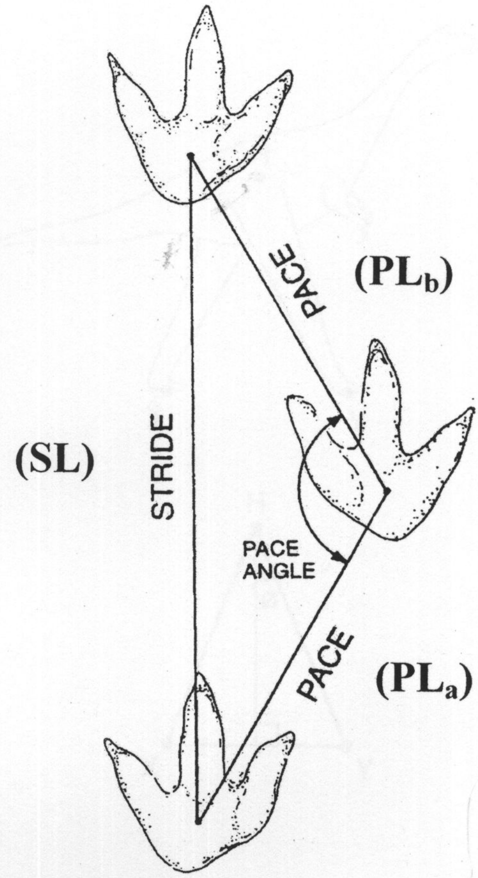



FIGURE 6 Pace angulation (ANG) in the trackway of a bipedal with measurements of two successive paces ($PL_a$ and $PL_b$), and of the stride length (SL).

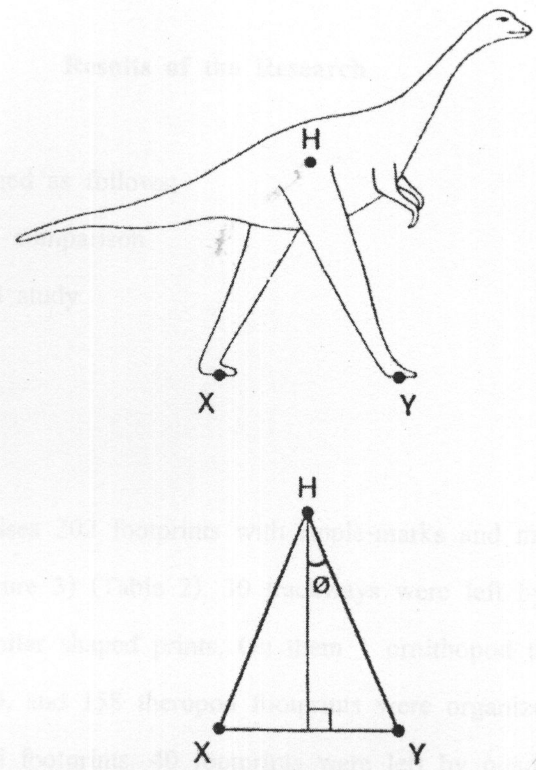



FIGURE 7 Trigonometric method for predicting height at the hip (H) in a dinosaurian track-maker. With a measurement of pace length (X-Y) and an assumption about angle of gait (2Ø), the height of the hip joint (H) above the ground may be estimated by simple trigonometry.

# Chapter 4

## Results of the Research

This chapter is arranged as follows;

1. Description and comparison
2. Palaeoecological study

### Description and Comparison

The main slab comprises 202 footprints with ripple-marks and mud-cracks. They are organized in 32 trackways (Figure 3) (Table 2). 30 trackways were left by bipedal animals with left-right sequences of similar shaped prints. On them 1 ornithopod trackway was composed of 4 footprints (T23), and 158 theropod footprints were organized in 29 trackways (100 footprints) and 58 isolated footprints. 40 footprints were left by quadrupedal animals, as they show both manus (fore foot) and pes prints (hind foot), 23 of these footprints are organized in 2 trackways (T19 and T26) and 17 isolated footprints.

TABLE 2 Measurement of vertebrate footprints

| No.TW | FW x FL (cm) | PL (cm) | SL (cm) | cosANG | h (cm) | speed (k/h) | no.Fp | Direction | Tw.length |
|---|---|---|---|---|---|---|---|---|---|
| T1.1 | 7.5 x 10 | 1-2 = 53.5 | 1-3 = 106 | | | | | | |
| T1.2 | 8 x 10 | 2-3 = 54 | 2-4 = | | | | | | |
| T1.3 | 9.5 x11 | 3-4 = 58 | 3-5=119.5 | | | | | | |
| T1.4 | 7.5 x 12 | 4-5 = 62 | | | | | | | |
| T1.5 | 7 x 10.7 | | | | | | | | |
| MEAN | 7.9 x 10.74 | 56.8 | 112.7 | 169->180 | 48.3 | 6.3 | 5 | 283 WNW | 235.5 |
| T2.1 | 9 x 13.5 | 1-2 = 72.5 | 1-3 = 138 | | | | | | |
| T2.2 | 11.7 x17.3 | 2-3 = 66 | | | | | | | |
| T2.3 | 11.2 x 15 | | | | | | | | |

TABLE 2 (continue)

| No.TW | FW x FL (cm) | PL (cm) | SL (cm) | cosANG | h (cm) | speed (k/h) | no.Fp | Direction | Tw.length |
|---|---|---|---|---|---|---|---|---|---|
| MEAN | 10.63 x 15.26 | 69.2 | 138 | 170 | 68.6 | 7.5 | 3 | 279 WNW | 150.5 |
| T3.1 | 9.5 x 15 | 1-2 = 82 | 1-3=162.5 | | | | | | |
| T3.2 | 8.2 x 17.5 | 2-3 = 83.5 | | | | | | | |
| T3.3 | 10 x 16 | | | | | | | | |
| MEAN | 9.23 x 16.16 | 82.7 | 162.5 | 169 | 72.7 | 8.3 | 3 | 282 WNW | 162.5 |
| T4.1 | 8.2 x 13.2 | 1-2 = 60.5 | 1-3 = 120 | | | | | | |
| T4.2 | 7.4 x 13 | 2-3 = 59.5 | | | | | | | |
| T4.3 | 8 x 13.5 | | | | | | | | |
| MEAN | 7.86 x 13.23 | 60 | 120 | 180 | 59.5 | 5.9 | 4 | 273 WNW | 120 |
| T5.1 | 7 x 12.5 | 1-2 = 61 | | | | | | | |
| T5.2 | 7 x 11.5 | | | | | | | | |
| MEAN | 7 x 12 | 61 | | | 54 | | 2 | 272 WNW | 61 |
| T6.1 | 8.5 x 10 | 1-2 = 60 | | | 54 | | 2 | | |
| T6.2 | 8 x 13.5 | | | | | | | | |
| MEAN | 8.25 x 12 | 60 | | | | | | 40 NE | 60 |
| T7.1 | 8.5 x 14 | 1-2 = 70 | 1-3=140 | | | | | | |
| T7.2 | 9 x 14 | 2-3 = 70 | | | | | | | |
| T7.3 | 9 x 15 | | | | | | | | |
| MEAN | 8.83 x 14.33 | 70 | 140 | >180 | 64.4 | 7.2 | 3 | 282 WNW | 140 |
| T8.1 | 8.5 x 16.4 | 1-2 = 56.5 | 1-3=109.5 | | | | | | |
| T8.2 | 11 x 18 | 2-3 = 53 | 2-4=109.5 | | | | | | |
| T8.3 | 10.2 x 14 | 3-4 = 56.5 | 3-5 = 112 | | | | | | |
| T8.4 | 12.2 x 13.5 | 4-5 = 56 | 4-6=111.5 | | | | | | |
| T8.5 | 10 x 14.9 | 5-6 = 55.5 | 5-7 = 111.5 | | | | | | |
| T8.6 | 11 x 14.5 | 6-7 = 56.5 | | | | | | | |

TABLE 2 (continue)

| No.TW | FW x FL (cm) | PL (cm) | SL (cm) | cosANG | h (cm) | speed (k/h) | no.Fp | Direction | Tw.length |
|---|---|---|---|---|---|---|---|---|---|
| T8.7 | 10.6 x 17 | | | | | | | | |
| MEAN | 10.5 x 15.47 | 55.8 | 110.8 | 173 | 69.6 | 4.5 | 7 | 295 WNW | 332.5 |
| T9.1 | 10.3 x 15.3 | 1-2 = 78.5 | 1-3=153.5 | | | | | | |
| T9.2 | 9.5 x 16 | 2-3 = 75.5 | 2-4=154.5 | | | | | | |
| T9.3 | 9.5 x 15.3 | 3-4 = 79.5 | | | | | | | |
| T9.4 | 10 x 16 | | | | | | | | |
| MEAN | 9.8 x 15.5 | 77.8 | 154 | 180 | 69.7 | 8.9 | 4 | 288 WNW | 233 |
| T10.1 | 11 x 17.1 | 1-2 = 81.5 | 1-3=163.5 | | | | | | |
| T10.2 | 11 x 16.6 | 2-3 = 82 | 2-4 =157.5 | | | | | | |
| T10.3 | 12.3 x 17.3 | 3-4 = 78 | 3-5=158 | | | | | | |
| T10.4 | 10 x 15.4 | 4-5 = 82 | 4-6=155.5 | | | | | | |
| T10.5 | 10.3 x 16.8 | 5-6 = 75.5 | | | | | | | |
| T10.6 | 12 x 16.3 | | | | | | | | |
| MEAN | 11.1 x 16.56 | 79.8 | 158.6 | 176 | 74.5 | 7.8 | 6 | 292 WNW | 315 |
| T11.1 | 7 x 11.4 | 1-2 = 78.5 | 1-3 = 156 | | | | | | |
| T11.2 | 7.9 x 13 | 2-3 = 77.5 | | | | | | | |
| T11.3 | 9 x 13 | | | | | | | | |
| MEAN | 7.96 x 12.46 | 78 | 156 | 176 | 56 | 11.6 | 3 | 262 WSW | 165 |
| T12.1 | 10.5 x 13 | 1-2 = | 1-3 = | | | | | | |
| T12.2 | 11 x 15.2 | 2-3 = 70.5 | 2-4=138.7 | | | | | | |
| T12.3 | 10 x 15.4 | 3-4 = 69 | 3-5=136.5 | | | | | | |
| T12.4 | 11.2 x 15.2 | 4-5 = 67.6 | | | | | | | |
| T12.5 | 10.2 x 16.4 | | | | | | | | |
| MEAN | 10.58 x 14.96 | 69.03 | 137.6 | 176 | 67.3 | 6.7 | 5 | 282 WNW | 206 |
| T13.1 | 9.5 x 16 | 1-2 = 71 | 1-3=147.5 | | | | | | |

TABLE 2 (continue)

| No.TW | FW x FL (cm) | PL (cm) | SL (cm) | cosANG | h (cm) | speed (k/h) | no.Fp | Direction | Tw.length |
|---|---|---|---|---|---|---|---|---|---|
| T13.2 | 10.5 x 16.4 | 2-3 = 77 | 2-4=145.5 | | | | | | |
| T13.3 | 11.5 x 17.3 | 3-4 = 69 | | | | | | | |
| T13.4 | 10 x 14.6 | | | | | | | | |
| MEAN | 10.37 x 16.07 | 72.3 | 146.5 | 170->180 | 72.3 | 7.7 | 4 | 287 WNW | |
| T14.1 | | 1-2 = | 1-3 = | | | | | | |
| T14.2 | | 2-3 = 70 | 2-4=143.5 | | | | | | |
| T14.3 | 11 x 16.7 | 3-4 = 72.5 | 3-5=143.6 | | | | | | |
| T14.4 | 11 x 16.4 | 4-5 = 71.5 | | | | | | | |
| T14.5 | 10 x 15.8 | | | | | | | | |
| MEAN | 10.66 x 16.3 | 71.3 | 143.5 | 171 | 73.3 | 6.7 | 3 | 279 WNW | ~215 |
| T15.1 | | 1-2 = | 1-3 = | | | | | | |
| T15.2 | | 2-3 = 65 | 2-4=118.5 | | | | | | |
| T15.3 | 9 x 12.7 | 3-4= 54.5 | 3.5 = 115 | | | | | | |
| T15.4 | 8.5 x 12.5 | 4-5 = 60.5 | | | | | | | |
| T15.5 | 8.4 x 12.6 | | | | | | | | |
| MEAN | 8.63 x 12.6 | 60 | 116.7 | 180 | 56.7 | 5.9 | 3 | 279 WNW | ~179 |
| T16.1 | 16.1 x - | 1-2 = 67 | 1-3 = 133 | | | | | | |
| T16.2 | 10 x 14.4 | 2-3 = 66.5 | 2-4=132.5 | | | | | | |
| T16.3 | 10.5 x 14.3 | 3-4 = 66.5 | | | | | | | |
| T16.4 | 9 x 14 | | | | | | | | |
| MEAN | 9.75 x 14.23 | 66.6 | 132.7 | 170 | 64 | 6.5 | 4 | 280 WNW | 200 |
| T17.1 | | 1-2 = 69 | | | | | | | |
| T17.2 | 10 x 15.9 | | | | | | | | |
| MEAN | 10 x 15.9 | 69 | | | 71.5 | | 2 | 303 WNW | 69 |
| T18.1 | | 1-2 = 67 | | | | | | | |

TABLE 2 (continue)

| No.TW | FW x FL (cm) | PL (cm) | SL (cm) | cosANG | h (cm) | speed (k/h) | no.Fp | Direction | Tw.length |
|---|---|---|---|---|---|---|---|---|---|
| T18.2 | 11 x 17.1 | | | | | | | | |
| MEAN | 11 x 17.1 | 67 | | | 76.9 | | 2 | 280 WNW | 67 |
| T.19 | | | | | | | | 63 ENE | |
| Pes 1 | 3 x 5 | 1-2 = 15 | 1-3 = 29 | | | | | | |
| Pes 2 | 3 x 6 | 2-3 = 18 | 2-4 = | | | | | | |
| Pes 3 | 3.5 x 5 | 3-4 = 19 | 3-5 = 32 | | | | | | |
| Pes 4 | 4 x 7 | 4-5 = 17 | 4-6 = 35 | | | | | | |
| Pes 5 | 3.5 x 5 | 5-6 = 21 | 5-7 = 38 | | | | | | |
| Pes 6 | 3.5 x - | 6-7 = 19 | | | | | | | |
| Pes 7 | ? X 5.5 | | | | | | | | |
| MEAN | 3.4 x 5.5 | 18.16 | 33.5 | 123 | | | 7 | | |
| Manus1 | | 1-2 = 13 | 1-3 = 31 | | | | | | |
| Manus2 | | 2-3 = 20 | 2-4 = | | | | | | |
| Manus3 | 3.5 x 3.3 | 3-4 = 18 | 4-5 = 36 | | | | | | |
| Manus4 | 3.5 x 4.5 | 4-5 = 18 | 4-6 = 35 | | | | | | |
| Manus5 | | 5-6 = 17 | 5-7 = 35 | | | | | | |
| Manus6 | 4 x 3.5 | 6-7 = 19 | | | | | | | |
| Manus7 | ? X 4 | | | | | | | | |
| MEAN | 3.66 x 3.76 | 17.5 | 34.2 | 157 | | | 5 | | |
| T20.1 | | 1-2 = | 1-3 = | | | | | | |
| T20.2 | | 2-3 = 54 | 2-4 =122 | | | | | | |
| T20.3 | 11.3 x 17.5 | 3-4 = 64 | 3-5=125.5 | | | | | | |
| T20.4 | 11 x 15.9 | 4-5 = 62 | | | | | | | |
| T20.5 | 11 x 16.5 | | | | | | | | |
| MEAN | 11.11 x 16.63 | 60 | 123.7 | >180 | 75.1 | 5 | 5 | 283 WNW | |
| T21.1 | 9.5 x 15.6 | 1-2 =56 | | | | | | | |

TABLE 2 (continue)

| No.TW | FW x FL (cm) | PL (cm) | SL (cm) | cosANG | h (cm) | speed (k/h) | no.Fp | Direction | Tw.length |
|---|---|---|---|---|---|---|---|---|---|
| T21.2 | 10.5 x 17.3 | | | | | | | | |
| MEAN | 10 x 16.45 | 56 | | | 74 | | 2 | 276 WNW | 56 |
| T22.1 | 10 x 16.45 | 1-2 = 74 | 1-3 = | | | | | | |
| T22.2 | 12.5 x 16.3 | 2-3 = 72.5 | | | | | | | |
| T22.3 | ? X 17.3 | | | | | | | | |
| MEAN | 11.25 x 16.53 | 73.25 | | | 74.3 | | 3 | 282 WNW | |
| T23.1 | 11.5 x 18.3 | 1-2 = 100 | 1-3=183.5 | | | | | | |
| T23.2 | 13 x 18.7 | 2-3 = 84 | 2-4 = 156 | | | | | | |
| T23.3 | 12 x 17.5 | 3-4 = 72 | | | | | | | |
| T23.4 | 12 x 17.5 | | | | | | | | |
| MEAN | 12.12 x 18 | 85.3 | 169.7 | 176 | 86.4 | 8 | 4 | 175 SSE | 271 |
| T24.1 | 8 x - | 1-2 = 51 | 1-3 = 106 | | | | | | |
| T24.2 | 8 x 11.2 | 2-3 = 52.5 | | | | | | | |
| T24.3 | 8.3 x 13.2 | | | | | | | | |
| MEAN | 8.1 x 12.2 | 51.7 | 106 | 180 | 54.9 | 6.3 | 2 | 278 WNW | 106 |
| T25.1 | 8 x 12 | 1-2 = 84.5 | | | | | | | |
| T25.2 | 11.5 x 15.3 | | | | | | | | |
| MEAN | 9.75 x 13.65 | 84.5 | | | 61.4 | | 2 | 270 WNW | 84.5 |
| T.26 | | | | | | | | 13 NNE | |
| Pes 1 | ? X 6 | 1-2 = 17 | 1-3 = 34.5 | | | | | | |
| Pes 2 | 3 x 4.5 | 2-3 = 19 | 2-4 = | | | | | | |
| Pes 3 | ? X 5.5 | 3-4 = 19 | 3-5 = 37 | | | | | | |
| Pes 4 | 2.5 x 5 | 4-5 = 19 | 4-6 = 37 | | | | | | |
| Pes 5 | | 5-6 = 19 | | | | | | | |
| Pes 6 | 2.5 x 4.5 | | | | | | | | |

TABLE 2 (continue)

| no.TW | FW x FL (cm) | PL (cm) | SL (cm) | cosANG | h (cm) | speed (k/h) | no.Fp | Direction | Tw.length |
|---|---|---|---|---|---|---|---|---|---|
| MEAN | 2.6 x 5.1 | 18.6 | 36.1 | 150 | | | 6 | | |
| Manus1 | | 1-2 = 16 | 1-3 = 34 | | | | | | |
| Manus2 | 2.5 x 2.5 | 2-3 = 18 | 2-4 = | | | | | | |
| Manus3 | | 3-4 = 18.5 | 3-5 = 37 | | | | | | |
| Manus4 | | 4-5 = 19 | 4-6 = 36 | | | | | | |
| Manus5 | | 5-6 = 17 | | | | | | | |
| Manus6 | | | | | | | | | |
| MEAN | 2.5 x 2.5 | 17.7 | 35.66 | 170 | | | 5 | | |
| T27.1 | | 1-2 = 50 | 1-3 = 105 | | | | | | |
| T27.2 | | 2-3 = 50 | 2-4 = 105 | | | | | | |
| T27.3 | 8 x 11.5 | 3-4 = 58 | | | | | | | |
| T27.4 | 8.5 x 13 | | | | | | | | |
| MEAN | 8.25 x 12.25 | 52.66 | 105 | 153->180 | 55.1 | 6.1 | 4 | 276 WNW | 162.5 |
| T28.1 | 9 x 13.5 | 1-2 = 62 | 1-3=123.5 | | | | | | |
| T28.2 | 8 x 10 | 2-3 = 60 | | | | | | | |
| T28.3 | 6 x 12 | | | | | | | | |
| MEAN | 7.66 x 11.83 | 61 | 123.5 | >180 | 53.2 | 8.3 | 3 | 277 WNW | 123.5 |
| T29.1 | | 1-2 = | 1-3 = | | | | | | |
| T29.2 | 9 x 13.5 | 2-3 = 58 | 2-4=116.5 | | | | | | |
| T29.3 | 8.5 x - | 3-4 = 58.5 | 3-5 = 115 | | | | | | |
| T29.4 | 9.3 x 13.5 | 4-5 = 54.5 | | | | | | | |
| T29.5 | 7.5 x 12.4 | | | | | | | | |
| MEAN | 8.57 x 13.13 | 57 | 115.7 | 180->180 | 59.1 | 5.5 | 4 | 277 WNW | |
| T30.1 | | 1-2 = | 1-3 = | | | | | | |
| T30.2 | | 2-3 = | 2-4 = | | | | | | |
| T30.3 | 9.7 x 15.7 | 3-4 = 58.5 | 3-5 = 120 | | | | | | |

TABLE 2 (continue)

| no.TW | FW x FL (cm) | PL (cm) | SL (cm) | cosANG | h (cm) | speed (k/h) | no.Fp | Direction | Tw.length |
|---|---|---|---|---|---|---|---|---|---|
| *T30.4* | *7.5 x 14* | *4-5 = 60* | | | | | | | |
| T30.5 | | | | | | | | | |
| MEAN | 8.73 x 14.85 | 59.2 | 120 | >180 | 66.8 | 6.2 | 3 | 279 WNW | |
| T31.1 | 9.5 x - | 1-2 = 70.5 | | | | | | | |
| T31.2 | 10 x 14.4 | | | | | | | | |
| MEAN | 9.75 x 14.23 | 70.5 | | | 64 | | | 277 WNW | 70.5 |
| T32.1 | | 1-2 = | 1-3 = | | | | | | |
| T32.2 | 11 x 16.3 | 2-3 = 65 | 2-4 = 129 | | | | | | |
| T32.3 | 10.5 x 16 | 3-4 = 64 | 3-5=125.5 | | | | | | |
| T32.4 | 10.5 x 14.8 | 4-5 = 67 | | | | | | | |
| T32.5 | | | | | | | | | |
| MEAN | 10.66 x 15.7 | 65.3 | 127.2 | 180 | 70.6 | 5.6 | 4 | 279 WNW | |

**Description of ornithopod footprints**

The ornithopod trackway is 2.7 m long. The footprints are tridactyl (Figure 8) with digits II, III and IV. The shape of digits are bluntly rounded (U-shape) without claw marks; digit III is longer than digit II and IV. T23.2 shows digits III and IV of almost equal length and overlap upper trackway T27.2. The ornithopod footprints are 18 cm long and 12.1 cm wide (mean) (Table 2). The direction of this trackway is 175° SSE and crosses several theropod trackways (T29, T27, T30, T32, and T20). The direction of trackway is opposite to the direction of ripple-marks indicating that the track-maker probably walked perpendicular to the shore of a river. Furthermore, the first 3 footprints were made on un-firm substrates, but no.2 walked on firm substrates. The height at the hip is 86.4 cm using Thulborn's formula (1989). The speed of the track-maker is 8 km/h using Alexander's formula (1976).

**Comparison of ornithopod footprints**

The footprints from this locality were compare with Lao footprints site. Thus the footprints are clearly tridactyl without claw marks, and they are more rounded than theropod footprints (Allain and others. 1997). Thulborn (1990) referred to an ornithopod on the basis of following characters: ornithopods are bipedal gait producing fairly narrow trackway, with pace angulation ranging from 150$^{O}$ to 170$^{O}$. Pace angulation of this trackway is 176$^{O}$ (Table 2). The ratio SL/FL is commonly between 4/1 and 8/1, though it may reach 20/1 in the track of fast-running animals (Wintonopus, Thulborn and Wade. 1984). The ratio of SL/FL of this trackway is 9/1. Each footprint is mesaxonic (the middle digit is larger) and tridactyl (digits II-IV), digit III is longer than digits II and IV, U-shape termination of digit (rounded claws), digit II and III more divergent than for theropod. Kuban (1994) referred to an ornithopod as follows: ornithopod tracks are normally wider than theropod tracks, with well rounded posteriors and relatively short, blunt digit marks reflecting hoof-like claws. From these comparisons, can be refered trackway T23 as a small ornithipod dinosaur.

**Description of theropod footprints**

The theropod trackways are 56 cm to 332.5 cm long. The direction of trackways is rather uniform, (most of them are in the same direction from 270 to 303 WNW : Table 2). Most trackways are parallel to the ripple-marks (Figure 3) indicating that the track-markers probably walked along some riverside. Only two trackways (T6, T11) and 4 isolate footprints crosses the others (Figure 3). From the ripple-marks indicate that T6 probably walked to the river (T6 is 60 cm long and it's direction is 40 NE) and that T11 probably walked from the river (T11 is 165 cm long and it's direction is 262 SW). 2 isolated footprints are also directed from the river, and 2 footprints are directed to the river. The theropod footprints are 6 cm to 16.1 cm wide and 10 cm to 18 cm long (Table 2). The size and shape of these footprint is similar to small theropod described by Le Loeuff and others (2003). The trackways are quit narrow, with 153° to >180° in pace angulation. The height at the hip varies from 48 cm to 75.1 cm using Thulborn's formula (1989). Speed is varies between 4.5 and 11.6 km/h. The footprints are tridactyl (three digits) with digits II, III and IV (Figure 9). They are mesaxonic, with digits II and IV subequal in length, while digit III is longer than the others. The digits are long and narrow; some footprints shows sharp claw impressions at the tip of digits (T8.6, T8.7, T10.4, T10.5, T10.6, T12.2, T12.3, T13.2, T22.2, and T31.1). The digit III of T2.1 is overlaped by the heel of T1.2 and digit II of T8.1 overlap with T9.1. T14.2 and T15.2 are missing because they were destroyed by the explosive, T20.2 can see only part of the heel. T27.2 is overlaped by the ornithopod footprint no.2 (T23.2). Some theropod footprints show skin impression.

**Comparison of theropod footprints**

Thulborn (1990) referred to theropod following characters: theropods are bipedal gait (left-right). Each footprint are tridactyl, with digits II, III and IV. The digits are long and narrow, with sharp, slender claw marks at the tip. Kuban (1994) referred to the theropod as follows: theropod tracks are typically exhibit relatively long and norrow digit, terminated with sharp, slender claw marks. The posterior ends are typically somewhat V shaped. Theropod track can divided in to two groups are coelurosaurs (small, gracile froms) and carnosaurs (large, robust froms). Coelurosaur tracks often exhibit digits held closely together, and distinct toe pads. The shapes and positions of the pads are useful in identifying particular ichnogenera. But in this footprints we can not found the pad. Carnosaur tracks; the digit marks are often more widely splayed and robust, with less distinct pads. Thus we can refer these footprints to small theropods.

**Description of crocodile footprints**

There are 2 trackways of crocodile (T19 and T26). T.19 is about 2 m far from T.26; they are not parallel, but both crosses the theropod trackways. They are quadrupedal gait, with manus and pes (Figure 10).The trackways T19 is 107 cm long and T26 is 95 cm long and there is no evidence for any tail drag-mark. Footprints are small and not well preserved. In the best preserved the prints are composed of 5 digits in the manus (T19.3) and 4 digits in the pes (T19.6, T26.2, T26.4, T26.5, and T26.6). Footprints are longer than wide, being 4.77 cm long and 3.07 cm wide (mean) (Table 2).

The measurement of Foot Width (FW), Foot Length (FL), *pace length, stride length and* calculated the pace angulation are following:

T.19 comprises 12 footprints composed of 7 pes prints and 5 manus prints. Foot Wide is 3.5 cm Foot Length is 4.8 cm (mean). The pace length of pes is 18.1 cm (mean), the stride length of pes is 33.5 cm (mean) and pace angulation of pes is 123° (mean). Pace length of manus is 17.5 cm (mean), the stride length of manus is 34.2 cm (mean) and pace angulation of manus is 157° (mean).

T.26 is made of 11 footprints (6 pes prints and 5 manus prints). Foot Wide is 2.6 cm (mean), Foot Length is 4.6 cm (mean). The pace length of pes is 18.6 cm (mean), the stride length of pes is 36.1 cm (mean) and we calculate the pace angulation of pes at 150° (mean). Pace length of manus is 17.7 cm (mean), stride length of manus is 35.6 cm (mean) and pace angulation of manus is 170° (mean). However, the size and the speed of the

track-maker do not estimate in this time. The footprints can refer to crocodile footprint on the basis of the following characters: quadrupedal gait; manus composed of 5 digits and smaller than the pes, the pes composed of 4 digits.

**Comparison of crocodile footprints**

The crocodile footprints from Haui Dan Chum Site were compared with the foot of modern crocodile as follows: the pes consist of 4 digits; no.1 shorter than the others with claw, no.2 longer than no.1 with claw, no.3 longer than no.2 with claw, no.4 longer than the others with out claw. The manus consist of 5 digits; no.1 shorter than the others with claw, no.2 longer than no.1 with claw, no.3 longer than the others with claw, no.4 shorter than no.3 with out claw, no.5 short and with out claw. The trackway of modern crocodile that we observed contains a tail drag-mark. But trackways of crocodile that we found from Tha U-Thane have no tail drag-mark. The character of modern croccodile referred to http://reptilis.net/crocodylia/moving.html for describing why we can not see the tail trackway : crocodilian can also walk in a near to fully erect stance (high walk) and they can raise their bodies high above the ground. High walks generally don't go very far or very fast, they tend to be used just to get from one bask in spot out to the side. The front legs of crocodylians do still out a bit in a sort of half pushup position, but similary position to that of birds.

**Palaeoecological Study**

According to the direction of trackway, all the theropods did not walk together at the same time. However, the trackway T27 and T30 probably walked togethers, trackway T14 and T12 probably walked togethers, trackway T13 and T10 probably walked togethers. This indicate that the dinosaur had a gregarious behavior.

Previously, footprints of small theropod and probably Deinonychosauria (two-digits) were found on displace slab from this site (Le Loeuff and others, 2003). Thus indicate this locality were habitat in the Early Cretaceous.

The ripple-marks indicate that they walked along some river side. In addition, the claw-marks indicate that they are meat-eaters.

1. Palaeoenvironmental study

The ripple-marks are asymmetry the direction is in WNW (Table 2), about the mud-cracks we have found not on all slab. That means the footprints are on the terrace zone (floodplain). From an ornithopod trackway and a difference in the footprints T23.1, T23.2 are walk in un-firm sediment but T23.3 , T23.4 are walk in firm sediment indicated that an ornithopod dinosaur walk from a river to a riverbank.

2. Taphonomy study

The taphonomy of footprints (the stamped story) suggest that after raining the herd of small theropod dinosaurs are walking along the riverbank and look for food (small animals) while the little crocodiles on the riverbank try to escape from the theropod to go to the river. After the theropod gone a small ornithopod walk from the river to riverbank and look for food (some kind of plant) on land. Two trackways (T16, T11) and 4 isolated footprints cross the others, suggesting that they probably walked before or after the other trackways.

3. Systematical study (Table 3)

202 vertebrate footprints were made by three difference kind of animal.

3.1 The biggest were made by a small ornithopod dinosaur (Figure 8)

Footprint size: 12 x 18 cm

Stride length: 170 cm

hip high: 86 cm

Speed: 8 km/h, walking

Diet: plant

3.2 The theropod dinosaurs were emu to ostrich-size (Figure 9)

Footprints size between 6 to 16 cm wide and 10 to 18 cm long

Stride length between 105 and 164 cm

Hip high between 48 and 75 cm

Speed is varies from 4.5 to 11.6 km/h

3.3 Crocodiles (Figure 10)

Footprint size:

Pes from 3.4 x 5.5 cm to 2.6 x 5.1 cm

Manus from 3.6 x 3.7 cm to 2.5 x 2.5 cm

Stride length:

Pes from 33.5 cm to 36 cm

Manus from 34.2 cm to 35.6 cm

Pace angulation:

Pes from 123° to 150°

Manus from 157° to 170°

TABLE 3 Systematic list of vertebrate ichnotaxa from Southeast Asia

| Vertebrate ichnotaxa | Occurrence | Material | Site |
|---|---|---|---|
| Class Reptilia | | | |
| Sup.O. Dinosauria | | | |
| 1. O. Saurischia | Phu Phan F. | | Phu Luang, Loei |
| SubO. Theropoda | | | province. (Buffetaut |
| Carnosaur | | 15 footprints | and others., 1985). |
| 2. O. Ornithischia | | | Hin Lat Pa Chad, Phu |
| SubO. Cerapoda | | | Wiang, Khon Kaen |
| InfraO. Ornithopoda | Phra Wihan F. | 40 footprints (25 pes, | province. (Le Loeuff |
| | | 15 manus) | and others., 2002). |

TABLE 3 (continue)

| Vertebrate ichnotaxa | Occurrence | Material | Site |
|---|---|---|---|
| 3. O. Saurischia | | | |
| SubO. Theropoda | | | Phu Faek, Kalasin province. (Le Loeuff and others., 2002). |
| Carnosaur | Phra Wihan F. | | |
| Small Theropod | | 7 footprints | |
| SubO. Sauropodomorpha | | ? | |
| InfraO. Sauropoda | | 4 footprints (2 pes, 2 manus) | |
| Sauropod | | | |
| 4. O. Ornithschia | Grès supérieurs F. | | Muong Phalane, Savannakhet province (Lao). (Allain and others., 1997). |
| SubO. Cerapoda | | | |
| InfraO. Ornithopoda | | 15 footprints | |
| O. Saurischia | | | |
| SubO. Theropoda | | 38 footprints | |
| SubO. Sauropodomorpha | | | |
| InfraO. Sauropoda | | 8 footprints | |
| 5. O. Saurischia | Khok Kruat F. | 39 footprints | Huai Dan Chum Site, Tha U Thane district, Nakhon Phanom province. (Le Loeuff and others., 2003). |
| SubO. Theropoda | | 2 footprints | |
| Small Theropod | | | |
| Deinonychosauria | | | |
| 6. O. Saurischia | | | |
| SubO. Theropoda | Khok Kruat F. | 158 footprints | Huai Dan Chum Site, Tha U Thane district, Nakhon Phanom province (this study). |
| Small Theropod | | | |
| O. Ornithischia | | | |
| SubO. Cerapoda | | 4 footprints | |
| InfraO. Ornithopoda | | | |
| Class Reptilia | | 40 footprints | |
| O. Crocodylia | | | |

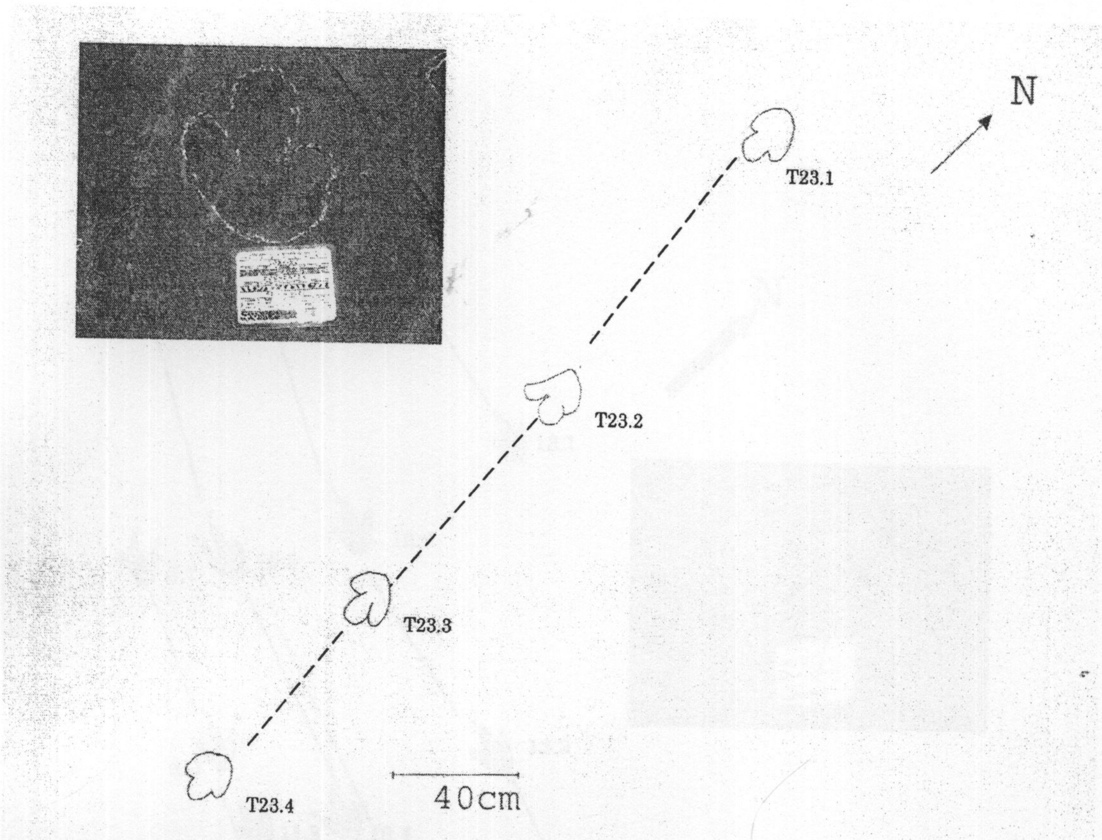



FIGURE 8 Ornithopod footprints, showing the step sequence T23.1-T23.4 and the direction of trackway.

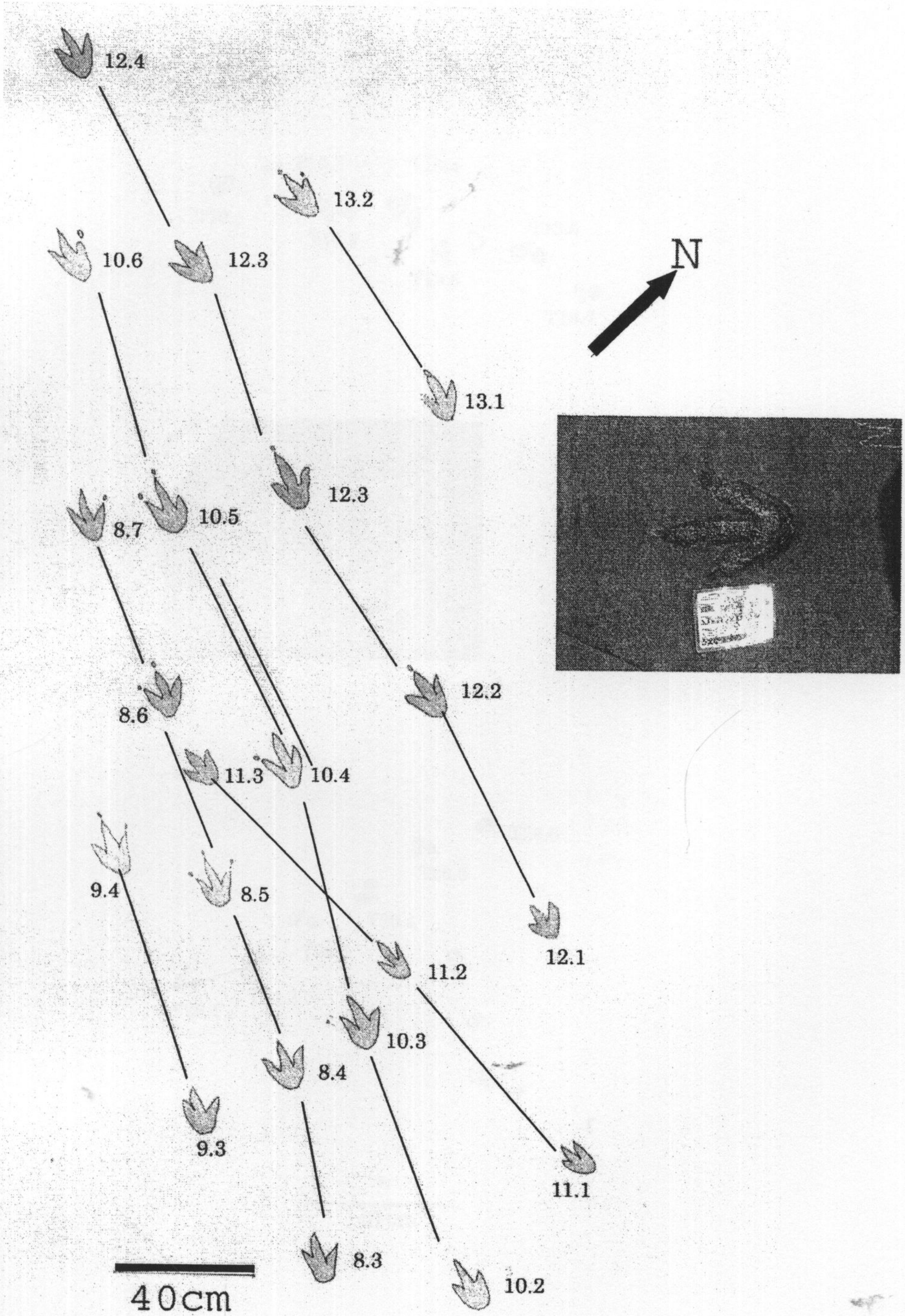



FIGURE 9 Theropod footprints, showing the craw-marks and the direction of trackways.

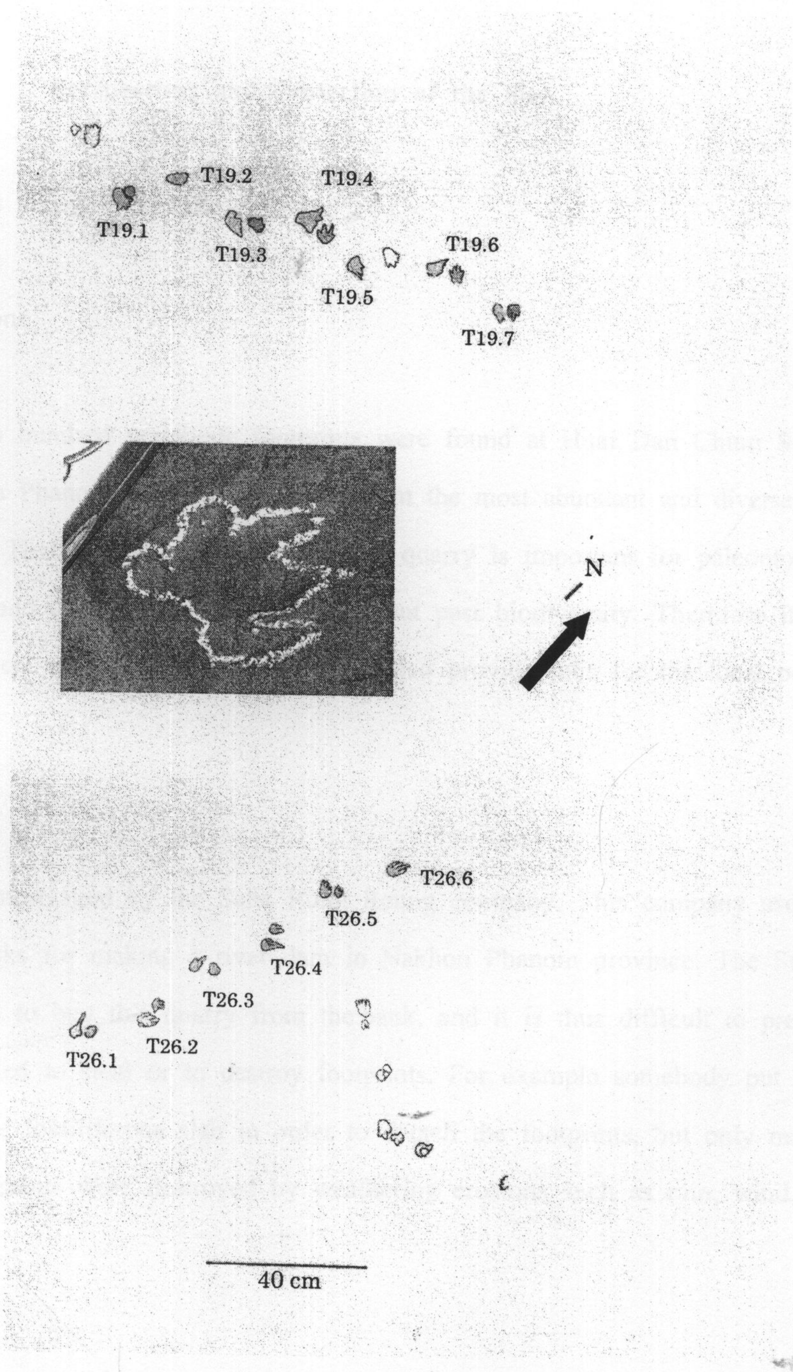



FIGURE 10 Crocodile footprints, showing the direction of crocodile trackways.

# Chapter 5

## Perspectives and Protection of the Site

This chapter is arranged as follows;

1. Problems
2. suggestions

More than two hundred vertebrate footprints were found at Huai Dan Chum Site, Tha U-Thane district, Nakhon Phanom province. They represent the most abundant and diverse in-situ footprints discovered in Thailand. The discovery of this quarry is important for paleontological research and education and also provide information about past biodiversity. Therefore it should be preserved for education and tourism. In addition, it also provide jobs for the local people.

**Problems**

This place is mortgaged by the Saha Rung Reung company. This company uses explosives to extract rocks for making a river dam in Nakhon Phanom province. The State does not have the funds to buy this quarry from the bank, and it is thus difficult to preserve it. Some people have tried to steal or to destroy footprints. For example somebody put a special cement inside the fossiliferous slab in order to detach the footprints, but only managed to break them. The footprints were destroyed by weathering erosions such as rain, wind, and sun.

**Suggestions**

1. All the footprints should be replicated in order to save the scientific information, and then used for the education of the general public.

2. As the State cannot buy the property, there should be a better cooperation between

government organizations in Nakhon Phanom province and the private company that owns the site to prevent these footprints to disappear because of natural (erosion) or non-natural (human) causes.

3. The government should provide adequate budget to buy the quarry, and then to build a Museum. The whole fossiliferous area should also be declared a protected area, where excavations by non-scientists will be prohibited.

# Chapter 6

# Discussion and Conclusion

This chapter is arranged as follows;

1. Discussion
2. Conclusion

## Discussion

202 individuals of vertebrate footprints are organized as followed: 29 trackways (100 footprints) and 58 isolated footprints of small theropods, 1 trackway (4 footprints) of ornithopod, 2 trackways (23 footprints) and 17 isolated footprints of crocodiles (Figure 3). They are in an area of approximately 2.6 x 15 m on the surface of the outcrop. This is the highest density of tracks for any dinosaur track-site in Thailand. Furthermore, the trackways are oriented in four preferred directions: NW, SE, SW and NE.

Most of the theropod trackways consist of parallel trackways oriented NW and show estimated speed ranging from 4.5 to 11.6 km/h (Table 2). From a statistical test about the correlation between the speed and the orientation of the theropod trackways, suggest that all the theropods did not walk together at the same time, because there is no correlation between the speed and the orientation of the trackways (Figure 3). However, if consider the speed, orientation and hip height (Table 2) of the track-makers, it suggests that trackway T27 and T30 probably walked together, trackway T14 and T12 probably walked together, trackway T13 and T10 probably walked together. The ripple marks indicate that they walked along some riverside, probably looking for small animal or for drinking water. Furthermore the claw-marks indicate that they probably were meat-eater. Two trackways (T6, T11) and 4 isolated footprints cross the others, suggesting that they probably walked before or after the others trackways. Previously Le Loeuff and others have found footprints of small theropods and probably Deinonychosauria (two digits) from the same site (Le Loeuff and others, 2003 : 83-91). They were on several large displaced slabs. All trackways present only two successive prints, the speed can not be calculated, only the height at the hip. At present we have found the highest density of tracks in Thailand and these tracks represent more than one species according to the morphology of footprints. They are all tridactyl tracks, indicating that they do not belong to Deinonychosauria.

The onithopod trackway (T.23) is oriented SE and the speed is 8 km/h (Table 2). The footprint no.2 of trackway T.23 overlaps the theropod footprint no.2 of trackway T.6 suggesting that the ornithopod came after the theropod. According to the direction of the ripple-marks and the fact that the footprints no.1 is deeper than no.2, no.3, no.4 respectively, the ornithopod dinosaur probably walked perpendicular to the river. Although many ornithopod bones and teeth have been recorded from the Khok Kruat Formation (Table 1), this is the first discovery ornithopod footprints in this formation.

According to the direction of the ripple marks, the crocodiles walked toward the river. As there are no tail drag-mark like in the modern crocodile that author videotaped and pictured (at Samut Prakan farm, on 3 February 2005 and http://reptilis.net/crocodylia/moving.html), it can be inferred that they used a high walk. However, the trackways show clear pes and manus imprints indicating that the track-makers were quadrupedal animals. The similarities between the pace length and stride length in the two trackways, indicate that they were produced by a single individual or at least by individuals of a similar size. The manus trackway is wider than the pes trackway which has a higher pace angulation. Although many crocodile bones and teeth have been found from the Khok Kruat Formation (Table 1), this is the first time for crocodile footprints to be found in this formation, as well as in Indochina.

**Conclusion**

1. According to their morphology, the vertebrate footprints were identified in to three groups; ornithopod, theropod and crocodiles.

2. From their direction, the theropods were probably walking in small herds following a riverbank, while ornithopod and crocodiles had different direction.

3. The presence of ripple-marks indicates that the theropods were walking along riverbank. The mud-cracks indicates that the locality had semi-arid to arid climate in the Early Cretaceous.

4. This site is a very interesting discovery, yielding a wealth of knowledge about Cretaceous Thai faunas. Thus we should protect this site in order to protect the very important data it possesses and to serve for the education of the public in Thailand. Furthermore, this site should develop for tourist purposes as part of an Eco-tourism program. It will also help pushing up people to be aware

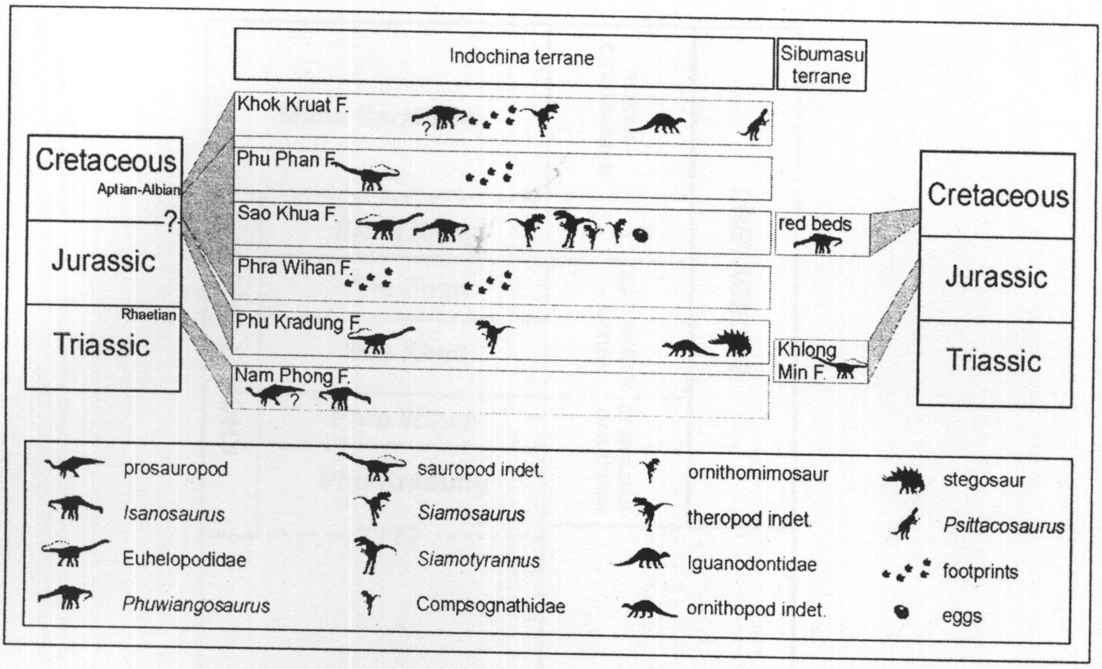



FIGURE 11 The distribution of dinosaurs in the Mesozoic of Thailand.

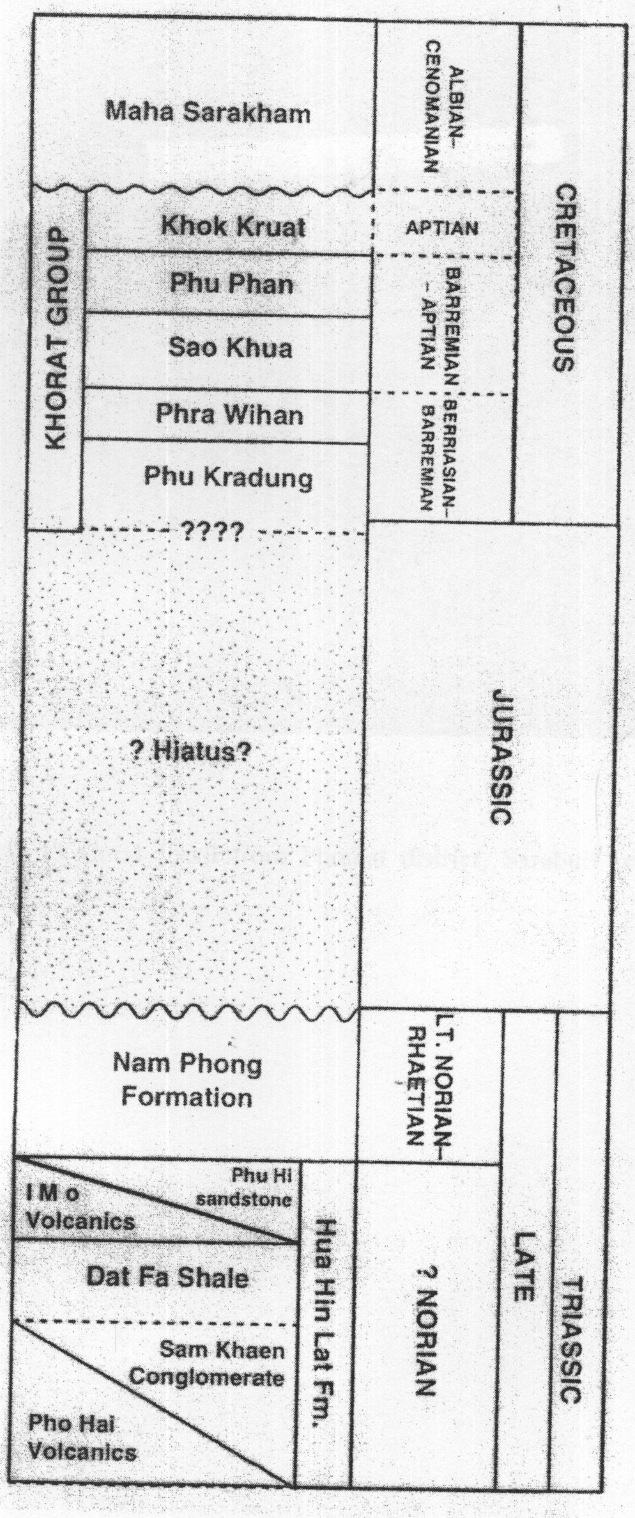



FIGURE 12 The chronostratigraphy of the Khorat Group. Dashed line indicates exact position of boundary is uncertain. Wavy line indicates unconformity.

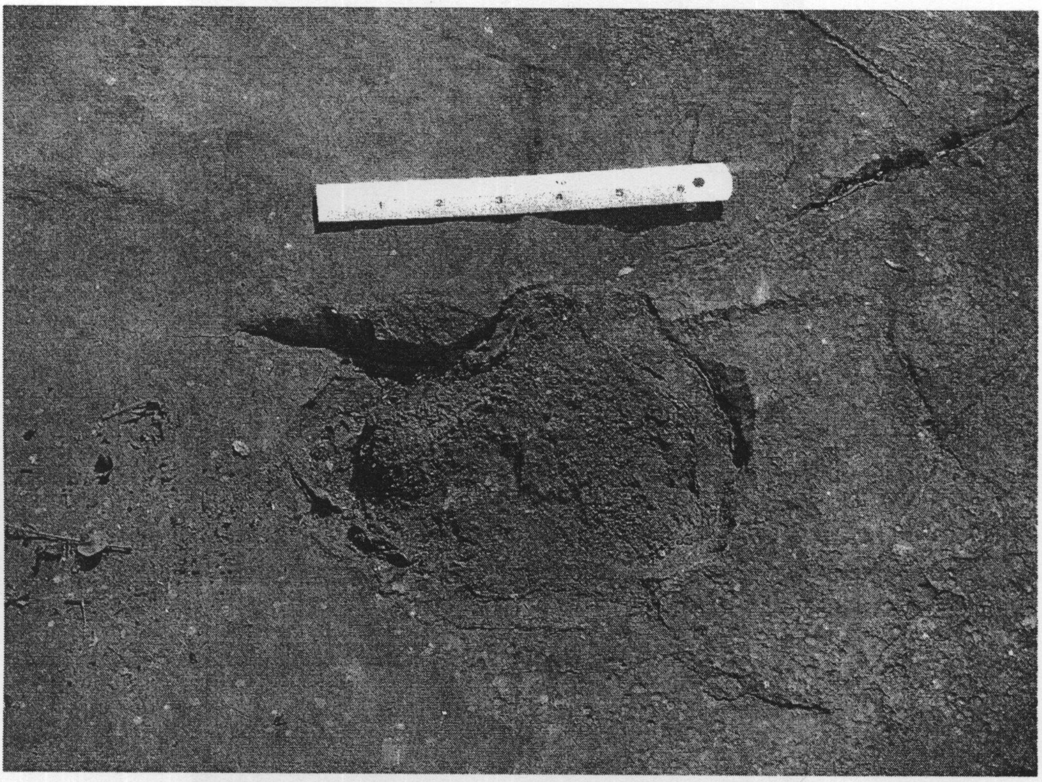


FIGURE 13 Coral fossil from Phrabat district, Saraburi province.

FIGURE 14 Large theropod footprint from Phu Luang Wildlife Sanctuary, Loei province.

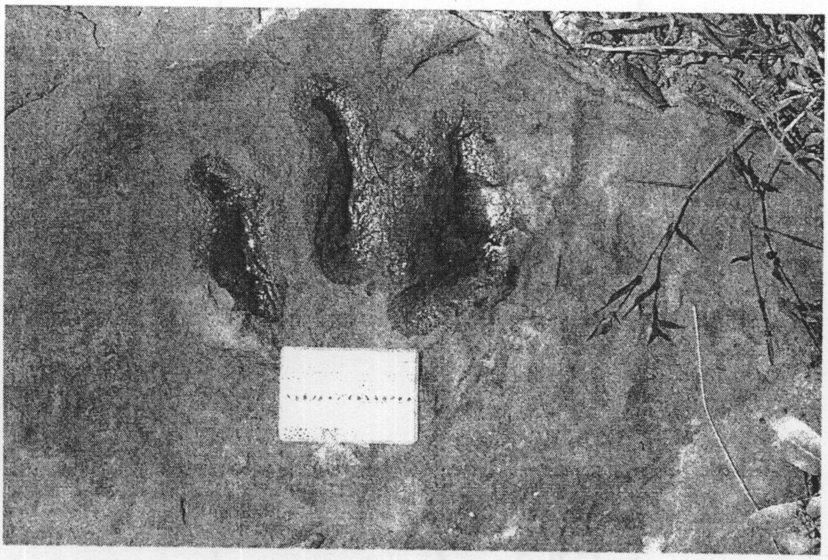


FIGURE 15 Large theropod footprint from Phu Wiang, Khon Kaen province.

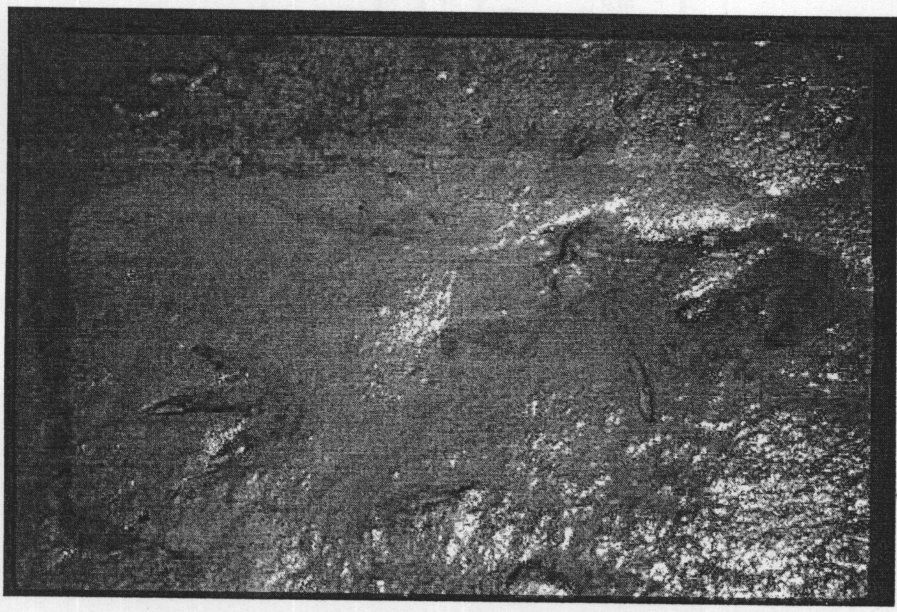


FIGURE 16 Small theropod footprints from Phu Wiang, Khon Kaen province.

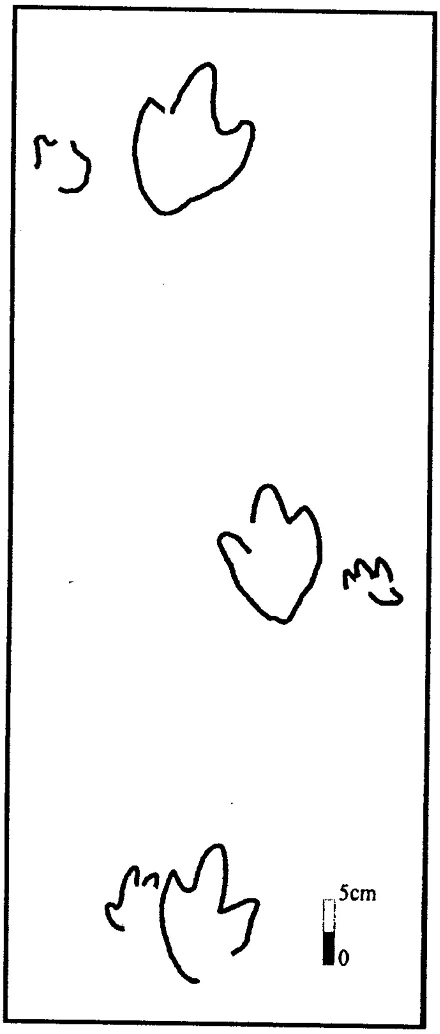



FIGURE 17 Small ornithischian footprints from Phu Wiang, Khon Kaen province.

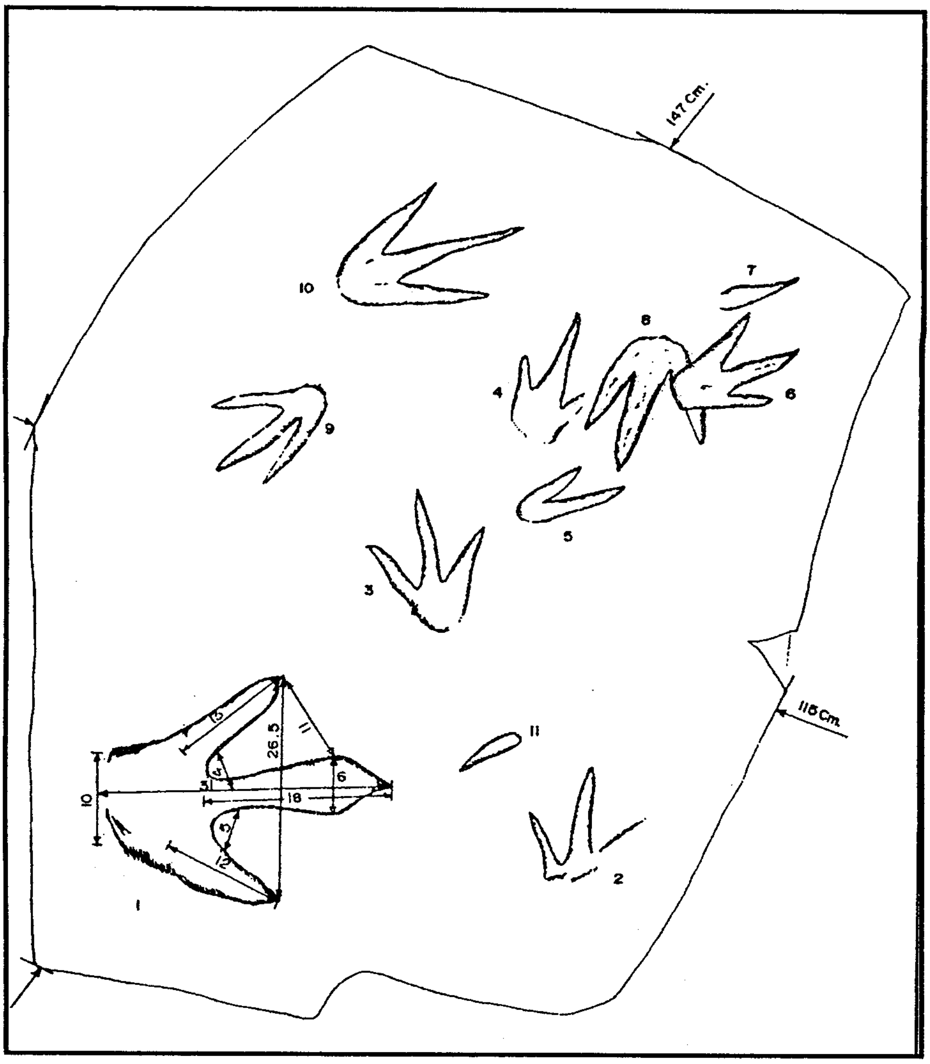



FIGURE 18 Large and small theropod footprints at Khao Yai National Park.

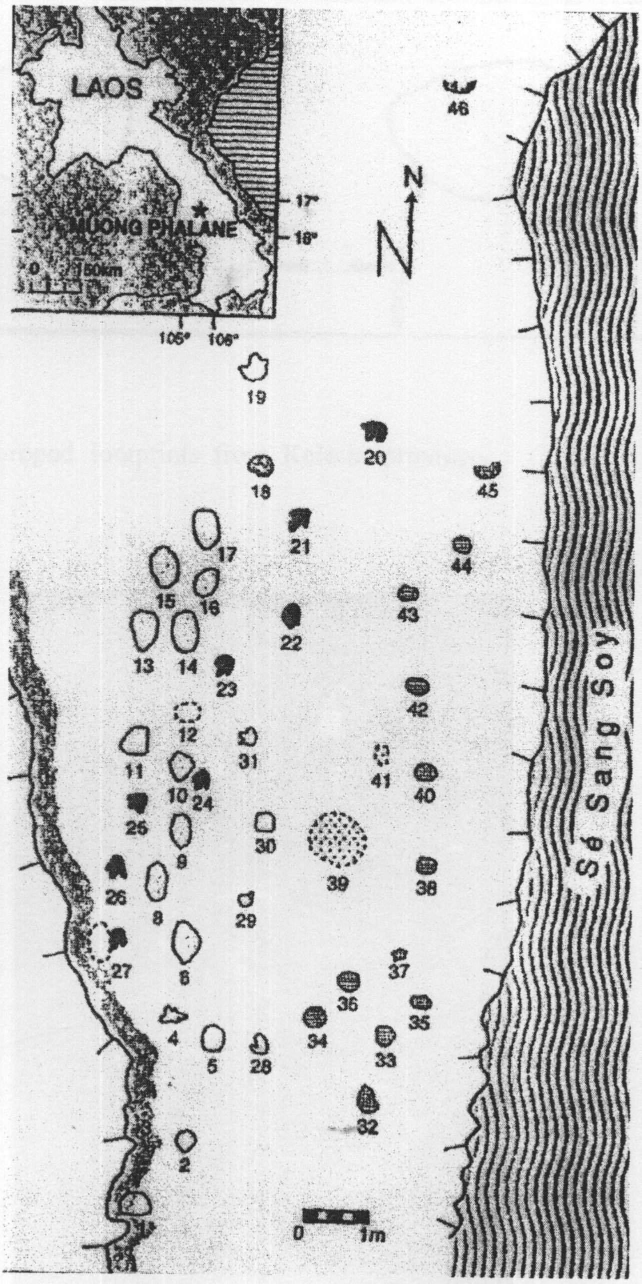
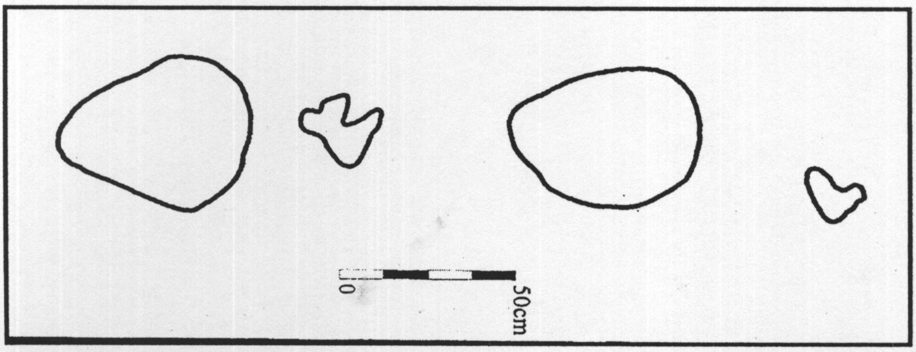



FIGURE 19 Dinosaur footprints in Muong Phalane, Savannakhet province (Laos).




FIGURES 20 Sauropod footprints from Kalasin province.

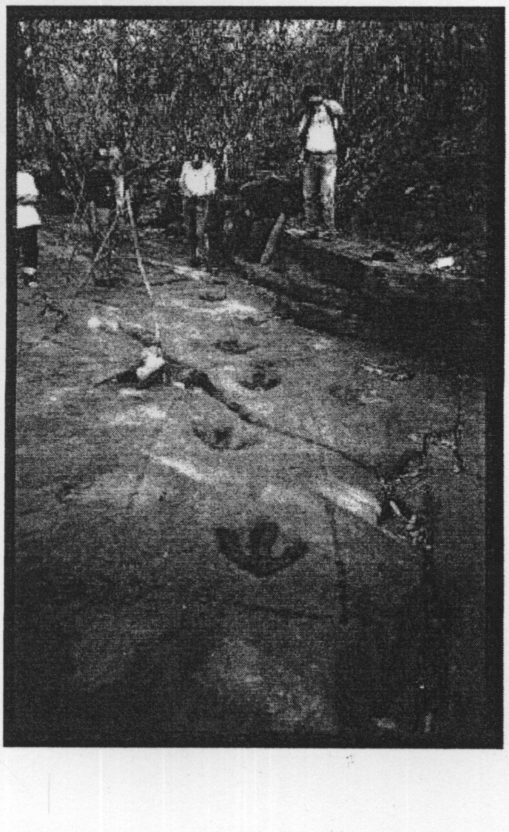


FIGURE 21 Large theropod footprints from Kalasin province.

FIGURE 22 Theropod footprint from Phu Kao, Nong Bua Lam Phu province.

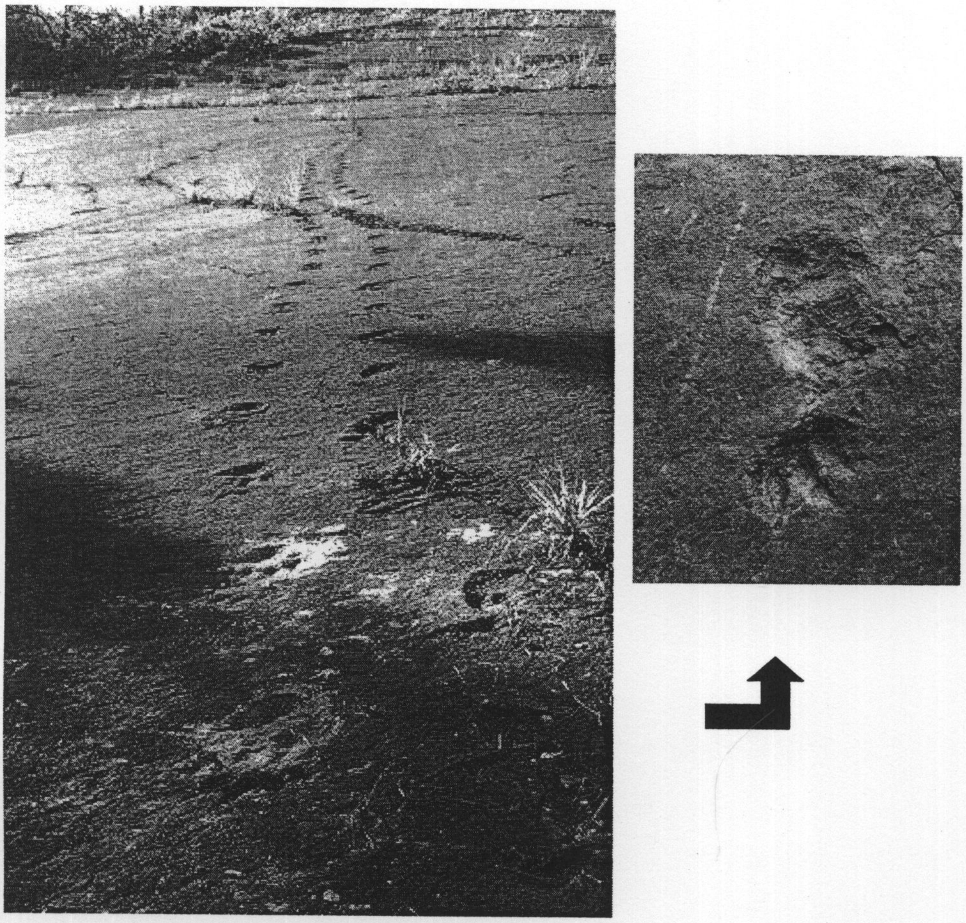


FIGURE 23 Quadrupedal animal from Tad Huai Nam Yai, Nam Naow distict, Petchaboon province.

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# VITA

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| | |
|---|---|
| NAME | Miss Tida Saenyamoon |
| DATE OF BIRTH | June 6, 1980 |
| PLACE OF BIRTH | Roi-Ed, Thailand |
| ADDRESS | 123 Moo 13, Amphoe Si Somdet, Roi-Ed 45260, Thailand. |
| POSITION | Geologist |
| WORK PLACE | Department of Mineral Resources |
| EDUCATION | |
| 1999 | Matthayomsuksa 6, Lau Law Wittayakom School, Si Somdet, Roi-Ed. |
| 2003 | Bachelor of Science degree (B.Sc.) in Biology, Mahasarakham University, Maha Sarakham. |
| 2006 | Master of Science degree (M.Sc.) in Biology, Mahasarakham University, Maha Sarakham. |