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Taxonomic Identification of Equid Fossils from the Khorat Sand pits

Miss Siriwarin Ninputsa

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A Report in Partial Fulfillment of the Requirement

for the Degree of Bachelor Science

Department of Geology

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นางสาวสิริวารินทร์ นิลพุทรา

5732754923

โครงงานนี้เป็นส่วนหนึ่งของการศึกษาตามหลักสูตรปริญญา
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Title	**Taxonomic Identification of Equid Fossils from the Khorat Sand pits**
Researcher	Miss Siriwarin Ninputsa
Department	Geology
Advisor	Dr. Kantapon Suraprasit

Accepted by Department of Geology, Faculty of Science, Chulalongkorn Univisity in Partial Fulfillment of the Requirement for the Bachelor's Degree

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(Dr. Kantapon Suraprasit)

Senior Project Advisor

การระบุชนิดทางอนุกรมวิธานของซากดึกดำบรรพ์วงศ์ม้าที่ค้นพบจากบ่อทรายโคราช

ผู้จัดทำโครงการ น.ส. สิริวารินทร์ นิลพุทรา

ที่ปรึกษาโครงการ อ.ดร. กันตภณ สุระประสิทธิ์

ภาควิชาธรณีวิทยา คณะวิทยาศาสตร์ จุฬาลงกรณ์มหาวิทยาลัย

บทคัดย่อ

จากการเข้าศึกษาซากดึกดำบรรพ์เมื่อ เดือน กรกฎาคม พ.ศ. 2560 ในบริเวณบ่อทราย อำเภอพิมาย และ อำเภอเฉลิมพระเกียรติ จังหวัดนครราชสีมา ทีมนักบรรพชีวินวิทยาจากจุฬาลงกรณ์มหาวิทยาลัยและกรมทรัพยากรธรณี ได้ค้นพบชิ้นส่วนชองซากดึกดำบรรพ์ฟันม้าทั้งหมด 16 ชิ้น ประกอบไปด้วย ฟันเดี่ยวจำนวน 6 ซี่ แบ่งเป็นฟันล่าง 2 ซี่ ฟันบน 4 ซี่ และ กรามจำนวน 10 ชิ้น แบ่งเป็นกรามล่าง 9 ชิ้น และกรามบน 1 ชิ้น จากการศึกษาทางอนุกรมวิธานเพื่อระบุสกุลของตัวอย่างเหล่านี้ โดยใช้วิธีการเปรียบเทียบขนาดและลักษณะของฟันกับผลการวิจัยที่เคยมีมา โดยการเปรียบเทียบลักษณะของหน้าฟันจะต้องทำในระดับความสูงของฟันเดียวกัน เนื่องจากฟันม้านั้นมีหน้าฟันที่มีการเปลี่ยนแปลงไปตามระดับการสึก เพื่อไม่เป็นการทำลายตัวอย่างจึงใช้วิธีการวิเคราะห์ภาพหน้าตัดฟันในแต่ละระดับการสึกจากผลของเครื่องเอกซเรย์คอมพิวเตอร์ (Computerized Tomography Scan, CT Scan) และนำภาพหน้าตัดในแต่ละระดับความสูงของฟันเหล่านั้นไปเปรียบเทียบกับฟันจากงานวิจัยอื่นๆที่ได้รับการตีพิมพ์ออกมาก่อนหน้าที่ระดับความสูงเดียวกัน ซึ่งทำให้การเปรียบเทียบนั้นมีความถูกต้องมากขึ้น ผลจากการศึกษาพบว่า ขนาดของฟันของตัวอย่างทั้งหมดอยู่ในช่วงขนาดปานกลาง โดยสามารถแบ่งออกได้เป็น 2 กลุ่ม ได้แก่ ตัวอย่างที่มีลักษณะคล้ายคลึงกับ *Hipparion* cf. *chiai* ซึ่งมีลักษณะของปุ่มโปรโตโคน (Protocone) ที่เป็นรูปเลนส์ ปุ่มไฮโปรโคน (Hyprocone) มีลักษณะเป็นเหลี่ยมเล็กน้อย และลักษณะรอยหยักในวงภายในฟันไม่ซับซ้อนมากนัก นอกจากนั้นยังมีภาพหน้าตัดของฟันล่างในแต่ละช่วงทีมีการเปลี่ยนแปลงคล้ายคลึงกัน ซึ่งการกระจายตัวของสิ่งมีชีวิตกลุ่มนี้อยู่ในบริเวณตอนกลางของประเทศจีนและอีกหนึ่งกลุ่มได้แก่ *Hipparion* sp. ที่มีขนาดเล็กกว่า และมีปุ่มโปรโตโคน (Protocone) ที่มีลักษณะกลมกว่า รอยหยักในวงภายในของฟันไม่ซับซ้อน ในฟันล่างปุ่มฟันที่มีลักษณะคล้ายเงื่อนผูกกันไว้ (double knot) มีลักษณะมนซึ่งแตกต่างจาก *Hipparion* ที่ค้นพบในปากีสถานและอินเดียที่ค่อนข้างเป็นเหลี่ยมที่ชัดเจน แต่คล้ายคลึงกับ *Hipparion* ส่วนมากที่พบในประเทศจีน สภาพแวดล้อมโบราณของบริเวณบ่อทรายนี้พบว่าเป็นพื้นที่ป่าและอายุของสิ่งมีชีวิตสกุลนี้อยู่ในช่วงสมัยไมโอซีนตอนปลาย

Taxonomic Identification of Equid Fossils from the Khorat Sand pits

Researcher: Miss Siriwarin Ninputsa

Advisor: Dr. Kantapon Suraprasit

Department of Geology, Faculty of Science, Chulalongkorn University

Abstract

In July, 2017, fossils from Phimai and Chalermprekiet sand pits (Nakhon Ratchasima province) were collected by paleontologists from Chulalongkorn University cooperated with the Department of Mineral Resources (DMR). The paleontological excavation has yielded 16 specimens of equid fossils consisting of 6 isolated teeth (4 upper and 2 lower teeth, 1 maxilla, and 9 mandibles. We identify here these equid fossils at the genus level. In order to understand the morphological changes through wear, we use a Computerized Tomography Scan (CT-scan) method to observe occlusal sections at the different high levels of tooth crowns because the cusps of teeth have morphologically changed in relation to different wear stages through the crown height of fossil equids. As a result of the study, we identify equid specimens as belonging to *Hipparion* cf. *chiai* and *Hipparion* sp. The former species is characterized by elongated and sub angular protocones, sub-angular shapes of hypocones, and short enamel plications of pre- and postfossettes. In addition, the morphological patterns of occlusal surface changes in each stages of wear in lower cheek teeth are similar to those of *Hipparion* cf. *chiai* (Li et al., 2017). *Hipparion* cf. *chiai* is widely distributed in the middle region of China and smaller-sized *Hipparion* sp. that has a rounded protocone and incomplete plication in pre- and posfossettes. Double knot in lower teeth of *Hipparion* sp. differs from *Hipparion* in Pakistan and India, but mostly similar to *Hipparion* in China. According to the presence of these equids, the paleoenvironments of Khorat sand pits corresponded to a forest and the age of this genus is thus considered to be the Late Miocene.

Keywords: *Hipparion,* equid fossil, protocone, Khorat sand pits and Computerized Tomography Scan (CT-scan)

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CHAPTER 1

INTRODUCTION

1.1 Rationale

Family Equidae, horses and their relatives, has a complex evolution through geologic time. The study of evolution of horses helps us understand their adaptation to the past environments. Fossil equid were widely distributed in the Old World continents, especially in Eurasia (Deng et al., 2016). The equid fossils were reported in many places in China such as the Late Miocene of Inner Mongolia (Deng et al. 2015). In the Late Miocene of the Linxia Basin, seven species of *Hipparion*: *H. dongxiangense*, *H. weihoense*, *H. chiai, H. dermatorhinum, H. platyodus, H. coelophyes,* and *H. ippidiodus,* were reported in the Liushu Formation (Deng et al., 2013). Two species, *H. fortenae* and *H. hippidious* were described from the Late Miocene of Gaojishan (Li et al., 2017). In the Lamagou fauna of Fugu, Shaanxi Province, China, Li et al. (2017) reported the dental ontogeny of Late Miocene *H.* cf. *chiai*. Furthermore, this genus was recorded in Turkey (Kaya and Forsten, 1998), France (Macfadden, 1980), Pakistan (Iqbal et al., 2009), North America (Macfadden, 1980) and Spain (Pesquero et al., 2007) during the Late Miocene. However, the equid fossils have never been documented from SE-Asian regions.

The paleontological excavation of several sand pits in Phimai and Chalermprakiat district, Nakhon Ratchasima province, has been conducted by paleontologists from Chulalongkorn University and Department of Mineral Resources (DMR) in July, 2017. Some sand pits have yielded numerous fossil plants and animal remains. From the preliminary taxonomic identification in the field, some taxa of proboscideans, rhinoceroses, suids, deer and horses were found. Consequently, we took this opportunity to taxonomically describe equid fossils recovered from the Phimai and Chalermprakiat sand pits in order to better understand the evolution of equids in Thailand.

1.2 Objective

To identify equid fossils at the genus level in the sand pits, Phimai and Chalermprakiat district, Nakhon Ratchasima province.

1.3 Scope of the study

This study will be focused on the teeth of equid fossils from the Khorat sand pits in Phimai and Chalermprakiat district, Nakhon Ratchasima province. All specimens will be identified at the genus level.

1.4 Expected results

1. Taxonomic status of equid fossils at the genus level.
2. More accurate age of the Phimai and Chalermprakiat fauna.
3. Paleoenvironments of the study area.

1.5 Study areas

The study areas are located in Phimai (Northeastern point) and Chalermprakiat (Southwestern point) district, Nakhon Ratchasima province, northeastern part of Thailand. The Phimai and Chalermprakiat sand pits are up to about 200 x 200 m. (Fig. 1.2) These two sand pits are positioned on Quaternary alluvial sediments according to DMR (2007). (Fig. 1.1)

The uppermost units in stratigraphic columns are covered with soils and laterites (Fig. 1.3–1.4). In the Chalermprakiat sand pit equid fossils are found from medium sand with cross bedding and wood fragments layer. In the Phimai sand pit equid fossils are found from the layer of sandy clay.

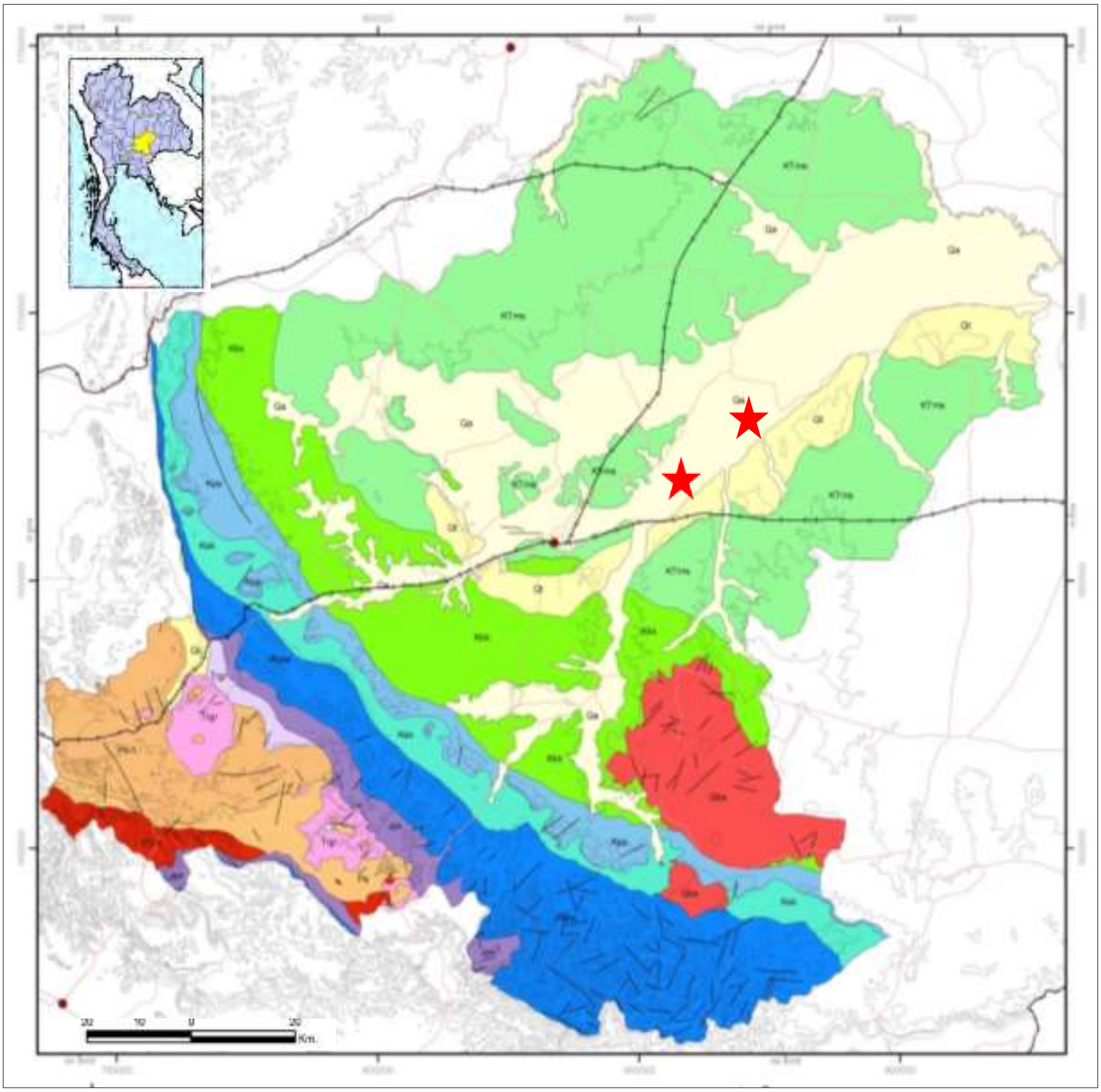


Figure 1.1 Geological map of Nakhon Ratchasima province; Phimai sand pit = Northeastern point; Chalermprakiat sand pit = Southwestern point (DMR, 2007)

Figure 1.2 The Google Earth satellite images showing (A) Phimai sand pit (B) Chalermprakiat sand pit

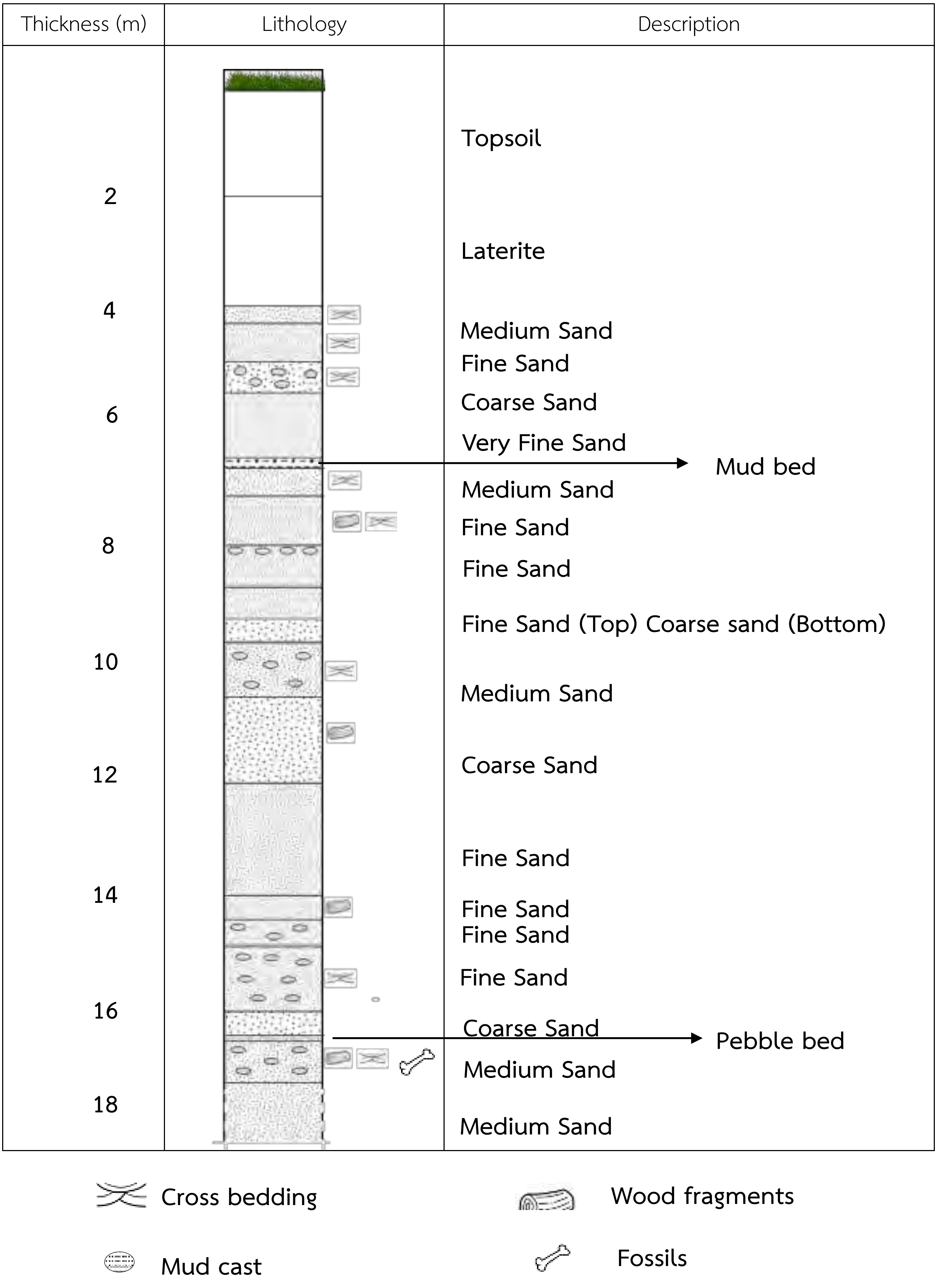


Figure 1.3 The stratigraphic column of Chalermprakiat sand pit

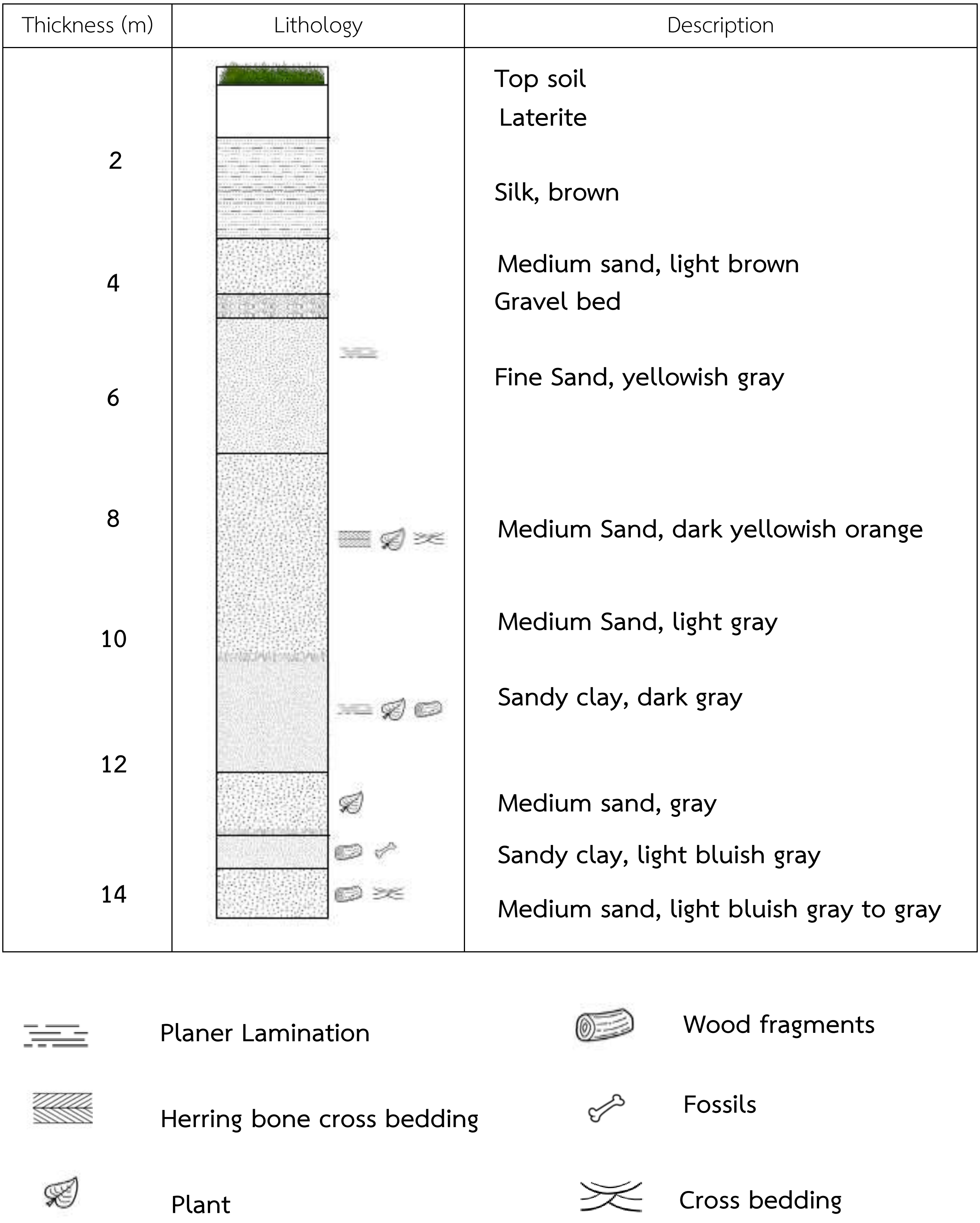


Figure 1.4 The stratigraphic column of Phimai sand pit

CHAPTER 2

LITERATUR REVIEWS

Hipparionine or *Hipparion* also called “horse” is characterized by isolated protocone on upper premolars and molars teeth and tridactyl feet (Bernor et al., 1996).

Hipparion is like the modern horses that bear hypsodont or high ratio crown teeth. There is no longer existing genus of Tertiary mammals associated with the three-toed horse that have on each foot a little lateral hoof on each side of the main central one in each foot. *Hipparion* is considered to be one of ancestral genera of the horse family, living in North America, Asia, Europe and Africa during the Miocene to Pleistocene. (Pang L.B., 2011)

2.1 Paleobiogeography and Chronological records

The “Old World” is referred to Africa, Asia and Europe regarded collectively as the part of the world before contact with the Americas and Oceania (New World). Both of continents have different evolution because the breakup of North and South America during Mesozoic has been affected the global climatic and oceanic regimes as well as the regional climates of the individual continents. Populations became isolated or were brought into contact with other populations, leading to evolutionary changes in the biota. (Wicander and Monroe, 2010) So *Hipparion* was widely distributed in the Old World continents, especially in Eurasia (Deng et al., 2016).

Deng et al. (2013) made a biostratigraphical range of Neogene mammalian fossils from the Linxia basin. All species of *Hipparion* are distributed in the Late Miocene–Early Pliocene. (Fig 2.1)

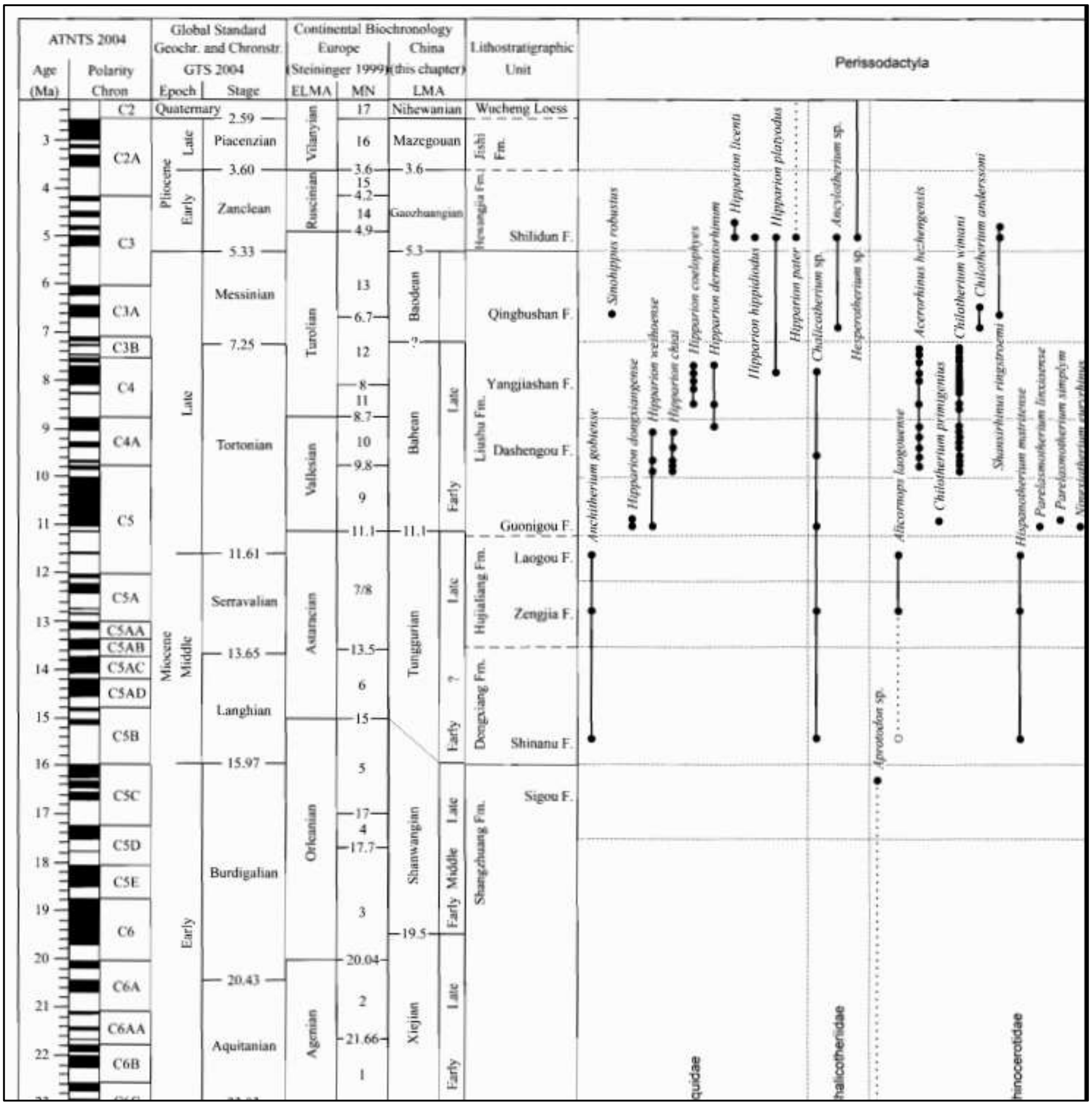


Figure 2.1 Biostratigraphical range of Neogene mammalian fossils from the Linxia basin. (Deng et al.,2013)

Deng et al. (2015) reported that *Hipparion tchikoicum* from Baogeda Ula in Abag, Inner Mongolia, China during the Late Miocene (6Ma).

Li et al. (2017) discovered that Hipparionine's skulls including 28 pieces and mandible fossils with an absolute age of about 7.4 Ma from Fugu, Shaanxi, Northwestern China (belonging to *Hipparion chiai* and *Hipparion* cf. *coelophyes*) show an age distribution in a continual development sequence. Four isolated upper cheek teeth and two lower cheek teeth were cut into pieces in the traditional manner for examination and for making summary of the ontogenetic laws of upper and lower cheek teeth (Table 2.1 and 2.2)

Table 2.1 The main ontogenetic laws of upper cheek teeth

Wear Stage	Opening of posterior wall of the postfossette	Degree of Plications	Protocone	Hypocone	Paracone and Metacone
Early wear I	N	arisen	small spindle	slender, obvious HC	P2/P3/P4/M3 is crescent-shaped, M1/M2 is triangular
Early wear II	N	developed	broaden and round	broaden, weaken HC	P2/P3 is trapezoidal, P4/M1 is triangular M2/M3 is half-round
Early wear III	P2	immobile	elongate	elongate, weaken HC	P2 is trapezoidal, P3/P4/M1/M2 is triangular, M3 is half-round
Early wear IV	P2 and P3	immobile	immobile	shorten	P2 is trapezoidal, P3 is rectangular P4/M1/M2/M3 is half-round
Early wear V	some of P2	immobile	shorten, similar to Early wear II	HC faded away	P2 is trapezoidal, P3/P4/M1/M2/M3 is half-round
Middle wear	N	weaken	widen to oval	immobile	P2 is trapezoidal, P3/P4/M1/M2/M3 is half-round or square
Late wear	N	weaken	more wider oval	shorten	P2 is trapezoidal, P3/P4/M1/M2/M3 is square

Table 2.2 The main ontogenetic laws of lower cheek teeth

Wear Stage	Degree of Plications	Protostylid	Depth of Ectoflexid in p3/p4	Depth of Ectoflexid in Molars	Constriction of Entoconid	Hypoconulid
Early wear II	developed	appeared from p3 to m2 in sequence, isolated	half	half	from obvious to weaken in m1/m2	developed
Early wear III	weaken	united in m1	p3 half, p4 more than half	completely	p2 obvious, p3/p4/m1/m2 weaken	developed
Early wear IV	weaken	united in p3	p3 more than half, p4 completely	completely	p2 weaken, p3/p4/m1/m2 gone	squeezed
Early wear V	N	appeared in m3	more than half or completely	completely	N	weaken
Late wear	N	united from p3 to m3	completely	completely	N	gone

Li et al. (2017) reported that Two *Hipparion* species, *H. forstenae* and *H. hippidiodus* from Gaojiashan locality in the Linxia Basin, Gansu, China. *Hipparion* from Gaojiashan has lower cheek teeth that bear deep ectoflexids, and after comparisons to other Chinese *Hipparion* fossils with deep ectoflexids, the mandibles with deep ectoflexids on the lower premolars suggest their attributions to *H. forstenae*.

2.2 Computed tomography (CT-scan)

CT or CAT scans is special digital tests that produce cross-section images of the body using X-rays and a computer. The CT-scan method is also referred as computerized axial tomography. This technique has been widely used in the field of paleontology. For example, Suraprasit et al. (2011) used the CT-scan technique to analyze the virtual occlusal surface changes from wear in fossil castorids, allowing an easier comparison to related species of *Steneofiber* cheek teeth without destroying.

2.3 Geology of Khorat Plateau

The Khorat plateau is located the Northeastern part of Thailand covering about 150,000 square kilometers. The Anticlinorium Phu Phan range from northwest-southeast divides the Khorat plateau into two basins: the Sakon Nakon Basin and the Khorat Basin. The thick Red beds consist of sandstones, siltstones, claystones, and conglomerates that have been transported by river during the Mesozoic. The lithologic description of the Khorat Group can be divided into nine formation including Huai Hin Lat, Nam Phong, Phu Kradung, Pha Wihan, Sao Khua, Phu Phan, Khok Kruat, Mahasarakham and Phu Tok on top. (Booth and Sattayarak, 2011) (Fig 2)

Tha Chang Sand Pits

The location of Tha Chang sand pits is close to the Mun River at the Nakhon Ratchasima Province. The fossils are found in the layers of unconsolidated sandstones, mudstones and conglomerate (Chaimanee et al., 2004; Hanta et al., 2008)

These sand pits are situated near the Mun River and are characterized by fluvial depositional environments. The age of the sand pits has been estimated around 7.4-5.9 Ma based on the associated mammal fauna (Chaimanee et al., 2006). The geological ages were spitted into the Middle Miocene, Late Miocene and Early Pleistocene according to the biostratigraphy correlation and the age of fossil apes from Thailand. (Nakaya et al., 2003; Saegusa et al., 2005)

The ages of sand pits are 0.8 Ma (Mid-Pleistocene). The sand pits were deposited by high energy with tektites event (Howard et .2003; Haines et al .2004). The interpretation of from seveal palynostratigraphical studies divides the section into two horizons. The lower horizon is around 20-25 m deep (Pliocene /Pleistocene) and the upper horizon is around 5-10 m deep (Pleistocene/Holocene) (Bunchalee, 2005) Moreover, there is high probability of reworking fossil in this area. (Putthapiban et al., 2012)

The floral assemblage comprises tree trunks identified as cf. *Corypha* (palm), cf. *Terminalia*, cf. *Parashorea* and *Dipterocarps.* Large mammals including proboscideans (*Deinotherium indicum*, *Gomphotherium* sp., *Stegolophodon* sp. and primitive *Stegodon*), anthracotheres, pigs (*Hippopotamodon sivalensis*), rhinocerotids (*Chilotherium palaeosinense*, *Brachypotherium perimense* and *Alicornops complanatum*), bovids, and giraffids (*Sivatherium* sp.) (Chaimanee et al., 2004)

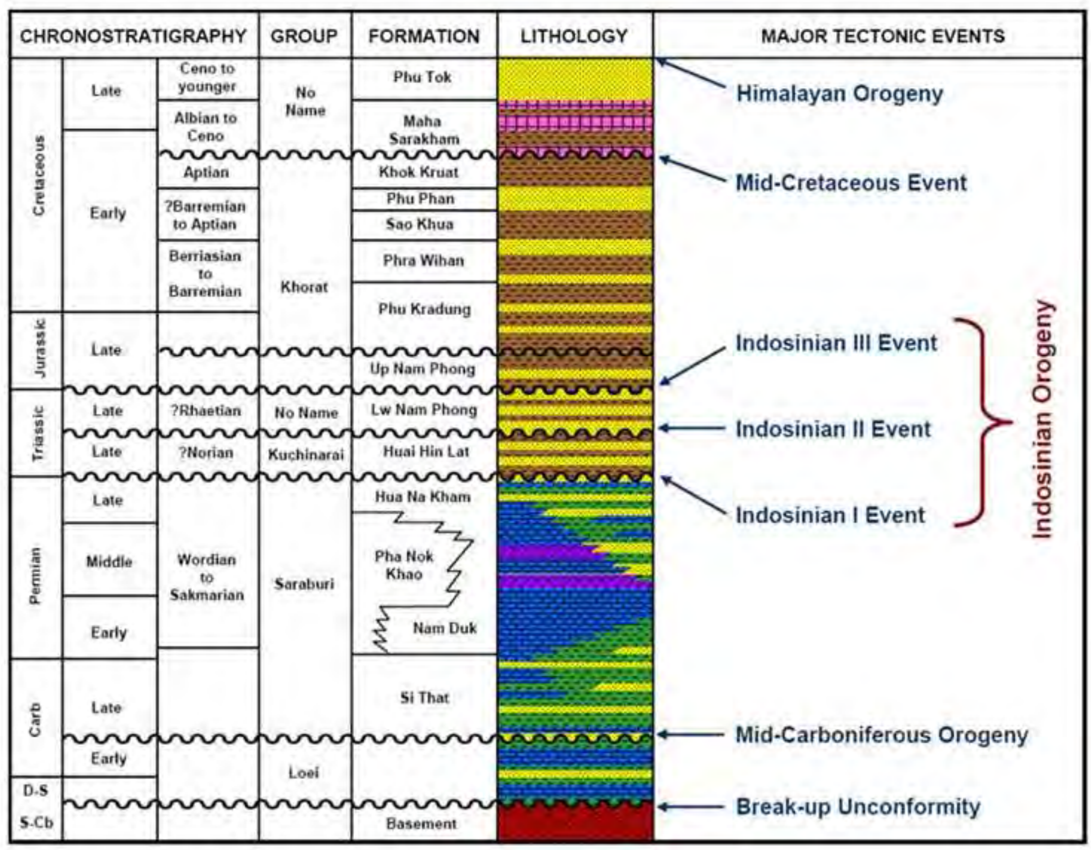


Figure 2.2 Stratigraphic column of the Khorat group with major tectonic events (Booth and sattayarak, 2011)

CHAPTER 3

METHODOLOGY

1. Stratigraphic columns of the Phimai and Chalermprakiat sand pits have been made.

2. Fossil specimens were sent to the Department of radiology, Faculty of medicine, Chulalongkorn University for performing computed tomography (CT-scan) analysis of the specimens.

3. Cross-section data from CT-scan were analyzed along the different height of teeth because the occlusal surface has changed from wear.

4. Morphological characters of cheek teeth were described, following the nomenclature of fossil equids proposed by Evander (2004).

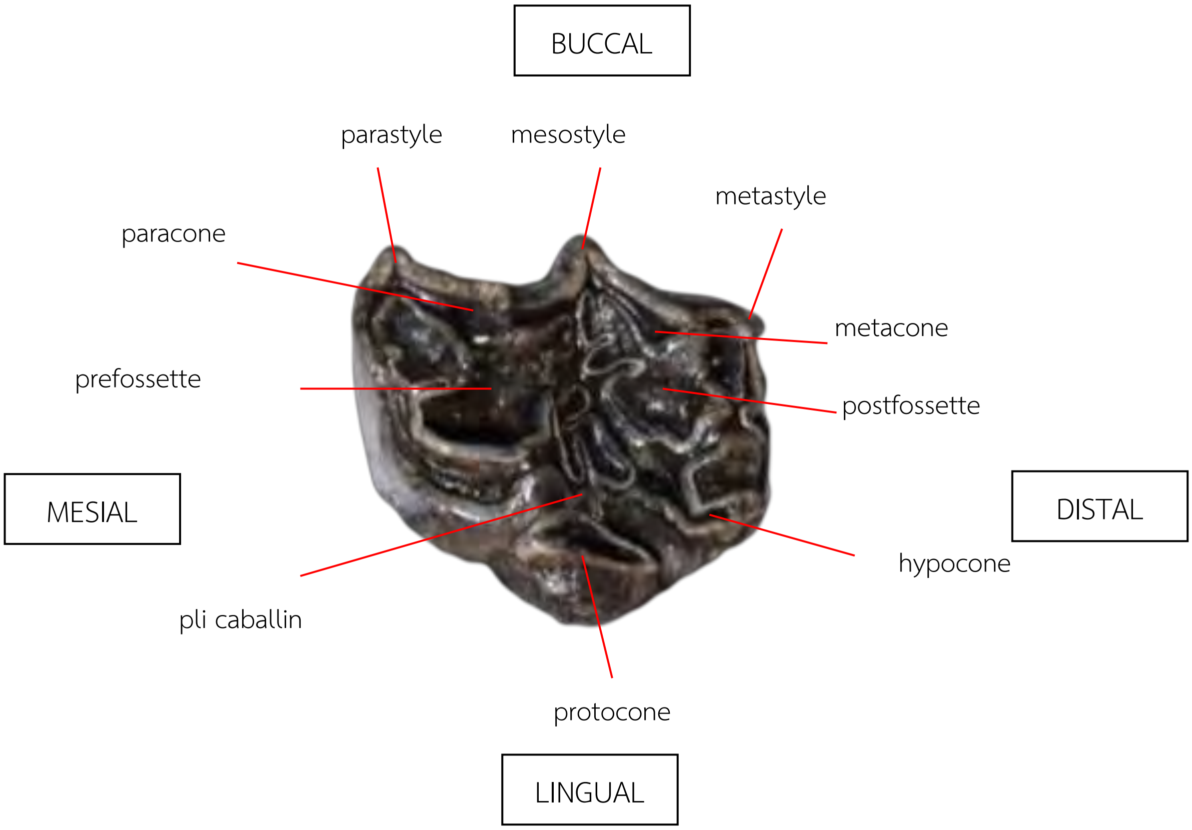


Figure 3.1 The nomenclature of upper cheek teeth of *Hipparion.*

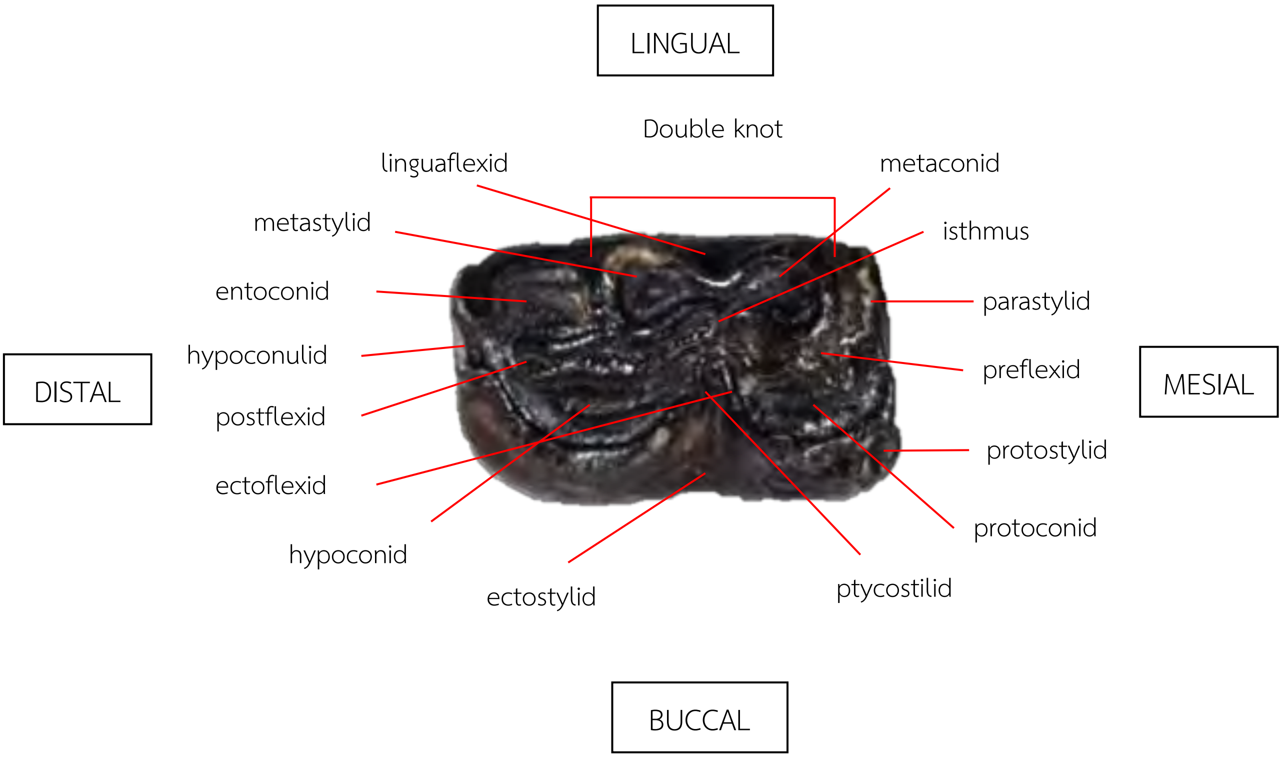


Figure 3.2 The nomenclature of lower cheek teeth of *Hipparion.*

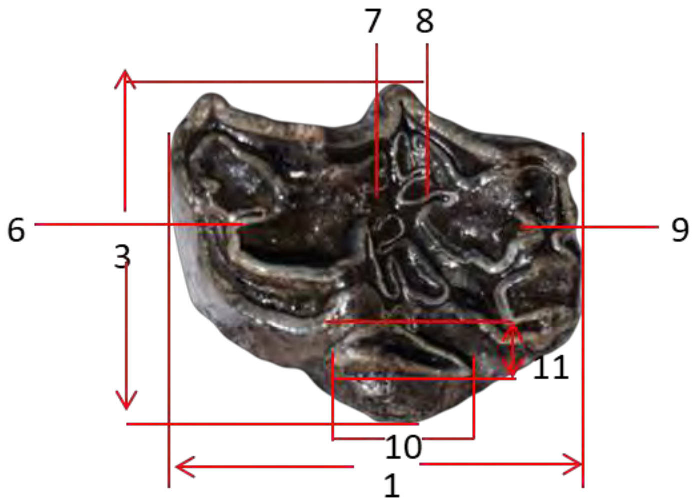
5. All of specimens have been measured using the methods proposed by Bernor et al. (1997, 2015).

Eleven measurements were taken on upper premolars and molars (M1= occlusal length; M2 = length 10 mm above the base of tooth crown (in isolated tooth only); M3 = occlusal width, taken across mesostyle - protocone; M4 = width 10 mm above the base of tooth crown (in isolated tooth only); M5 = mesostyle height; M6 = Number of plication on the mesial border of prefossette; M7= number of plication on the distal border of prefossette; M8 = number of plication on the mesial border of postfossette; M9 = number of plication on the distal border of postfossette; M10 = length of protocone; M11 = width of protocone)

Ten measurements were taken on lower premolars and molars (M1= length at occlusal level; M2 = length 10 mm above the base of tooth crown (in isolated teeth); M3 = length of double knot; M4 = length of the prefossette; M5 = length of postfossette; M6 =. width across linguaflexid-ectoflexid; M7. width 10 mm above the base of tooth crown; M8. width across metaconid-protoconid enamel bands;

M9. width across metastylid-hypoconid enamel bands; M10. height along a mesial surface of the tooth)

A



B

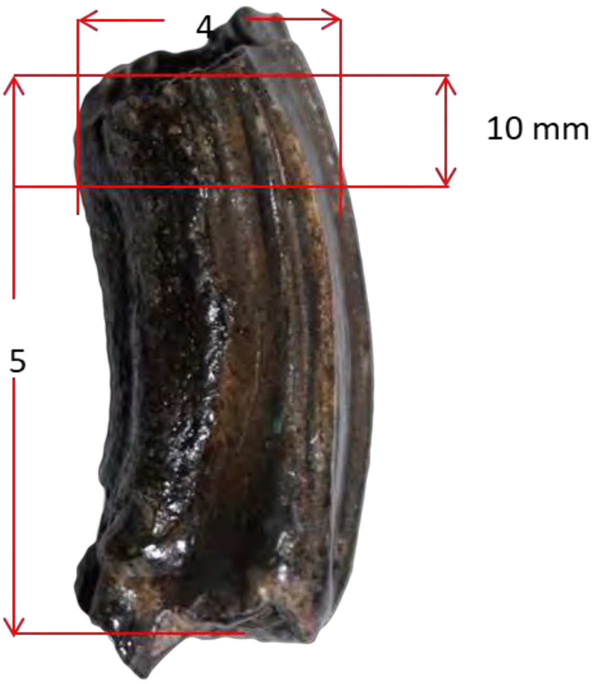


Figure 3.3 Measurements of upper cheek teeth: A. occlusal view; B. lateral view

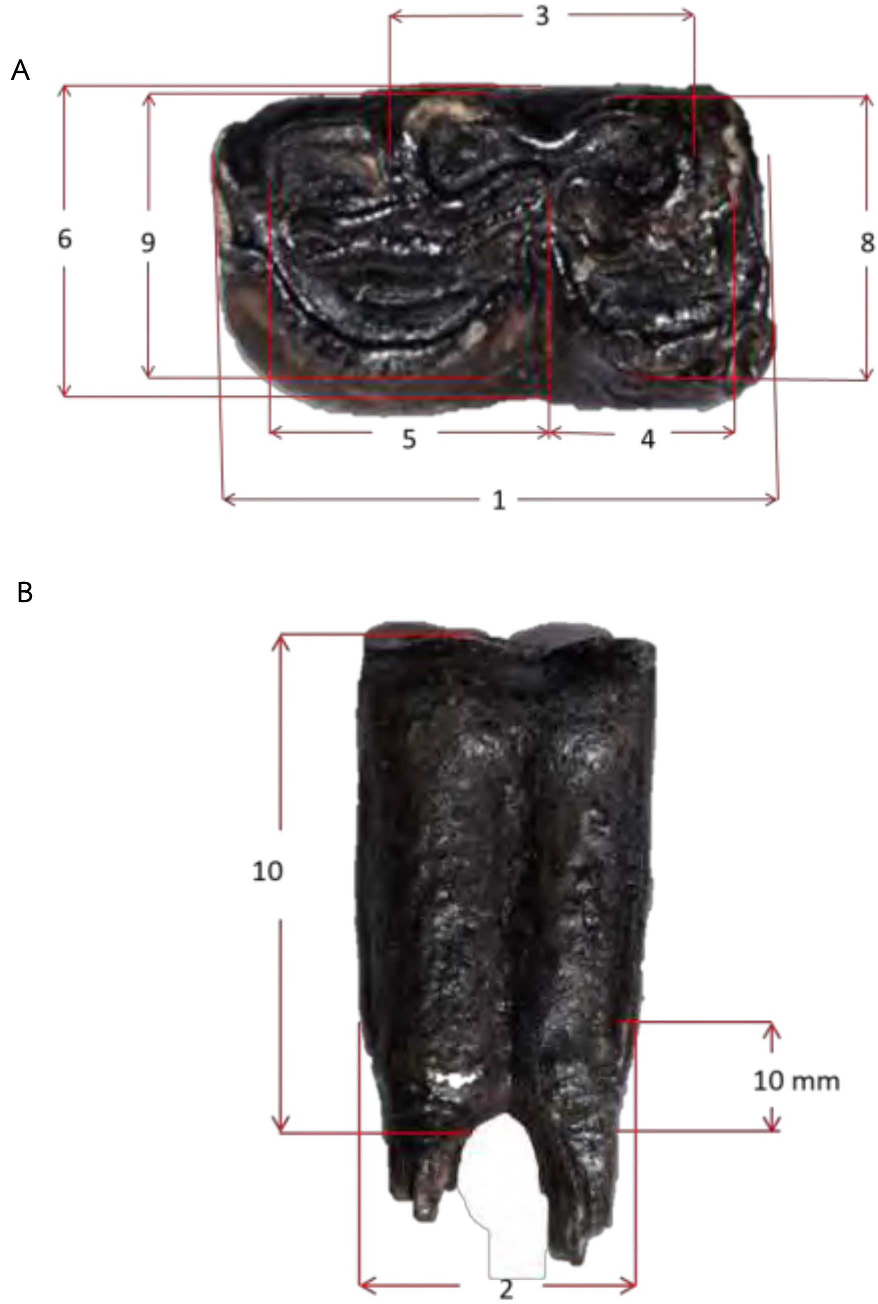


Figure 3.4 Measurements on lower cheek teeth: A. occlusal view; B. buccal view

6. Scatter diagrams between dental widths and lengths have been plotted for comparing the size of our specimens with the other related Hipparionini tribe.

CHAPTER 4

RESULTS

4.1 Systematic paleontology

Order Perissodactyla Owen, 1848

Family Equidae Gill, 1872

Genus *Hipparion* de Christol, 1832

Hipparion cf. *chiai* Liu, 1978

Referred specimens: (Fig. 4.1, 4.2)

A right mandible with p2-m3 (PPNO1000181), a left mandible with p2-m2 (PPNO1000182) and 5 Isolated cheek tooth: right M3 (PPNO1000129), right P4 (PPNO1000130), right M1 (PPNO1000131), left P4 (PPNO1000133) and right p4 (PPNO1000132)

Locallity: Chalermprakiat sand pit, Chalermprakiat district, Nakhon Ratchasima Province

Stratigraphic Horizon: Medium sand with mud lens (Fig. 1.3)

Type specimen: IVPPV.3117.0, a mandible with p2-m3

Type Locallity: Lantain, Shensi, Northwestern of China

Figure 4.1 4 Isolated cheek teeth: (A) left M3 (PPNO1000129), (B) left P4 (PPNO1000130), (C) left P4 (PPNO1000131), (D) right M1 (PPNO1000133) and lower cheek tooth: (E) right p4 (PPNO1000132) (Scale bar = 1 cm)

Figure 4.2 (A) a left mandible with p2-m2 (PPNO1000182), (B) a right mandible with p2-m3 (PPNO1000181) (Scale bar = 2 cm)

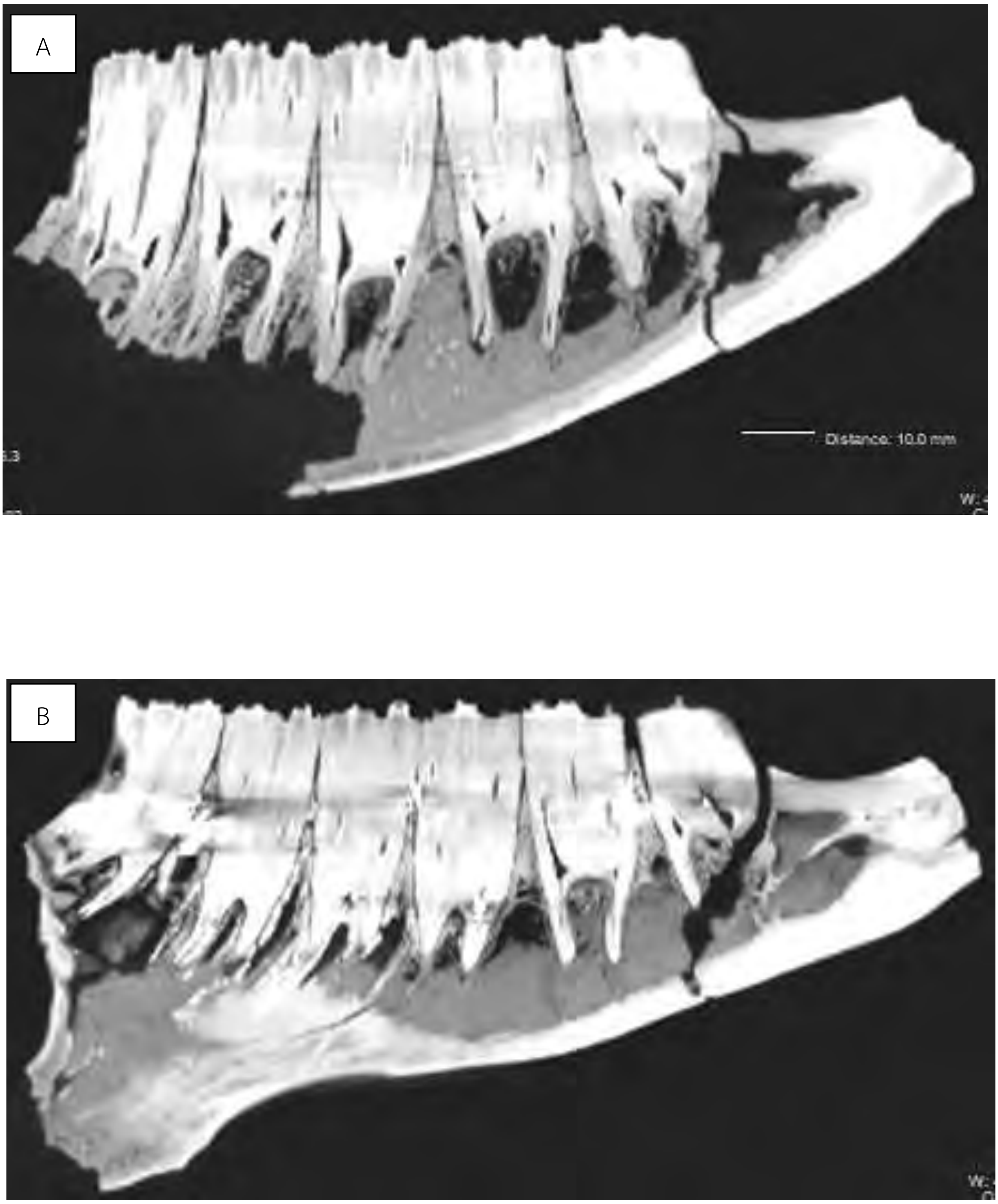


Figure 4.3 CT–scan images of (A) a left mandible with p2-m2 (PPNO1000182), early wear II (labial view), (B) a right mandible with p2-m3 (PPNO1000181), early wear II (Lingual view) (scale bar = 1 cm)

Description of specimens

This description is based on referred specimens (p2-m3: PPNO1000181, p2-m2: PPNO1000182, and on Isolated cheek teeth (left M3: PPNO1000129, left P4: PPNO1000130, left M1: PPNO1000131, right P4: PPNO1000133). right p4: PPNO1000132)

Upper dentition: The occlusal outlines of cheek teeth are rectangular, their lengths exceeding their widths except PPNO1000133.

P4: PPNO1000130 belongs to an early wear **II** (age 4-5). (Fig. 4.1, B) The protocone is slightly triangular. The hypocone is broadened and nearly closed loop. The paracone and matacone are triangular. Both of the anterior and posterior borders of the shallow prefossette display four plications. The anterior and posterior borders of the shallow postfossette show five and four plications. The pli cablline is twin and long that close the buccal margin of the protocone. The parastyles and mesostyle are wider than PPNO1000129. So these differ from PPNO1000131 (P4) (Fig. 4.3, C) which is early wear **I** (age 3.5-4). The protocone is elongated. The paracone and matacone are crescent-shaped. The anterior and posterior borders of the shallow prefossette display two and eight plications respectively. Both of the anterior and posterior borders of the shallow postfossette show eight plications.

M1: PPNO1000133 has a broadened and rounded protocone (Fig 4.1, D). The hypocone is semicircle. The paracone and matacone are triangular. The anterior and posterior borders of the shallow prefossette show two and seven plications respectively. The anterior and posterior borders of the shallow postfossette show six and four plications respectively. The pli cablline is single but not reach to the protocone. The parastyles and mesostyle are elongate and narrow.

M3: PPNO1000129 represents early wear **I** (age 3.5-4) (Fig. 4.1, A). The protocone is spindle, elongate and compression. The hypocone is slender and elongate. The paracone and the matacone are crescent and triangular respectively. The anterior and posterior borders of the deep prefossette show three and seven plications respectively. The anterior and posterior borders of the deep postfossette show eight and nine plications. The pli cablline is dual and one of this is long and nearly reaches the buccal margin of the protocone. The parastyles and mesostyle are shot and narrow.

Lower dentition: Both of PPNO1000181-182 and isolated cheek tooth PPNO1000132 are early wear II (age 4 to 5) which have the protostylid from p3 to m2 in sequence.

Table 4.1 The length of the dental series of *Hipparion* cf. *chiai.*

Specimens	Premolar row (mm)	Molar row (mm)
PPNO1000181	73.95	69.50
PPNO1000182	74.00	-

p2: (Fig. 4.2) In prominent the paraconid is triangular. The labial walls of the protoconid and hypoconid are convex but the hypoconid is longer than the paraconid. The mataconid is rounded while the matastylid is sub rounded. The entoconid is trapezoid-shaped. The ventral of the preflexid is convex. The postflexid is long and crescent-shaped. The ectoflexid is shallow. The linguafliexid is V-shaped.

p3: (Fig. 4.2) The labial walls of protoconid and hypoconid are strongly convex. The mataconid and matastylid are round and triangular but the matastylid is wrinkle. The entoconid is a parallelogen and reaches the metastylid. The vantral of the preflexid is convex. The postflexid is long and slightly wrinkled. The ectoflexid is shallow. The linguafliexid is U-shaped.

p4: (Fig. 4.1, E, 4.2) The labial walls of protoconid and hypoconid are strongly convex. The double knots are round and triangular with slightly wrinkle line. The entoconid is slightly wrinkle parallelogen and reaches the metastylid. The ventral of preflexid is convex like asymmetrical horns. The postflexid is long and slightly wrinkled. The ectoflexid is shallow. The linguafliexid is U-shaped. The ptycostilid is narrow.

m1: (Fig 4.2) The labial walls of protoconid and hypoconid are strongly convex. The double knots are round and triangular with slightly wrinkle line but the metaconid is larger than the metastylid. The entoconid is C-shaped and extending to reach the metastylid. The ventral of preflexid is convex like asymmetrical horns, with a fold of the anterior wall and a triangular notch on the posterior wall. The postflexid is short and straight. The ectoflexid is shallow and wide. The linguafliexid is U-shaped.

m2: (Fig 4.2) The labial walls of protoconid and hypoconid are strongly convex but the protoconid is wider than the hypoconid. The double knots are round and triangular with slightly wrinkle line but the metaconid is larger than the metastylid. The entoconid is wrinkle rounded and narrow. The ventral of preflexid is convex like symmetrical horns. The postflexid is wavy. The ectoflexid is shallow and wide. The linguafliexid is U-shaped.

m3: (Fig. 4.2) The labial walls of protoconid and hypoconid are slightly convex. The double knots are round and triangular with slightly wrinkle line. The entoconid is wrinkle oval. The ventral of preflexid is convex like asymmetrical horns. The postflexid is wavy. The ectoflexid is slightly deep and wide. The linguafliexid is U-shaped.

Description of wear stages on the occlusal surface

All specimens have been sent to make CT-scan images, but the specimens are broken inside, so mostly of specimens have no cross-section data from CT-scan images, except for PPNO1000132 (Appx., Fig. A) that belongs to *Hipparion* cf. *chiai*. (Fig 4.1, E)

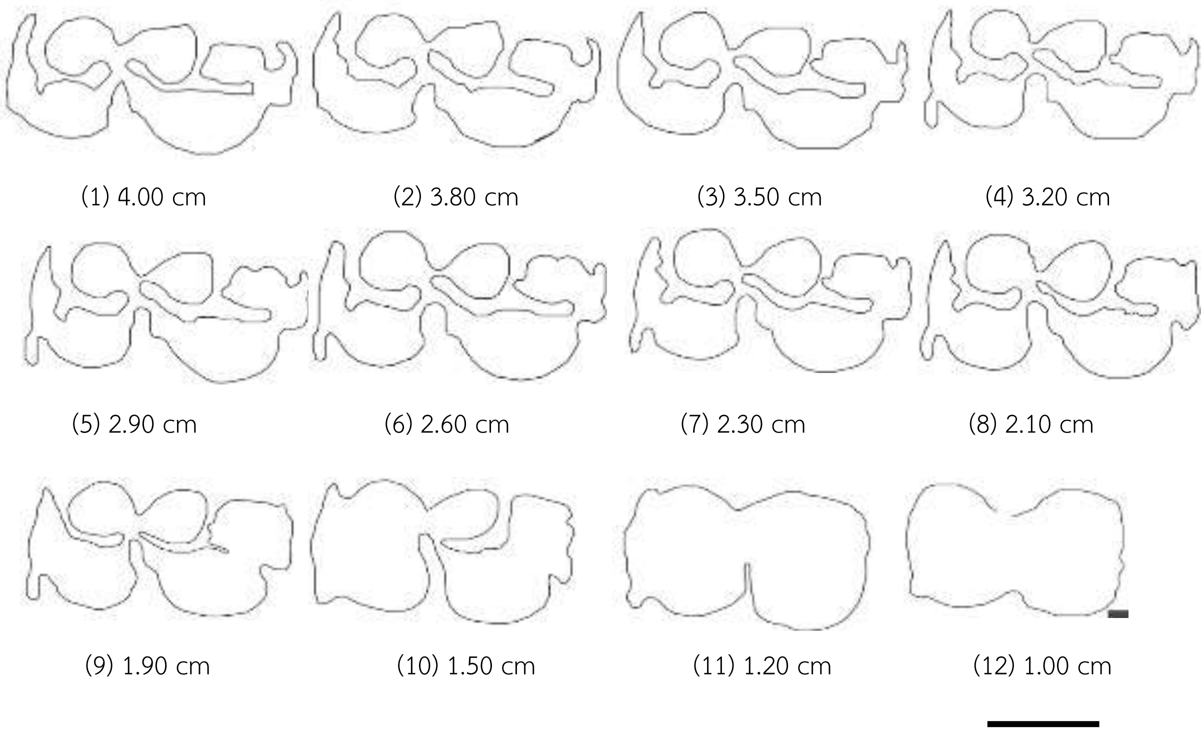


Figure 4.4 Line diagram of occlusal section of PPNO1000132 (p4) (scale bar = 1 cm)

In the earliest stage (1-3), the protostylid is not connected to protoconid but in CT- scan image is not clear. The mataconid is larger than the metastylid. The hypoconulid is separated from the entoconid. In 4-7 stage, the hypoconulid is narrow and close the entoconid. The double knots are rounder than those in 1-3 stage. The protostylid is fused with protoconid. In 8-9 stage, the hypoconulid is narrow and close to the entoconid. The preflexid and postflexid are smaller than those in 4-7 stage. The ectoflexid is close to the isthmus. In 10 stage, the preflexid is absent. The entoconid is connected to the protoconid. The protostylid becomes broader.

Hipparion sp.

Referred specimens: (Fig. 4.5)

A right maxilla with P3-M1 (CUF-MB-2), a right mandible with p4-m2 (CUF-MB-3), a left mandible with p4-m3 (CUF-MB-4), a left mandible with p3-m1 (CUF-MB-5), a left mandible with p2-p4 (CUF-MB-6), a left mandible m1-m2 (CUF-MB-7), a right mandible with m2-m3 (CUF-MB-8) and left isolated m3 (CUF-MB-9)

Locallity: Phimai sand pit, Phimai district, Nakhon Ratchasima Province

Stratigraphic Horizon: light bluish gray sandy (Fig. 1.4)

Type Locality: Mt. Luberon in southern France

Type status: When de Chirstol (1832) first proposed the genus *Hipparion*, no holotype was indicated. Later, Gervais (1849) designated a syntypic series of *Hipparion* from Mt. Luberon, including *H. prostylum, H. mesostylum* and *H. diplostylum.* Osborn (1918) considered *H. prostylum* to be type species for the genus *Hipparion*. Sondaar (1974) mentioned that the holotype of *H. prostylum*, which consists of fragmentary plate with P4-M2 (see Gervais 1849, pl, 19, fig. 2), is probably contained in the collection in the Musee Requien, Avignon.


A
B
C
D

Figure 4.5 (A) a right maxilla with P3-M1 (CUF-MB-2); (B) a left mandible with p4-m2 (CUF-MB-3); (C) a right mandible with p4-m3 (CUF-MB-4); (D) a right mandible with p3-m1 (CUF-MB-5); (E) a right mandible m1-m2 (CUF-MB-7); (F) a right mandible with p2-p4 (CUF-MB-6); (G) a right mandible with m 2-m3 (CUF-MB-8) and lower cheek tooth: (H) left m3 (CUF-MB-9) (Scale bar = 1 cm)

Description of specimens

This description is based on a right maxilla with P3-M1 (CUF-MB-2), a right mandible with p4-m3 (CUF-MB-4) and a right mandible with p2-p4 (CUF-MB-6) which is more completed than others.

Upper dentition: The occlusal outlines of cheek teeth are rectangular, P4 widths exceeding their lengths. CUF-MB-2 has middle wear teeth (age 9-10)

P3: (Fig. 4.5) The protocone is oval. The hypocone is shot and wide. The paracone and matacone are half-round. Plication of the anterior border in the shollow prefossette is weak. The posterior border of the shallow prefossette show six plications. The anterior and posterior borders of the shallow postfossette display seven and one plications. The pli cablline is dual and one of them is shot and nearly reaches the buccal margin of the protocone. The parastyles and mesostyle are long and narrow.

P4: (Fig. 4.5) The protocone is oval. The hypocone is shot and wide. The paracone and matacone are square. The anterior and posterior borders of the shallow prefossette display three and nine plications, respectively. The anterior and posterior borders of the shallow postfossette show three and one plications; pli cablline are dual. The parastyles and the mesostyle are shot but the mesostyle is wider than the parastyle.

Lower dentition

p2: (Fig 4.5) In prominent the paraconid is triangular. The labial walls of the protoconid and hypoconid are convex but the hypoconid is longer than the paraconid. The mataconid is oval while the matastylid is rounded. The entoconid is large, rounded and enlarging nearly to reach the metastylid. The preflexid is weak. The postflexid is small and slender so, the entoconid connects to the hypoconid. The ectoflexid is shallow. The linguafliexid is V-shaped. The hypoconulid is present.

p3: (Fig 4.5) The labial walls of protoconid and hypoconid are strongly convex. The mataconid is rounded and the matastylid is oval. The entoconid is quadrangular and enlarging nearly to reach the metastylid. The preflexid is small and slightly convex in bottom. The postflexid is slender and slightly wrinkled. The ectoflexid is shallow. The linguafliexid is V-shaped. The hypoconulid is present.

p4: (Fig 4.5) The labial walls of protoconid and hypoconid are strongly convex. The mataconid is rounded and the matastylid is triangular. The entoconid is oval and enlarging nearly to reach the metastylid. The preflexid is small with slightly wrinkled. The postflexid is slender and slightly wrinkled. The ectoflexid is slightly deep. The linguafliexid is U-shaped. The hypoconulid is narrow.

m1: (Fig 4.5) The labial walls of protoconid and hypoconid are convex. The mataconid is rounded with wrinkle line and the matastylid is wrinkle triangular. The entoconid is rounded and enlarging to reach the metastylid. The ventral of preflexid is convex. The postflexid is slender and wrinkled. The ectoflexid is slightly deep. The linguafliexid is V-shaped. The ptycostilid is nearly the isthmus. The hypoconulid is extended.

m2: (Fig 4.5) The labial walls of protoconid and hypoconid are convex. The mataconid is rounded with wrinkle line and the matastylid is wrinkle triangular. The entoconid is rounded and enlarging to reach the metastylid. The preflexid and postflexid is slender. The ectoflexid is slightly deep and close to the isthmus. The linguafliexid is V-shaped. The ptycostilid is weak. The hypoconulid is extended.

m3: (Fig 4.5) The labial walls of protoconid and hypoconid are slightly convex. The mataconid is roundly triangular and the matastylid is oval. The entoconid separates from the matastylid. The preflexid and postflexid are slender. The ectoflexid is shallow. The linguafliexid is U-shaped

Table 4.2 Measurements of upper cheek teeth (mm) of *Hipparion* cf. *chiai* and *Hipparion* sp.

Teeth	M1	M2	M3	M4	M5	M6	M7	M8	M9	M10	M11
Hipparion sp.											
CUF-MB2 (P3)	-	-	-	-	-	-	6	7	1	-	-
CUF-MB2 (P4)	22.80	-	21.12	-	-	3.	9.	3	1	8.37	4.83
CUF-MB2 (M1)	16.90	-	-	-	-	-	-	-	-	-	-
Hipparion cf. *chiai*											
PPN01000129	21.54	23.56	18.79	19.78	41.56	3	6	5	3	8.09	2.78
PPN01000130	24.58	23.26	23.58	22.06	43.79	4	4	5	4	7.01	3.89
PPN01000131	25.14	21.60	21.46	21.56	48.09	2	8	8	8	9.05	3.58
PPN01000133	20.83	20.74	21.93	21.09	38.35	2	7	6	4	7.25	4.39

Table 4.3 Measurements of lower cheek teeth (mm) of *Hipparion* cf. *chiai* and *Hipparion* sp.

Teeth	M1	M2	M3	M4	M5	M6	M7	M8	M9	M10
Hipparion cf. *chiai*										
PPN01000181 (m2)	26.15	-	10.80	6.84	11.39	12.16	-	9.50	12.46	-
PPN01000181 (p3)	23.82	-	14.58	7.91	11.68	16.34	-	13.74	13.62	-
PPN01000181 (p4)	23.51	-	14.53	8.34	12.04	15.83	-	13.34	13.10	-
PPN01000181 (m1)	22.15	-	13.73	8.19	8.75	15.00	-	12.52	11.36	-
PPN01000181 (m2)	21.35	-	12.34	7.70	7.77	13.64	-	11.01	10.45	-
PPN01000181 (m3)	24.75	-	10.55	7.01	6.67	11.20	-	9.36	8.36	-
PPN01000182 (p2)	25.99	-	10.80	7.63	11.05	12.88	-	9.22	12.31	-
PPN01000182 (p3)	23.88	-	14.16	8.66	11.84	16.37	-	13.18	13.83	-

PPN01000182 (p4)	22.95	-	13.67	8.02	11.37	16.64	-	-	13.23	-
PPN01000182 (m1)	21.67	-	13.43	7.27	7.95	14.73	-	12.05	12.21	-
PPN01000132 (p4)	24.34	23.27	13.09	7.75	11.75	14.03	14.10	11.79	11.94	42.64
Hipparion sp.										
CUF-MB3 (p4)	21.87	-	12.94	-	10.44	16.81	-	12.37	11.72	-
CUF-MB3 (m1)	21.56	-	12.90	8.10	9.40	14.20	-	10.00	9.71	-
CUF-MB3 (m2)	23.12	-	11.69	-	8.01	12.70	-	8.32	8.27	-
CUF-MB4 (p4)	23.50	-	12.25	8.70	10.72	16.23	-	11.95	11.90	-
CUF-MB4 (m1)	21.41	-	11.71	8.2	10.16	14.39	-	10.73	10.11	-
CUF-MB4 (m2)	21.16	-	11.52	6.51	9.73	12.69	-	9.50	9.40	-
CUF-MB4 (m3)	26.08	-	10.34	6.41	7.84	10.93	-	7.88	6.90	-
CUF-MB5 (p3)	-	-	-	-	10.35	-	-	-	11.10	-
CUF-MB5 (p4)	22.81	-	13.32	8.32	7.63	12.22	-	11.17	10.35	-
CUF-MB5 (m1)	23.28	-	13.48	8.04	8.78	12.36	-	10.21	-	-
CUF-MB6 (p2)	21.79	-	9.39	4.62	6.04	10.82	-	9.29	12.77	-
CUF-MB6 (p3)	18.69	-	12.09	6.19	7.50	14.30	-	12.67	12.24	-
CUF-MB6 (p4)	18.25	-	11.96	5.25	7.27	14.07	-	13.05	11.43	-
CUF-MB7 (p4)	22.61	-	13.94	6.12	11.47	16.12	-	13.11	13.58	-
CUF-MB7 (m1)	20.93	-	12.78	6.14	9.74	14.82	-	11.28	11.03	-
CUF-MB8 (m2)	-	-	-	-	3.51	10.82	-	-	8.81	-
CUF-MB8 (m3)	23.45	-	-	-	4.64	-	-	-	-	-
CUF-MB9 (m2)	20.70	18.63	10.70	6.43	-	7.00	8.33	9.01	8.05	-

4.2 Scatter diagrams

Scatter diagrams plotted between width and length of Hipparionini tribe and our specimens. The sizes can be divided visually into three groups: large size (red), medium size (yellow) and small size (blue).

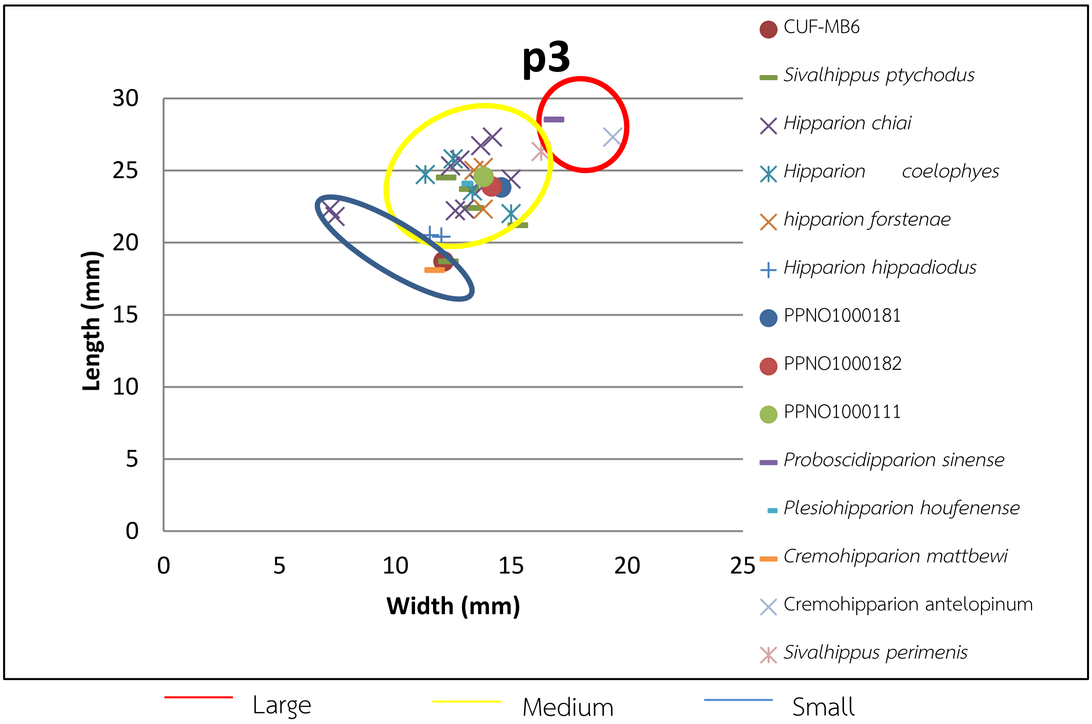


Figure 4.6 Scatter diagram between width and length of p3

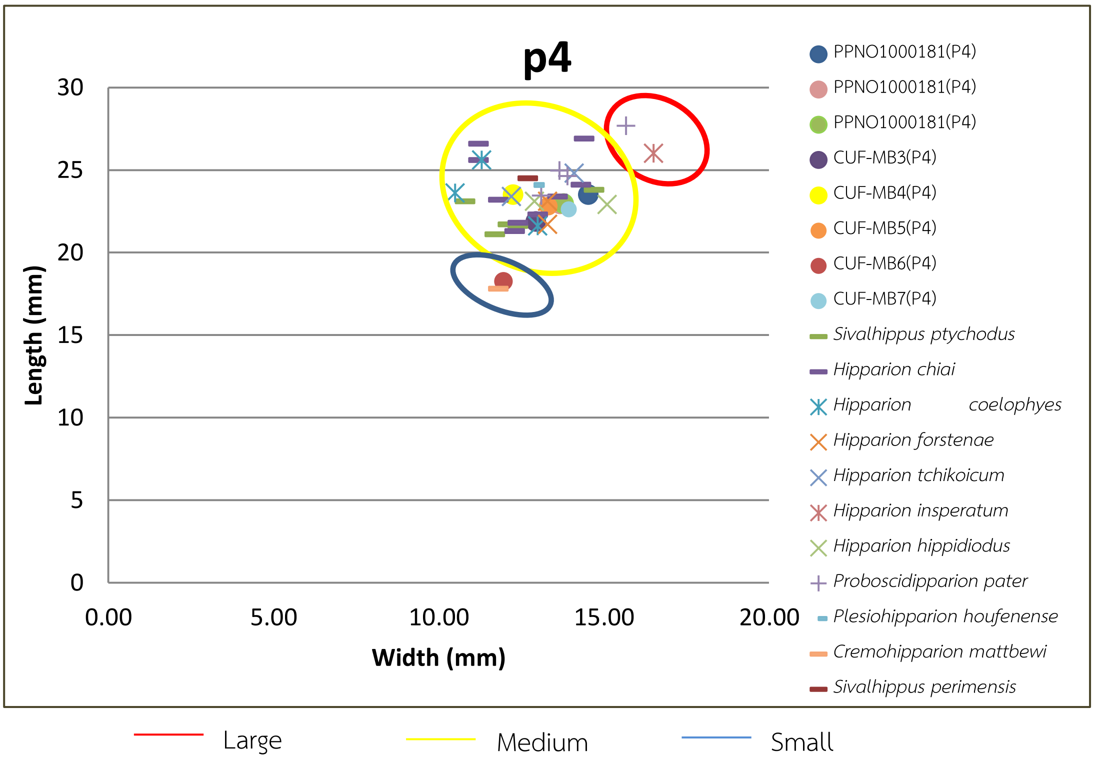


Figure 4.7 Scatter diagram between width and length of p4

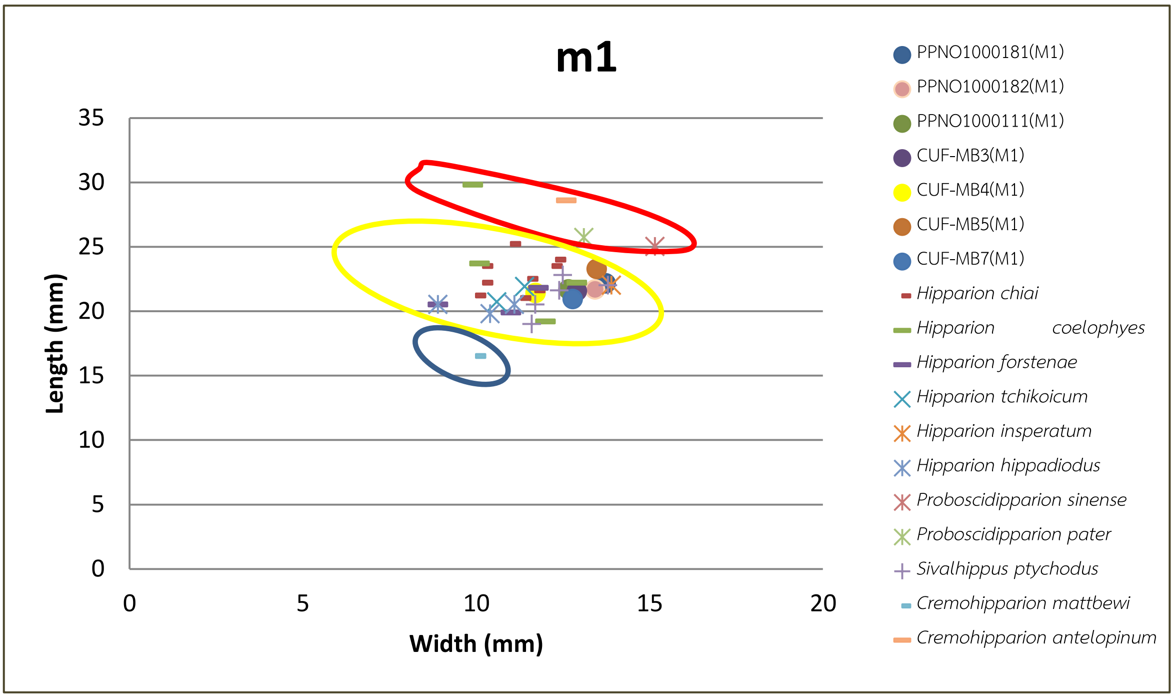


Figure 4.8 Scatter diagram between width and length of m1

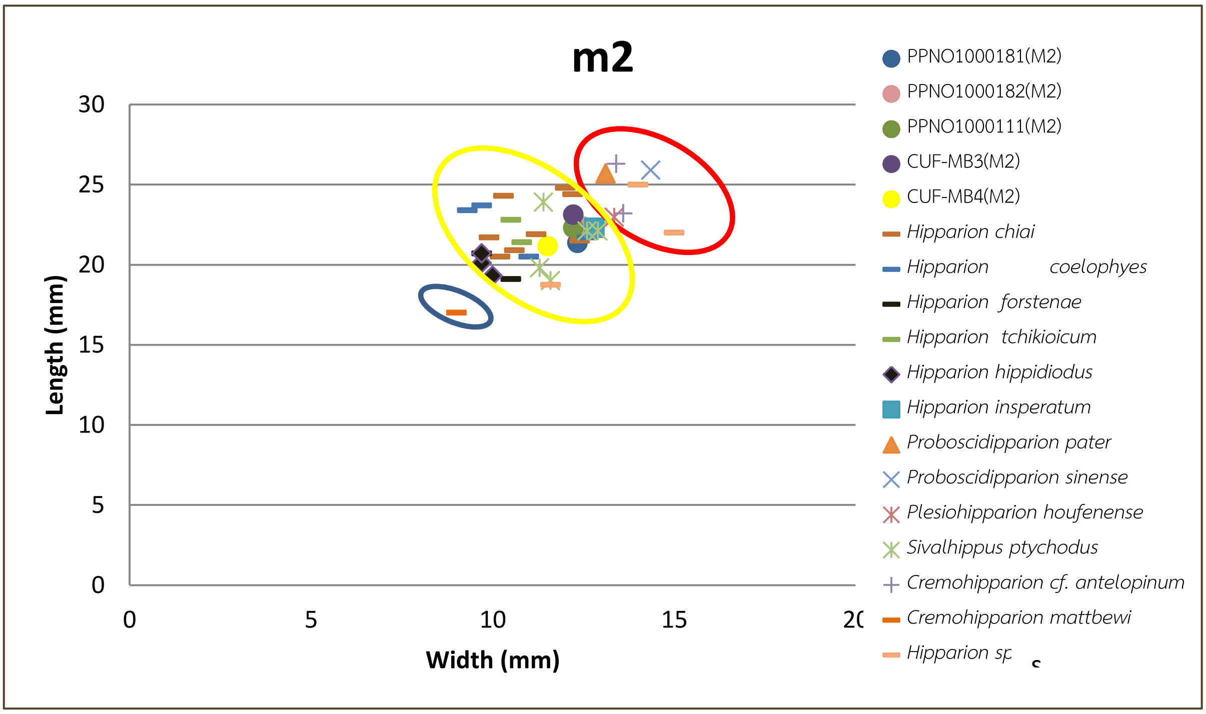


Figure 4.9 Scatter diagram between width and length of m2

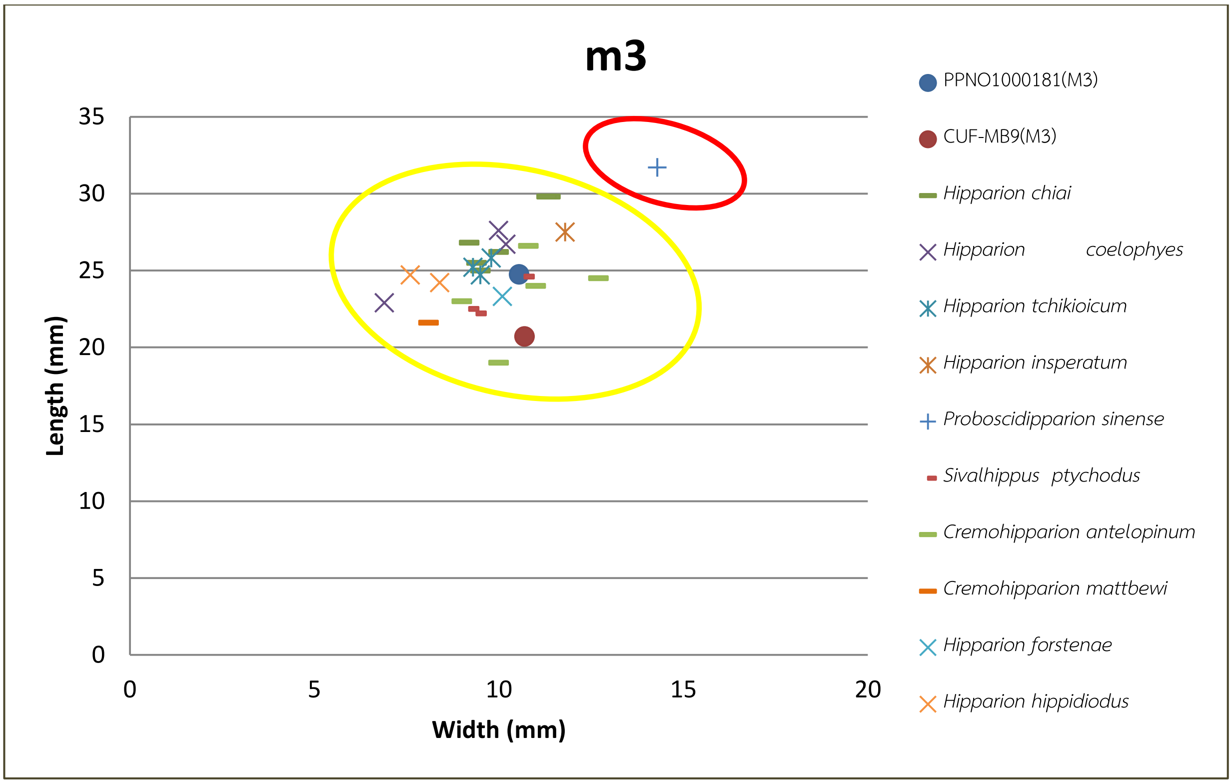


Figure 4.10 Scatter diagram between width and length of m3

4.3 Comparisons

Specimens of Phimai sand pit and Chalermprekiat sand pit are medium-sized but fossils from Phimai sand pit are of smaller-sized. From the scatter diagrams, *Silvalhippus* and *Hipparion* are medium-sized. In upper cheek teeth of *Silvalhippus* in china, plications of the anterior and posterior borders of the prefossette are frequently in the same way, the anterior and posterior borders of the postfossette are also frequently. The protocone is rounded. In lower cheek teeth, double knots are strongly wrinkled (Sun et al., 2018). So it is different from fossils in the Chalermprekiat sand pit in having the spindle protocone elongated and compressed, rounded and triangular double knots with slightly wrinkle line. It is different from Phimai fosslis in having fine and shot plications of the anterior and posterior borders of the prefossette and rounded double knots. For these characters, fossils from Phimai and Chalermprekiat sand pits belong to *Hipparion.*

We identify here equid specimens as belonging to *Hipparion* cf. *chiai* and *Hipparion* sp. *Hipparion* cf. *chiai* is characterized by elongated and sub angular protocones, sub-angular shapes of hypocones, and short enamel plications of pre- and postfossettes. On the other hand, the protocone of *H. hippidiodus* is wide and oval (Li et al., 2017), but the protocone of *H. tchikoicum* (Deng et al., 2015) *and H. forstenae* (Li et al., 2017) is small and oval, In addition, the morphological patterns of occlusal surface changes in each stages of wear in lower cheek teeth PPNO1000132 (Fig. 4.4) are similar to those of *Hipparion* cf. *chiai* (Li et al., 2017). Double knots of *Hipparion* sp. are rounded or oval, differing from *Hipparion* in Pakistan and India, but mostly similar to *Hipparion* in China.

4.4 Age and Paleoenvironments

The age of this *Hipparion* cf. *chiai* from Chalermprekiat sand pit is considered to be the Late Miocene based on biostratigraphical range of Neogene mammalian fossils from the Linxia basin. (Deng et al., 2013) Phimai and Chalermprakiat sand pits are located near Mun River. So, our specimens have transported to deposit in this area. In the Qaidan Basin, using carbon isotope to identify paleoenvironments that is the substantial wooded environment. Streams were a significant component in local habitat of *Hipparion.* (Wang et al., 2007) Moreover, the Qaidam Basin accumulated fluviolacustrine sediments from at least Late Eocene to the present time that is similar to study areas. So, paleoenvironments of *Hipparion* cf. *chiai* and *Hipparion* sp. to have corresponded to forested environments close to the river channel.

CHAPTER 5

CONCLUSION

5.1 Conclusion

Equid fossil specimens compose of 1 maxilla, 9 mandibles, and 6 isolated teeth (4 upper and 2 lower teeth) from Phimai and Chalermprekiet sand pits, Nakhon Ratchasima province. They were identified as belonging to *Hipparion* cf. *chiai* and *Hipparion* sp. Both of species were possibly close to Chinese species. CT-scan images of occlusal cross-sections of *Hipparion* cf. *chiai* can be divided into 5 stages of wear including the earliest stage with separated of the hypoconulid, second stage with squeezed of the hypoconulid, third stage with small-sized of the preflexid and the postflexid, fourth stage with disappeared of the preflexid and the root of teeth in last stage. Dead ages of *Hipparion* can anticipate according to the morphologic changes in each dental wear. On the basis of the biostratigraphical range of Neogene mammalian fossils from the Linxia basin, *Hipparion* cf. *chiai* is considered to be the late Miocene. The paleoenvironments of sand pits corresponded to a forest during the Late Miocene.

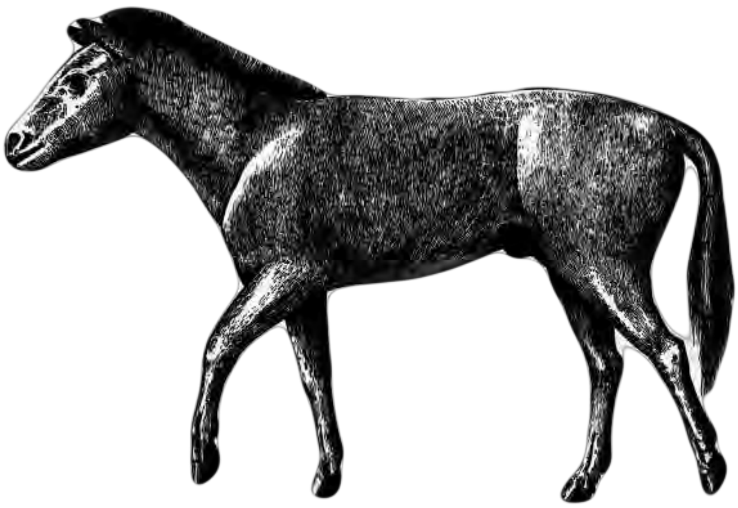


Fig 5.1 Picture of *Hipparion* (Bernor et al., 1997)

5.2 Future Perspective

More accurate identification of *Hipparion* cf. *chiai* and *Hipparion* sp. in the future should be useful. Finding the new material from the same locality and nearby sand pits in Nakon Ratchasima Province needs to be done in the future.

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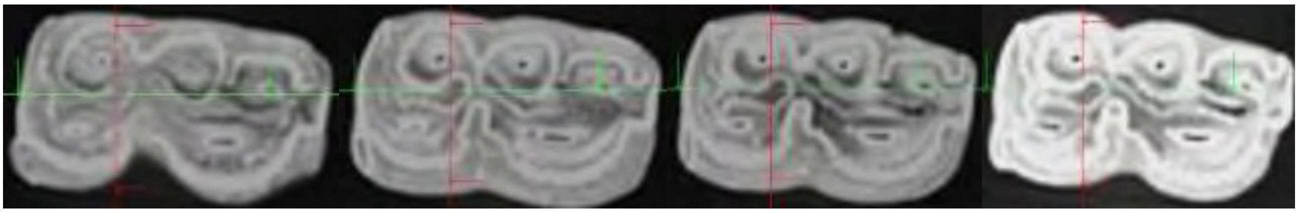
APPENDIX



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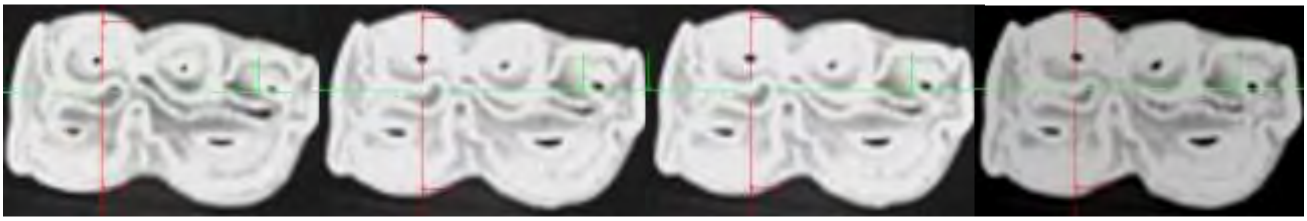
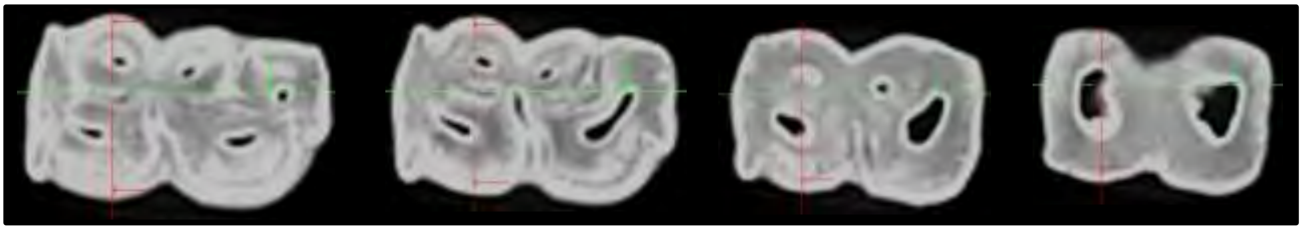


(5) 2.90 cm (6) 2.60 cm (7) 2.30 cm (8) 2.10 cm



(9) 1.90 cm (10) 1.50 cm (11) 1.20 cm (12) 1.00 cm

Fig. A CT-scan image of occlusal section of PPNO1000132 (p4)