SPINOSAURID DIVERSITY AND DEPOSITIONAL ENVIRONMENT OF THE KHOK KRUAT FORMATION FROM NORTHEASTERN THAILAND

KAMONLAK WONGKO

A thesis submitted in partial fulfillment of the requirements for

the Master of Science in Palaeontology

at Mahasarakham University

March 2018

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The examination committee has unanimously approved this thesis, submitted by Miss Kamonlak Wongko, as a partial fulfillment of the requirements for the Degree of Master of Science Program in Palaeontology at Mahasarakham University

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ABSTRACT

The sedimentological analysis (lithology and fossil remains) of the three localities in the Khok Kruat Formation, i.e., Lam Pao Dam, Sam Ran and Khok Pha Suam, suggested that the Khok Kruat sediments were formed in a meandering river system deposit. Lam Pao Dam Unit shows conglomerate channel deposits, characterizing a point bar sequence and seems that it was deposited in high energy river current. Sam Ran Unit is composed of sandstone and siltstone channel deposits corresponding crevasse splay sequence while Khok Pha Suam Unit consists of siltstone and claystone channel deposits classical of flood plain sequence. Both of them were deposited in low energy current, which the lower energy current being observed in Khok Pha Suam Unit. The Khok Kruat spinosaurid teeth were found two morphotypes, that is, Morphotype I or Khok Kruat morphotype which has been found only in the Khok Kruat Formation. The second is Morphotype II or *Siamosaurus* morphotype which distributed in both the Sao Khua and Khok Kruat Formations. Teeth specimens from Lam Pao Dam, Sam Ran and Khok Pha Suam localities belong to morphotype I or Khok Kruat morphotype based on smooth enamel surface at the apex and wrinkled enamel with finely ridge only at base of the crown. On the other hand, Morphotype II or *Siamosaurus* morphotype which has been found only in Lam Pao Dam and Khok Pha Suam localities, show wrinkled enamel surface at the apex and base of the crown with coarsely ridge. Hitherto, on the basis of teeth morphotype differences, it seems that there are at least two spinosaurid taxa found in Thailand.

Key Words: Spinosaurid, Diversity, Khok Kruat Formation, Depositional environment, Northeastern Thailand

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ชื่อเรื่อง ความหลากหลายของไดโนเสาร์สไปโนซอริด และสภาพแวดล้อมการสะสมตัวของหมวดหินโคกกรวด ภาคตะวันออกเฉียงเหนือของประเทศไทย
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บทคัดย่อ

จากผลการศึกษาด้านตะกอนวิทยา (ลักษณะทางกายภาพของหินและซากดึกดำบรรพ์) ในแหล่งซากดึกดำบรรพ์ของหมวดหินโคกกรวด ประกอบด้วย แหล่งเขื่อนลำปาว แหล่งสำราญ และแหล่งโคกผาส้วม สามารถอธิบายได้ว่าลักษณะของการสะสมตะกอนในหมวดหินโคกกรวด แสดงระบบการสะสมตัวของตะกอนแบบแม่น้ำโค้งตวัด โดยในพื้นที่แหล่งเขื่อนลำปาว มีการสะสมตัวของตะกอนของร่องน้ำหินกรวดมน แสดงสภาพแวดล้อมที่มีการกระทำจากกระบวนการของธารน้ำที่มีพลังงานสูง ทำให้เกิดบริเวณที่มีการสะสมตัวของตะกอน แหล่งสำราญพบว่ามีการสะสมตัวของตะกอนของร่องน้ำหินทรายและหินทรายแป้ง สามารถเปรียบเทียบได้ถึงสภาพแวดล้อมของการสะสมตัวของตะกอนในบริเวณที่กระแสน้ำได้ไหลทะลักเข้ามายังบริเวณด้านข้างของระบบแม่น้ำโค้งตวัด และแหล่งโคกผาส้วมมีการสะสมตัวของตะกอนของร่องน้ำหินทรายแป้งและหินโคลน แสดงสภาพแวดล้อมการสะสมตัวของตะกอนบริเวณที่ราบน้ำท่วมถึง โดยทั้งแหล่งสำราญและแหล่งโคกผาส้วมมีการกระทำจากกระบวนการของธารน้ำที่มีพลังงานต่ำเรียงตามลำดับ นอกจากนั้นการศึกษาลักษณะของฟันไดโนเสาร์สไปโนซอริดในหมวดหินโคกกรวดพบว่า มีลักษณะฟันสองรูปแบบ ได้แก่ลักษณะฟันแบบที่ 1 หรือลักษณะฟันแบบโคกกรวด แสดงลักษณะเด่นคือมีผิวฟันบริเวณตัวฟันเรียบและสันของฟันมีจำนวนมาก ซึ่งพบเฉพาะในหมวดหินโคกกรวดเท่านั้น และลักษณะฟันแบบที่ 2 หรือลักษณะฟันแบบ*สยามโมซอรัส* แสดงลักษณะเด่นคือมีผิวฟันบริเวณตัวฟันขรุขระและสันของฟันมีจำนวนน้อย ซึ่งพบได้ทั้งในหมวดหินเสาขัวและหมวดหินโคกกรวด โดยตัวอย่างฟันจากแหล่งเขื่อนลำปาว และแหล่งโคกผาส้วม พบทั้งลักษณะฟันแบบที่ 1 หรือลักษณะฟันแบบโคกกรวด และ ลักษณะฟันแบบที่ 2 หรือลักษณะฟันแบบ*สยามโมซอรัส* ส่วนแหล่งสำราญ พบเฉพาะลักษณะฟันแบบที่ 1 หรือลักษณะฟันแบบโคกกรวด ลักษณะของฟันที่แตกต่างกันแสดงให้เห็นว่าในประเทศไทยมีไดโนเสาร์สไปโนซอริด สองชนิด

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CHAPTER 1

INTRODUCTION

1.1 Background

In Thailand, Spinosaurid is represented in the Sao Khua and Khok Kruat Formations, by several taxa. *Siamosaurus suteethorni* is an enigmatic dinosaur known only by the peculiar isolated teeth which have tall and slightly compressed crowns with a ribbed enamel and very faint or non–existant serrations. Based on the isolated teeth, this dinosaur strongly evoked a spinosaurid theropod, but more material was needed to confirm possible affinities (Buffetaut *et al.*, 2003). *Siamosaurus*, teeth are relatively common. At Khok Pha Suam, in Ubon Ratchathani Province, a number of blade-like teeth, with serrations on both margins, have been collected. However, differences in their size and morphology strongly suggest that there are several spinosaur taxa in Thailand (Buffetaut *et al.*, 2005) . Post-cranial remains had never been found from Thailand until recently a partial skeleton of a large theropod has been recently discovered at an outcrop of the Khok Kruat Formation near the city of Khon Kaen. This locality called Sam Ran has been excavated by the Department of Mineral Resources. The material recovered from Sam Ram clearly confirms the occurrence of a spinosaurid in the Khok Kruat Formation (Milner *et al*., 2009). Several cervical and dorsal vertebrae have been found, as well as elements of the pelvis. The vertebrae are extremely similar to those of the spinosaurid *Baryonyx walkeri*, from the Wealden of England (Charig and Milner, 1997).

The discovery of these remarkable elements of a spinosaurid dinosaur put in light the necessity of conducting detailed palaeoenvironment studies. This lead the author to synthesize the stratigrapphic columnar section of the Sam Ran locality. Then we have compared all spinosaurid localities from the Khok Kruat Formation, namely including Sam Ran, Khok Pa Suam and Lam Pao Dam in order to understudy the biogeography and palaeoenvironment of Thai Spinosaurid.

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1.2 Objective

To reconstruct of the depositional environment and study diversity of the Spinosaurid in the Khok Kruat Formation from Northeastern Thailand.

1.3 Scope of research

There are three localities in the Khok Kruat Formation which have yielded spinosaurid material: Sam Ran is located in Muang District, Khon Kaen Province; Lam Pao Dam is located in Muang District, Kalasin Province, and Khok Pa Suam is located in Sri Muang Mai District, Ubon Ratchathani Province. The reconstruction of the palaeoenvironment of Spinosaurid bearing strata in the Khok Kruat Formation consisted of two parts. The first part of this work is the description of the lithostratigraphy and sedimentology in each locality in order to make geological sections and correlate the sites to Khok Kruat type section or Khok Kruat reference type section. The second part hinges on diversity of fossils, especially Spinosaurid in order to provide a reconstruction of the palaeoenvironment of the Khok Kruat Formation. These two steps included both field activity and laboratory work (conducted at the Sirindhorn Museum, Department of Mineral Resource and at the Palaeontological Research and Education Centre, Maha Sarakham University

1.4 Significance of the research

This study was conducted to provide new geological and palaeontological data to reconstruct the palaeoenvironment of Spinosaurid in the Khok Kruat Formation from Northeastern Thailand including a comparison with the other locality where spinosaurid element were found especially in Asia such as in Laos, South China and Japan to interpretation the palaeoenvironment of Asian spinosaurids.

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CHAPTER 2

LITERATURE REVIEW

The objective of this research is to get new information about Spinosaurid in the Khok Kruat Formation. To achieve the above objective, literature (published papers and unpublished reports) has been consulted for gathering preliminary information concerning: Geological setting of Northeastern Thailand, distribution of the Khok Kruat Formation, fossil assemblages of the Khok Kruat Formation, spinosauridae and distribution of spinosaurid, palaeoenvironment of the Spinosauridae and continental sedimentary environment,

2.1 Geological setting from Northeastern Thailand

In the study of the stratigraphy of Northeastern Thailand, Ward and Bunnag (1964), proposed the term “Khorat Group” instead of “Khorat Series” and the term “Formation” instead of “Member”. They subdivided the group into six formations and one unnamed rock, including the Nam Phong, Phu Kradung, Phra Wihan, Sao Khua, Phu Phan and Khok Kruat Formations, and Unnamed rocks, respectively in ascending order. They defined three new formations: the Nam Phong, Sao Khua and Khok Kruat Formations. They made 5 sections including the type sections of the Nam Phong, Phu Kradung, Phra Wihan, Sao Khua, Phu Phan and Khok Kruat Formations.

The lowermost formation in the Khorat Group, the Nam Phong Formation, lies unconformably over the Huai Hin Lat Formation. The top of the group is marked by the Mahasarakham evaporites, which were recently included as part of the Khorat Group (Mahasarakham Formation: Mouret *el al.*, 1993). However, there is an apparent major temporal gap between the Nam Phong Formation and the overlying units, which suggests that it does not belong to the Khorat Group.

Meesok (2000) interpreted the Khorat Group consist, mainly of the nonmarine Cretaceous rocks, which expose are widespread in the northeastern part of Thailand. They belong to the Phra Wihan, Sao Khua, Phu Phan and Khok Kruat Formations of the Khorat Group and the overlying Maha Sarakham Formation. Reddish brown to light gray

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sandstones, conglomeratic sandstones, siltstone, claystone and conglomerate are the main lithologies of these rocks; calcrete nodules and silcretes are also present in claystone but salts and gypsum are found only in the Maha Sarakham Formation. The rocks are interpreted as having been deposited by the meanderingriver and braided river system in semi arid to arid conditions. Age determinations are based mainly on vertebrates, bivalves and palynomorphs, indicating that the rocks are reassigned to the late Early to Late Cretaceous. Previously known, lime nodule conglomerates and silicified wood like beds and nodules have been re-interpreted as paleosols and silcretes, respectively. These paleosols and silcretes are widespread in maroon to reddish brown claystones of the Khorat Group particularly in the Sao Khua Formation. Petrographically and geochemically, paleosols and silcretes are similar to those in semi-arid to arid climate silcretes in South Africa, Canada and other regions. As a result, paleosols and silcretes may be used as paleoclimate indicators for the Cretaceous rocks, indicating that the rocks were deposited in the meandering river system during semi arid paleoclimate.

Racey (2009) defined the Khorat Group as a thick sequence of Mesozoic continental red bed sediments, which were deposited over much of northeast Thailand and neighboring parts of southeast and central Laos (around Vientiane, Savannakhet and Pakse) and Cambodia (Figure 2.1). It underlies much of the Khorat Plateau in northeast Thailand and has an aerial extent of around 200,000 km^2 with a maximum present-day preserved width of around 500 km and maximum preserved sediment thickness of around 4.5 km. Possible coeval red beds also occur in southern Peninsular Thailand and in Peninsular Malaysia (within the Gagau and Tembeling Groups). Although the Khorat Group crops out on the Indochina Block it does partly extend westwards across the Loei–Petchabun and Sukothai Fold Belts onto the Sibumasu Block, the two blocks having been sutured together since at least the Late Triassic (Figure 2.1 and 2.2). The Indochina Block comprises eastern Thailand, Laos, Cambodia and Vietnam, and is also referred to in the old literature as the Indosinian Block, whereas the Sibumasu Block comprises western Thailand, eastern Burma, Peninsular Malaysia and Sumatra, and is also referred to in the literature as the Shan-Thai Block (Figure 2.2).

The original epicenter of the Khorat Basin appears to have been oriented roughly northwest to southeast and superficially it has the appearance of a typical sag

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basin with each formation gradually overstepping the previous formation towards the edge of the basin.

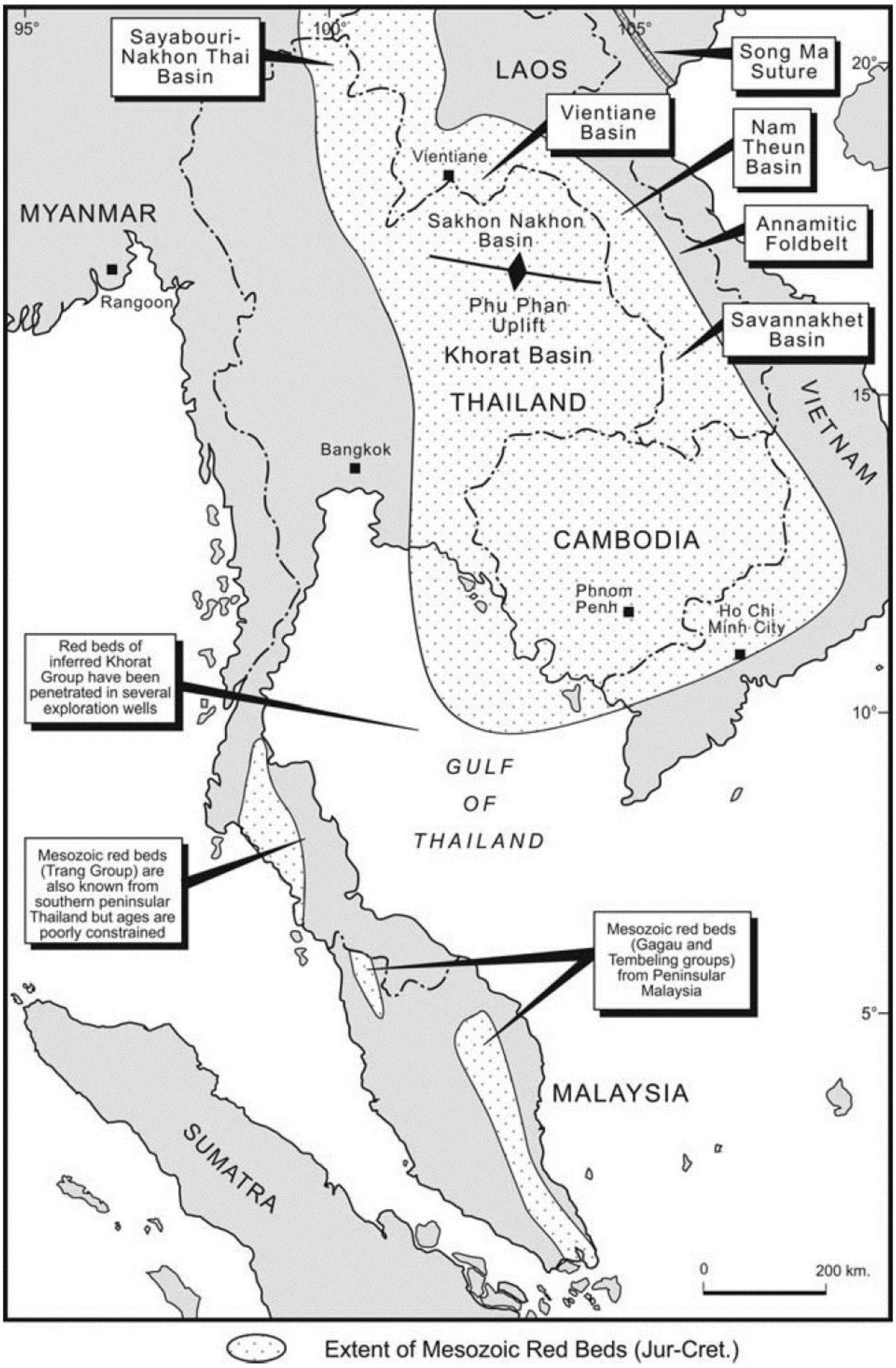

Figure 2.1 Extent of Jurassic - Cretaceous red beds and principal basins in mainland SE Asia (Racey, 2009).

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The Khorat Plateau has an uplifted western and southern margin (up to 1300 m above sea level) with a mesa-like appearance formed as a result of compressional deformation along its western margin (Loei–Phetchabun Fold Belt), which marks the western margin of the Indochina Block and the approximate boundary between the Indochina and Sibumasu Blocks. The central region of the Khorat Plateau is at present only a few hundred meters above sea level.

The generally accepted model for the region is that the continental collision between the Sibumasu Block and mainland Indochina Block occurred in the Late Triassic (Indosinian Orogeny). Uplift and orogenic faulting associated with this event led to the formation of intermontane thermal sag basins, which were rapidly infilled with Jurassic–Cretaceous continental sediments (Khorat Group and its equivalents) over a broad area from eastern Peninsular Malaysia across the South China Sea into the Khorat Basin of northeast Thailand, southern Laos, Cambodia and Vietnam (Racey, 2009).

According to Racey (2009) the sedimentary fill comprises a non-marine red bed sequence of the Khorat Group, which is unconformably overlain by continental evaporites and clastic deposits of the Albian–Cenomanian Maha Sarakham Formation and is underlain by Late Triassic fluvial and lacustrine sediments with associated volcanic rocks of the Huai Hin Lat and Lower Nam Phong Formations and Late Palaeozoic marine sediments (Figure 2.3). Traditionally the Khorat Group comprises six formations, which are from bottom to top: the Nam Phong, Phu Kradung, Phra Wihan, Sao Khua, Phu Phan and Khok Kruat Formation (Figure 2.3). Based on seismic and well data, the Nam Phong Formation varies in thickness from 2,500 m in the central portion of the basin to <500 m along its flanks. The formation is clearly divisible on seismic sections into an Upper Nam Phong Formation and Lower Nam Phong Formation separated by an unconformity. Thus according to Racey (2009) the Lower and Upper Nam Phong Formations do not belong to the Khorat Group which he considers as an essentially Lower Cretaceous unit. The Phu Kradung Formation varies from 1,200 m in the basin centre to around 500 m in thickness on the basin flanks. The Phra Wihan Formation varies in thickness from around 50 to 300 m, and the Sao Khua Formation varies widely in thickness from around 100 to 700 m. The Phu Phan Formation is generally 50–100 m thick, and the Khok Kruat Formation shows marked variations in thickness because of erosion, from 200 m in the northwest to 850 m in the southeast

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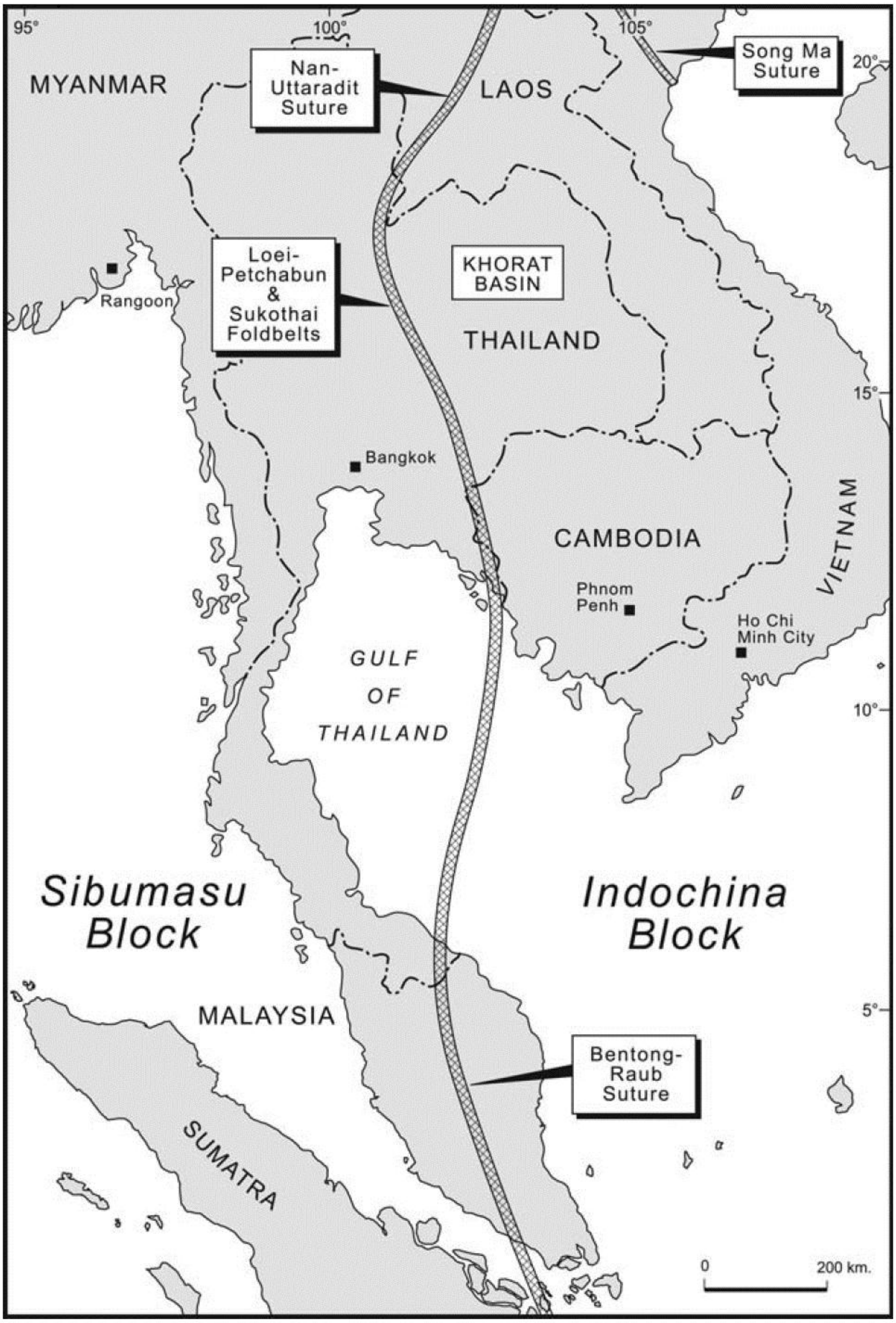

Figure 2.2 Inferred locations of the key sutures and blocks within the study area (Racey, 2009).

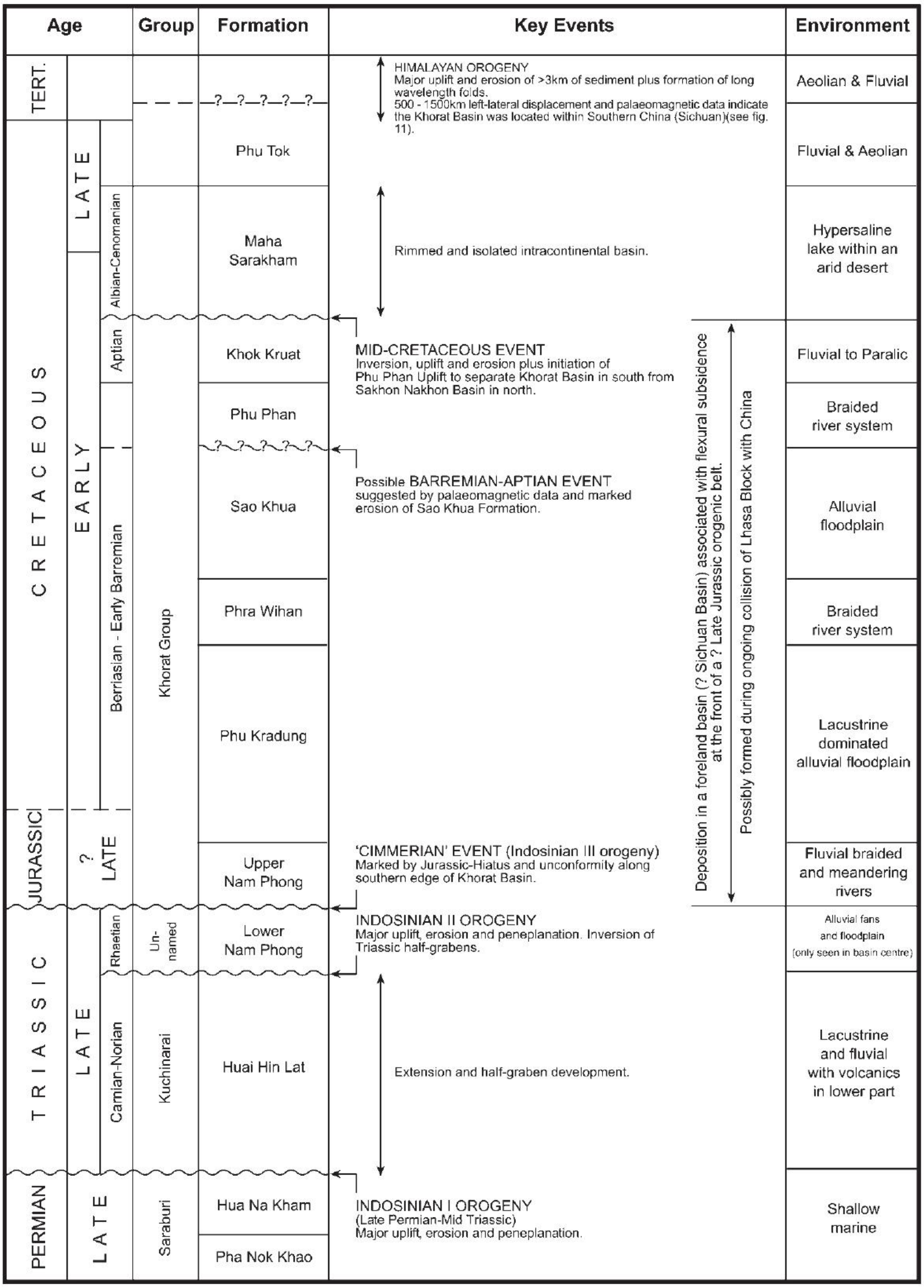

Figure 2.3 Revised stratigraphic column for the Mesozoic of NE Thailand with the main depositional environments and key tectonic events (Racey, 2009).

2.2 Distribution of the Khok Kruat Formation

Ward and Bunnag (1964) interpret as here named and described, the khok kruat Formation includes the lower part of the unnamed upper member of the Khorat series of Jalichan and Bunnag (1954). The type section of the Khok Kruat Formation is in Nakhon Ratchasima province along Thanon Mittraphap (Friendship Highway) between kilometer posts 207 and 239 where it is exposed only intermittently in outcrops and road material pits. Much more detailed information is provided by the log of water well M7 that was core-drilled by the Ground Water Section of the Department of Mineral Resources at Ban Khok Kruat about 500 meters north to northwest of km 238 and by wells M13 at km. 215.3 and M15 at 209.2. Well M7 penetrated the upper 295 m of the formation, M13 and M15 the lower 152 m. The boundary between the Khok Kruat Formation and the overlying unnamed salt-bearing rocks at the top of the Khorat Group is transitional, and marks a slight change in the topography as well as changes in lithology. Sandstone of the Khok Kruat Formation is more resistant than those of the overlying beds, and they form low, poorly defined cuestas in the topography. The thin gypsum beds in the upper part of the Khok Kruat Formation are succeeded by thick beds of gypsum and salt in the overlying rocks. The tops of sections 1 and 2 are in the boundary zone between the Khok Kruat Formation and the overlying rocks and the indicated thickness of the Khok Kruat Formation is 709 meters in section 1 and 432 meters in section 2. Cores from wells M7, M13 and M15 reveal that about 30% of the Khok Kruat Formation is sandstone in units up to 15 meters thick. The sandstone content decreases from about 60% near the base to 20% near the top. The sandstone are pale red to grayish red and reddish brown, thick bedded to flaggy, cross bedded in the thicker units and are usually friable and easily weathered. They are fine- grained varying to medium and very fine- grained; some beds are slightly to moderately calcareous, and some beds are moderately to slightly silty and/or micaceous. About one half of the exposed beds are slightly conglomeratic with pebbles of reddish brown caliche and siltstone and, rarely, of quartz and chert. The siltstones which are the main constituent of the Khok Kruat Formation are seldom exposed. Logs of the water wells reveal them to be similar in color but darker than the sandstone and many are slightly mottled, streaked or spotted with light greenish gray. They are calcareous and micaceous to about the same extent as

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the sandstone. Although not found in outcrop and exposures, gypsum occurs as thin beds and scattered crystals in some of the siltstones and sandstones that were penetrated in water well M7 and M11. Caliche-siltstone pebble calcareous conglomerates, similar to that that occur throughout the Khorat Group, are well M13 is light bluish-gray to pinkish gray and is exposed as large residual boulder. The thickest of these conglomerates found on the Khorat Plateau is near the top of section 1. The bed may exceed four meters in thickness and it is partly exposed in very large residual boulders that are quarried south of the highway at km. 236.4 for road building materials in the city of Nakhon Ratchasima province. Both of the conglomerates contain unidentified bone fragments, and the upper one has yielded unidentified teeth up to 2 cm long with a single blunt point at the middle of a serrated edge which extends the length of the tooth. A tooth found in a much thinner conglomerate near the top of section 2 is similar to one found in the Sao Khua Formation of section 4 that was identified in Hayami *et al.*, 1962) as originating from an ichthyosaur. The only occurrence of carbonaceous material noted in the Khok Kruat Formation is the coaly material and carbonaceous bands in sandstone that was cored in well M13. Thick, resistant beds are rare in the Khok Kruat Formation and thus the topographic expression is one of low relief and poorly defined cuestas with only minor escarpments. Although it is present in a broad belt bordering the topographically conspicuous the Phu Phan Formation, only section 1 and 2 of the present study include significant section of the formation.

The Khok Kruat Formation is assigned to the top of the Khorat Group, because the overlying the Maha Sarakham Formation is separated from the Khok Kruat Formation by an unconformity. Both formations are well distributed in the central low-lying areas of the Plateau and the outer parts of the Phu Phan Range bounded along the outer rims of the Phu Phan Formation with apparently conformable contacts. The sharp contact with the basal anhydrite of the overlying the Maha Sarakham Formation is observed and is reported on seismic profiles. In general, the formation consists of reddish brown, fine- to medium- grained sandstone, siltstones and mudstone, conglomerates are also present. The formation was deposited by meandering rivers system (Meesok, 2000).

According to Buffetaut *et al*., (2005), the age of the Khok Kruat Formation is fairly well constrained by biostratigraphical evidence. The occurrence of the peculiar

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freshwater hybodont shark *Thaiodus ruchae*, which is also known from the Aptian-Albian Takena Formation of Tibet, suggests a similar age for the Khok Kruat Formation (Cappetta *et al.*, 1990). In addition, palynomorphs indicating an Aptian age have been reported from its upper part (Sattayarak *et al.*, 1991; Racey *et al.*, 1996). An Aptian age is therefore well supported. The Khok Kruat Formation mainly consists of red siltstones, sandstones and conglomerates, indicative of a predominantly fluvial depositional environment (Racey *et al.*, 1996). Vertebrate remains occur, sometimes in abundance, in the various lithological types. Both body fossils and footprints have been reported. The main fossil localities are in Nakhon Ratchasima, Chaiyaphum, Khon Kaen and Ubon Ratachathani Provinces.

2.3 Fossil assemblages of the Khok Kruat Formation

The vertebrate assemblages record from the Khok Kruat Formation includes hybodont sharks comprise *Thaiodus***,** *Hybodus*, *Heteroptychodus*, *Khoratodus* and *Acrorhizodus* Cuny *et al.*, 2008, bony fishes comprise Sinamiidae *indet*., Semionotidae *indet*. Cavin *et al.*, 2009). As stated by Cuny *et al.*, (2005) the peculiar freshwater sharks of the Khok Kruat Formation may represent the result of endemic evolution from a basal stock which became isolated from the assemblages of other land masses at an early period (Jurassic?).

Tetrapods include cryptodiran chelonians of the families Carettochelyidae **(**Kizylkumemys khoratensis Tong et al., 2009**)** and Adocidae (*Shachemys* sp.**).** As remarked by Tong *et al.*, (2009) this turtle fauna resembles those of the late Early Cretaceous (Aptian-Albian) of Laos and the Late Cretaceous of Central Asia.

Various dinosaurs are known belonging to four different groups (Spinosauridae, Titanosauriformes, Psittacosauridae, Iguanodontidae). Buffetaut *et al.* (2005) reported the discovery of sauropod teeth resembling those of the Titanosauriformes *Phuwiangosaurus sirindhornae*, which is the most frequent dinosaur in the Sao Khua Formation (see also Suteethorn, 2009). No evidence of broad-toothed sauropods has yet been found in the Khok Kruat Formation, whereas they occur, although less frequently than *Phuwiangosaurus*, in the Sao Khua Formation. Peculiar theropod teeth of the *Siamosaurus* type were also reported by Buffetaut *et al.*, (2005) as

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well as classical theropod teeth. Buffetaut & Suteethorn, (2011) have recently described the iguanodontian *Siamodon* whereas Shibata *et al.*, (2011) described as *Ratchasimasaurus suranareae* other iguanodontian remains also found in the Khok Kruat Formation. The psittacosaurid *Psittacosaurus sattayaraki* was also described by Buffetaut and Suteethorn in 1992. Possible pterosaur teeth were also found in Sam Ran during this work, representing the first known pterosaur remains from the Khok Kruat Formation.

The crocodiles of the Khok Kruat Formation consist of *Khoratosuchus jintasakuli*, Lauprasert *et al.*, 2009 the most advanced non-Eusuchian crocodile from Southeast Asia. A dwarf atoposaurid and a possible goniopholid are also represented by skulls, teeth, jaws, osteoderms, etc. (Lauprasert, 2006; Lauprasert *et al.*, 2009).

Le Loeuff *et al.* (2005, 2009, and 2010) have studied the vertebrate footprints from Huai Dam Chum in northeastern Thailand (Nakhon Phanom province), describing theropod, ornithopod and crocodile footprints.

As noted by Buffetaut *et al.*, (2005) a major difference between the dinosaur assemblages from the Sao Khua and Khok Kruat Formations is that no ornithischians have yet been found in the Sao Khua Formation (which has yielded thousands of dinosaur bones), whereas they are abundant in the Khok Kruat Formation, with *Psittacosaurus* and advanced iguanodontians. This suggests an important faunal event during the time span separating the Sao Khua and Khok Kruat Formations, marked by the arrival of iguanodontians in South East Asia. As a result, the sauropod-dominated fauna of the Sao Khua Formation was replaced by an assemblage in which sauropods are still present but less diverse, and ornithopods play a significant part. The possible evolutionary and palaeobiogeographical reasons for this change are still obscure.

In other parts of eastern Asia, *Psittacosaurus* seems to be present at an earlier date in the Early Cretaceous. There is also some evidence that iguanodontians were present in Japan earlier than in Thailand (Buffetaut and Suteethorn, 1998b). The dinosaur assemblage from the Khok Kruat Formation clearly provides opportunities to investigate faunal change during the Early Cretaceous in South-East Asia, with potentially important consequences for our understanding of the evolutionary history of dinosaurs in Asia as a whole. It can be expected that continued field work in northeastern Thailand will add to our knowledge of this interesting fauna.

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Prehistoric Khorat special publication for celebrations on the Auspicious Occasion of His Majesty the King's 7 th cycle Birthday Anniversary 5 th December 2011 and the World Conference on Paleontology and Stratigraphy 2011 reported that during deposition of the Khok Kruat Formation, Nakhon Ratchasima province was still a land of dinosaur. Recently, fossil dinosaurs have been recovered from calcareous conglomeratic sandstone of the Khok Kruat Formation. The Thailand – Japan Dinosaur Excavation Project had unearthed a fossil site in Ban Saphan Hin, Mueang Nakhon Ratchasima, between 2007 and 2010. The excavations yielded over ten thousand pieces of bones, teeth, coprolites, shell plates, fins and scales of dinosaurs, pterosaur, turtle, crocodiles, fishes, and plant remains but they are mainly fragmentary. Some of them are well enough preserved, such as teeth of iguanodont and allosaur, dorsal vertebrae and distal part of a femur of iguanodont, partial dentary of hadrosaur, a tooth of pterosaur (a flying reptile), crocodile teeth, teeth of hybodont shark and tail fins and scale of Lepidotes fishes. All specimens are now housed at the Norteastern Research Institute of Petrified Wood and Mineral Resources. This assemblage of fossils has enabled researchers to depict the scenery of Cretaceous Khorat's landscape that was occupied by diversified species of dinosaurs and other land and flying reptiles together with aquatic creatures in the river like the hybodont shark and Lepidotes fishes. However, the systematic descriptions and identifications are still awaiting study and further excavations will be carried out in the early coming year. In 2011, two new species of iguanodontian dinosaurs have been reported from Ban Pong Malaengwan and Ban Saphan Hin, Mueang Nakhon Ratchasima district. The first species was described from a complete left densitary with no teeth designated as *Ratchasimasaurus suranareae* (Shibasa *et al.,* 2011). Another piece of fossil is described from a nearly complete left maxilla bearing several teeth designated as *Siamodon nimngami* (Buffetaut and Suteethorn, 2011). These two species are from two different fossil sites, about 500 meters from each other, but belonging to the same rock formation, the Khok Kruat Formation. The *Ratchasimasaurus suranareae* and *Siamodon nimngami* are considered as advanced iguanodontians. They diversified in Early Cretaceous, not only in the East but also in Southeast Asia. They may first appears in Asia before they dispersed to North America. However, future discoveries in North America may easily lead to revise this scenario (Shibasa *et al.,* 2011; Buffetaut and Suteethorn, 2011).

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2.4 Classification and distribution of Spinosauridae

Tor Bertin, 2010 reported, Spinosaurids, a highly morphologically specialized group of tetanuran theropod dinosaurs most distinctly characterized by their laterally compressed snouts and subconical crocodilelike teeth have undergone a substantial surge of study and interest in recent years. the clade was fist erected on the basis of a series of disarticulated bones and teeth uncovered in the Cenomanian dated Bahariya oasis of northcentral egypt by an expedition funded by the German paleontologist ernst freiherr Stromervon reichenbach (1870-1952) (Stromer, 1915). Among these fossils was a group of dorsal vertebrae with markedly hypertrophied neural spines (some up to 1.65 meters in height), which Stromer referenced when naming the taxon *Spinosaurus aegyptiacus*. however, the holotype and all referred material were demolished in an Allied air raid on the city of Munich April 12/13, 1944 and for some time remained something of a paleonto ogical mystery, thankfully, our understanding of these remarkable animals has grown a great deal due to the many discoveries made within the last several decades. partial skeletons have been described from the Cenomanian of egypt, the Aptian of niger (Sereno *et al.*, 1998) and the Barremian of england (Charig & Milner, 1997), as well as several remarkable cranial and axial fossils from what is likely the Albian and Cenomanian of South America. Aside from these fossils, spinosaurid material generally tends to be quite rare, most frequently consisting of isolated teeth and bone fragments. Recent phylogenetic analyses suggest that the clade can be split into two separate groups (Figure 2.4), primarily distinguishable by cranial and dental differences: the Spinosaurinae and Baryonychinae (Charig & Milner, 1986, Sereno *et al*., 1998, holtz *et al*., 2004). Cranially, baryonychines are distinguished from spinosaurines by an increased number of teeth in the mandible, a lesser degree of retraction of the anterior margin of the external nares (limited to the half of the maxillary tooth row), and differing premaxillary tooth size. Specifially, the premaxillary alveolus 1 is only slightly smaller in diameter than alveoli 2 and 3, whereas in spinosaurines the premaxillary alveolus 1 is less than one half the diameter of premaxillary alveoli 2 and 3. Though all spinosaurid teeth display a degree of conical shape (thought to be indicative of an at least partly piscivorous lifestyle, baryonychine teeth are generally more laterally compressed in form than those attributed to the Spinosaurinae. Additionally, spinosaurine teeth lack

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serrated carinae and on average display less posterior curvature when compared to their baryonychine counterparts (pers. obs.) whose teeth are typically quite finely serrated. Though ribbing or ‘flting’ structures have been reported on the crowns of both subclades, the texture tends to be more distinctive in spinosaurine teeth, whereas baryonychine ribbing is most often light and restricted to the lingual face. however, a fair amount of morphological variation has been reported for spinosaurid teeth, and identifiation should be done with a degree of caution. Spinosaurid fossil traces have been reported from europe, Asia, Africa, and South America (holtz *et al*., 2004). As yet, no confimed north American spinosaurid fossils have been found. they have a wide temporal distribution, with documented discoveries spanning the late Jurassic (Buffetaut, 2008b) through the late Cretaceous (Figure 2.5).

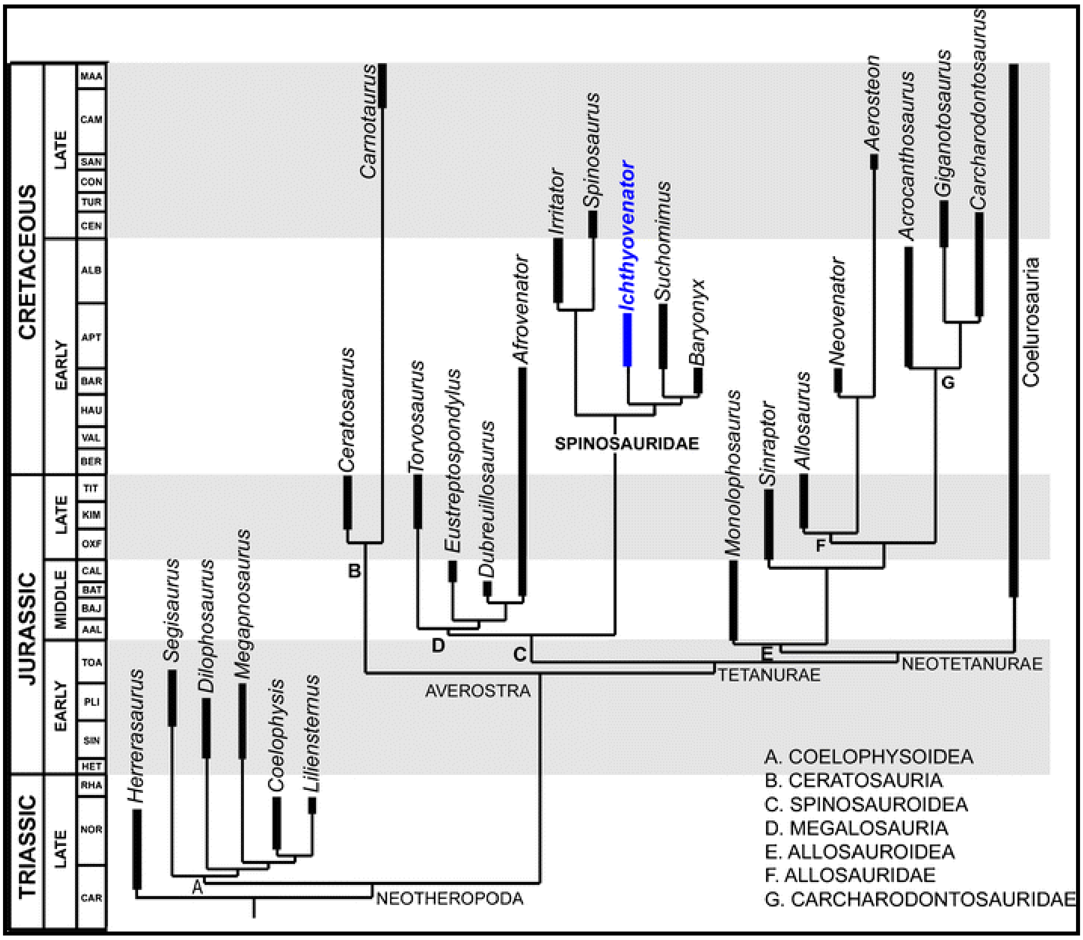

Figure 2.4 The phylogenetic of Spinosauridae (Allain *et al.*, 2012).

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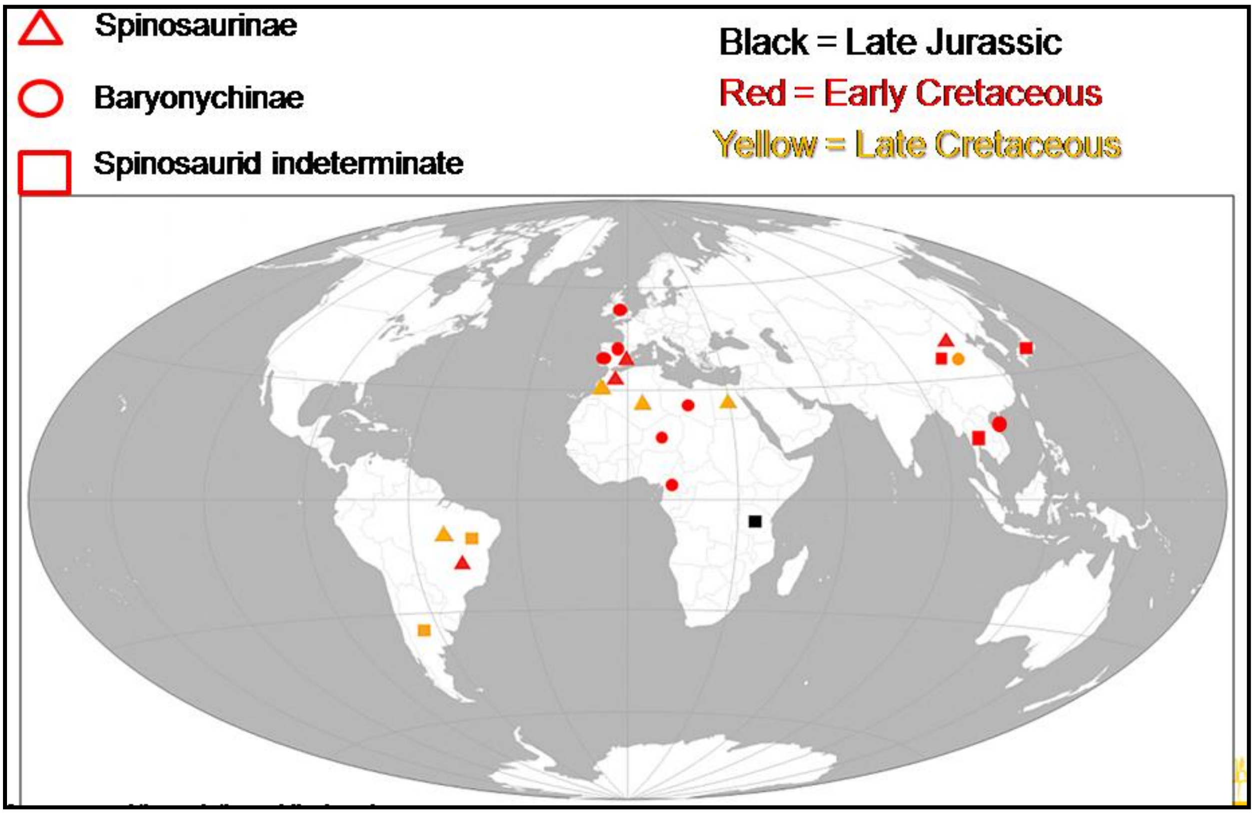

Figure 2.5 The biogeographical distributed of spinosaurid (http://commons.wikimedia.org).

2.5 Description and palaeoenvironment of the Spinosaurid

Spinosaurids are one of the most striking groups among the theropods, featuring an elongated, distinctive skull and conical teeth with fluted enamel and small deticles (Charing and milner 1997; Sereno *et al.*, 1998; Buffetaut 2013). These characters have been interpreted as evidence of a dominant piscivorous tendency in their eating strategies, a hypothesis supported by several observations relating to features such as the skull morphology, stomach content (Charing and milner 1997) and the oxygen isotopic composition of the bones (Amiot *et al.* 2010), though there is also evidence of spinosaurids feeding on other vertebrates such as pterosaurus (Buffetaut *et al.* 2004), fish indicated by a long and narrow snout (Taquet 1984) and ornithopods (Charing and milner 1997; Allain *et al.*, 2012).

Spinosaurids had a wide distribution both in space and time during the Late Jurassic, the Early Cretaceous and the older part of the Late Cretaceous. It has been thought that the first reported spinosaurids appeared during the Late Jurassic (Buffetaut 2012) although new research suggests that early spinosaurids are Middle Jurassic in age (Serano - Martinez *et al.*, 2016). They became abundant in the Early Cretaceous, disappearing during the Late Cretaceous (Hone *et al* 2010). Spinosaurids remains are mainly distributed in North Africa, Europe and South America althounght there is other evidence of them in Asia and Australia (Buffetaut and Ingavat 1986; Hasegawa *et al.* 2003; Allain *et al.* 2012).

Buffetaut and Ingavat (1986) reported about unusual theropod dinosaur teeth from the Sao Khua Formation of Phu Wiang (Northeastern Thailand) having a straight, faintly compressed crown with unserrated carinae and covered with well marked ridges. They referred these teeth to a new unusual theropod, *Siamosaurus suteethorni*, which they tentatively referred to the family Spinosauridae. The teeth of *Siamosaurus suteethorni*, which in some respects resemble those of fish-eating reptiles such as longirostrine crocodilians or plesiosaurs, can be interpreted in the same way.

A possible spinosaurid tooth from Gunma, in Japan, has been reported from the Sebayashi Formation, a unit considered as uppermost Barremian to Aptian in age based upon ammonites collected from the underlying Ishido Formation and overlying Sanyama Formation. The Lower Member consists of dark gray fine to medium grained thick sandstone with thin poorly sorted conglomerate layer. During the time of deposition of the Sebayashi Formation the sea level regime changed from transgression to regression. Yoshikazu and other (2003:1-2), described theropod tooth, the crown is conical and slender with very little recurvature, which distinguishes it from crocodilian teeth. It is slightly compressed labiolingually and the cross section is almost oval.
As preserved, the crown is 51 mm in TCH, 20 mm in FABL, and 14 mm in BW. A very small wear facet (reaching a maximum length of approximately 5 mm) is present. There are distinctive anterior and posterior carinae, but the anterior carina is not well preserved. It is not possible to determine if this is from the upper or lower jaw and it is also not possible to firmly identify which side of the crow is labial or lingual.
The crown surface is covered with distinctive striations. Each striation runs along almost the entire length of the crown, unlike the striation of some marine reptile. There are twelve striations on either side of the crown. Observations with high magnification reveal that the enamel has a finely granular appearance somewhat similar

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to that reported in *Baryonyx walker*, a spinosauroid from the Barremian Upper Weald Clay of England.It is almost identical to those of the possible spinosaurid theropod *Siamosaurus* from the Early Cretaceous Sao Khua Formation of Thailand and it is tentatively referred to the Spinosauridae. The tooth represents the second dinosaur species to be identified from the Sebayashi Formation and the second report of the family Spinosauridae in Asia.

An Early Cretaceous tooth from Napai Formation in Fusui county, Guangxi Zhuang Autonomous Region (South China), initially described as the sauropterygian *Sinopliosaurus fusuiensis*, was redescribed as belonging to a spinosaurid theropod closely allied to *Siamosaurus suteethorni*, from the Early Cretaceous of Thailand (Buffetaut *et al.,* 2008). Vertebrate remains, from purple marls intercalated with sandstone, were listed as consisting of a hybodont shark tooth, fragmentary plate of a cryptodiran turtle, five teeth of a pliosaurid (*Sinopliosaurus fusuiensis*), a spatulate tooth, three incomplete cervical vertebrae and ribs of a brachiosaurid sauropod (*Asiatosaurus kwangshiensis*) and four teeth of a megalosaurid theropod (*Prodeinodon kwangshiensis*). In 1980 Dong described a stratigraphic section of the Napai Formation which consists of red calcareous shale and sandy mudstones representing littoral lacustrine and lacustrine deposits. The lower section's purple red mudstones and shale produce *Asiatosaurus kwangshiensis, Prodeinodon kwangshiensis and Sinopliosaurus fusuiensis*.

Allain and other (2012) reported the discovery of a new spinosaurid theropod from the late Early Cretaceous, Grès supérieurs Formation. Grès supérieurs Formation of the Savannakhet basin of southern Laos recovered the skeleton of a new unquestionable spinosaurid that exhibits an extraordinary dorsosacral sail. The presently known postcranial material was found in close association within a layer of red sandstone, on a surface area of less than 2 m^2. Grès supérieurs Formation is considered here the lateral equivalent of the Khok Kruat and Phu Phan Formation in Thailand. The non marine Cretaceous bivalve *Trigonioides kobayashi – Plicatounio Suzuki* assemblage (Hoffet, 1973), which is the only known assemblage recovered in Tang Vay area suggests that *Ichthyovenator* is Aptain in age (Allain *et al*., 1999; Sha 2007). This new taxon, *Ichthyovenator laosensis* gen. et sp. nov., includes well – preserved and partially articulated postcranial remains. Although possible spinosaurid teeth have been reported from various Early Cretaceous localities in Asia, the new taxon *I. laosensis* is the first definite record of Spinosauridae from Asia.

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The Chenini sandstones (early Albian) of Jebel Miteur, which is part of the Dahar escarpment, near the town of Ghoumrassen, in southern Tunisia. Vertebrate specimens found in the bone - bed at Jebel Miteur include shark teeth, lungfish toothplates, *Lepidotes* - like teeth and scales, crocodilian teeth, sauropod bones, and teeth referred to the *Carcharodontosaurus* and *Spinosaurus*. The bone - beds of the Chenini sandstones were apparently deposited in a fluvial enviroment. The age of the Chenini sandstones is referred to the middle - late Albian on the basis of ammonites, including *Knemiceras*. A new specimen discovered incomplete spinosaurus dentary is extremely similar to the corresponding part of the type of *Spinosaurus aegyptiacus* STROMER, 1915, and is identified as *Spinosaurus* cf. *aegyptiacus*. A review of African spinosaurids shows that baryonychines were present in the Aptian, and apparently became replaced by spinosaurines in the Albian and Cenomanian, perhaps as part of a more general faunal change betwee the Aptian and Albian. Spinosaurines may have been derived from the less advanced baryonychines.

Jaw fragment bearing teeth found from the Barremian of Boca do Chapim (Lisboa e Setubal Province, Portugal). Boca do Chapim considered these marly sandstones as belonging to the Almargem Beds, of Aptian to early Albian age. Rey (1972, 1992, 2006) showed that they are in fact early Barremian in age. They are considered as lagoonal sandstones (Rey, 2006) filling a valley at the beginning of a transgressive phase. As described by Sauvage (1897 - 1898), the vertebrate assemblage from Boca do Chapim, identified mainly on the basis of isolate teeth, included a chimaeroid fish, the purported crocodilian *Suchosaurus girardi*, the theropod *Megalosaurus superbus*, the sauropod *Pleurocoelus valdensis* and the ornithopod *Iguanodon mantelli*. *Suchosaurus girardi* are redecribed and referred to the spinosaurid dinosaur Baryonyx, on the basis of comparison with *Baryonyx walkeri*, from the Barremian of England. This extends the geographical distribution of this unusual theropod genus to Portugal.

Spinosaurus aegyptiacus is a bizarre predatory dinosaur found in Upper Cretaceous rocks of the Bahariya Formation (Stromer, ref). Smith *et al.*, (2006) wrote that the Bahariya Formation is composed of variegated shales alternating with sandstone, siltstone and limestone. The shale is varicolored, thinly laminated, grayish green to green, calcareous and silty in part, the siltstone and sandstone is grayish white to yellowish white,

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glauconitic and pyritic. These rocks represent a gradational fining upward sequence that is conformable with the overlying Abu Roash. The formation is dated as early to middle Cenomanian (see Le Loeuff *et al.*, in press). Zobaa *et al.* (2008) noted the presence of a diverse marine dinoflagellate assemblage in comparison to terrestrially derived sporomorphs in the sieved slides, indicating a shallow marine depositional paleoenvironment in general for the studied sedimentary sequence. The majority of the dinoflagellates have short and thin processes, suggesting a near shore, moderate to high-energy paleoenvironment. This environment experienced a high input of phytoclasts. These results show that there is no discernible change in depositional environment for the Bahariya and basal Abu Roash, which is in contrast to the lagoonal environment inferred for the latter unit by Hantar (1990). Differences in interpretation may be due to prevailing local conditions within the juxtaposed basins in the Western Desert. The high abundance of *Afropollis* indicates an arid to semi arid warm climate (Herngreen *et al.*, 1996; Ibrahim, 2002; Mahmoud and Moawad, 2002). However, the occurrence of fern spores, mainly produced by hygrophilous plants, associated with freshwater algae suggests the possibility of local or seasonal humid conditions (Schrank and Mahmoud, 2000).

Some large theropod teeth found in the Eocenomanian of the Alcântara Formation, Itapecura Group (Northeastern Brazil) show the typical spinosaurine morphology while in others an intriguing morphology was observed: teeth combining typical features of the presence of spinosaurine spinosaurs (smooth carinae with wrinkles on its base) (Manuel Alfredo Medeiros, 2006). The Alcântara Formation outcrop extensively along the coast and consists in dominantly sandy deposits, with well cemented conglomeratic layers which have yielded a remarkable concentration of fossil material (Corréa Martins, 1997) reworked from continental deposits. The palaeoenvironmental conditions are interpreted as a dominantly arid to semi-arid landscape with large size vegetation restricted to the fluvial system, mainly estuaries, which supported the dinosaurian megafauna. Such conditions would have been maintained by a seasonal climate with a short but stormy rainy season

The result of Amiot *et al.*, (2009) reported about oxygen isotope compositions of continental vertebrate remains from eight localities of the Khorat Group have been used to investigate environmental conditions that prevailed in NE Thailand during the

Jurassic – Early Cretaceous. Ecological aspects of dinosaur faunas have also been inferred. When compared with various present-day tropical and subtropical climate estimate $\delta^{18}O_w$ values of past meteoric water for the Khorat Group suggest a transition from dry tropical climate with low amounts of precipitation for the Phu Kradung Formation to wet – dry tropical climates for the Sao Khua and Khok Kruat Formation, characterized by high amounts of seasonal precipitation of several thousand millimeters per year, similar to present – day monsoon climate. However, a possible high altitude origin of the low $\delta^{18}O_w$ values observed in some localities cannot be excluded. Significant offsets in $\delta^{18}O_p$ values observed between theropods, sauropods and the spinosaurid *Siamosaurus* are interpreted in terms of difference in ingested water sources (river, pond or plant water), and also suggest that *Siamosaurus* had semi-aquatic living habits similar to those of crocodilians or turtles.

2.6 Continental sedimentary environment

We define here following Laporte some sedimentary structures used in our discussion. Cross-bedding (or cross-stratification) refers to an internal layering of sedimentary grains that is inclined to the principal surface of deposition. Since the inclination of the cross-strata points in the direction of local current movement, it is possible to determine from an analysis of cross-bedding within a sedimentary rock not only the general current direction but also the direction of the sediment's source.

Graded bedding – the sediment deposited by a turbidity current is usually laid down in such a way that the coarse grains are dropped first, followed by the finer grains. This changes occurs when the current's velocity decreases, the coarsest pebbles and sand grains being deposited initially. This coarse layer will then be slowly buried by finer-grained sand, silt, and clay as they settle out of suspension from the overlying turbid water. This regular variation in grain size from the base of a sedimentation unit to the top is called graded bedding and although it can also be found in other sedimentary environments, it is quite typical of rock sequences laid by turbidity currents.

Ripple-marks – a surface of loose sediment may develop an undulating or rippled appearance as air or water currents move across it. Where the current is moving uniformly from one direction to another, the ripple-marks will be asymmetrical, with

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their stepper sides facing downstream (or downwind in the case of aeolian deposits), while oscillating currents will form symmetrical ripples. Like cross-bedding, asymmetrical ripple marks can be used to infer former current directions.

Harold G. Reading (2001) reported that these early environment models were created with limited understanding of the physical processes involved. This changed with the explosion of process sedimentology, particularly with the appearance in 1965 of the classic SEPM special Publication edited by Middleton (1965) and Allen's (1968) in depth study of the physical processes that formed sedimentary structures. From them on, it was possible to develop environmental models based on measurement of outcrops, particularly sequences and cycle in ancient rocks, to interpret sedimentary structures in term of physical processes and compare such structures and the composition of sedimentary rocks with comparable features in modern sediments.

The best known and most influential studies on fluvial sediments were those of Allen (1964, 1965a, 1970) who published a series of papers on the fining upward cycle of the alluvial Old Red sandstone of England and Wales interpreting them as a consequence of lateral migration of point bars in meandering rivers that periodically switched their course. The full cycle consisted of a sharp, challed base overlain by an intraformational conglomerate of caliche fragments that passed gradually upward through paralled – bedded, cross – bedded, cross – laminated sandstones to siltstone capped by calcrete soil bed. The meandering river model was used extensively by workers all over the word, sometimes to the detriment of alternative explanations for such fining upward cycle, demonstrating the danger of a single, simple model becoming too fashionable. One alternative model, particularly suitable for sediments deposited in semi arid climates, is that the cycle are the result of ephemeral rivers the flowed for limited periods of time, the channeling and deposition of sandstones occurring during the wet (pluvial) periods, with flows diminishing as rainfall is reduced. Another explanation for many of the smaller cycles is that they were caused by flash floods of very limited duration that can deposit graded beds of some thickness.

As noted by Einsele, gerharh (1991) the most distinctive features of fluvial systems are large- scale phenomena, such as the size and geometry of channels, their sinuosity and ability to migrate, associated compound bars, and the occurrence of more or less extended over bank deposits, natural levees, etc. In present-day fluvial environments,

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the channel system and its sinuosity are the most striking, diagnostic features. With the aid of these criteria, one can distinguish between several types of fluvial systems, although there are no sharp boundaries between these depositional environments (Figure 2.6)

1) Alluvial fans and fan deltas (bedload channels).

2) Braided rivers and braidplains (bedload channels).

3) Meandering river systems (mixed-load and suspended-load channels)

4) Anastomosed river systems (predominantly suspended-load channels).

The factors controlling these large-scale structures are more complex than those generating small- and medium-scale phenomena. In the case of meandering channels, for example, it is a general rule that the wave length and width of the meanders grow with increasing river discharge and slope of the river valley or fluvial plain. Braided stream systems with channels of low sinuosity tend to form in environments of large sediment supply and relatively steep gradients.

Braided steams usually consist of several individual channels separated by bars and islands and therefore form a wide shallow stream bed (Figure 2.7). Braided rivers develop near areas of high relief, which deliver relatively large amounts of debris, gravel and sand into the fluvial system. A typical vertical sequence of a proximal braided system is shown in Figure 2.7. The dominant sediments are multistory gravel unit, originating from channel bars. Many bars are somewhat graded. Interbedded with the gravels are thin lenses of sand representing deposition in abandoned channels or sand wedges at the edge of bars. In places, one can observe repeated successions of fining-upward gravel-sand sequences, 1 to 2 meter thick, but in general it is difficult to identify the bottoms of former channels and the geometry of their fills. The reason is that the underlying and neighboring sediments also consist largely of gravel. Downstream, the predominantly gravelly beds grade into beds consisting partly of smaller pebbles and sand. In addition, the bed forms and internal sedimentary structures progressively decrease in size.

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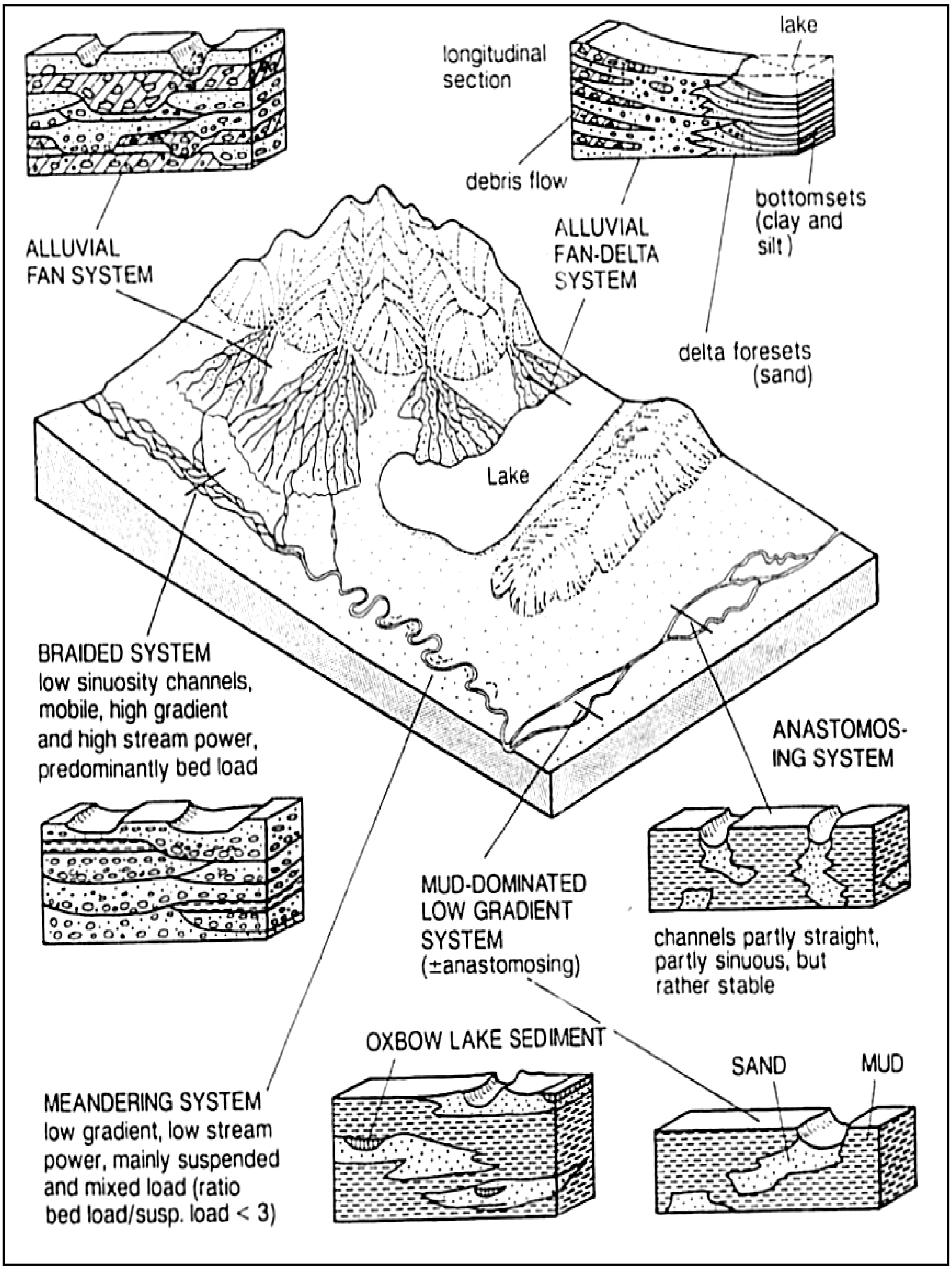

Figure 2.6 Principal types of fluvial system and generalized characteristics of their cross section (Gerhard Einsele, 1991).

Meandering river systems develop one principal, relatively narrow channel of high sinuosity. They are dominated by mixed load or predominantly suspended load; their overall sand content therefore often averages 20% to 40 %. If meandering rivers are associated with a wide floodplain, the channel sediments may be restricted to a comparatively narrow zone within the flood basin where they form a meander belt. The different architectural elements of the fluvial sediments, shown in figure 2.8, can be observed best in meandering systems. In a sinuous channel segment, one can distinguish the following morphological features and depositional sub-environments (Figure 2.8)

1) Channels and channel fills is usually covered by lag sediments consisting of the coarsest material transported by the river during peak flood. This channel lag may also contain mud clasts or blocks eroded from the banks. Lag sands and gravel usually accumulate between scour pools and form flat, elongate bars displaying either imbrications of gravel or crudely laminated and planar cross-beded gravelly sand.

2) Point bar and lateral accretion complexes accumulate on the inner sides of river bends, while on the outer side material from the bank is eroded. In this way, the curvature of the meander tends to become increasingly exaggerated until the river produces short-cuts, leaving behind abandoned channel segments (oxbow lakes, Figure 2.8a). Most of the point bar material is eroded from the upstream channel banks. It is deposited in areas of lower velocity turbulence. Because sediment move up and out of the channel onto the bar, cross sections of point bars often show fining-upward sequences, with sand on top of channel lags (Figure 2.8c and d). Similarly, the internal structures grade from horizontal bedding (upper flow regime) to large- and small- scale trough cross-bedding (lower flow regime). The most distinctive feature of point bars is lateral accretion (low-angle, “epsilon” cross - bedding) which may be visible at the surface by the development of a ridge- and –swale topography (Figure 2.8b). The swales can be filled with mud, and older portions of the point bar are covered by levee sands and silts or floodplain sediment. This idealized point bar architecture is often modified in nature by chute bars, small terraces associated with different water stages in the main channel, or other irregularities. The resulting internal structures of such a “ lateral accretion complex”, a term which is preferred by some experts on fluvial sediments, is less regular and more variable than the major architectural units of the fluvial deposition shown in Figure 2.6 and 2.8

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3) Chute bars result from chute channels which direct part of the river flow across the surface of a point bar during flood stage. In this way relatively coarse-grained bedload material can be deposited as lag or chute bar on the eroded top of a lateral accretion complex (Figure 2.8b and d). While channel lag deposits are common on the upstream part of the chute, the down-stream part is often characterized by imbricated pebble sheets and large-scale planar and trough cross-bedded sand.

4) Channel plugs (oxbow lakes) are infilling of cutoff meander segment (oxbow lakes). Since the further influx of bedload is terminated, the abandoned channel segments are slowly filled with fine-grained material washed in from the neighboring floodplain (Figure 2.8f). In humid climates, organic matter (including peat) may accumulate in the lake or swamp.

5) Levee and crevasse splay deposits. Many meandering channels are accompanied by flat ridges or dams sloping away from the channel into the floodplain. These levees are built up during moderate floods which just reach the elevation of the channel bank or ridge. Due to decreasing flow velocity, sand is deposited along the channel banks, grading into silt somewhat farther away. Locallt, channel water may spill over the levees into the floodplain, forming crevasse splays can also contribute to the buildup of the levees. The prevailing internal structures of these sand sheets may resemble those of thin sandy turbidies, showing some grading, horizontal lamination and small-scale ripple cross-bedding, including climbing ripples and occasional convolute or contorted cross-bedding. These structures are, however, often mashed or destroyed by the roots of vegetation. Whereas distal crevasse splays become interbedded with fine- grained floodplain deposits, levee sands often tend to be reworked by subsequence channel migration

6) Alluvial floodplain deposits accumulate during rare inundation. They consist predominantly of suspended load, i.e., silt and mud, though fine sand may also be present in areas where the peak flood currents are sufficiently strong to transport this grain size (Figure 2.8e). The deposits from individual large floods reach thicknesses of only a few millimeters or, locally, a few centimeters. Such thin beds may be either somewhat graded, or internally finely laminated or cross-bedded. A series of flood layers can show distinct lamination. Floodplains may be wetland and back swamps or areas of dessication and calcrete development. Therefore, primary sedimentary structures are

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often destroyed by vegetation, mud cracking, salt precipitation, concretion formation (such as carbonate nodules or caliche), and other soil forming processes.

7) Fluvial red beds. Originally gray or brown flood deposits may become red through time, if they contain little or no organic matter, as for example in arid and semi- arid regions. In this case, brownish iron hydroxides deposited with the original sediment can be later transformed into hematite and thus produce very fine- grained, evenly dispersed red pigment. Another mechanism generating red beds is the weathering of iron-bearing silicate minerals within the sediment during shallow – burial digenesis (Walker 1967; van Houten 1973; Füchtbauer 1988). Comparatively unstable minerals, such as biotite, hornblende, and smectite can release irons which, under oxic conditions, slowly form hematite.

8) Swamps. In humid climate and on very gently sloping alluvial plains, the groundwater level can reach the part of the interchannel area (cf. Figure 2.8c). These depressions are filled either with sediments delivered by crevasse spalays and peak floods forming flat, deltaic sequences and well – laminated fine muds or they accumulate organic detritus and peat. Numerous coal deposits, with individual coal seams usually limited in extent and thickness, formed on alluvial plains

Anastomosed river systems are predominantly suspended-load channels

9) Anastomosed rivers develop an inter – connected network of straight to sinuous channels, which are relatively narrow and deep (Figure 2.9). Because their banks are built up of fine-grained sediment, usually covered with vegetation, channels and islands are remarkably stable. The channels are filled with sand and gravel. Since vertical aggradations proceeds comparatively rapidly, rather thick and narrow ribbons of channel sand can form bounded by the sandy silts of the levees. Interchannel areas are topographically low relative to the channel levees and filled by crevasse splay marsh, and lacustrine sediments. On the widely extended river plain or in the wetlands between the channels, laminated silty clays and clayey silts accumulate. In addition, back swamp deposits and peats containing large amounts of organic matter and iron sulfides may develop. Such systems appear to result from (1) a sediment source rich in mud, (2) a very low river gradient, and (3) a seasonal water budget. To accumulate and preserve anastomosed river deposits of some thickness, a very low gradient in a subsiding basin has to be maintained for considerable time. This mechanism is possible in various

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tectonic basin settings, but foreland basins seem to be particularly well suited for the formation of anastomosed river sediments. In contrast to the braided and meandering river systems, anastomosed rivers and their deposits are known only from a limited number of recent and ancient examples.

10) Mud - dominated low-gradient rivers are, in contrast to anastomosed rivers, characterized by mud-rich channel fills, apart from muddy overbank fines. These braided or meandering river systems occur in areas of very low relief with seasonally or perennially hot, dry climates and deeply weathered clayey soils. In these cases, the mud occurs in sand-sized pedogenic aggregates, which originate from desiccation the land surface and on the channel floors during dry periods. Bioturbation and vegetation within the channels may aid in the generation of aggregates.
The aggregates are transported by running water like sand or small pebbles as bed (or traction) load over long distances.

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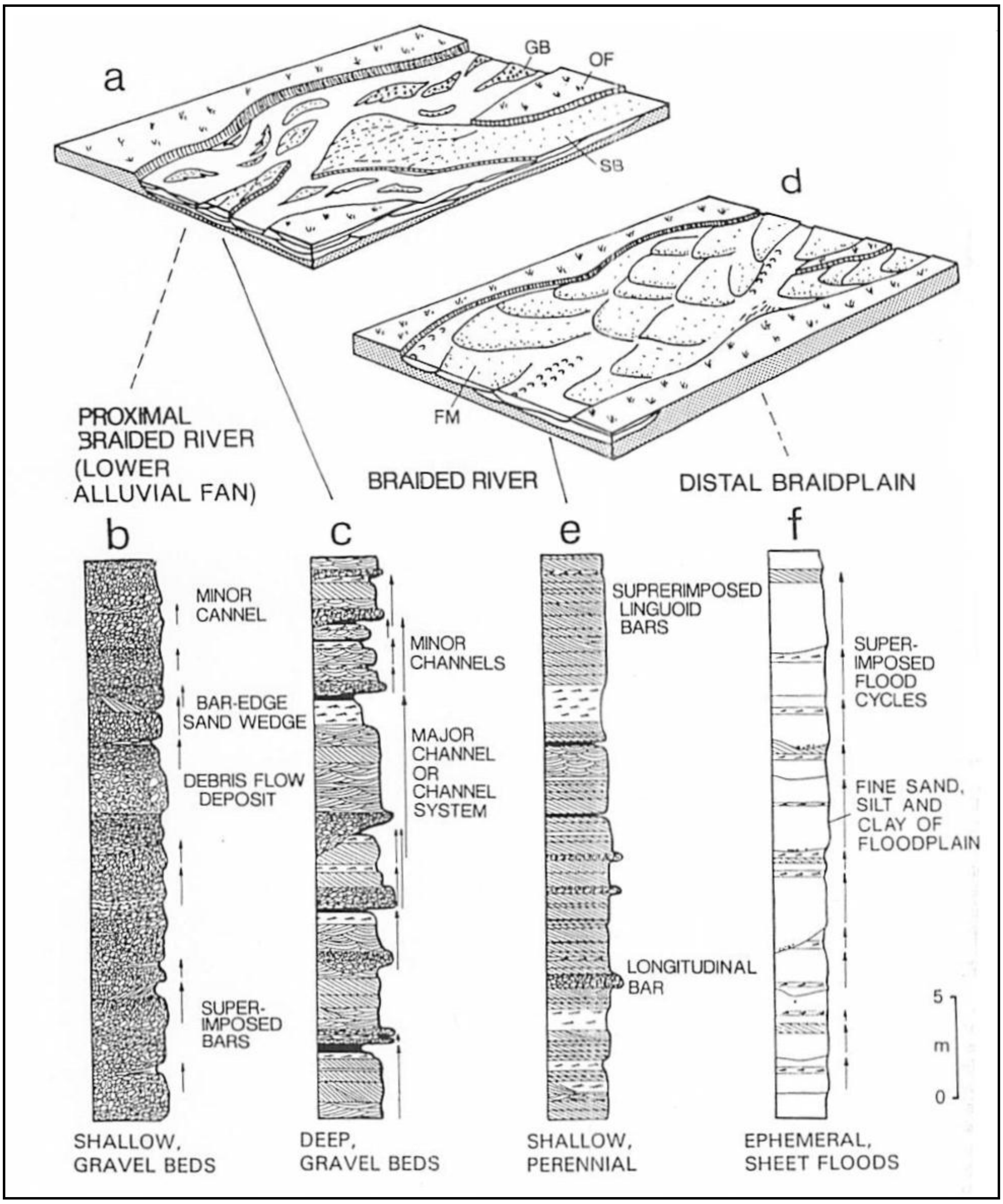


Figure 2.7 Braided river system; a-c. Proximal to middle reaches, gravel-dominated, b. or sand-dominated, c with minor proportion of gravel, d-f. Distal, sand-dominated system with wide channel and flat, linguoid sand bar, d and e. or wide floodplain rarely inundated by flash floods (Gerhard Einsele, 1991).

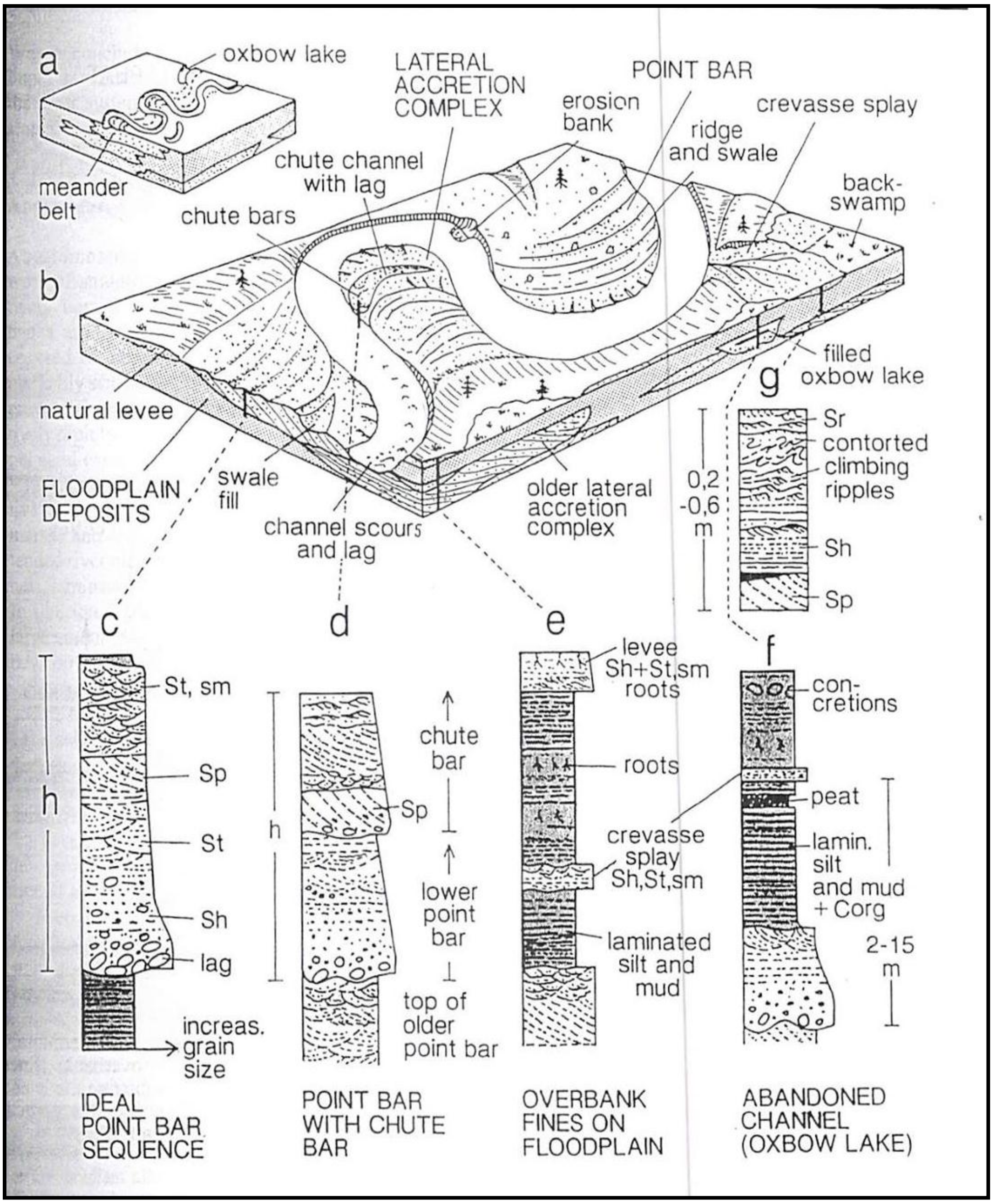


Figure 2.8 Meandering river system; a. Formation of sandy meander belt within a flood basin, b. Different subenvironments of meandering channel, e - g Characteristic vertical sections of the youngest sediments of the flood basin, h One fluvial (autocyclic) (Gerhard Einsele, 1991).

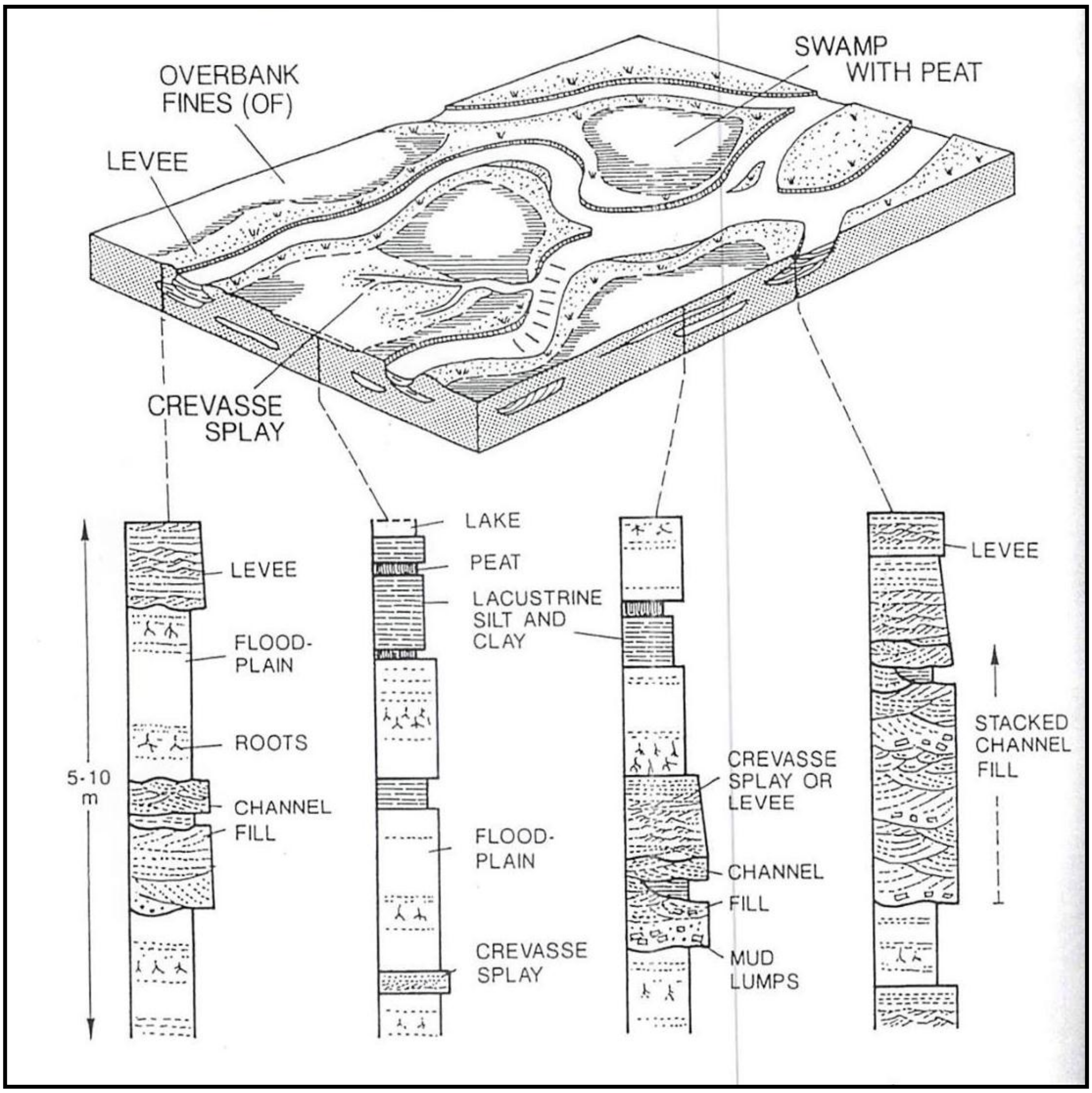


Figure 2.9 Anastomosing fluvial systems with low to high form isolated ribbon sand bodies, often accompanied by fine sandy to silty levee deposits. Lateral accretion deposits play a minor role. Crevasse channels and crevasse splays are common. Interchannel areas accumulate overbank fines (floodplain deposits) or shallow lascustrine muds and peat (Gerhard Einsele, 1991).

CHAPTER 3

METHODOLOGY

This chapter is arranged as follows:

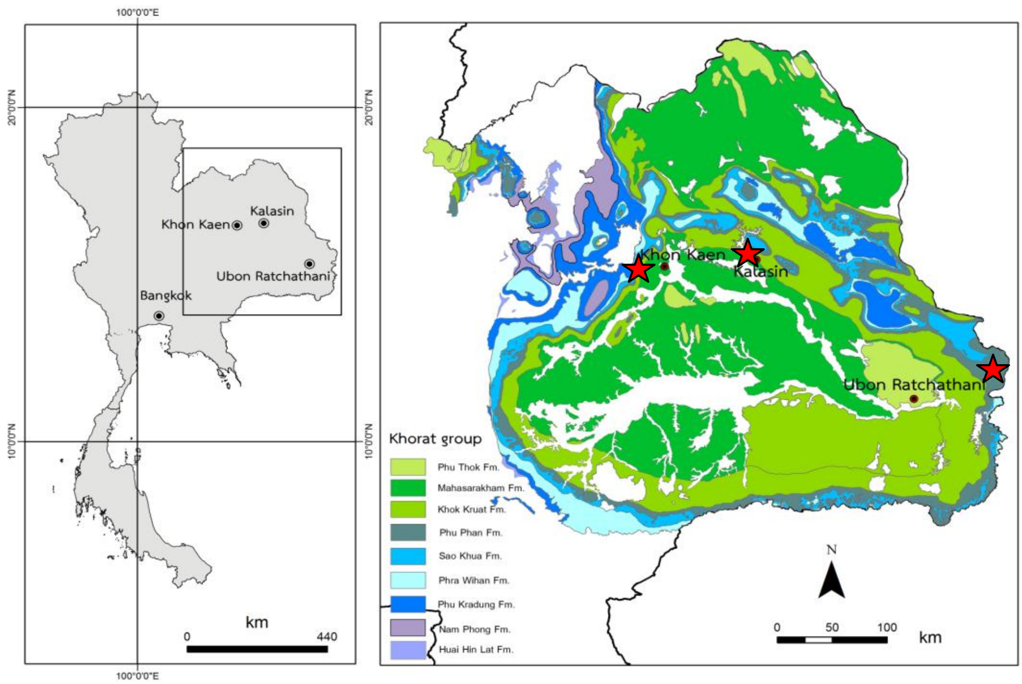
Studied locality

Field Work

Laboratory work

3.1 Studied locality

Three localities (Figure. 3.1) known to preserve abundant fossil material were studied: (1) the Lam Pao Dam locality Muang district, Kalasin Province (2) the Sam Ran locality Muang district, Khon Kaen Province (3) the Khok Pha Suam locality Sri Muang Mai district, Ubon Ratchathani Province



★ Study locality

Figure.3.1 Geological map of the Khorat Plateau showing three studied localities.

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3.1.1 Lam Pao Dam location

The spinosaurid specimen described here come from an outcrop at beside of the Lam Pao river and inside of the spring - way, near Lam Pao Dam, Lam Pao subdistrict, Muang district, Kalasin Province (Figure 3.2 - 3.3).

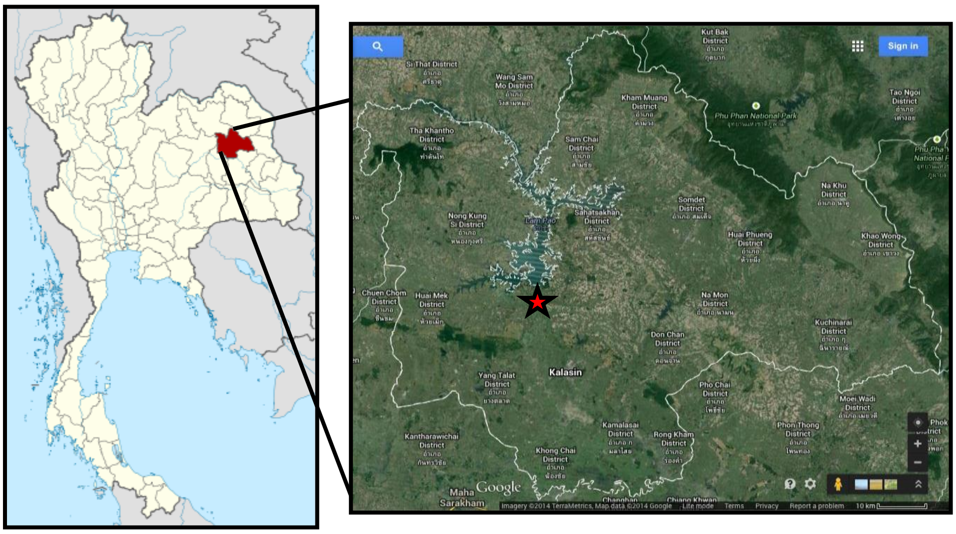

Figure 3.2 Geographical location of Lam Pao Dam, Kalasin Province. Exposures of location are marked in the red star.

Figure 3.3 Showing the outcrop of Lam Pao Dam, Kalasin Province.

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3.1.2 Sam Ran location

The partial skeletons of spinosaurid come from the outcrop near the railway close to the city of Khon Kaen; the specimen is currently being excavation by the Department of Mineral Resource (Figure 3.4 - 3.5).

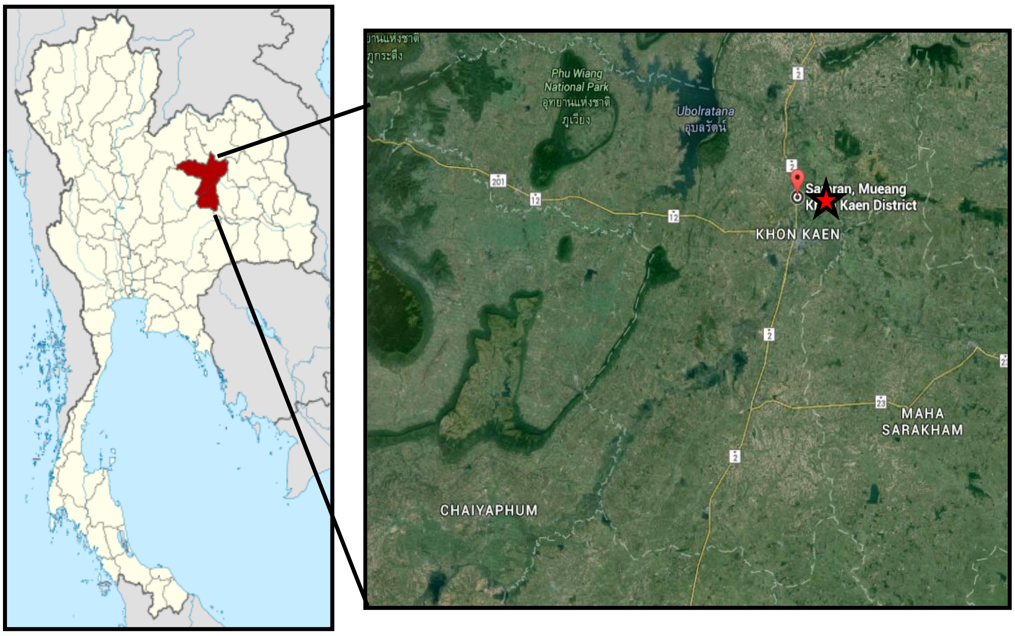

Figure 3.4 Geographical location of Sam Ran, Khon Kaen Province. Exposures of location are marked in the red star.

Figure 3.5 Showing the outcrop of Sam Ran, Khon Kaen Province.

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3.1.3 Khok Pha Suam location

We found the teeth of spinosaurid on the erosion surface; from the outcrop in Khok Pha Suam locality, Sri Muang Mai ditrict in Ubon Ratchathani province. (Figure 3.6 - 3.7).

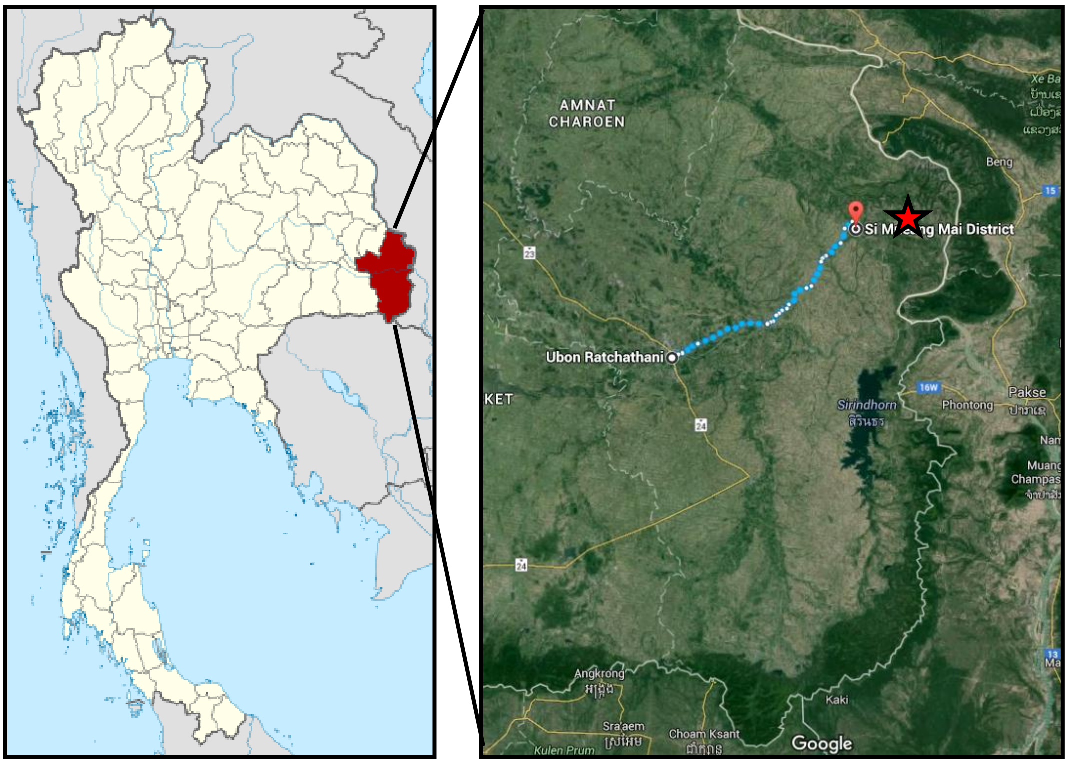

Figure 3.6 Geographical location of Khok Phu Suam, Ubon Ratchathani province. Exposures of location are marked in the red star.

Figure 3.7 Showing the outcrop of Khok Phu Suam, Ubon Ratchathani province.

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3.2 Field Work

Field works include planning and collecting data.

Planning and collecting.

Following literature review, the first step involves mainly data collection in order to acquire preliminary available information about the study area and relevant information for subsequent step.

Field survey

Field investigation includes the establishment of a geological map and sample collection through the organization of paleontological excavations. The lithostratigraphic columnar sections were made for the localities of Lam Pao Dam locality Sam Ran locality, Khok Pha Suam locality and Ban Sapan Hin locality

Description of a rock unit should include colour (fresh and weathered); lithologic composition; grain size, sorting and shape; sedimentary structures; indurations; type of cement; fossil content and pedogenic features. The nature of the contacts bounding a unit is extremely important to the palaeoenvironment. Contacts are most often characterized as erosional (underlying beds or structures are truncated), sharp (no truncations but knife – edge change in lithology) or gradational. The geometry of a rock unit (lenticular, tabular, wedge - shaped) should be determined whenever possible. Field descriptions can be augmented by detailed petrography.

Palaeontology

A database was created for all the fossil specimens recovered from the three localities and stored in the Sirindhorn Museum, Kalasin Province and Palaeontological Research and Education Centre, Mahasarakham University.
The material was measured and photographed at Phu Wiang Fossil Research Center and Dinosaur Museum.

Analysis and conclusion

The palaeontological results are combined with the analysis of lithology and sedimentary structures. All data were discussed and used for the reconstruction of palaeoenvironments of the Khok Kruat Formation.

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3.3 Laboratory work

1. List and determination: A Selection of the specimens is made with the specific data and quality of preservation (Figure 3.8).

2. Measurements: The material is measured in length and width (Smith et al., 2005).

3. Illustrations and photographs: Drawings are made from the photographs with the scale indicated on the figures (Figure 3.9).

4. Description and interpreting the specimens in detail, for example, the characters of the teeth in the term of anatomy. We follow the morphometric terminology (Figure 3.10) definitions of Smith et al (2005).

Mesial: Toward the premaxillary symphysis.

Distal: Away from the premaxillary symphysis.

Apical: Toward the tip of the crown.

Basal: Toward the base of the crown.

Labial: Toward the lips.

Lingual: Toward the tongue.

The crown base length (CBL) is the mesiodistal length of the crown at the level of the cervix; the crown base width is the labiolingual width of the crown at the cervix level, perpendicular to CBL. The crown base ratio (CBR) is the ratio of CBW to CBL and shows the labiolingual compression; crown height (CH) is the basoapical extent of the distal margin of the crown, from the most distal point of the cervix to the most apical point of the apex. The crown height ratio (CHR) is the ratio of CH to CBL and shows the crown elongation.

The apical length (AL) is the basoapical extent of the mesial margin of the crown. The mesial serration density is number of denticles per mm on the mesial margin; initials change according to the position of the denticles (MA refers to mesioapical denticles per mm; MC refers to mesiocentral denticles per mm;MB refers to mesiobasal denticles per mm). The distal serration density is number of denticles per mm on distal margin (DA, distoapical denticles per mm; DC distocentral denticles per mm; DB distobasal denticles per mm). The average mesial serration density (MAVG) is the arithmetic mean of denticles per mm along the mesial carina (MA+MC+MB/3). The average distal serration density (DAVG) is the arithmetic mean of denticles per mm along the distal carina (DA+DC+DB/3).

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Figure 3.8 The specimens of spinosaurid teeth from Khok Kruat Formation.

Figure 3.9 Showing are made from the photographs with the scale indicated on the figures.

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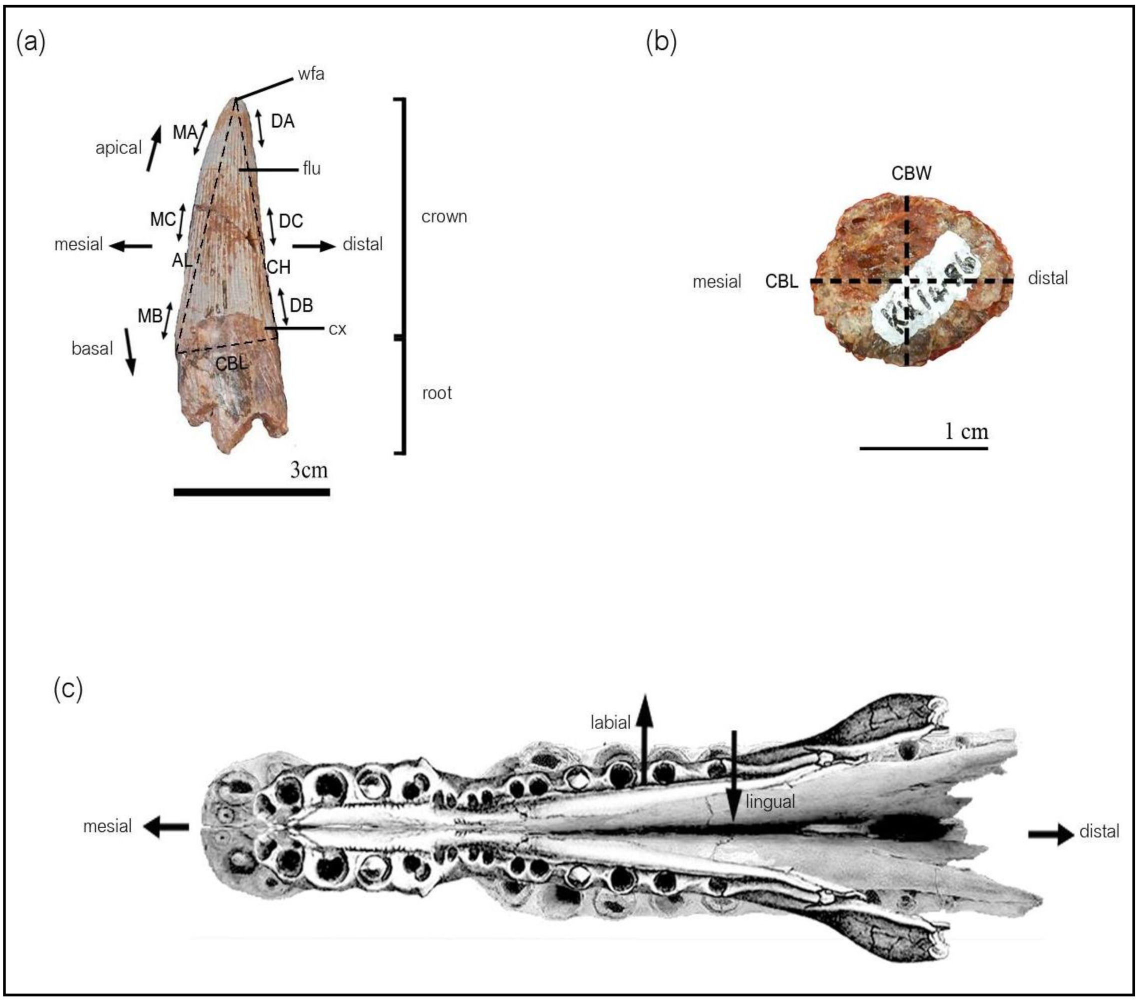

Figure 3.10 Positional and tooth nomenclature; (a) Spinosaurid tooth in lateral view, (b) Cross – section of the tooth at the level of the cervix, (c) Dorsal view of an upper jaw of *Spinosaurus* (Modified from Alonso Antonio *et al.*, 2015 by Ployphan Chittarach 2017).

CHAPTER 4

RESULT

Sediments of the Khok Kruat Formation have been observed and recorded in order to interpret the environment of the Early Cretaceous of the Khorat group in Thailand. The lithostratigraphic, sedimentary structures, type of Spinosaurid and accompanying vertebrate fossil fauna of three localities were studied, i.e. Lam Pao Dam (Kalasin Province) Sam Ran (Khon Kaen Province), and Khok Pha Suam (Ubon Ratchathani Province).

4.1 Lam Pao Dam locality

4.1.1 Lithostratigraphic and sedimentology

This section was made clearly at beside of the Lam Pao River and near the spillway; thickness of this section is about 6.5 meters. (Figure 4.1)

Lithology and sedimentary structure: The Lam Pao Dam sedimentary sequence consists of stacked fining-upward sequences, each defined by a basal reddish purple calcareous pebble to cobble conglomerate grading upward into reddish brown sandstone. The dip of these strata is 02/145 to south-east. A repetitive cycle of sandstone interbedded with thin siltstone and claystone at the top of the upper layer can be observed.

The lower part is 2 meters thick. These are sequences of reddish brown to maroon sandstone intercalated with reddish brown to maroon siltstone. The strata are medium to thick-bedded, fine-to medium-grained, rounded, moderately sorted sandstone. The beds of sandstone show small cross-bedding and rip up casts in medium-grained sandstone. The bottom of the sequence has a conglomerate, maroon in color

The middle part shows 1.6 meters of cycle of the well bedded medium to coarse grained reddish brown sandstone interbbeded well thin bedded greenish gray siltstone. Abundant bone fragments and teeth of spinosaurids, crocodile, turtle, bony fishes and shark are preserved in calcareous pebble-cobble conglomerate layers. Most

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of them are incomplete except some teeth and some scales. The bottom of the sequence has mud cracks, ripple-marks and burrows.

The upper part is 2.4 meters thick. These are very clearly zones with cycles of siltstone interbedded claystone. The strata are thin to medium-bedded, very fine to medium -grained sandstone.

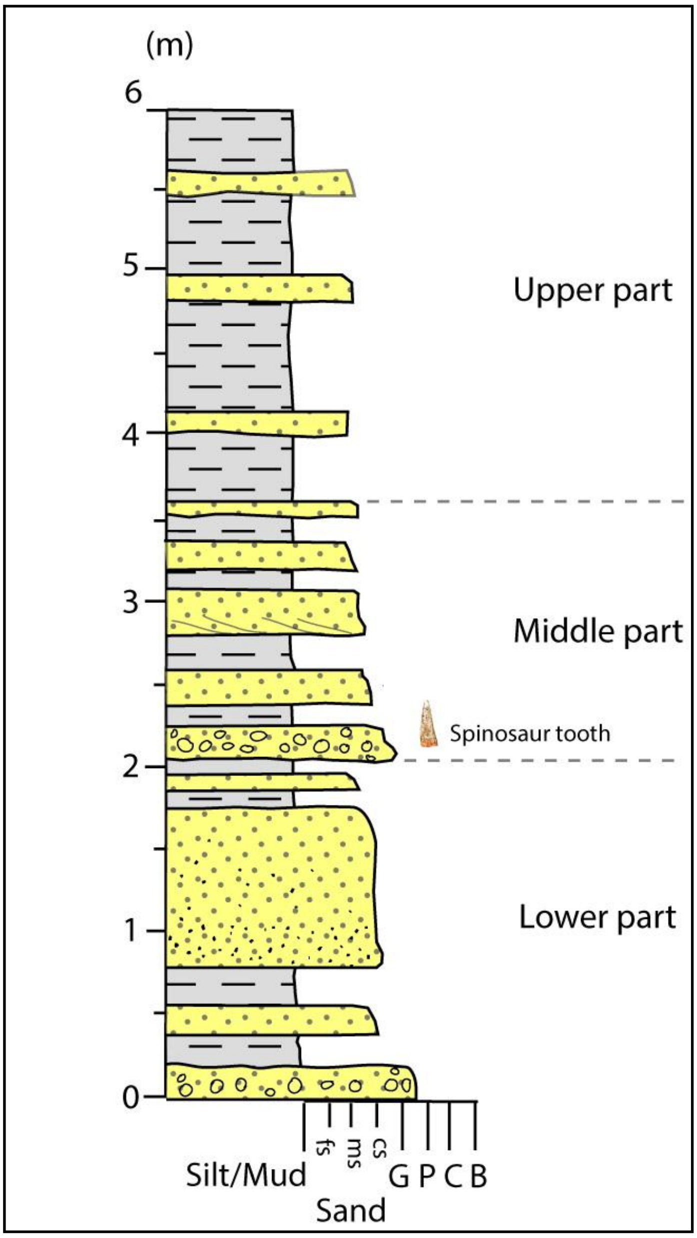

Figure 4.1 The lithostratigraphical column of Lam Pao Dam locality.

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4.1.2 Type of spinosaurid material

Material: PM2016 – 1 – 007, PM2016 – 1 – 008, PM2016 – 1 – 009 and PM2016 – 1 – 010 (Table 4.1)

All the teeth are not complete and no root. PM2016 – 1 – 009 and PM2016 – 1 – 0010 show a finely ridge than PM2016 – 1 – 007, PM2016 – 1 – 008. The ridge and the enamel surface of the crown are different kinds of description. Based on the number of ridge and striation, two morphotypes are recognized:

Morphotype I:

Total length of the tooth is 60 mm, the mesiodistal length of the crown at the level of the cervix is 16 mm, the width of the crown base is 11 mm, the ratio of the crown base width to the crown base length is 0.68, the height of the crown is 46.3mm, the ratio of the crown height to the crown base length is 2.89 and the basoapical extent of the mesial margin of the crown is 52.3 mm (Figure 4.2 a - c). The cross – section is oval in shape and well – pronounced carinae. The teeth are present distinct ridges. Carinae are present clearly extending from the base of the crown to its apex. The serrations of carinae are unclear. They are irregular morphology similar to undulating rope. Enamel surface of the crown are smooth (Figure 4.2 d) while base of the crown enamel surface show the wrinkled (Figure 4.2 e). The crowns show mesiodistal curvature. Number of ridge on each side of PM2016 – 1 – 009 and PM2016 – 1 – 010 is finely than PM2016 – 1 – 007 and PM2016 – 1 – 008, about 32.

Morphotype II:

Total length of the tooth is 69.7 mm, the mesiodistal length of the crown at the level of the cervix is 15 mm, the width of the crown base is 14.6 mm, the ratio of the crown base width to the crown base length is 0.97, the height of the crown is 56.8 mm, the ratio of the crown height to the crown base length is 3.78 and the basoapical extent of the mesial margin of the crown is 59.9 mm (Figure 4.3 a - c). The cross – section is sub - oval in shape and well – pronounced carinae. The teeth are present distinct ridges. Carinae are present clearly extending from the base of the crown to its apex. The serrations of carinae are unclear. They are irregular morphology similar to undulating rope. Enamel surface of the crown and base of the crown enamel surface show the wrinkled (Figure 4.3 d - e). The crowns show mesiodistal curvature. Number of ridge on each side is about 18.

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Table 4.1 Teeth characters from Lam Pao Dam locality, Kalasin Province.

character	PM2016 – 1 – 007	PM2016 – 1 – 008	PM2016 – 1 – 009	PM2016 – 1 – 010
The crown base length (CBL*)	15 mm	7.1 mm	16 mm	32.6 mm
The crown base width (CBW**)	14.6 mm	4.7 mm	11 mm	22.7 mm
The crown base ratio (CBR***)	0.97	0.66	0.69	0.69
The crown height (CH****)	56.8 mm	24.6 mm	46.3 mm	75.1 mm
The crown height ratio (CHR*****)	3.78	3.46	2.89	2.30
The apical length (AL******)	59.9 mm	25.2 mm	52.3 mm	77.6 mm
Tooth crown sub-oval to sub-circular in cross-section	yes	yes	yes	yes
Presence of flutes	yes	yes	yes	yes
Carinae bearing 6 or more denticles per mm	no	no	no	no
Enamel surface of the crown	wrinkled	wrinkled	smooth	smooth
Base of the crown enamel surface	wrinkled	wrinkled	wrinkled	wrinkled
Number of flutes	11	18	32	36
45 degree orientation of enamel sculpture near interdenticle sulci	no	no	no	no
Well-pronounced carinae	yes	yes	yes	yes
Curvature of the crown	yes	no	yes	no

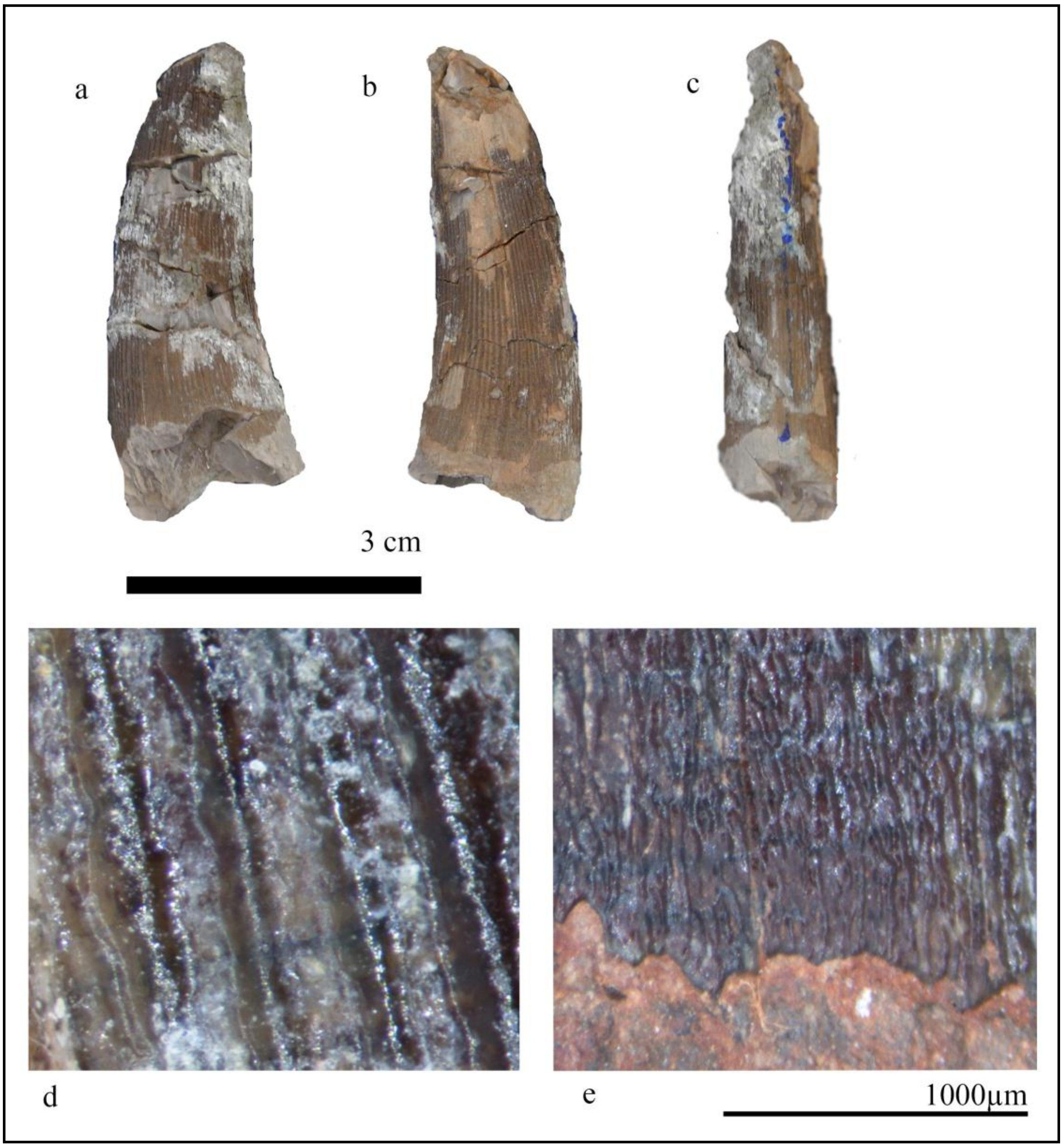

Figure 4.2 Spinosaurid (PM2016 – 1 – 009) isolate tooth from the Khok Kruat Formation in Lam Pao Dam locality, Kalasin Province; lingual (a) labial (b) anterior (c) smooth enamel surface of the crown (d) wrinkle base of the crown enamel surface; Scale bars: 3 cm (a - c) and 1,000 µm (d - e).

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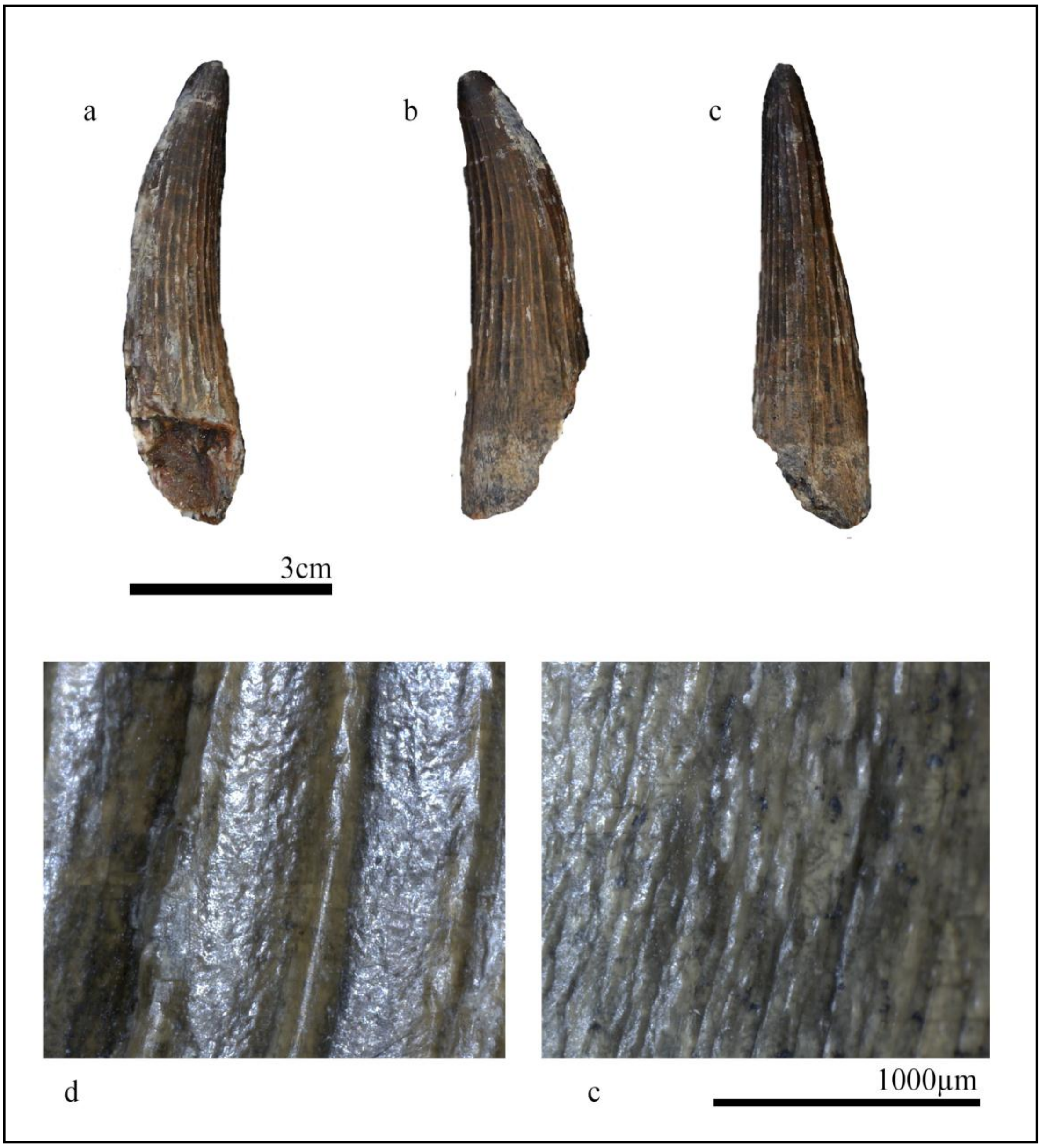

Figure 4.3 Spinosaurid (PM2016 – 1 – 007), isolate tooth from the Khok Kruat Formation in Lam Pao Dam locality, Kalasin Province; lingual (a) labial (b) anterior (c) wrinkle enamel surface of the crown (d) wrinkle base of the crown enamel surface; Scale bars: 3 cm (a - c) and 1,000 μm (d - e).

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4.1.3 Accompanying vertebrate fossil fauna

The vertebrate fauna of the Lam Pao Dam has been found the teeth of sharks, teeth and scale of actinopterygian fishes, turtle carapace fragment, scutes and teeth of crocodilians, teeth of large theropod dinosaurs (including the teeth of spinosaurid specimen) fragmentary bones and theropod footprint (Table 4.2).

4.1.3.1 Sharks

The locality has yielded rich assemblages of freshwater hybodont sharks. An isolated teeth of fourth hybodont species are described from Lam Pao Dam, consists of *Hybodus aequitridentatus*, *Heteroptychodus steinmanni*, and *Khoratodus foreyi*.

4.1.3.2 Fishes

The locality has found fish teeth and scales; there is only one fish tooth similar to Lepidotes in the parallel dot on surface scales with button teeth shape. Fish remains are rare scales, there are that found on the surface in calcareous pebble – cobble conglomerate. The fish specimens of large scale represent a new taxon (sp. A), smooth and rough surface scales, but not clear.

4.1.3.3 Turtle

Turtle remain is very rare and fragmentary, there are slightly and small pieces. Several specimens cannot identify from taxon, but also indicate the environment of freshwater.

4.1.3.4 Crocodile

The teeth crocodylomorphs have been found a lot of this locality, consists of good preservation and fragmentary, all teeth crocodylomorphs indicate by slender shape and ornamentation with alternative grooves and ridges indicate that these teeth had evolved for predating on similar Goniopholididae by Komsorn (2006).

4.1.3.5 Theropod

We found the teeth and the footprint of large theropod. The teeth of theropod dinosaur show difference in size and morphology. One specimen looks like blade, with serration on the both margins and D-shaped in cross-section. Another one showing short conical cone – shaped crown, extremely reduced serrations and clear robbing have been found. The possible theropod footprint show characteristic is bipedal gait, which the size and shape of these footprint is similar to large theropod described by Thulborn (1990).

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4.1.3.6 Ichnofossils

The locality has been found the theropod dinosaur footprint, burrow such as Lockeia, Phycodes, Planolites and Skolithos. The trace fossil provides us with indirect evidence of palaeoenvironment.

4.1.4 Palaeoenvironmental interpretation

The presence of lithostratigraphy and sedimentary structure such as stacked fining-upward sequences, small cross-bedding, rip-up clast and conglomerate at the bottom sequences indicate high – energy current, meandering channel conglomerates deposit or point – bar deposit (Figure 4.4). The poor preservation of the fossil, this locality has found the only teeth and scale of fish, shark, crocodile and theropod dinosaur. The trace fossil, such as theropod dinosaur footprint, Lockeia, Phycodes, Planolites and Skolithos are indicated moderately to well drain floodplain. It could have been arid – semiaridity in subtropic climate, indicated by the caliche-siltstone granule calcareous sandstone deposits.

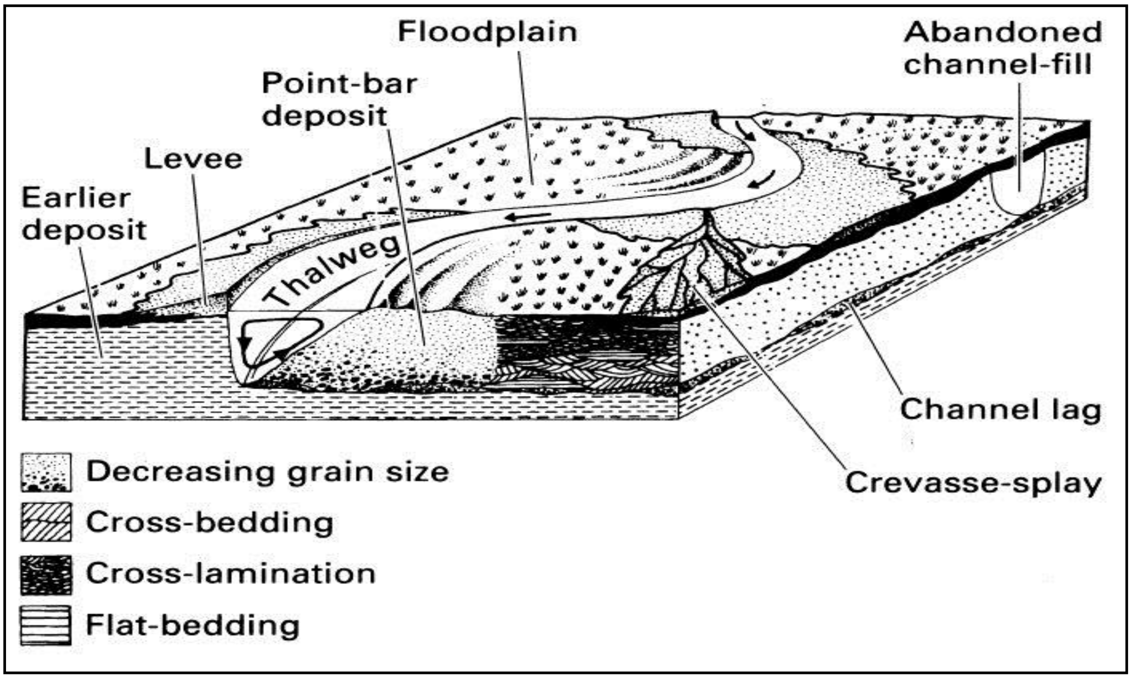

Figure 4.4 Model of channel is that of a meandering river, which consists of point – bar deposit in Lam Pao Dam locality, Kalasin Province (Allen, 1964).

4.2 Sam Ran locality

4.2.1 Lithostratigraphic and sedimentology

This section was made at the outcrop near the railway close to the city of Khon Kaen; the thickness of this section is about 4.5 meters (Figure 4.5).

Lithology and sedimentary structure*:* The deposits exposed at Sam Ran are reddish brown, pedogenetically-modified siltstones trisected by rip-up cast weathering siltstone. The dip of these strata is 10/125 to south-east.

The lower part shows 0.5 meters, which has fining-upward sequence of siltstone interbedded with fine- to meduim-grained sandstone where the fossils were found.

The middle part, which is 1.5 meters thick, consists of reddish brown and thin well-bedded siltstone interbedded with fine- to medium- grained, very thin to thin bedded sandstone. The bed of sandstone shows load-cast, rip-up cast and large-scale horizontal cross- bedding; the dip of cross-bedding is 19/195 to S-SW.

The upper part shows 2.5 meters thick weathering zone with load- cast, rip-up cast and horizontal cross-bedding. The sediment consists of medium- to coarse- grained reddish brown and thick to very thick bedded sandstone interbedded thick to very thick bedded siltstone.

4.2.2 Type of spinosaurid material

Material: PM2016 – 1 – 001 and PM2016 – 1 – 002 (Table 4.2)

Specimens are incomplete. The tip of PM2016 – 1 – 002 is broken while PM2016 – 1 – 001 is preserved only part of the crown to the tip. Total length of the tooth is 20.8 mm, the mesiodistal length of the crown at the level of the cervix is 12.8 mm, the width of the crown base is 9.5 mm, the ratio of the crown base width to the crown base length is 0.74, the height of the crown is 20 mm, the ratio of the crown height to the crown base length is 1.56 and the basoapical extent of the mesial margin of the crown is 21.7 mm (Figure 4.6 a - c). The cross – section of these teeth are oval in shape. The teeth show well – pronounced carinae and shape ridges. The carinae are present on the mesial and distal margins of the teeth. They are slightly serrated. The ridges are lightly undulating and presence of flutes Enamel surface of the crown is smooth and resorption (Figure 4.6 d) while base of the crown show the

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wrinkled which similar to the tip of apex (Figure 4.6 e). Number of ridge on each side of PM2016 – 1 – 001 is 21 and PM2016 – 1 – 002 is 22.

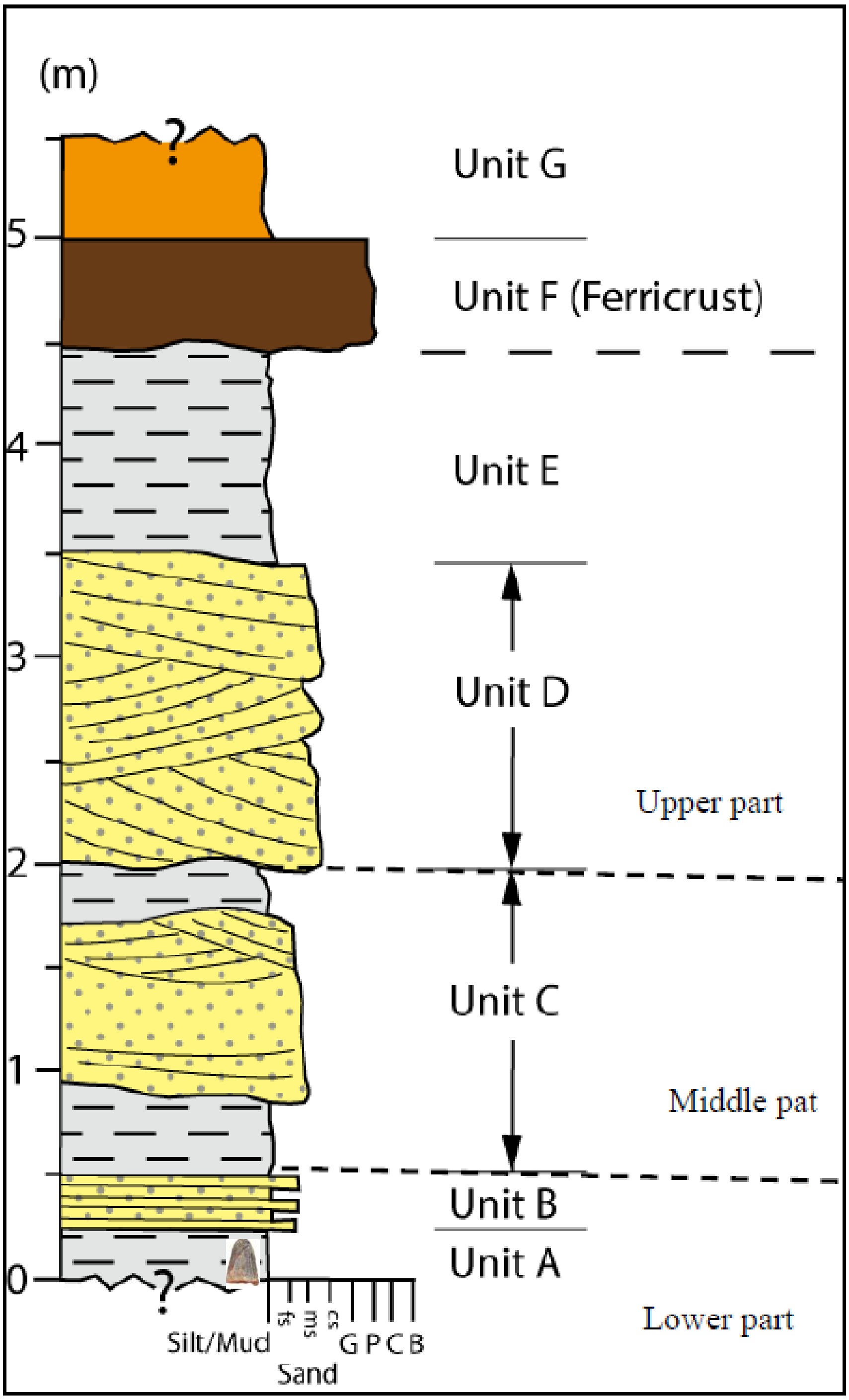

Figure 4.5 The lithostratigraphical column of Sam Ran locality.

Table 4.2 Teeth characters from Sam Ran locality, Khon Kean Province.

character	PM2016 – 1 – 001	PM2016 – 1 – 002
The crown base length (CBL)	12.8 mm	15.4 mm
The crown base width (CBW)	9.5 mm	14.3 mm
The crown base ratio (CBR)	0.74	0.93
The crown height (CH)	20.0 mm	33.6 mm
The crown height ratio (CHR)	1.56	2.18
The apical length (AL)	21.7 mm	35.2 mm
Tooth crown sub-oval to sub-circular in cross-section	Yes	yes
Presence of flutes	Yes	yes
Carinae bearing 6 or more denticles per mm	No	no
Enamel surface of the crown	smooth	smooth
Base of the crown enamel surface	n/a	n/a
Number of flutes	21	22
45 degree orientation of enamel sculpture near interdenticle sulci	no	no
Well-pronounced carinae	yes	yes
Curvature of the crown	n/a	n/a

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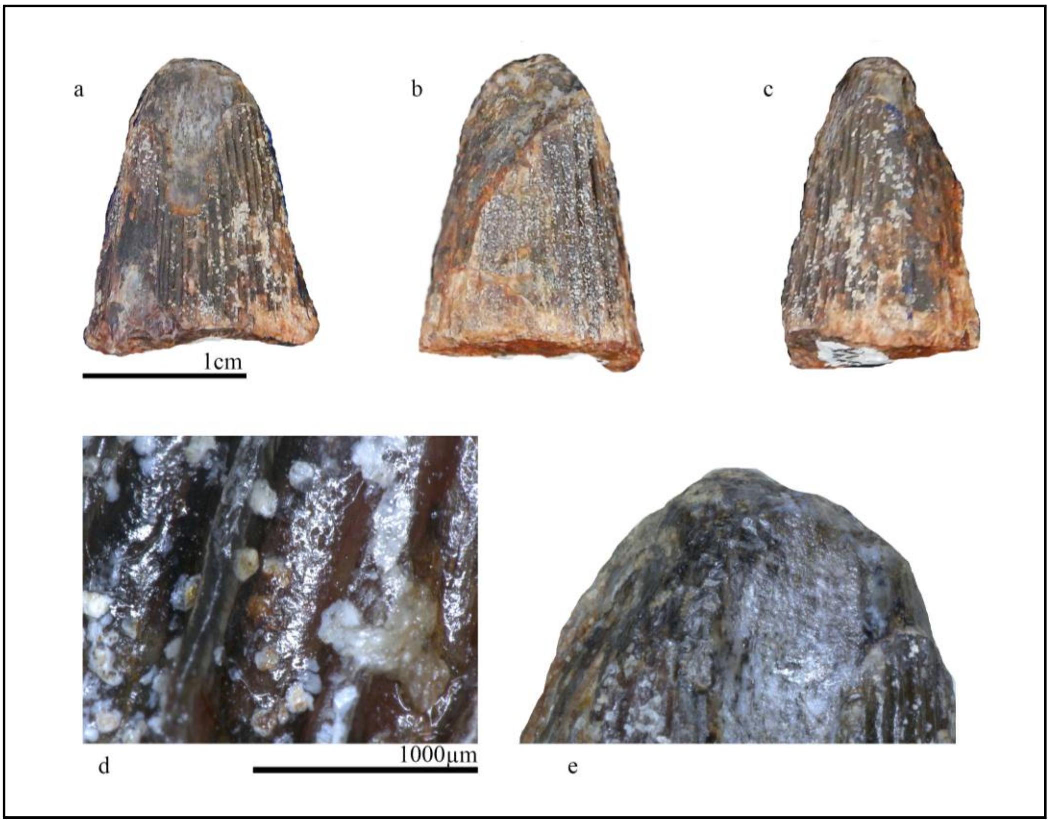

Figure 4.6 Spinosaurid (PM2016 – 1 – 001), isolate tooth from the Khok Kruat Formation in Sam Ran locality, Khon Kaen Province; lingual (a) labial (b) anterior (c) smooth enamel surface of the crown (d) wrinkle base of the apex enamel surface; Scale bars: 3 cm (a - c) and 1,000 µm (d - e).

4.2.3 Accompanying vertebrate fossil fauna

Many groups of vertebrates have been found from Sam Ran locality, which the teeth of sharks, scale of actinopterygian fishes, turtle plate, teeth of crocodilians, bones and teeth of large theropod dinosaurs (including the partial skeleton of spinosaurid specimen).

4.2.3.1 Sharks

The locality has yielded rich assemblages of freshwater hybodont sharks. An isolated dorsal fin spine and teeth of five hybodont species are described from Sam Ran locality, consists of *Hybodus aequitridentatus*, *Heteroptychodus steinmanni*, *Thaiodus ruchae*, *Khoratodus foreyi* and *Acrorhizodus khoratensis*. These sharks show a wide range of diet and many of them appear to be restricted to a freshwater environment.

4.2.3.2 Fishes

Fish remains are rare scales. One of the more diagnostic specimens recovered to date is an isolated scale collected at locality. The scale consists of slightly thin scales in average, and the ganoid surface is ornamented with parallel or slightly diverging a groove that sometimes marks the posterior edge of the ganoin with a denticulate pattern. These are the characteristic of scales indicated Semionotidae.

4.2.3.3 Turtle

Several fragment of turtle shell can be collected from the locality, although relatively uncommon, a number of specimens referable to turtle have been recovered, including elements of both thin plastron and carapace. Incomplete preservation precludes a more specific taxonomic assignment at this time.

4.2.3.4 Crocodile

This discovery represents the scute, fragmentary teeth and complete teeth. This tooth is referred to Crocodyliformes on the basis of its conical crown with apically directed grooves.

4.2.3.5 Theropod

We found teeth and skeleton of theropod dinosaur. The teeth are oval to sub- oval shape, alternative grooves and rides ornamentation. A partial skeleton of cervical and dorsal vertebrae have been found, as well as elements of the pelvis.

4.2.4 Palaeoenvironmental interpretation

The presence of sedimentary structure such as fining upward, planar cross bedding, load clast, rip-up cast indicate meandering channel deposit and crevasse splay sequences (Figure 4.7). The very good preservation of the vertebrate fossils, notably the partial skeleton of a spinosaurid is due to low-energy current. The calcisol with pedogenetic carbonates is an indication of a semi-arid climate. *Thaiodus* and *Heteroptychodus* are also found in deltaic and/or marine environments outside Thailand, but are nevertheless restricted to the Asian continent. It seems that the appearance of three different palaeobiogeographical provinces (Europe, Asia and Africa–South America) around the Tethys during the Early Cretaceous led to the highest diversity at the generic level in the history of hybodont sharks (Cuny *et al.*, 2006).

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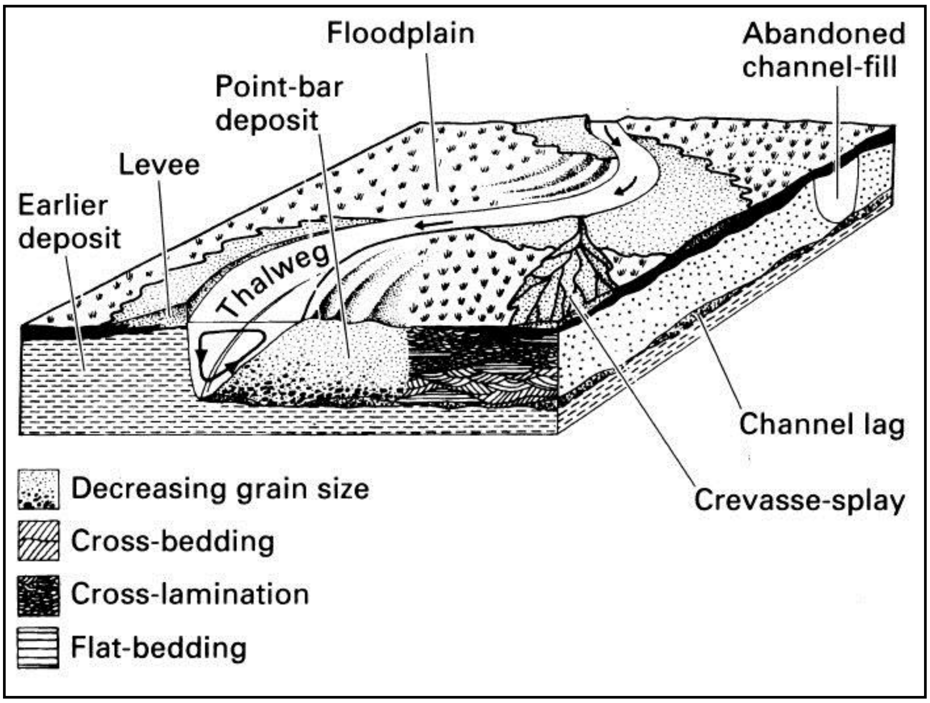

Figure 4.7 Model of channel is that of a meandering river, which consists of crevasse splay deposit in Sam Ran locality, Khon Kaen Province (Allen, 1964).

4.3 Khok Pha Suam locality

4.3.1 Lithostratigraphic and sedimentology

This section was made at the outcrop near the junk place area; the thickness of this section is about 4 meters (Figure 4.8).

Lithology and sedimentary structure: The deposits exposed at Khok Pha Suam are siltstone and very fine sandstone with some carbonate caliche pebble conglomerate. The fining- upward sequence is pale red to grayish – red and reddish brown in color. The dip of these strata is 10/135 to south-east.

The lower part shows 1.0 meters thick consists of reddish brown very thin to thin bedded claystone grading up to thin bedded siltstone interbedded with fine-grained sandstone. Sandstone bed has a micro-cross bedded. This layer has been found the vertebrate and not well preservation.

The upper part is 3 meters thick consists of reddish brown, thin- to medium-

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bedded, medium-grained sandstones interbedded siltstones, claystones. The top of layer has been found calcrete horizon (Paleosol).

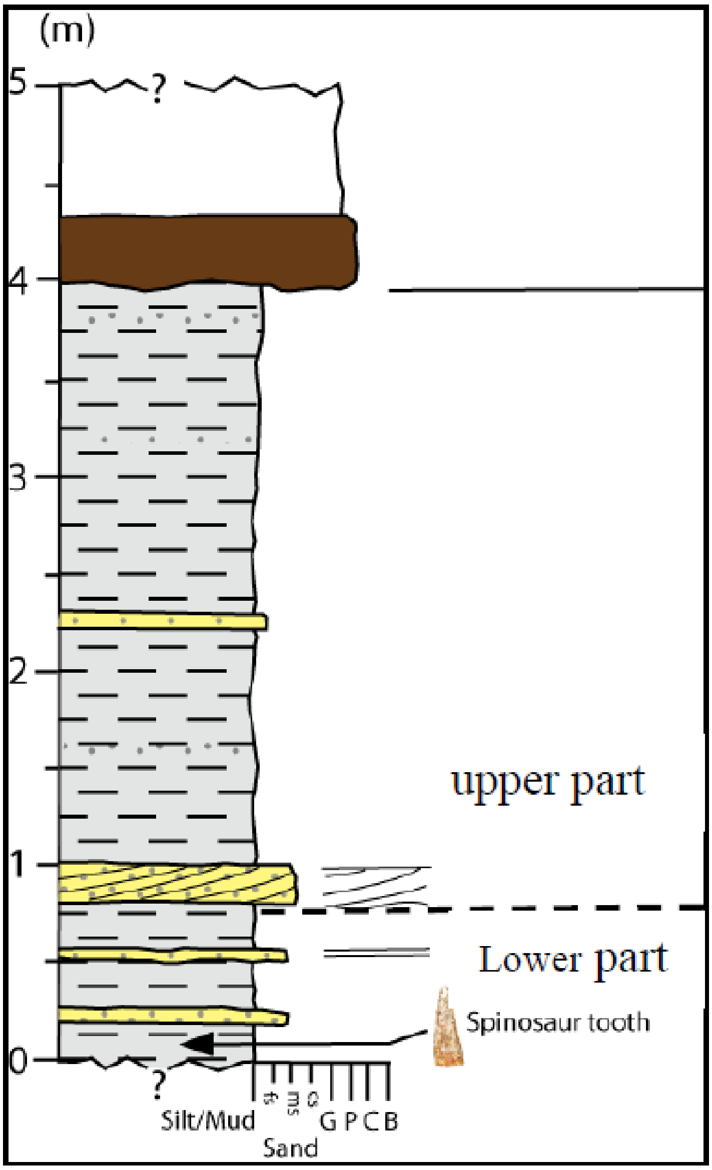

Figure 4.8 The lithostratigraphical column of Khok Pha Suam locality.

4.3.2 Type of spinosaurid material

Material: PM2016 – 1 – 003, PM2016 – 1 – 004, PM2016 – 1 – 005 and PM2016 – 1 – 006 (Table 4.3)

The specimens are complete isolated teeth with their roots and well preservation. PM2016 – 1 – 003 and PM2016 – 1 – 004 show a finely ridge than PM2016

– 1 – 005, PM2016 – 1 – 006. The ridge and the enamel surface of the crown are different kinds of description. Based on the number of ridge and striation, two morphotypes are recognized:

Morphotype I:

Total length of the tooth is 59.9 mm, the mesiodistal length of the crown at the level of the cervix is 16.7 mm, the width of the crown base is 13.1 mm, the ratio of the crown base width to the crown base length is 0.78, the height of the crown is 44.3 mm, the ratio of the crown height to the crown base length is 2.65 and the basoapical extent of the mesial margin of the crown is 46.2 mm (Figure 4.9 a - c). The teeth show oval shape in cross – section with well – pronounced carinae. They present fine and shape ridges. The carinae are present on the mesial and distal margins of the teeth and slightly serrated. They are irregular morphology look like undulating rope. The crown surface is covered with distinctive striation. Each striation runs along almost the entire length of the crown. Enamel surface of the crown are smooth while base of the crown show the wrinkled which similar to the apex of crown (Figure 4.9 d - e). The crown shows mesiodistal curvature. Number of ridge on each side of PM2016 – 1 – 003 and PM2016 – 1 – 004 is finely than PM2016 – 1 – 005 and PM2016 – 1 – 006, about 22 and 25.

Morphotype II:

Total length of the tooth is 55.7 mm, the mesiodistal length of the crown at the level of the cervix is 19.6 mm, the width of the crown base is 14.7 mm, the ratio of the crown base width to the crown base length is 0.75, the height of the crown is 39.8 mm, the ratio of the crown height to the crown base length is 2.03 and the basoapical extent of the mesial margin of the crown is 42.6 mm (Figure 4.10 a - c). The cross – section is oval in shape and well – pronounced carinae. The teeth are present distinct ridges. Carinae are present clearly extending from the base of the crown to its apex. The serrations of carinae are unclear. They are irregular morphology similar to undulating rope. Enamel surface of the crown and base of the crown enamel surface show the wrinkled (Figure 4.10 d -e). The crowns show mesiodistal curvature. Number of ridges on each side is about 16.

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Table 4.3 Teeth characters from Khok Pha suam locality, Ubon Ratchathani Province

character	PM2016 – 1 – 003	PM2016 – 1 – 004	PM2016 – 1 – 005	PM2016 – 1 – 006
The crown base length (CBL)	16.7 mm	16.9 mm	10.1 mm	19.6 mm
The crown base width (CBW)	13.1 mm	13.1 mm	8.1 mm	14.7 mm
The crown base ratio (CBR)	0.78	0.77	0.80	0.75
The crown height (CH)	44.3 mm	43.3 mm	23.1 mm	39.8 mm
The crown height ratio (CHR)	2.65	2.56	2.29	20.3
The apical length (AL)	46.2 mm	45.1 mm	26.5 mm	42.6 mm
Tooth crown sub-oval to sub-circular in cross-section	yes	yes	yes	yes
Presence of flutes	yes	yes	yes	yes
Carinae bearing 6 or more denticles per mm	no	no	no	no
Enamel surface of the crown	smooth	smooth	wrinkled	wrinkled
Base of the crown enamel surface	wrinkled	wrinkled	wrinkled	wrinkled
Number of flutes	25	22	16	16
45 degree orientation of enamel sculpture near interdenticle sulci	no	no	no	no
Well-pronounced carinae	yes	yes	yes	yes
Curvature of the crown	yes	yes	yes	no

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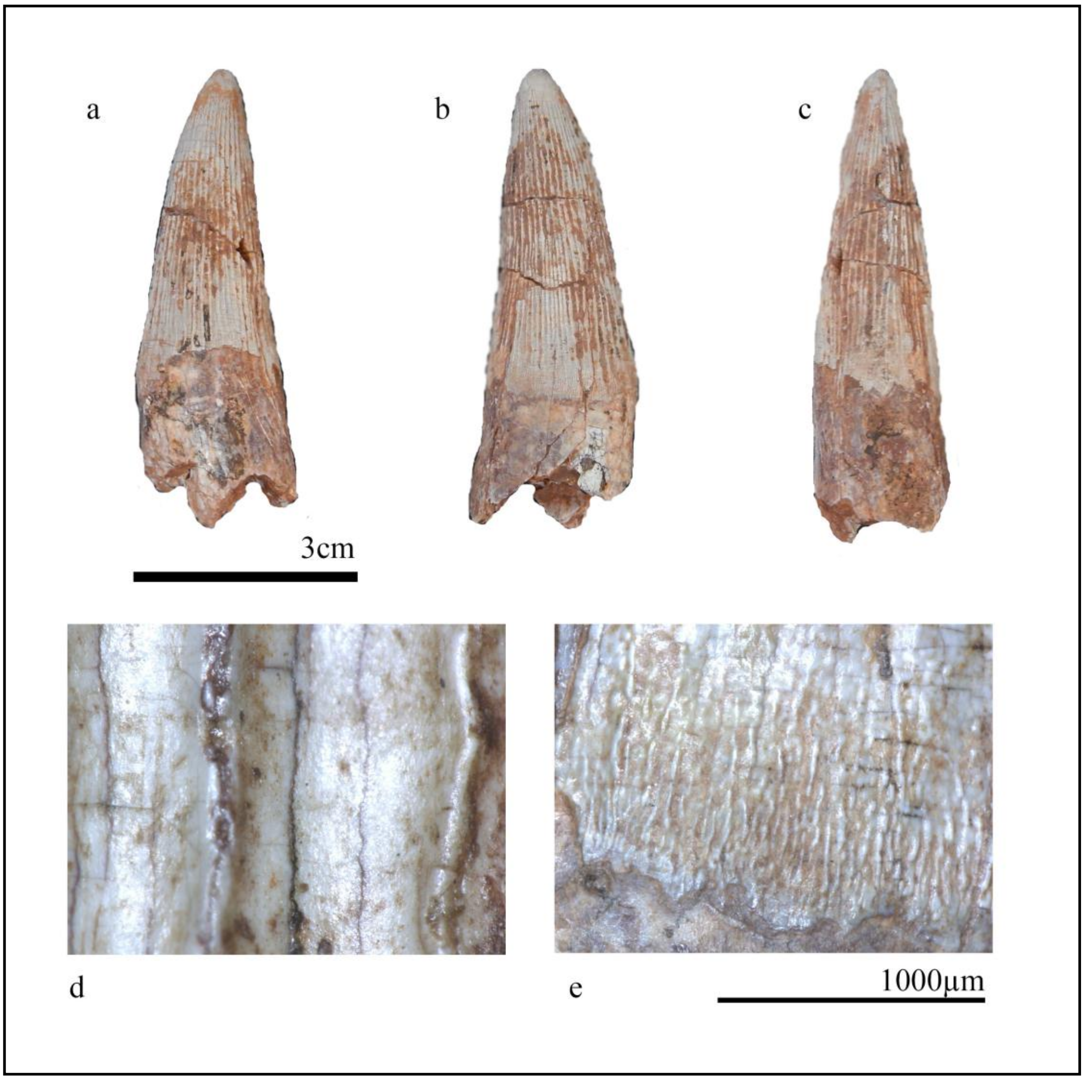

Figure 4.9 Spinosaurid (PM2016 – 1 – 003), isolate tooth from the Khok Kruat Formation in Khok Pha Suam locality, Ubon Ratchathani Province; lingual (a) labial (b) anterior (c) smooth enamel surface of the crown (d) wrinkle base of the crown enamel surface; Scale bars: 3 cm (a - c) and 1,000 µm (d - e).

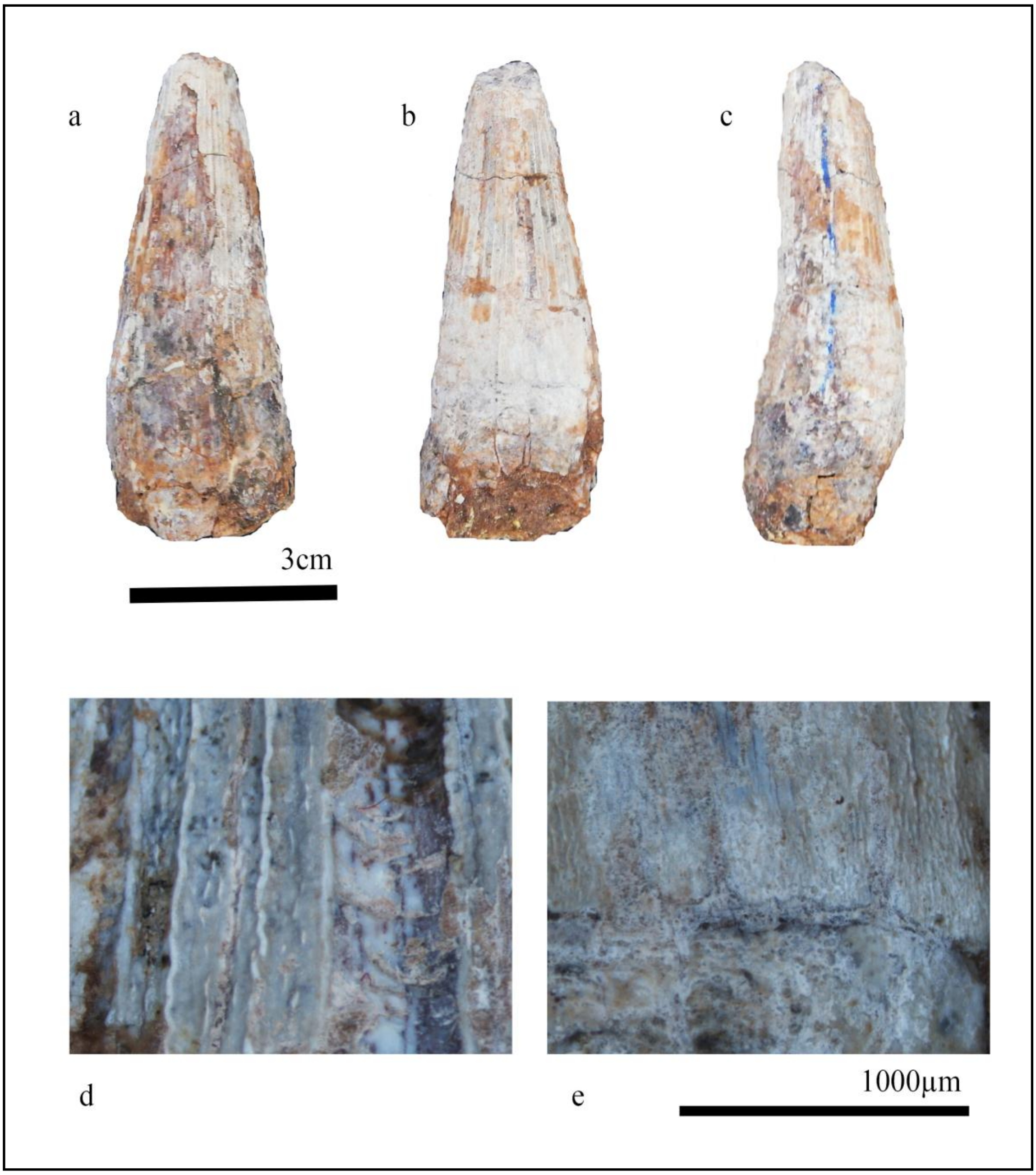

Figure 4.10 Spinosaurid (PM2016 – 1 – 006), isolate tooth from the Khok Kruat Formation in Khok Pha Suam locality, Ubon Ratchathani; lingual (a) labial (b) anterior (c) wrinkle enamel surface of the crown (d) wrinkle base of the crown enamel surface; Scale bars: 3 cm (a - c) and 1,000 µm (d - e).

4.3.3 Accompanying vertebrate fossil fauna

The vertebrate fauna of the Khok Pha Suam locality has been found the teeth of sharks, teeth and scale of actinopterygian fishes, turtle carapace fragment, scutes and teeth of crocodilians, bones and teeth of large theropod dinosaurs (including the teeth of spinosaurid specimen), bone and teeth of iguanodontians and sauropod teeth.

4.3.3.1 Sharks

The hybodont sharks from Khok Pha Suam show adaptations towards various diets and isolated teeth containing five different genera and species consists of *Hybodust aequitridentatus*, *Acrorhizodus khoratensis*, *Heteroptychodus steinmanni*,, *Khoratodus foreyi* and *Thaiodus ruchae* . *Hybodust aequitridentatus* and *Acrorhizodus khoratensis* were probably opportunistic feeders, but the low cusps of their teeth indicate some specialization towards rather hard shelled prey. *Heteroptychodus steinmanni* and *Khoratodus foreyi* possess flat teeth which indicate some specialization toward durophagy. Finally, the serrated teeth of *Thaiodus ruchae* would usually indicate feeding on large prey. The teeth of are strongly interlocked, which would also made them capable of cutting through tough material (Cuny *et al.*, 2008).

4.3.3.2 Fishes

The locality of Khok Pha Suam found the centra, posterios fragment of a basioccipital, fragments of jaw, apiece of dermopterotic and scoles. They can easily be separated into two different taxa. One taxa is represented by smooth ganoid scales, with the lateral face showing a narrow band. The other taxa consist of slightly larger scales in average, and the ganoid surface is ornamented with parallel (Cavin *et al.*, 2007).

4.3.3.3 Turtle

Turtle remain is rare and fragmentary. They include two fresh – water turtle, both of them trionychoid and an adocid. The carapace of the trionychoid is covered with a strong ornamentation. The adocid is found fragment of carapace, it is covered with tiny and pits.

4.3.3.4 Crocodile

The locality has been found several crocodile teeth and scute on the outcrop surface; consist of fragmentary and good preservation. Crocodile teeth can

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divide into 4 morphotype. The morphotype I have a robust, high and conical in shape. The morphotype II have a slender and conical in shape. The morphotype III have a roughly triangular shape. The morphotype IV have relatively short and slightly in shape (Lauprasert *et al.*, 2006).

4.3.3.5 Theropod

The teeth theropod have been found a lot of this locality, consists of good preservation and fragmentary. The teeth of theropod dinosaur show difference in size and morphology. One specimen looks like blade, with serration on the both margins and D-shaped in cross-section. Another one showing short conical cone – shaped crown, extremely reduced serrations and clear robbing have been found. They resemble crocodilian teeth.

4.3.3.6 Sauropod

Sauropod remain is rare and fragmentary. The sauropod teeth are of the peg – shape type, with a slender, nearly cylindrical crown. They strongly resemble the teeth of *Phuwiangosaurus* sp. from the Sao Khua Formation.

4.3.3.7 Ornithopod

This area was found several specimens belonging to iguanodontid ornithopod. Besides a limb bones and caudal centrum resembling those of iguanodontids. Many of the teeth are heavily worn shed and show few distinctive characters. Some teeth from Khok Pha Suam are very similar to those of *Siamodon nimgnami* nov.gen, nov.sep. (Buffetaut *et al.*, 2008).

4.3.4 Palaeoenvironmental interpretation

The palaeoenviroment in which spinosaurid is preserved in Khok Pha Suam present that lithostratigraphy and sedimentary structure composed of fining – upward sequences, carbonate caliche horizon, micro cross- bedding, load – cast and rip – up clast, micaceous fine sand and silt which also forms scattered thin lenticular beds and laminated carbon peat at the sequences indicate low – energy current, floodplain deposits (Figure 4.11). The fossiliferous has yielded only fragmentary fossils it means that were transported under high energy condition and deposited in the low- energy current. It could have arid – semiaridity in subtropic climate, indicated by the caliche pebble conglomerate.

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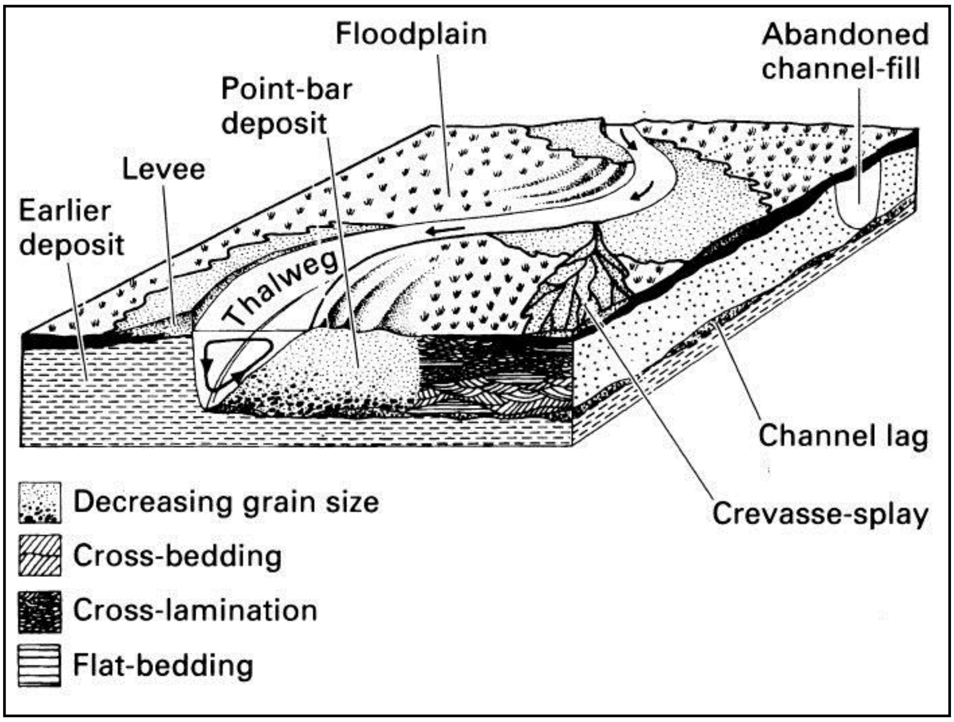

Figure 4.11 Model of channel is that of a meandering river, which consists of floodplain deposit in Khok Pha Suam locality, Ubon Ratchathani Province (Allen, 1964).

4.4 Interpretation of sedimentary environments

4.4.1 Lithostratigraphical correlated between study localities and reference type section of Khok Kruat Formation

The Khok Kruat Formation is well distributed in the outer parts of Phu Phan Range bounded along the outer rims of the Phu Phan Formation with presumable contacts. The sharp contact with the basal anhydrite of the overlying Maha Sarakham Formation was observed (Hite 1974; Hite and Jappakasetr, 1979) and was reported on seismic profiles (Sattayarak *et al.*, 1991). Generally, the formation consists of reddish brown, fine- to medium-grained sandstones, siltstones and mudstones; conglomerates are also present. The lithostratigraphical columns of the three localities have been correlated to the reference type section of the Khok Kruat Formation, by Chaikham *et al.*, 2014 (Figure 4.12). The section of Lam Pao Dam is correlated to the lower part of

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Khok Kruat Formation whereas the Sam Ran section is correlated to the middle part of the Khok Kruat Formation. The top layer of Sam Ran section overlaps the bottom of the lower part of the Khok Pha Suam section. Thus the Lam Pao Dam section is the oldest, followed by the Sam Ran and Khok Pha Suam sections, respectively.

4.4.2 Comparison of spinosaurid teeth in Khok Kruat Formation from Northeastern Thailand

The spinosaurid teeth from Khok Kruat Formation under discussion can be classified into two morphotype (Table 4.4): Teeth specimens from Lam Pao Dam, Sam Ran and Khok Pha Suam localities indicated morphotype I. These show specific characters, smooth enamel surface of the crown while base of the crown enamel surface show the wrinkled (Figure 4.13 a, b and c) and finely ridge. Morphotype II has been found in Lam Pao Dam and Khok Pha Suam localities. The characters show the wrinkled of enamel surface of the crown and base of the crown enamel surface (Figure 4.13 d and e) and coarsely ridge. In addition Khok Kruat teeth are close to *Siamosaurus suteethorni* from the Sao Khua Formation of Khon Kaen province, in north-eastern Thailand (Buffetaut and Ingavat, 1986) which is older than the Khok Kruat Formation. They are difference in the number of ridges on each side and in the enamel surface. This indicates that several siponsaurid taxa occur in Thailand.

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Table 4.4 Teeth characters in spinosaurid from Lam Pao Dam, Sam Ran and Khok Pha Suam localities from Khok Kruat Formation Northeastern Thailand

character	PM2016 – 1 – 007	PM2016 – 1 – 008	PM2016 – 1 – 009	PM2016 – 1 – 010	PM2016 – 1 – 001	PM2016 – 1 – 002	PM2016 – 1 – 003	PM2016 – 1 – 004	PM2016 – 1 – 005	PM2016 – 1 – 006
The crown base length (mm)	15	7.1	16	32.6	12.8	15.4	16.7	16.9	10.1	19.6
The crown base width (mm)	14.6	4.7	11	22.7	9.5	14.3	13.1	13.1	8.1	14.7
The crown base ratio	0.97	0.66	0.69	0.69	0.74	0.93	0.78	0.77	0.80	0.75
The crown height (mm)	56.8	24.6	46.3	75.1	20.0	33.6	44.3	43.3	23.1	39.8
The crown height ratio	3.78	3.46	2.89	2.30	1.56	2.18	2.65	2.56	2.29	20.3
The apical length (mm)	59.9	25.2	52.3	77.6	21.7	35.2	46.2	45.1	26.5	42.6
Tooth crown sub-oval to sub-circular in cross-section	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes
Presence of flutes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes
Carinae bearing 6 or more denticles per mm	no	no	no	no	no	no	no	no	no	no
Enamel surface of the crown	wrinkled	wrinkled	smooth	smooth	smooth	smooth	smooth	smooth	wrinkled	wrinkled
Base of the crown enamel surface	wrinkled	wrinkled	wrinkled	wrinkled	n/a	n/a	wrinkled	wrinkled	wrinkled	wrinkled
Number of flutes	11	18	32	36	21	22	25	22	16	16
45 degree orientation of enamel sculpture near interdenticle sulci	no	no	no	no	no	no	no	no	no	no
Well-pronounced carinae	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes
Curvature of the crown	yes	no	yes	no	n/a	n/a	yes	yes	yes	no

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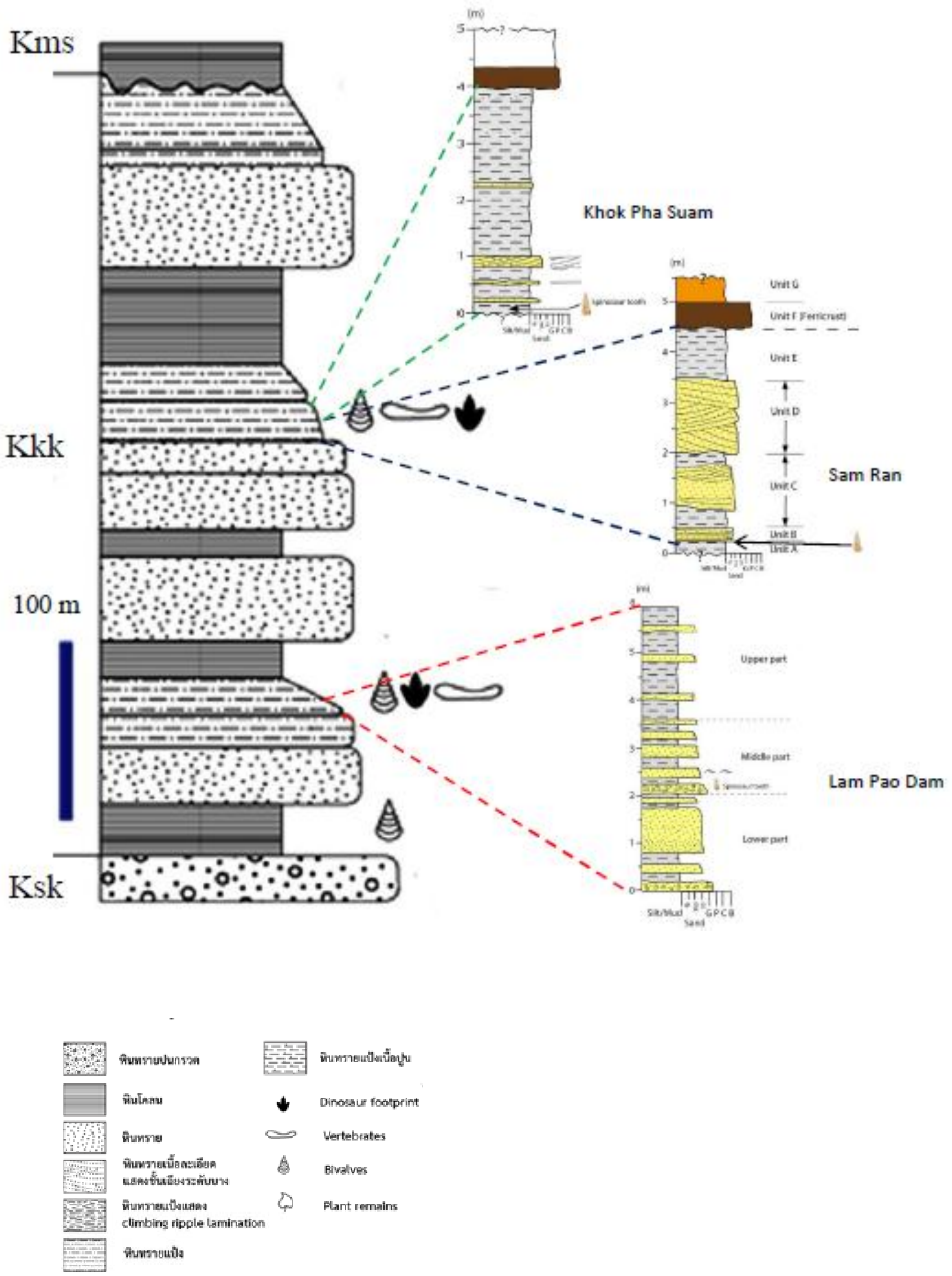

Figure 4.12 Lithostratigraphical correlated between study localities and reference type section of Khok Kruat Formation (Chaikham *et al.*, 2014).

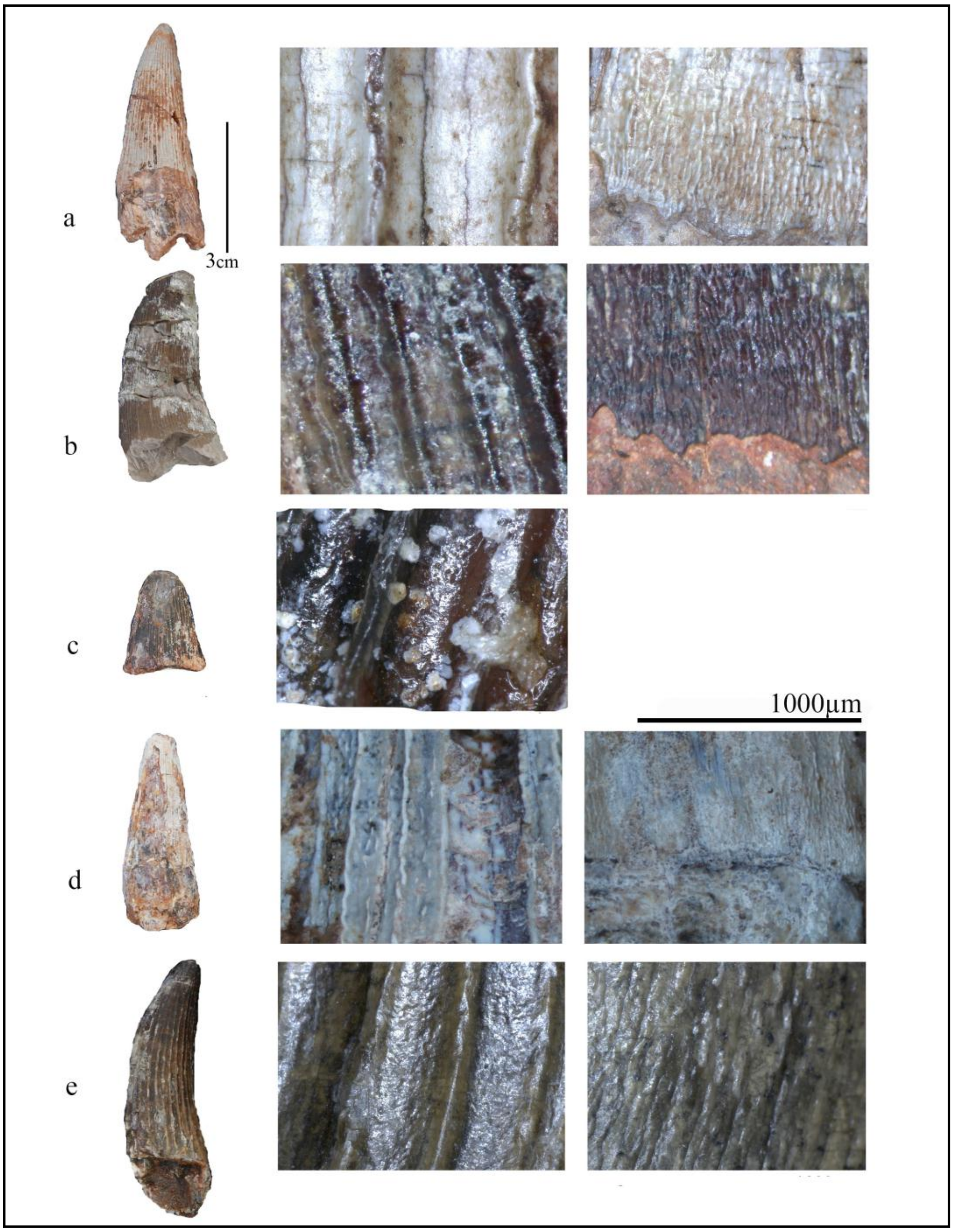

Figure 4.13 Showing the spinosaurid teeth from Khok Kruat Formation can be classified into two morphotype: a –c Morphotype I; tooth from Khok Pha Suam locality (a) tooth from Lam Pao Dam locality (b) and tooth from Sam Ran locality (c), Morphoype II; tooth from Khok Pha Suam locality (d) and tooth from Lam Pao Dam locality (e)

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4.4.2 List of vertebrate fossil fauna from study localities

Diversity of vertebrate fossils fauna from three localities of the Khok Kruat Formation i.e., Lam Pao, Kalasin province; Sam Ran, Khon Kaen province and Khok Pha Suam, Ubon Ratchathani province were compared (Table 4.4). The highest diversity of hybodont sharks appeared in Khok Pha Suam and Sam Ran localities (5 taxa) i.e., *Hybodus aequitridentatus, Heteroptychodus steinmanni*, *Khoratodus foreyi*, *Thaiodus ruchae* and *Achorhizodus khoratensis* while those of the Lam Pao Dam was found 3 taxa including *Hybodus aequitridentatus*, *Heteroptychodus steinmanni*, and *Khotatodus foreyi*. In addition, the Khok Pha Suam and Lam Pao Dam localities showed the numerous of the bony fishes and dinosaurs remains than Sam Ran locality.

Table 4.5 Check - list of vertebrate fossil fauna from the Khok Kruat Formation.

Taxa	Lam Pao Dam	Sam Ran	Khok Pha Suam
Spinosaurid teeth type I	x	x	x
Spinosaurid teeth type II	x	-	x
Spinosaurid bone	-	x	-
Large theropod teeth	x	x	x
Sauropod teeth	-	-	x
Iguanodontian bone	-	-	x
Iguanodontian teeth	-	-	x
Theropod dinosaur footprint	x	-	-
Total Taxa	3	3	5
Crocodilian	x	x	x
Total Taxa	1	1	1
The turtle; the carapace of the trionychoid is covered with a strong ornamentation	x	x	x
The turtle; the carapace of the trionychoid is covered with tiny and pits.	-	x	x
Total Taxa	1	2	2
Actinopterygian fishes type 1 base on smooth ganoid scales	x	-	x
Actinopterygian fishes type 2 base on the ganoid surface is ornamented with parallel	x	x	x
Lepidotes teeth	x	-	x
Total Taxa	3	1	3
Hybodus aequitridentatus	x	x	x
Heteroptychodus steinmanni	x	x	x
Khoratodus foreyi	x	x	x
Thaiodus ruchae	-	x	x
Achorhizodus khoratensis	-	x	x
Total Taxa	3	5	5

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CHAPTER 5

DISCUSSION AND CONCLUSION

This study composes of three main parts, lithostratigraphy, accompanying vertebrate fossil fauna and morphology of spinosaurid teeth in the Khok Krut Formation, Northeastern Thailand. Three localities including Lam Pao Dam, Kalasin Province, Khok Pha Suam, Ubonratchathani Province and Sam Ran, Khon Kean Province are good representative spinosaurid-bearing localities. The remarkable post-cranial elements of spinosaurdid have been discovered in Sam Ran locality which presents the first reported skeletal remains of an Asian spinosaurid (Buffetaut *et al.*, 2005). The teeth comparisons show different morphotypes of the teeth. Lithostratigraphy and accompanying vertebrate fossil faunas in this formation is provided for understanding of palaeoenvironment.

5.1 Palaeoenvironment implication

The lithostratigraphical column of the three localities has been compared to the reference type section of the Khok Kruat Formation, by Chaikham *et al.*, 2014. The section of Lam Pao Dam is correlated to the lower part of Khok Kruat Formation whereas the Sam Ran section is correlated to the middle part of the Khok Kruat Formation. The top layer of Sam Ran section overlaps the bottom of the lower part of the Khok Pha Suam section. Thus the Lam Pao Dam section is the oldest, followed by the Sam Ran and Khok Pha Suam sections, respectively.

The sedimentological analysis (lithology and sedimentary structures) of the three localities suggest that they were formed in a meandering system deposit. Lam Pao Dam Unit shows conglomerate channel deposits, characterizing a point bar sequence (Einsele, 1992). Sam Ran Unit is composed of sandstone and siltstone channel deposits corresponding crevasse splay sequence. Khok Pha Suam Unit consists of siltstone and claystone channel deposits classical of flood plain sequence (Einsele, 1992). It seems that the Lam Pao Dam Unit was deposited in high energy river current. The Sam Ran Unit was deposited in low energy current, an even lower energy current being observed in Khok Pha Suam Unit.

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Fossil remains from the Lam Pao Dam locality are well preserved in conglomerate. Most of them are small bone fragments and teeth. Those from the Sam Ran Unit are well preserved and more complete such as a partial vertebral column of spinosaurid. Fossil remains from the Sam Ran Unit were collected from a small area which might suggest a small channel and low energy current. Fossils of Khok Pha Suam Unit are well preserved but very fragile, bones being only exceptionally fossilized. These bones in Khok Pha Suam were collected from a large area, much more than the area at Sam Ran. This might indicate a large channel with low energy current.

Diversity of vertebrate fossil faunas from three localities from the Khok Kruat Formation, Lam Pao Dam locality has been found 3 taxa of sharks, 3 taxa of bony fishes, 1 taxa of turtle, 2 taxa of crocodiles and 2 taxa of dinosaurs. Sam Ran locality has been found 5 taxa of sharks, 1 taxa of bony fish, 2 taxa of turtles, 1 taxa of crocodile and 2 taxa of dinosaurs and Khok Pha Suam has been found 5 taxa of sharks, 2 taxa of bony fishes, 2 taxa of turtles, 1 taxa of crocodile and 4 taxa of dinosaurs.

Three study areas in the Khok Kruat Formation have been descripted of the lithostratigraphic and sedimentology in each locality in order to make geological sections and correlate the sites to Khok Kruat reference type and check list of diversity of vertebrate fossils fauna, which make the reconstruction of the palaeoenvironment of Spinosaurid - bearing strata in the Khok Kruat Formation (Figure 5.1).

5.2 Spinosaurid teeth in Khok Kruat Formation from Northeastern Thailand

The Khok Kruat teeth specimens were collected from three localities, i.e., Sam Ran locality, Khon Kaen Province, Khok Pa Suam locality, Ubonratchathani Province and Lam Pao Dam locality Kalasin Province. The teeth show oval shape in cross – section with well – pronounced carinae. They present fine to coarse ridges. The carinae are present on the mesial and distal margins of the teeth and slightly serrated. They are irregular morphology look like undulating rope. The crown surface is covered with distinctive striation. Each striation runs along almost the entire length of the crown. Enamel surface of the crown are smooth to wrinkled while base of the crown show the wrinkled which similar to the apex of crown. The crown shows mesiodistal curvature. Number of ridges on each side is about 11 - 32. The ridge and the enamel

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surface of the crown are different kinds of description, which can be classified into two morphotypes (Figure 5.2). Teeth specimens from Lam Pao Dam, Sam Ran and Khok Pha Suam localities belong to morphotype I or Khok Kruat morphotype. This morphotype show the specific characters including smooth enamel surface of the crown while base of the crown enamel surface show the wrinkled and finely ridge. Morphotype II or *Siamosaurus* morphotype has been found in Lam Pao Dam and Khok Pha Suam localities. The teeth characters show the wrinkled of enamel surface of the crown and base of the crown enamel surface and coarsely ridge.

The Khok Krut teeth belong to the Family Spinosauridae. In addition the Khok Kruat teeth are closely related to *Siamosaurus suteethorni* from the Sao Khua Formation of Khon Kaen province, in northeastern Thailand (Buffetaut and Ingavat, 1986) which is older than the Khok Kruat Formation. They are some differences in the number of ridges on each side and in the enamel surface. This indicates that several siponsaurid taxa occured in Thailand. On the other hand, Buffetaut *et al.*, (2005) have reported spinosaurid vertebrae from the Khok Kruat Formation of Khon Kaen Province but they have not yet been described in detail. They probably can support to identified as the Spinosaurine. The discovery of spinosaurids in Laos *(Ichthyovenator laosensis)*, Japan (*Siamosaurus* – like teeth), China (*Siamosaurus* – like teeth) and Thailand (*Siamosaurus suteethorni* and Khok Kruat spinosaurine teeth) highlights the diversity of spinosaurids and the wide rang distribution of these dinosaurs in Asia.

5.3 Recommendation and Suggestion

Teeth of spinosaurid were recently found in fossil localities from Sao Khua Formation and some fossil localities from Khok Kruat Formation, the teeth were represented a different characters. Moreover, Buffetaut *et al.*, (2005) have reported spinosaurid vertebrae from the Khok Kruat Formation of Khon Kaen province but they have not yet been described in detail. They probably can help to provide a more precise systematic position. The discovery of spinosaurids in Laos *(Ichthyovenator laosensis)*, Japan (*Siamosaurus* – like teeth), China (*Siamosaurus* – like teeth) and Thailand (*Siamosaurus suteethorni* and Khok Kruat spinosaurine teeth) highlights the diversity of spinosaurids and the wide distribution of these dinosaurs in Asia. Further study,

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microstructure ornamentation of spinosaurid teeth should be study on the spinosaurid teeth. It is necessary to identify taxonomic status and it might be help to explain their affinity.

Figure 5.1 Hypothetical reconstruction of the depositional environment and diversity of the Spinosaurid in the Khok Kruat Formation from Northeastern Thailand.

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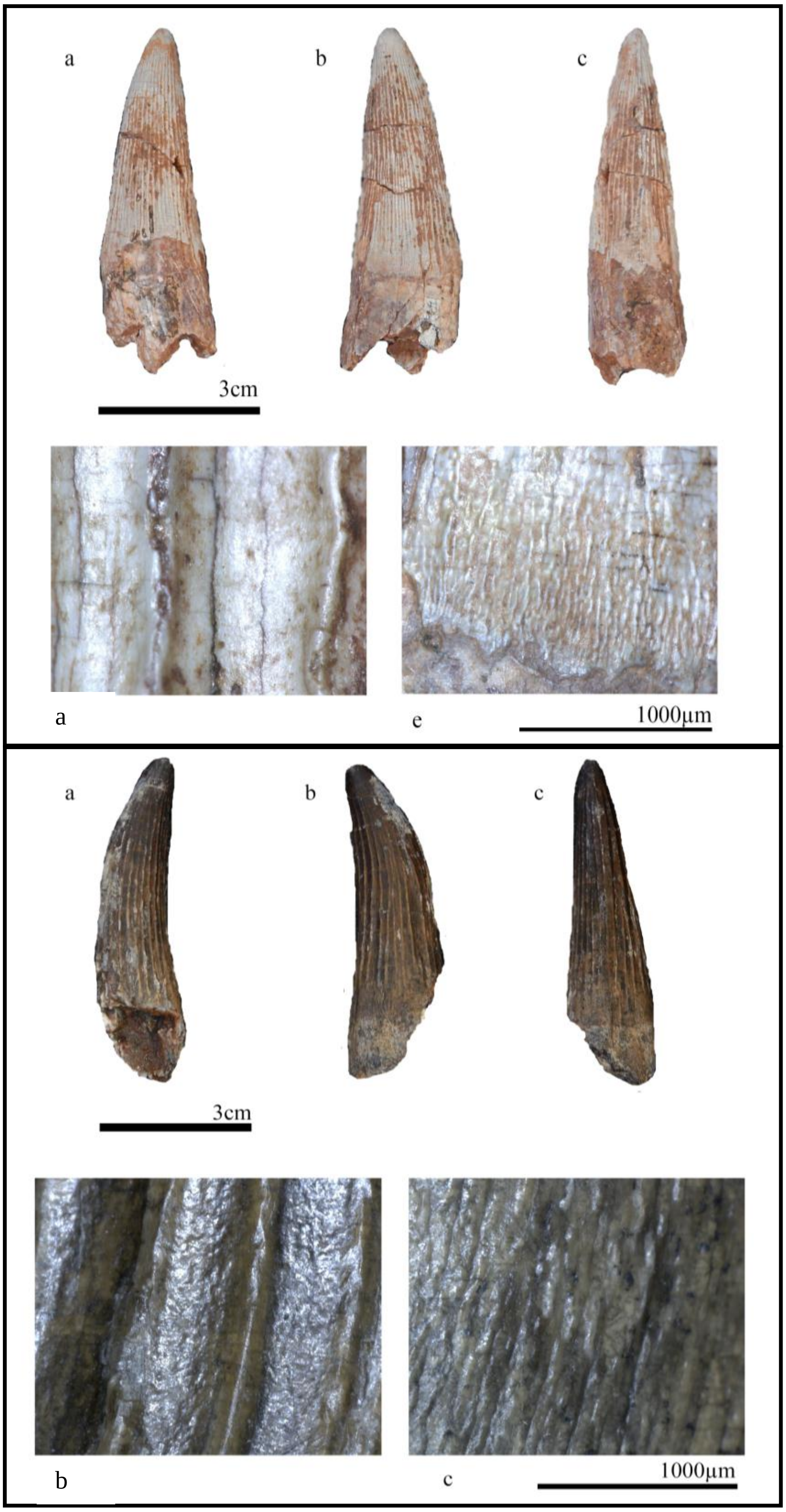

Figure 5.2 Spinosaurid teeth from the Khok Kruat Formation: a, Morphotype I or Khok Kruat morphotype; b, Morphotype II or *Siamosaurus* mophotype.

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