CHAPTER I

INTRODUCTION

The Phu Wiang area has long been known as the first locality of dinosaur fossil discovery in Thailand (Ingavat and Taquet, 1978). Since then, the continuous researches have been done through 3 decades, all animal fossils were only found from the Sao Khua Formation including three new dinosaurs (Suteethorn, 2002), one new crocodile, fish remains, turtle plates, sauropod tooth, blade-like carnosaur teeth and pointed theropod teeth were found in weathering soft siltstone (Buffetaut and Ingavat, 1983), and Hybodont shark teeth were also reported (Cuny *et al.*, 2003). However, paleontological reports on invertebrate fossils are rare; there are only the reports of bivalve fossils by Meesook and Wongprayoon (1999), Jearanaiwong (2000), and Wongprayoon and Meesook (2002). They reported bivalve fossils as *Trigonoioides* sp., *Plicatunio* sp., *Unio* sp., *Nippononaia* sp. and *Exogyra* sp. both workers neither indicated the precise stratigraphic horizon nor described in detail of lithology of bivalve horizons.

In the present study, lithostratigraphic columnar sections were done. Palaeontological and taxonomical studies of bivalves were also done. The information from this study might be useful to gain a better understanding of palaeo-depositional environment of bivalve fossil beds and make more diversity of fauna in the Sao Khua Formation from the Phu Wiang area, which lead to better understanding in the Early Creataceous palaeocommunity of this area.

1.1 Study area

Phu Wiang, a mountain range in northwest of Khorat plateau in northeastern Thailand, is located in Amphoe Phu Wiang, Changwat Khon Kaen, between latitudes 16° 32'N to 16° 52'N and longitudes 102° 8'E to 102° 22'E (Figure 1.1). It covers topographic map on the scale 1:50,000 Series L7017 map sheet 5442 I (Amphoe Si Bunruang), 5442 II (Amphoe Phu Wiang), 5442 III (Amphoe Chum Phae), 5442 IV (Amphoe Si Chomphu) and geologic map on the scale 1:250,000 sheet NE 48-13 (Changwat Khon Kaen). Phu Wiang mountain range consists of two concentric ranges, and the topography of the Phu Wiang area is generally cuesta mountains with gentle slope towards the low-lying area in the center and steep slope on outside. The outer range is higher than the inner range with highest point about 844 m above mean sea level, and the highest point of the inner range is about 465 m above mean sea level (Figure 1.2).

The study area is limited in the inner range and the central lowland, which can be accessed by highway number 2 from Bangkok to Khon Kaen about 445 km, and taking highway number 12 from Khon Kaen to Chum Phae about 40 km, and turn right to take highway number 2038 to Amphoe Phu Wiang and entrance of Phu Wiang mountain about 32 km, and taking the village road to Phu Wiang National Park about 18 km, totally about 535 km.

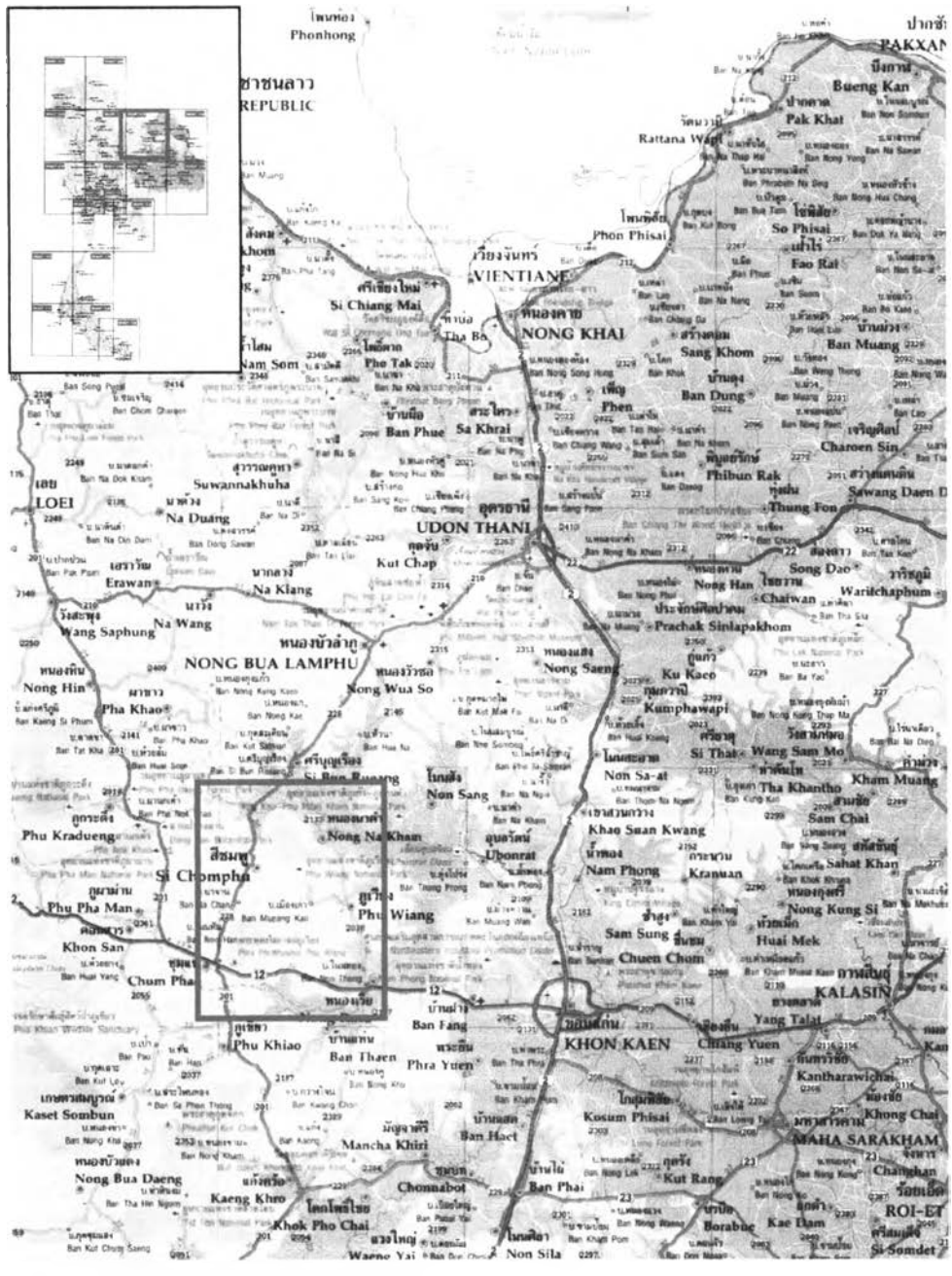
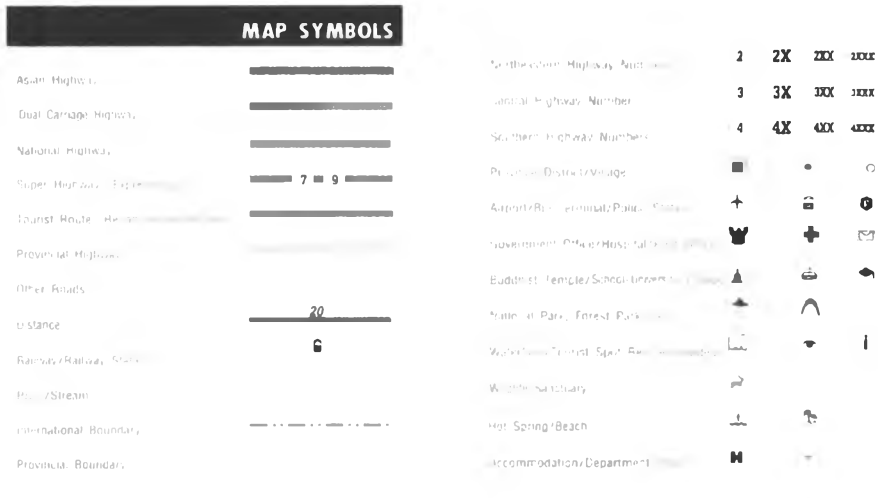


Figure 1.1 Location of the Phu Wiang area (PN MAP, 2003) ☐ the Phu Wiang area



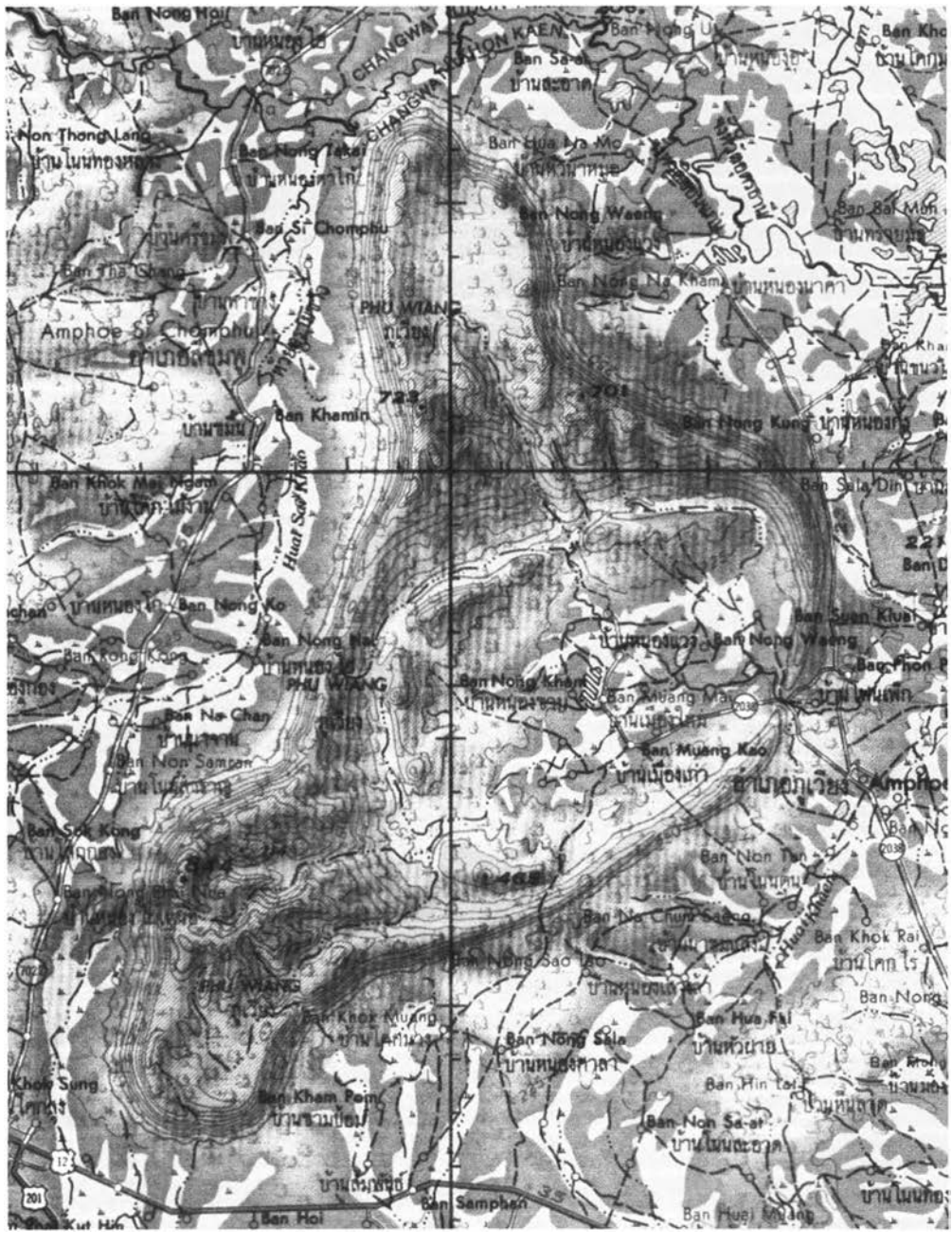
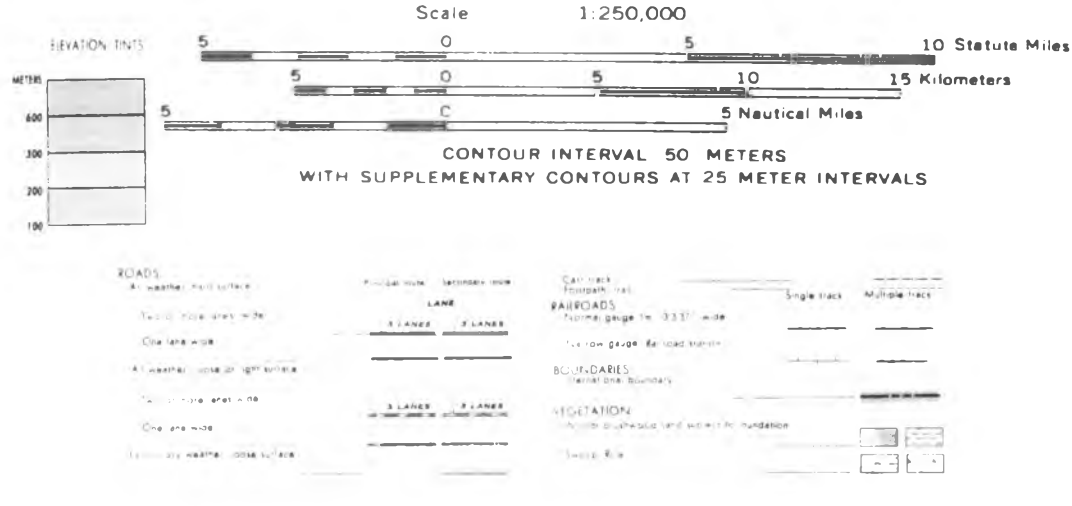


Figure 1.2 The topography of the Phu Wiang area



1.2 Objectives

1.2.1 To prepare the lithostratigarphic columnar sections and fix the fossil horizons, which contain the freshwater molluscan assemblages.

1.2.2 Palaeontological study of the molluscan assemblages from the Sao Khua Formation in the Phu Wiang area, Changwat Khon Kaen

1.2.3 To reconstruct the palaeoenvironments by sedimentary structures and palaeoecological analysis of freshwater molluscan assemblages.

1.3 Methodology

1.3.1 Before field investigation, the geomorphological map was made by aerial photograph interpretation.

1.3.2 Field investigation, geological map, and sample collection were done in May-June 2004, October-December 2004, January 2005, and March-May 2005.

1.3.3 The lithostratigraphic columnar sections were made in all molluscan localities. The occurrences of fossils orientation were checked in outcrop on both vertical section and bedding surface.

1.3.4 The molluscan horizons were collected by block sampling method. Each block, sized 25x25x20 cm, was cut out from the outcrop by explosive cement for palaeontological study, such as fossil orientation, articulation, fragmentation, abrasion, sorting, fossil density, and size frequency distribution.

1.3.5 The loose blocks of these fossil horizons were collected for taxonomic aspect, the body fossils were separated by hammer, soak in mixing of detergent and water at least 1 month, clean by small chisel, air pen, and sand blaster, respectively. Both a small scalpel and a small paint brush were used to carefully clean the fine shell sculptures in the last stage, which these characters are beneficial and very important for identification of molluscan fossils.

1.3.6 The molluscan assemblages and their occurrences in each bed were analyzed. These results are combined with the analysis of lithology and sedimentary structures of sandstones.

1.3.7 The results were shown in geologic columns. All of them were discussed and used for reconstruction of palaeodepositional environment of the Sao Khua Formation in the Phu Wiang area.

1.4 Previous works

1.4.1 Palaeontology

Ingavat and Taquet (1978) reported the first discovery of dinosaur bone in Thailand at a temporary creek in the Phu Wiang area and determined this bone as the distal end of left femur of sauropod.

Buffetaut and Ingavat (1983) described new species of Mesosuchian crocodile from the incomplete left dentary as *Goniopholis phuwiangensis*. This specimen was found near the top of Phu Pratu Tee Ma, Phu Wiang mountain range at about 422 m high in a slope of weathered siltstone. The other fossils collected from this place include fish remains, turtle plates, a dinosaur bone, a sauropod tooth, blade-like carnosaur teeth, and pointed theropod teeth. It is closely related to crocodile fossils from the Upper Jurassic of North America and Europe and the Lower Cretaceous of

Europe. They suggested the Late Jurassic to Early Cretaceous age for the Sao Khua Formation. The occurrences of this taxon in Khorat Plateau are indicative of Laurasian faunal affinities.

Buffetaut *et al.* (1995) summarized the advance of knowledge on the dinosaur fauna of the Sao Khua Formation from Phu Wiang in Khon Kaen, Phu Pha Ngo and Wat Sakawan in Kalasin. They referred to the small bones of juvenile sauropods, which had been found at several sites in the Phu Wiang area, these fossils were identified as *Phuwiangosaurus sirindhornae* because of the morphological resemblances with adult of that species. In addition, *Compsognathus* sp., *Siamosaurus suteethorni*, incomplete skeleton of a large theropod, and the ornithomimosauria were also reported at the Phu Wiang area

Buffetaut *et al.* (1996) described new species of Tyrannosaurid dinosaurs *Siamotyrannus isanensis* by using the partial skeleton including the left half of pelvis, sacrum, thirteen anteriormost caudal vertebrae, and five dorsal vertebrae. These bones were found in red sandstone of the Sao Khua Formation at fossil site Phu Wiang 9. The age of this formation was considered as ante-Aptian (Early Cretaceous) on the basis of palynological evidences of the underlying Phra Wihan Formation and the top of Khorat Group, Khok Kruat Formation. Therefore, this new species is at least 20 million years older than the earliest previously known tyrannosaurids.

Meesook and Wongprayoon (1999) reported the bivalve fossils collected from 3 localities in reddish-brown claystones and siltstone of the Sao Khua Formation (including Phu Wiang). These fossils have been preliminarily identified as *Trigonioides* sp., *Plicatounio* sp., *Unio* sp., and *Nippononaia* sp.

Jearanaiwong (2000) studied the bivalve fossils collected from Phu Phratu Tee Ma and Sam Bak Lo in Phu Wiang National Park, which he identified as *Unio* sp., *Trigonioides* sp., and *Exogyra* sp., the lithostratigrahic section of both localities were presented.

Cuny *et al.* (2003) reported 9 taxa of hybodont sharks from the Khorat Group. One of them is *Heteroptychodus steinmani* Yabe and Obata, 1930 found in several localities of the Sao Khua Formation (including fossil site Phu Wiang 1A) and the Khok Kruat Formation. This genus has the largest distribution, which has been recorded in Thailand, Japan, Kirghisia, and Mongolia.

1.4.2 Geology and Stratigraphy

Ward and Bunnag (1964) studied stratigraphy of Mesozoic Khorat Group in Northeastern Thailand. They proposed the term "Khorat Group" instead of "Khorat Series" and the term "Formation" instead of "Member". They subdivided the group into 7 formations include the Nam Phong, Phu Kradung, Phra Wihan, Sao Khua, Phu Phan, and Khok Kruat Formations, and Unname rocks. Three new formations are defined include, the Nam Phong, Sao Khua, and Khok Kruat Formation. They made 5 sections include the type sections of the Nam Phong, Phu Kradung, Sao Khua, Phu Phan, and Khok Kruat Formations.

Inthuputi and Suwanasing (1978) reported that the outcrop of sandstone and conglomeratic sandstone of Phu Pratu Tee Ma contains radioactive minerals, the beds have strike approximately N-S and dip 10^{O}-12^{O} E. They subdivided the exposed rocks into 4 units from top to bottom as Unit A-D: Unit A, 0.3-0.5 m thick, is pale pinkish gray conglomerate with quartz siltstone pebbles. Unit B, 5-10 m thick, is arkosic sandstone and conglomeratic sandstone. Unit C, about 10.5 m thick, is sandstone and silty claystone. Unit D, 5-9 m thick, is fine to medium grained sandstone. The uranium-bearing units are recognized in unit B and Unit D. They also used diamond

drilling along with gamma-ray logging in the holes to investigate the concentration of uranium in unit B and unit D. As a result, the ore bodies are lenticular and nearly parallel to the bedding. Petrified wood and fossil-bone were found. They also found brachiopod in lime-nodule conglomerate.

Gocht and Kaewbaidhoon (1982) summarized the work on geological investigation in the Phu Wiang area during 1979 to 1981 concerning the uranium mineralization, the host rocks, and the source rocks. The result of the investigation indicated uneconomic uranium deposits because the mineralization is low grade and the ore lens are small.

Inthuputi and Pluhar (1982) divided the Sao Khua Formation at uranium deposit locality into 3 units as follows, unit A on the top is siltstone and mudstone, unit B is sandstone, conglomeratic sandstone, unit C is siltstone and mudstone. By using the gamma-logging of drill core, the result indicates that uranium is concentrated perfectly in the gray to greenish conglomeratic or pebbly sandstone at the base of unit B. They found silicification of coalified plant fragments and concluded that uranium ore is tabular and lenticular, parallel to bedding plane, which deposited in fluviatile environment. Uranium was introduced by uranium bearing solution and coprecipitated with $CaCO_3$ cement. It is distributed within mudstone pebble in conglomeratic sandstone.

Kroker and Yuthagasemsan (1982) studied petrography of the rock from the Sao Khua Formation in Unit B of Phu Wiang Uranium Site (subdivided by Inthuputi and Suwanasing, 1978). The rocks are lithic arenite to subarkose, the modal analysis yielded quartz 59-76% of monocrystalline and polycrystalline, feldspars 4-7.5% of alkali feldspar and plagioclase feldspar, mica 0-16% of biotite and muscovite, chert/ porphyric matrix 5-11% calcite (matrix and cement) 1-23% and clay or fine micaceous matrix 0-8%. These rocks yield the following heavy minerals: hematite, limonite, ilmenite, pyroxene, tourmarine, rutile, garnet and zircon. Grain size analysis shows analogies to grian size distribution of the recent Missisppi Delta. They also evaluated granulometric curves of the Unit B, which similar to the example of recent and old river sediment or channel sand studied. They deduced that the mud pebbles came from the channels overflowed their banks and broken off the mudcracks and deposited together with lime pebble in the channel's conglomeratic horizons. Whereas the cross bedding directions show the unimodal distribution, current directions of the Sao Khua Formation in Phu Wiang and Phu Kao (Northeast of Phu Wiang) were from NE to SW. The limited variability of flow direction indicates a relatively rectilinear flowing river. Finally, they deduced that the potential source rock and source areas were metamorphic, acid to intermediate volcanic, plutonic, and their source area is thus either to be found in the basement of the Khorat Group northeast of Phu Wiang or even in Triassic to Lower Jurassic volcanic in Khorat Group bed, which may be aerially transported tuff from the Si Chiang Mai Pak Chom volcanic Belt.

Schlag and Gunnaleka (1982) studied petrology and geochemistry of extrusive rocks in the Pak Chom-Si Chiang Mai, Loei-Chiang Karn, Chum Phae-Lom Sak, Petchabun, and Saraburi areas. They assumed the alkali-rhyolite of the Pak Chom- Si Chaing Mai area as potential uranium sources for uranium ore in Phu Wiang.

Gocht (1982) studied the hydrogeochemical test of subsurface and groundwater wells in the Phu Wiang basin, which the results in 1979 have shown the uranium content in groundwater increased at the beginning of rainy season and is also high during the rainy season, and its content is decreasing off the orebody.

Trakoolngam (1999) constructed detailed lithostratigraphic columns of the Sao Khua Formation from the 12 selective sections of the southern Phu Phan Range. The

rocks consist of siltstone, and conglomerate. The Sao Khua Formation conformably overlies the Phra Wihan Formation with transitional contact and conformably underlies the Phu Phan Formation with a sharp contact, also with local unconformity of an erosional contact.

Wongprayoon and Meesook (1999) studied the geology and stratigraphy of the northern Phu Phan Range area, northeastern Thailand covering 3 topographic map sheets scale 1:50,000: King Amphoe Phu Phan (5742-I), Amphoe Sahat Sakhan (5742-III), and Amphoe Kam Muang (5742-IV). The study areas comprise Phu Kradung, Phra Wihan, Sao Khua, Phu Phan, and Khok Kruat Formations, in ascending orders. The overlying Maha Sarakham Formation is unconformable with the Khok Kruat Formation. Age determinations based mainly on vertebrates, bivalves and palynomorphs indicate that the Phu Kradung Formation is dated as Late Jurassic whilst the Phra Wihan, Sao Khua, Phu Phan, and Khok Kruat Formations are reassigned to the Early Cretaceous. The Maha Sarakham Formation is Early to Late Cretaceous.

Srisuriyon (2000) studied the characteristics of the Phra Wihan, Sao Khua, and Phu Phan Formations at Ban Thap Boek, Amphoe Lom Kao, Changwat Petchabun. He subdivided the Sao Khua Formation into 4 members as A, B, C, and D based on the combination of lithology and sedimentary features. It is interpreted that the Sao Khua Formation deposited in the meandering rivers.

Wongprayoon and Meesook (2002) studied the geology and stratigraphy of the north-western rim of the Khorat Plateau covering 2 topographic map sheets scale 1:50,000: Amphoe Phu Wiang (5442-II), and Ban Khok Sung (5542-III). The study areas comprise Nam Phong, Phu Kradung, Phra Wihan, Sao Khua, Phu Phan, and Khok Kruat, and Maha Sarakham Formations, in ascending orders. The Maha Sarakham Formation unexposed in the area, consists of red to reddish-brown clastic rocks with disseminated salts and gypsum by reporting of core well data. According to field investigation and published research, the unconformable contact is concluded for the Phu Kradung and Nam Phong Formations, and the Khok Kruat and Maha Sarakham Formations. Age determinations based mainly on vertebrates, bivalves and palynomorphs, and stratigraphic relation indicating that the Nam Phong Formation is dated as Late Triassic. The Phu Kradung Formation is dated as the Middle to Late Jurassic whilst the Phra Wihan, Sao Khua, Phu Phan, and Khok Kruat Formations are reassigned to be the Early Cretaceous. The Maha Sarakham Formation range in age from the Late Cretaceous to Early Tertiary. They interpreted the irregular shape calcrete nodule as inplaced concrete horizon, and then were transported to redeposit in the overlying conglomerate beds. The *Exogyra* bed is lens in siltstone, indicating deposited in saline water in arid climate.

1.4.3. Interpretation of Palaeoenvironment

Hahn (1982) interpreted the red bed facies of the Khorat Group as oxidizing environment. The deposition took place in big shallow claypans under semiarid to arid climatic conditions. Caliche was found on the mudstone surface, it developed by the process of capillary action and evaporation. Pollens were found in the plant-bearing horizons in unit of whitish-grey sandstone with grey or green shale intercalation, which he interpreted that during this period of deposition the climate changed to sub-tropic humid. He deduced that the Phu Kradung, Phra Wihan, and Phu Phan Formations and partly the Sao Khua Formation were deposited in a fluvio-lacustrine environment. He also deduced the episodic marine ingression occurring in various horizons of the Sao Khua Formation as evidenced by the occurrence of grey,

calcareous conglomerates containing the thick shell bivalves *Cardinioides magnus* Kobayashi and Hayami, 1963 as well as Plesiosaur and Ichthyosaur teeth. The deltaic deposition environment was assumed for the uranium bearing channel sandstone of the unit B of the Sao Khua Formation in the western and southwestern parts of the Phu Wiang and the Phu Kao synclines and an area east of Nong Bua Lamphu. This assumption is based on the occurrence of *Cardinioides*-bearing calcareous conglomerates within the sandstone and limnic brackish ostracodes from intercalating grey or green shale beds. The age of this Formation is probably Upper Jurassic as indicated by ostracodes, pollen and dinosaur femur.

Buffetaut and Suteethorn (1989) discovered a partial sauropod skeleton in red siltstone at Phu Pratu Tee Ma, these skeletons that were still partly articulated and isolated carnosaur teeth were found close to these skeletons. They interpreted this fossil locality as floodplain deposit and one or several carnosaur fed on the sauropod carcass before it was buries. Whether the sauropod was killed by carnosaur before it was eaten by them, or whether they merely acted as scavengers on the sauropod carcass, which had died from other cause, cannot be determined on the basis of the available data. These fossils used as a taphonomic indicator of non-transportation. They also interpreted the two distinct facies of fossil localities at Phu Pratu Tee Ma. Fossil fish, crocodile, turtle, dinosaur bones, and dinosaur teeth are abundance but completely disarticulated and often worn in fine-grained greenish sandstone which can be interpreted as channel deposit. Vertebrate remains are less abundance but articulated or parts of dinosaur skeleton occur, and fossil of aquatic animals are rare in red or variegated siltstone which can be interpreted as floodplain deposits.

Meesook (2000) summerized the Cretaceous environments of northeastern Thailand including the Phra Wihan, Sao Khua, Phu Phan, and Khok Kruat Formations of the Khorat Group and the overlying Maha Sarakham Formation. The Sao Khua Formation consists of an alternation of reddish-brown silty claystones, siltstones, and fine to medium-grained sandstones with numerous thin caliches, carbonate nodules, and bedded and nodular silcretes. Lime-nodule conglomerates and silicified wood-like beds that widespread in maroon to reddish-brown claystone had been interpreted as paleosols and silcretes, which can be used as palaeoclimate indicator. The rocks were deposited in the meandering fluvial system during semi-arid palaeoclimate. This palaeoclimate of silcrete is suggested by the void fills composed of length-slow fibrous chalcedony and microcryptalline quartz. The low concentration of titanium dioxide (TiO_2 <0.03) also supported this palaeoclimate interpretation.

1.4.4. Age of the Sao Khua Formation

Konno and Asama (1973) reported the plant fossil, *Sphenopteris goeppati*, whichits range is Early Jurassic to Early Cretaceous. Pollens were also reported, their ranges are Early to Middle Jurassic.

Kobayashi (1984) divided the Khorat Group into three subgroups, including Upper, Lower, and Basal Khorat Subgroup, which the Phra Wihan Formation in the lower Khorat Subgroup inclusive the Sao Khua member was recognized as Middle to Upper Jurassic from the evidences of *Mytilus (Pachymytilus?) rectangularis* and *Cardinioides magnus*, because their ranges from Carnic to Liassic in Japan. The other is *Goniomya khoratensis*, which its range is Upper Jurassic.

Racey *et al.* (1994) proposed the new age data for the Khorat Group from their new palynological data; the Phra Wihan Formation is Early Cretaceous (Berriasian-Barremian). The Sao Khua and Phu Phan Formations are Early Cretaceous (Barremian-Aptian).

Meesook *et al.* (1994) reported the bivalve fossils from the Sao Khua Formation, which indicated Early Cretaceous in age.

Meesook *et al.* (1995) summarized the bivalve fossils from the Sao Khua Formation, based on these fossils, *Trigonioides* (s.s.) *trigonus* and *Trigonioides* ? cf. *guangxiensis* give Aptian-Albian (Early Cretaceous) for the Sao Khua Formation.