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REVIEW OF THE CONTINENTAL MESOZOIC STRATIGRAPHY OF THAILAND

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INTRODUCTION

The continental Mesozoic redbeds are widely distributed throughout the country, especially in the Khorat Plateau, from which the group's name was obtained. The rocks are predominantly red clastic, i.e., sandstone, siltstone, claystone, shale and conglomerate. The Khorat Group rests unconformably on older rocks, generally of Paleozoic age, but occasionally it overlies the Permo-Triassic igneous rocks and/or Lower to Middle Triassic sedimentary rocks.

The Khorat Group was previously reviewed in Thai by Nakornsri (1975) and in English by Kulasing (1975) and Ramingwong (1978). This paper is an attempt to update the knowledge so far reported about the Khorat rocks and their equivalents.

REVIEW OF PREVIOUS WORKS

Lee (1923) was the first geologist who noted the non-marine Mesozoic rocks in the Khorat Plateau and divided them into Upper and Lower Group, the Triassic age was given.

Brown et al. (1953) named the **Khorat Series** to represent the continental redbeds and the marine Triassic limestone of northern Thailand. The sequence consists of interbedded sandstone, conglomerate, shale and marly limestone. No fossil was found except some petrified wood.

La Moreaux et al. (1956) divided the Khorat Series, following Chali-
chan and Bunnag (1954), into three members and assigned the age of this sequence to the Triassic period. Their subdivision are as follows:

Phu Kradung Member is the oldest member it lies unconformably on Paleozoic rocks. The lowest part began with the basal conglomerate and was subsequently overlain by massive purple shale with minor sandstone.

Phra Vihan Member lies conformably on the Phu Kradung Member and consists mainly of sandstone, whose color varies from green to grey to tan and white. Layers of lignite and petrified wood were reported.

Phu Phan Member consists predominantly of white arkosic sandstone and conglomerate. They cropped out as hills and escarpments of the Khorat plateau.

They also noted the occurrence of the unnamed redbeds, which was underlain by the Khorat Series in the central part of the plateau. Its age was probably Cretaceous or younger.

Ward and Bunnag (1964) started using the name **Khorat Group** instead of the Khorat Series. They measured 5 type sections and divided the Khorat Group into 7 formations from the oldest to the youngest.

Nam Phong formation is the Lowest unit of the Khorat Group. It consists of alternating thick-bedded siltstone and resistant sandstone and conglomerate. This formation overlies the Paleozoic rocks. The thickness at the type section was 1,465 meters.

Phu Kradung Formation: overlies the Nam Phong Formation or Ratburi (Permian) limestone where the Nam Phong Formation was absent. The formation comprises soft siltstone and non-resistant sandstone with greenish gray calcareous conglomerate. Bone fragments and teeth were collected, one of them was identified as a Plesiosaur tooth (Hayami, et al. 1962). The formation was 1,001 meters thick at its type location.

Phra Vihan Formation consists predominantly of white quartz sandstone and thin laminations of red siltstone. The thickness varied from 56 to 136 meters. Silicified wood and lignite (as jets) were reported.

Sao Khua Formation consists of a thick sequence of non-resistant siltstone and conglomeratic sandstone. Its thickness at the type section was 512 meters. Fossils were identified as: *Naticoid* gastropods, and marine bivalves *Cardinoides magnus* and *Mytilus rectangularis* (Kobayashi, et al. 1962). An Ichthyosaur tooth was also found (Takai, 1962). The ages of the fossils were considered to be Jurassic, probably Liassic.

Phu Phan Formation is characterized by thick-bedded and cross-bedded conglomeratic sandstone. Occurrences of a few unidentified bone fragments and some carbonaceous materials have been recorded. The thickness was 114 meters at the type section.

Khok Kruat Formation comprises soft siltstone and moderately resistant sandstone and caliche-siltstone pebble calcareous conglomerate. Fossil teeth were identified as belonging to an *Ichthyosaur* (Takai, 1962). The thickness was 709 meters at its type locality.

Unnamed Rock represents the section of soft siltstone and sandstone that contain thick beds of salt and gypsum. The estimated thickness exceeded 600 meters.

Kobayashi (1964 a) reported a fossil wood *Eomiodon chumphonensis* (Hayami, 1960) from the vicinity of Chumphon, southern Thailand, whose age was considered to be Middle Jurassic. He also suggested that the Khorat rocks were paralic deposits occasionally soaked with saline water.

The Thai-Japanese expedition members (Iwai et al., 1964) classified the Khorat Series into members as follows.

5. Lower Cretaceous, Ban Na Yo formation
4. Phu Phan white sandstone formation
3. Phra Wihan variegated formation containing *Brachyphyllum* and *Sphenopteris* beds.
2. Phu Kradung red formation; sandstone, shale and marl yielding *Araucarioxylon*.
1. Huai Hin Lat formation, conglomerate, limestone conglomerate, sandstone and marl containing *Neocalamites* and *Clathropteris* floras.

Kobayashi (1964 b) recorded the non-marine Cretaceous mollusks from Ban Na Yo. The faunas were *Nippononaiia mekongensis*, *Trigonioides* sp., *Plicatounio* sp., *Paranodonta* (?) *khoratensis*. These faunal assemblage resembled *Trigonioides - Plicatounio* faunas which Hoffet (1937) found along the Laotian border. The latter faunas were also embedded with *Titanosaurus* and *Mandschurosaurus* which were Upper Cretaceous (Senonian) in age, whereas, the pelecypod fauna was reported to belong to the Lower Cretaceous age.

Kobayashi et al., (1964) subdivided the Khorat Group into 3 units, namely:

The Lowest Khorat series is characterized by gently folded beds containing Liassic bones. The sequence rests unconformably on strongly folded strata.

The Middle Khorat series yielded the Lower Cretaceous faunas.

The Upper Khorat series ranges in age from the Upper Cretaceous to Tertiary. It was found in both the north and south basins probably lying slightly unconformably on the Middle Khorat series.

Borax and Stewart (1965) divided the Khorat Group into 3 units, viz., the Upper, the Middle and the Lower Khorat unit. Their correlation is shown in Table 1.

Haworth et al., (1966) reported the *Hybodont* tooth as identified by Dunkel (1965) in the Khok Kruat Formation. Moreover, they named the Salt Formation which was equivalent to the Unnamed Rocks of Ward and Bunnag (1964).

Iwai et al., (1966) divided the Khorat Group into 6 formations, as follows:

Huai Hin Lat Formation is the lowest formation and consists of conglomerate with pebbles of limestone, rhyolite porphyry, and other rock fragments, gray to dark gray sandstone, siltstone, shale and limestone conglomerate. Numerous plant fossils were found and were identified as *Neocalamites* sp., *Equisetites* sp., *Cladophebis* sp., *Clathropteris* cf. *meniscoides* BRONGNAIRT, and *Pterophyllum* sp. Rhaetian to Liassic ages were assigned to this formation. The thickness was 140 meters at its type location.

Phu Kradung Formation overlies the Huai Hin Lat Formation or the Paleozoic rocks where the former was absent. Only silicified wood was found. The age was designated as Early Jurassic.

Phra Wihan Formation was related to both the Phra Vihan and Sao Khua Formation of Ward and Bunnag (1964). The fossil plants were found and identified as *Sphenopteris* sp. and *Brachyphyllum* sp. These fossils were collected from the upper part of the sequence which Ward and Bunnag (1964) mapped as the Sao Khua Formation. A 72 m thickness was measured and the Middle Jurassic age was assigned.

Phu Phan Formation was the same as that classified by Ward and Bunnag (1964). No fossil was found that the formation was considered to be Late Jurassic. The thickness varied from 100 to 400 meters.

Ban Na Yo Formation consists of the sequence of red sandstone, siltstone, shale with interbedded calcareous conglomeratic sandstone, sandy limestone and calcareous siltstone. The formation is 420 meters in thickness. The bivalve faunas found in this formation suggest a Lower Cretaceous age (Kobayashi, 1964 b).

Besides, the **Lom Sak Formation** which yielded *Sequoia concinna* HERR as identified by Engo (1963), was mentioned. The Lom Sak Formation consists of red-gray tuff, breccia tuff and green tuff interbedded with yellowish, pale green, fine-grained sandstone, dark gray shale and calcareous shale. Correlation with other formations was not made due to faulting.

Endo and Fujiyama (1966) described the plant fossils from the Lom Sak Formation as *Sequoia ambigua* HERR of the Upper Cretaceous age.

Gardner et al. (1967) proposed the name **the Maha Sarakham Formation** to replace the Unnamed Rocks and the Salt Formation of Ward and Bunnag (1964) and Haworth et al. (1966), respectively. The formation consists of salt-bearing claystone, mudstone, siltstone and sandstone. The Lower contact with the Khok Kruat Formation was a transition. The salt might have occurred in Lower Cretaceous in some areas and Upper Cretaceous in the others, and probably as late as Early Tertiary. The total thickness of the formation was about 1,000 meters. The thickness of the salt beds varied from a fraction of a centimeter to more than 250 meters.

Hayami (1968) identified the non-marine bivalves collected by Iwai et al. (1966), from the Phu Kradung Formation, as follows: *Unio thailandica* n. sp., *Unio* (?) sp. indet and *Neomiodon* (?) *khoratensis* n. sp. The age

was thought to be Lower Jurassic.

Kobayashi (1968) identified the non-marine pelecypods found in the Phu Phan Formation from the Nam Phung Dam site, as follows: *Plicatotrigonioides* (?) *subovalis* Kobayashi, n. sp., *Pseudohyria* (?) sp., *Nippononaia carinata* Kobayashi, n. sp., *Nippononaia (Mechongichoncha) subquadrata* Kobayashi, n. subgen, and sp., *Nippononaia (Mechongichoncha) robusta* Kobayashi, n. subgen, and sp., *Plicatounio namphungensis* Kobayashi, n. sp., '*Unio*' *sampanoides* Kobayashi, n.sp.

The age of the faunas was considered to be Lower Cretaceous. Moreover he reassigned the age of the Ban Na Yo Formation to Upper Cretaceous, since it rested directly on top of the Phu Phan Formation.

Iwai et al. (1968) studied the rock exposures along the Phitsanulok-Lom Sak Highway and classified them into 5 formations, as follows:

Phu Kradung Formation consists of reddish gray shale, siltstone, medium-to coarse-grained sandstone and calcareous conglomerate. The base of the formation was unknown.

Phra Wihan Formation consists of light coloured orthoquartzite, occasionally conglomeratic.

Phu Phan Formation consists of light coloured medium-to coarse-grained orthoquartzite, conglomeratic in part. The thickness was about 100 meters.

Ban Na Yo Formation consists of red and reddish gray shale, siltstone and sandstone. The thickness was more than 300 meters.

Moreover, the Lom Sak Formation was divided into 3 units, viz., (1) reddish conglomerate with tuffaceous matrix, sandstone, siltstone and friable shale, (2) variegated pyroclastic rocks with lava in part, and (3) an alternation of tan and/or light yellowish gray, medium to fine-grained sandstone and thinly bedded shale or siltstone. The stratigraphic relations of these three units were unknown.

Iwai (1968) studied the ripple marks and the cross-stratification of the Khorat rocks. Unfortunately, the paleocurrent direction was not clearly proved as this work was a reconnaissance in nature. The aim of his work was to present guidelines on further systematic research work to resolve problems of paleogeography and dispersal of the sediments.

Baum et al. (1970) reported the non-marine Mesozoic redbeds of Northern Thailand and classified them into 5 units as follows:

- J5 red sandstone and claystone, more or less sandy.
- J4 whitish gray to greenish gray arkosic sandstone with subordinate conglomerate and shaly intercalations. Fresh water fish, pelecypods and plant remains were found.

J3 conglomerate, red sandstone, claystone and locally marine sandstone.

J2 acid to intermediate volcanic series, accompanied by tuffs.

J1 conglomerate, red sandstone, and claystone.

The sequence was considered to be deposited in limnic and fluviatile environments with occasional marine invasions. The lower part rested unconformably in some areas and conformably in others, on older rocks. The age of the group was Upper Triassic to Cretaceous.

Bunopas et al. (1970) divided the rocks along the Phitsanulok-Lom Sak Highway into 3 formations, viz., The Sao Khua, Phra Wihan and Phu Kradung formation. The subdivision can be correlated to the Bau Na Yo, Phu Phan plus Sao Khua, plus Phra Wihan, and Phu Kradung plus Lom Sak Formation of Iwai et al., (1966, 1968). The reassignment of the age of the Lom Sak Formation was because (1) similar rocks exposed elsewhere rested on beds containing *Halobia* fossil which was Triassic in age. (2) The Lom Sak Formation can be correlated with J1, J2 and J3 of Baum et al., (1970), and (3) The fossil leaves of *Sequoia ambigua* HERR were probably misidentified.

Bunopas (1971) considered the Nam Pha Formation as the lowest part of the Khorat Group. The Rhaetian age was given based on *Estheria* sp. The type section was in the vicinity of the Nam Phrom Dam. The formation consists of calcareous gray and brown siltstone, sandstone interbedded with gray to dark gray, bedded argillaceous limestone in the lower part, and calcareous gray and red siltstone, mudstone, shale and red argillaceous limestone in the upper part. The formation was more than 550 meters thick and can be correlated with the Huai Hin Lat Formation of Iwai et al. (1966).

Moreover, Bunopas included the red-bed sequence overlying the Nam Pha Formation into the Phu Kradung Formation and divided it into 3 members.

Phu Kradung Member consists of a sequence of soft siltstone and occasional non-resistant sandstone.

Nam Phong Member consists of alternating thick beds of siltstone, resistant sandstone and thin-bedded conglomerate.

Nam Phrom Member consists of thick sandstone with intercalations of siltstone, conglomerate and quartz sandstone.

The formation was considered to be equivalent to the Nam Phong and Phu Kradung Formation of Ward and Bunnag (1964), whereas the Nam Phrom member was related to the Lower part of the Nam Phong Formation. The exact boundaries between these three members were not clear.

Iwai (1972) studied the pelletal limestone of the Phu Kradung Formation from its type section. The deposition was believed to have occurred

in shallow lake, rich in carbonate, with loads of hematite suspension.

Piyasin (1972) mapped the Mesozoic continental sediments in the Lampang area as shown in the 1:250,000 geologic map of the Lampang sheet, as the Khorat Group. Phu kradung and Phra Wihan Formations were identified in that area. The age of the rocks was reported to be Middle to Upper Jurassic, based on the fact that they rested conformably on the Volcanic Group, which rested on the Triassic Lampang Group.

Moreover, in his previous work (Piyasin, 1971), the Pha Daeng (redbeds) Formation of the Lampang Group was considered to be a terrestrial or near-shore origin. The age was given as Uppermost Norian to Rhaetian based on the presence of *Hettangia* in a dark-gray argillaceous coquinoid limestone.

The Union Oil Company of Thailand drilled a dry hole at the Kuchinara-rai Anticline, Kalasin in 1972. The Phu Kradung Formation was found from the surface to the depth of about 3,500 feet. The Nam Phong Formation was encountered from 3,500 ft. downward to the total depth of 11,000 feet.

However, strata deeper than 3,500 feet were excluded from the Khorat Group by the geologists of the Department of Mineral Resources because it was thought to be of Lower to Middle Triassic age.

These strata underlie the Khorat Group with a weak unconformity and consist mainly of red beds with some buff-coloured limestone and grayish white-coloured sandstone beds.

Konno and Asama (1973) identified the plant fossils from the upper part of the Huai Hin Lat Formation as *Equisetites arenaceous* (Jaeger) Schenk, *E. naitoi* KONNO, *Neocalamites cf. hoerensis* (shrimper) Halle pteropsida, *Clathropteris meniscoids* BRONGNIART, *Todites goeppertianus* (Muenster) Krasser cycadopsida, *Nilssonia thailandica* KONNO, *Anomozamites minor* (Brongn) Nahorst Conteropsida and *Elatocladus* sp. The floras indicated the Upper Triassic age, probably more characteristic of Norian than Carnian.

The floras from the Phra Wihan Formation were identified as follows:

Jurassic to Lower Cretaceous: *Brachyphyllum* sp., *Frenelopsis* (?) sp.
Upper to Lower Cretaceous: *Shenopteris (Ruffordia) goepperti* Dunker.

Haile (1973) described the pollens and spores from the Nam Pha Formation near the Nam Phrom Dam. The microfloras were identified as *Ovalipollis lunsensis*, *Cycadopites carpenticri*, *Alisporites* sp., *Zebrasporit fimbriatus*, *Camerosporites* sp., *Concavisporites lunsensis* and *Verrucosporites* sp. The Carnian-Norian (Upper Triassic) age was assigned to them.

Iwai (1973) studied the thinly bedded limestone of the Phu Kradung Formation from the localities at 152 and 157 kilometer posts along the highway from Khon Kaen to Loei. (These locations were recently mapped as the Huai Hin Lat Formation). These outcrops were described as dolomitized

limestone. The environment of deposition was believed to be lacustrine and dolomitization occurred after the precipitation of CaCO₃.

Asama (1973) confirmed the Upper Cretaceous age for the Lom Sak Formation, on the basis of *Pterophyllum* sp. and *Sequoia ambigua* which represented the Upper Carboniferous to Upper Cretaceous, and Upper Cretaceous ages, respectively.

Phiancharoen (1973) subdivided the Khorat Group on the 1:500,000 Hydrogeological Map of Northeastern Thailand into 3 members:

1. **Upper Khorat** (Cretaceous) is equivalent to the Khok Kruat and Unnamed Rocks of Ward and Bunnag (1964).

2. **Middle Khorat** (Jurassic) is composed of the Phu Phau, Sao Khua and Phra Vihan Formations of Ward and Bunnag (1964).

3. **Lower Khorat** (Upper Triassic to Jurassic) represents the Phu Kradung and Nam Phong Formations of Ward and Bunnag (1964).

Nakornsri (1974) subdivided the Khorat Group, in the area covered by the 1:250,000 geologic map of the Ban Mi sheet, into 7 formations viz., The Khok Kruat, Phu Phan, Sao Khua, Phra Wihan, Phu Kradung, Sap Mai Daeng and the Huai Hin Lat Formations. The first five formations follows those of Ward and Bunnag (1964), and the Jurassic age was given to them. The **Sap Mai Daeng Formation** consists of pale brown, medium-grained, cross-bedded, friable, pebbly sandstone with pebbles of volcanic rocks and limestone. It was so named and given the formation status due to vague correlation with other strata. The age was considered to be Jurassic. The lowest unit, the Huai Hin Lat Formation, comprises conglomerates with poorly sorted, rounded to subrounded pebbles of limestone and volcanic rocks. The age given was Triassic.

Hinthong (1974) mapped the geology near the Khao Yai National Park and reported the occurrence of the Phu Kradung and Phra Wihan Formations in that area. The former rested unconformably on the Permo-Triassic volcanic complexes. The age was reported as Late Triassic to Early Jurassic.

In addition, undifferentiated rock unit consisting of calcareous, gray and thinly laminated shales and sandstones interbedded with light brown thinly bedded siltstone and light coloured limestone was found to rest unconformably on Late Triassic granite. This unit was probably equivalent to the Nam Pha Formation of Bunopas (1971) due to the presence of some brackish water bivalves resembling *Estheria* sp.

Hite (1975) noted the evaporite cycles of the Maha Sarakham Formation from one bore hole, from bottom to top, as follows:

- A - Siltstone, red
- B - Siltstone, greenish gray
- C - Nodular and laminated gypsum
- D - Halite, smoky gray, banded by organic rich anhydrite laminae. The bands were undisturbed by flowage or folding.

- C - Anhydrite, laminated, grading downward into nodular texture
- B - Siltstone, greenish gray
- A - Siltstone, red

The red colour of unit A indicated an oxidizing environment which slowly changed into a reducing environment within unit B. He also suggested that the upper cycle may also consist of rock salt but it had probably been dissolved by groundwater.

Piyasin (1975) subdivided the Khorat Group on the 1:250,000 geologic map of the Uttaradit sheet into 3 formations. The subdivisions agreed with those of Ward and Bunnag (1964): Phu Kradung, Phra Wihan and Sao Khua Formations. *Hettangia* sp. (?) was found in the Phu Kradung Formation and indicated Rhaetian-Liassic age.

Kobayashi (1975) referred to his first note on the *Euestheria mansuyi* (Kobayashi, 1973), identified and described the *Conchostracean* faunas from the Huai Hin Lat Formation. It consists of *Euestheria mansuyi* Kobayashi, *E. thailandica* Kobayashi, sp. nov., *E. buravasi* Kobayashi sp. nov., *Khoratetheria macroumbo* Kobayashi, gen. et sp. nov., *Metarhabdosties* (?) sp., and *Asmussia symmetrica* Kobayashi, sp. nov.,

Iwai et al. (1975) described the Khorat Group as consisting of the Huai Hin Lat, Phu Kradung, Phra Wihan, Phu Phan Ban Na Yo and Lom Sak Formations. Mainly, their lithologies resembled those of Iwai et al., (1966). In the Huai Hin Lat Formation, they mentioned the intercalation of dark gray limestone and limestone conglomerate in the middle part of the sequence. In addition, the Huai Hin Lat Formation was considered to be equivalent to the lowest part of the Phu Kradung Formation. The Ban Na Yo Formation was classified into 2 parts, namely, Ban Na Yo Formation SI and Ban Na Yo S.STR. The units represent the redbeds which conformably overlie the Phu Phan Formation and the redbeds found at Ban Na Yo respectively.

The Ban Na Yo Formation SI comprises mainly red, grayish and red sandstone, siltstone and shale and occasional calcareous conglomeratic sandstone, sandy limestone and calcareous siltstone. Salt and gypsum were found in a deep well. This formation was identical to the Khok Kraut Formation of Ward and Bunnag (1964).

Iwai et al. also proposed the name **The Nam Phung unit** on the basis that it included neither the Phu Phan or the Ban Na Yo Formation S.STR. This new unit consists of conglomerate, sandstone and shale with intercalations of fossil pelecypods-bearing calcareous siltstone. They also summarized the Khorat biota so far reported.

The environments of deposition were discussed. The lower and upper parts were limnic and aluvio-lacustrine deposits, whereas the middle part may be paralic or estuarine-lagoonal sediments. Marine ingressions during Jurassic time was conjectural. The Khorat Group was also considered as a deposit in a tectonically active area under a consistently strong oxidizing condition.

Garson et al. (1975) described the Mesozoic Ko Yao Formation. The sequence comprises sandstone, siltstone and conglomerate. The thickness was estimated at less than 400 meters.

Kobayashi (1976) pointed out that the Khorat Basin was brought to birth behind the older Mesozoic folded mountains and the Noric and younger non-marine sediments were subsequently deposited. Late Mesozoic orogeny accompanied by batholithic emplacement of granitic magma on a grand scale caused the Khorat Plateau region and other parts of the country to become land.

Hahn (1976) pointed out that the Nan-Phayao basin represents the basin of deposition of the non-marine Mesozoic sediments in northern Thailand. This sub-basin was connected to the Khorat basin. The sequence was subdivided into 5 units, from bottom to top as follows:

ms 1 consists of red, sandy claystone and fine-grained sandstone of red, light red, reddish brown, purple, gray-brown, gray and beige colour. The unit rested conformably on the marine Triassic strata in the central part of the basin. At the flanks of the basin it formed on angular unconformity. On the basis of the fossils found in the underlying marine strata, the ms 1 was considered to be younger than Carnian or Late Carnian age. The thickness was 300 meters.

ms 2 is characterized by intermediate to acid effusive rocks (andesite, rhyodacite, rhyolite) and associated tuff. The unit rested more or less conformably on the non-marine redbeds in the basin center, whereas at the flanks and in the upland areas, it overlies unconformably the Triassic and/or Permian rocks. Thickness varied from 300 to 350 meters.

ms 3 is the major transgressive unit covering the eastern part of northern Thailand completely. Where it directly overlies the ms 2 unit, it begins mostly with conglomerates which changes gradually upward to sandstone and shale. The thickness is 300 to 400 meters. Lithologically, it resembles ms 1. Typical for the whole unit are the conglomerates which occur throughout the basin. Limestone beds are found locally and presumably indicated the marine ingressions over the uplifted areas. Limestone breccias are probably remnants of strata deposited during marine ingressions. Unidentified bone fragments, fish teeth and scales were found in this bed.

ms 4 is characterized by quartzitic, partly arkosic sandstones of white, white-gray, yellowish, gray, gray-green, light brown and subordinately, reddish and red-brown colour. Some conglomeratic beds and intercalations of gray, gray-green and red claystone were also reported. The formation is 400 to 500 meters thick.

ms 5 is composed of red, reddish-gray, gray-brown and red brown, fine-grained sandstone, intercalated with red claystone. Salt producing wells indicate rock salt intercalations in units ms 3 to ms 5 (Credner, 1935). The entire sequence was interpreted to be of Norian to Late Jurassic age.

Von Braun and Jordan (1976) recognized a sequence of clastic redbeds disconformably overlying the Jurassic Upper Mae Moei Group, which could be compared with part of the Khorat Group.

Bunopas (1976) reported the basal conglomerate of the Nam Pha Formation which he did not notice in his previous work (Bunopas, 1971). The conglomerate was much alike the Huai Hin Lat conglomerate of Iwai et al. (1966). He also suggested a transitional deposition of the marine Late Triassic to the continental Jurassic sediments, based on the fact that the Nam Pha Formation conformably underlies the Phu Kradung Formation.

The Khorat Group was informally subdivided into 4 units, from bottom to top, as follows (Bunopas, 1976) Gray beds, Lower Redbeds, Middle sandstone and the Upper Redbeds.

The distribution of the Mesozoic redbeds was noted in 8 areas of the country, namely: (1) The Khorat Plateau (2) Uttaradit-Dan Sai Synclorium (3) Nan-Phrae-Chiang Rai area (4) Lampang area (5) Tak area (6) Kanchanaburi area (7) Trat-Cambodia Synclorium and (8) Chumphon-Nakorn Sri Thammarat area. It was concluded that only in localities 1, 2 and 7 complete Mesozoic redbeds were present. In localities 3, 4 and 8 only the lower redbeds to the lower part of the middle sandstone were known. In localities 5,6 and northwestern part of locality 8, only the lower redbeds were found. Continuation of outcrops of the redbeds could be traced from localities 1 to 2 and 3, but in all other area the redbeds were isolated from each other.

Chonglakmani and Sattayarak (1978) combined the Huai Hin Lat and Nam Pha Formation into one Formation, due to their equivalence in lithostratigraphy. The name Huai Hin Lat Formation was selected according to the rule of priority. The formation was subdivided into 5 members, from bottom to top, as follows:

1. **The Pho Hai Member** consists mainly of volcanic rocks, i.e. tuff, agglomerate, rhyolite and andesite including some intercalation of sandstone and conglomerate. The thickness was 210 meters at its type location.

2. **The Sam Khaen Member** is chiefly basal conglomerate intercalated with red siltstone, shale, and locally limestone beds.

3. **The Dat Fa Member** is characterized by gray to black, carbon-rich, calcareous, well bedded shale with numerous argillaceous limestone.

4. **The Phu Hi Member** consists of gray sandstone, shale and argillaceous limestone with some intercalation of conglomerate beds.

5. **The I Mo Member** consists of diorite and its associated volcanic facies intercalated with the well-bedded gray shale, sandstone and limestone. This member was found locally.

The formation was chronostratigraphically correlated with part of the Lampang Group, and was considered as a lacustrine and deltaic deposits.

Ingavat and Taquet (1978) reported the first discovery of dinosaur remains in Thailand and identified it as a *Sauropod* of Jurassic age. The bone fragment was found in the Sao Khua Formation.

Inthuputi and Suwanasing (1978) studied the uranium-copper deposit in sandstone in Phu Wieng district. The mineral -bearing beds were the purplish gray to light greenish gray carbonaceous sandstone and conglomeratic sandstone. The most likely host rocks for uranium deposits appeared to be the Phra Wihan, Sao Khua and Phu Phan Formations of Jurassic age.

The rocks in the studied area were subdivided into four units, which were, from top to bottom: Unit A, B, C and D (Inthuputi and Suwanasing, 1978). Detailed descriptions are as follows:

Unit A consists mainly of a pale pinkish gray conglomerate. The thickness ranges from 0.3 to 0.5 meter.

Unit B is from 5 to 10 meters in thickness and consists of arkosic sandstone and conglomeratic sandstone.

Unit C has an average thickness of 10.5 meters and consists mainly of sandstone and silty claystone, light brown to pale reddish brown in colour.

Unit D ranges in thickness from 5 to 9 meters and consists of gray sandstone and interbedded lenses of limestone.

The uranium-bearing strata are recognized within the Unit B and D.

Pitakpaivan and Chonglakmani (1978) named the Khorat-Phayao basin as the depositional basin of the continental Mesozoic rocks in Thailand. The Nam Phong Formation was considered as the lowest strata in the Phayao sub-basin, whereas, in the Khorat sub-basin the non-marine sediments started with the Huai Hin Lat Formation.

Workman (1981) published the photogeologicla map of the Khorat Plateau and southern Laos, using satellite imagery. The extension of the Khorat rocks from the Khorat Plateau into Laos was noted.

Asama et al. (1981) noted the plant remains from the redbeds of Trang, southern Thailand. They were comparable to those of the Gagau Group of Malasia and were the first record of the Lower Cretaceous plant in Thailand. The floras were identified as,

FILICALES	:	<i>Gleichenoides gagauensis</i>	Kon'no
		<i>Gleichenoides pantiensis</i>	Kon'no
BENNETTITALES	:	<i>Otozamites gagauensis</i>	Kon'no
		<i>Otozamites</i> sp.	
CONIFERALES	:	<i>Podozamites pahangensis</i>	Asama
		<i>Frenelopsis</i> sp.	

Piyasin (1982) pointed out that the Nam Pha Formation of Bunopas (1971) should be separated from the Khorat Group, since it could be correlated with the marine Triassic Lampang Group. The Pha Daeng Formation of the Lampang Group resembled the Nam Phrom and Nam Phong member of the Phu Kradung Formation of Bunopas (1971) or the Nam Phong Formation of Ward and Bunnag (1964).

Asama (1982) identified the silicified woods from the Phu Kradung Formation as *Araucarioxylon japonicum* SHIMAKURA. The age was given as Lower Jurassic.

Hahn (1982 a) noted the depositional environment of the Khorat Group, as follows:

The Phu Kradung Formation was a fluvio-lacustrine deposit. Its age was given according to the pollen analysis as Upper Triassic to Lower Jurassic (Madler, 1980). The floras were *Ballosporites*, *Calamospora*, *Classopollis*, *Classopollis striatus* Madler, *Ballosporites hians* Madler, ? *Ovalipollis*, cf. *Cyclotriletes subgranulatus* Madler and *Cyathidites*.

The Phra Wihan Formation was also deposited under a fluvio-lacustrine environment. Pollens of Upper Triassic to Lower Jurassic were identified namely: *Cyathidites*, *Classopollis*, *Ballosporites hians* Madler, *Lycopodiacidites*, *Calamospora*, *Monosulcites* sp., *Ballo-sporites* cf. *Cyclotriletes subgranulatus* Madler, *Minutosaccus* sp., and *Chasmatosporites*, cf. *Anulatzonites*.

The Sao Khua Formation was considered as the deposits in the big, shallow clay pans or lacustrine basins with psammitic flood-plain sediments, occasionally, river channel deposits cut into the underlying argillaceous sediments. A deltaic depositional environment was assumed for the uranium-bearing channel sandstone of the Unit B of Inthuputi and Suwanasing (1978). A *plesiosaur* tooth (Wolfart, 1980) was found. The fossils which indicate the Upper Jurassic to Early Cretaceous are: pollens: *Circulina*, smooth *Triletes*, *Disaccites*, *Vitreisporites* cf. *pallidus*, *Ephedripites*, similar *Cicatricosisporites* (Madler, 1980) marine pelecypod: *Solemya* sp. (Wolfart, 1981), ostracods: *Cetacella* sp., *Darwinula* sp., *Rhinocypris* ?, *Cyridea* sp., *Eoparacypris* ? sp. (Gramann, 1980).

The Phu Phan Formation was considered a typical fluviatile deposit with the clay pan sedimentation. The paleocurrent measurements in Nong Wua So area revealed a S-SW trending current direction which coincided more or less with that of the Unit B sandstone of the Sao Khua Formation.

Throughout the sequence, the marine ingression was periodically occurred.

Hahn (1982 b) reported the continental red series of the Scythian in the marginal basins (Lampang and Mae Sariang Basin) of the Chiang Mai Geanticline. Lithostratigraphically, the equivalent facies were found in the Kanchanaburi Province.

The rock series of the Norian time showed a gradual transition from the marine Lampang Group into the red sediments of the Khorat Group.

Maranate (1982), on his paleomagnetic study of the Khorat Group, considered the ages of the various units, as follows: The so-called Lom Sak Formation was Middle Triassic and was probably unconformed with the Upper formations. The Nam Phong Formation was Lower most Jurassic with the possibility of the base being uppermost Rhaetian in age. The Phra Wihan Formation was Lower Jurassic. The Sao Khua Formation is early Upper Jurassic in age. It probably underlies unconformably with the upper formation. The Phu Phan, Khok Kruat and Maha Sarakham Formations are Upper Jurassic, Upper Jurassic to Middle Cretaceous, and Upper Cretaceous in age respectively.

Japakasetr and Workman (in print) described the sequence of the Maha Sarakham Formation as comprising 6 units, from bottom to top, as follows:

The basal anhydrite ranges in thickness from 0.8 to 3.3 m. The contact with the underlying Khok Kruat siltstone was typically very sharp and suggested a possible disconformity.

The Lower Rock Salt is the thickest salt unit and is characterized by massive halite and potassium minerals. The thickest part of this unit was recorded at 437 meters.

The Lower claystone is generally reddish-brown with green mottling. Veinlets of carnallite and halite are common. The average thickness is 35 meters.

The Middle Rock Salt consists essentially of halite, whereas, in some areas, thin beds of anhydrite or gypsum are found. The thickness is 99 meters on the average.

The Middle claystone resembles the lower unit except for the lacking of carnallite veinlets. The average thickness is 39 meters.

The Upper Rock Salt varies in thickness from 3 to 65 meters. No trace of any potassium minerals was found in this member.

The Upper claystone was described as the upper part of the Unnamed Rocks (Ward and Bunnag, 1964) or Maha Sarakham Formation (Gardner et al., 1967). It consists of claystone and interbedded siltstone and sandstone. This unit contains two probable unconformities and thus may comprise a separate formation.

The non-marine vertebrate fossils from the Khorat Group were reported by the Thai-French expedition as follows:

From the Sao Khua Formation: Crocodile teeth, dinosaur bone fragments, theropod teeth, fish spines and fragments of turtle plate (Ingavat. pers. com.).

From the Phu Kradung Formation: the lower jaw of the new crocodile species, *Sunosuchus thailandicus* (Buffetaut and Ingavat, 1980).

From the Huai Hin Lat Formation: *Cyclotosaurus* cf. *posthumus* Frass (Ingavat and Janvier, 1981), *Ceratodus* cf. *szechuanensis* (Dipnoi) (Martin and Ingavat, 1982), aquatic *chelonian* gen. et sp. indet. (Broin et al.), *Phytosaur* (Buffetaut and Ingavat, 1982).

SUMMARY

The continental Mesozoic rocks in Thailand can be divided provincially into the Khorat-Phayao basin and other small separated basins (Bunopas, 1978, Pitakpaivan and Chonglukmani, 1978). The Khorat-Phayao basin is part of the huge basin, so-called "Indochina basin". It is believed that this basin covered the areas of the eastern part of northern Thailand, the eastern Thailand, the northern part of Campuchea, the northeastern Thailand and can be traced across the border to Laos and probably to southern China. The basin is roughly trending NW-SE direction. Thus, the source rocks are the Chieng Saen massif, the Khun Tan granite, the concealed igneous rocks in the central plain, the Chon Buri massif, the Pailin massif in Campuchea, the Kontum, Rao Co and Song Ma massif in Viet Nam. The basin is probably connected to the Lampang sea by the NW end and/or probably to another sea in Campuchea. The thickness variation of the Nam Phong and Phu Kradung Formation shows that the basin center is more or less parallel to the line between Khon Kaen and Maha Sarakham. Lower to Middle Triassic Sediments.

Lower to Middle Triassic Sediments

The Indosinian orogeny uplifted the Permian basin. Compressional forces caused the Permian series to be folded and faulted. The continental Mesozoic sediments started to accumulate since the Scythian in some area in the north, contemporaneously with the beginning of the Marine Triassic Lampang Group (Hahn and Sieberhuner, 1982).

From the field observation in the northeastern and north-central Thailand, e.g. at Phu Hin Kong, Chum Phae, just west of the Huai Hin Lat type locality, the redbeds start with basal conglomerate containing pebbles of limestone. Overlying the redbeds is the interbedded sequence of reddish brown conglomerate and sandstone with an intercalation of volcanic rocks at the upper part. Subsequently, conglomerate beds with pebbles of volcanic rocks are encountered again. The sequence is followed by the black shale of the Huai Hin Lat Formation.

The section along the Pitsanulok-Lom Sak Highway and its vicinity starts with the basal conglomerate that rests unconformably on the Permian limestone. The sequence is followed by predominant gray beds, but redbeds were observed locally. After that the pyroclastic rocks appear. Redbeds are found again in the upper part showing an intercalation with the volcanic rocks. The true redbeds belonging to the Khorat Group overlies this sequence with an inferred contact. The correlation between these two strata above both conglomerate beds is inferred, but, possibly they are equivalent.

The difference in natures of folding was found in these two sequences, together with the presence of igneous dikes in the lower unit, and, in addition, the Permian limestone was found as a thrust sheet above the volcanic rocks. The latter two criteria are not seen in the nearby Khorat Group. The data suggest possibly an unconformity. The environment of deposition is considered to be a fluvio-lacustrine type. Unidentified bone fragments and fossil plants are found. The age of the unit is Middle Triassic (Maranate, in print) and probably a continuation from the Lower Triassic. These continental sediments occurred in the north-central and northeastern part of the country while in the western and northern part marine deposits were found. By the reasons already mentioned, the new rock unit is suggested.

The Huai Hin Lat Formation

After the late stage of the Indonesian orogeny, probably in Carnian, the Huai Hin Lat sediments were deposited in the separated paleo-basins. The contacts with the older Triassic rocks were more or less unconformable. The depositional environment was considered to be a fluvio-lacustrine type. Restricted basins were typical, and the limestone is believed to be a lacustrine deposit (Broin et al. 1982). According to the paleogeography it can be noted that, in some areas, the Huai Hin Lat Formation comprises only redbeds, while in other areas it may contain a minor gray beds. Since the positions of the Norian beds are located in the middle part of the sequence, the base of the Huai Hin Lat Formation are considered to be Carnian (Chonglakmani and Sattayrak, 1978).

The Nam Phong Formation

Just before or when all small-separated basins were filled with the Huai Hin Lat sediments, the Nam Phong Formation started its accumulation. The deposits were transitionally changed into redbeds from the gray beds below. As the matter of fact, the Nam Phong Formation is the lowest formation of the Khorat Group where the Huai Hin Lat is absent, e.g. in the high lands and the basin flanks. It is predominantly reddish brown and resistant sandstone, siltstone and conglomerate. No fossil was found but the age is considered to be between those of the Huai Hin Lat and of the Phu Kradung Formation, i.e., Rhaetian. The fluvio-lacustrine environment was its depositional environment.

The Phu Kradung Formation

Deposition of the Phu Kradung Formation took place when the Indochina basin was a huge basin. This unit rests unconformably on the Pre-Khorat rocks at the basin flanks. Ward and Bunnag (1964) noted the contact between the Nam Phong and Phu Kradung Formation at the limestone alternating zone. The formation is characterized by predominantly claystone in the lower part, and with some massive sandstone intercalation in the middle part, while the upper part consists of massive sandstone interbedded with claystone. The interpreted marine ingression based on the presence of a Plesiosaur tooth at Nong Bua Lam Phu (Ward and Bunnag, 1964) was doubtful due to a recent discovery of the fresh water crocodile bones (Buffetaut and

Ingavat, 1980) probably at the same locality. The fluvio-lacustrine depositional environment is again assigned to the Phu Kradung sediments (Hahn, 1982 a). The claystone represented the flood plain deposits, while sandstone was the channal sand of the meandering streams. The upper sequence characterized a gradually change to the Phra Wihan rocks's environment. The age of this formation is Lower Jurassic (Hayami, 1968, Hahn, 1982 a).

The Phra Wihan Formation

The formation comprises massive, resistant, light-coloured sandstone with some interbedded siltstone and conglomerate. Pebbly sandstone usually are encountered in the upper part of the section. The sequence reveals a deposition of braided streams. In some areas, it resembles the fluvio-lacustrine deposits (Hahn, 1982 a). The fossils indicated the Upper Triassic to Lower Jurassic age. The age of the formation is considered to be the Middle Jurassic.

The Sao Khua Formation

This formation is known as the less-resistant, reddish brown-coloured siltstone lying in between the more resistant sandstone. Aside from the marine pelecypods (Ward and Bunnag, 1964, Huhn, 1982 a), Plesiosaur tooth (Hahn, 1982 a) and Ichthyosaur tooth (Takai, 1963), other types of fossils and the rock characteristics suggest the continental depositional environment. The age of the Sao Khua Formation is Upper Jurassic.

The Phu Phan Formation

This formation is characterized by massive beds of light-coloured, pebbly sandstone and conglomerate. The average thickness is about 80 meters, but at Nam Phung Dam site, it is about 400 meters thick. The middle part of the Nam Phung section comprises the redbeds containing Lower Cretaceous pelecypods (Kobayashi, 1968). Paleocurrent measurements in the northern part of the Khorat Plateau was studied by the author. The result suggests the S-SW and/or W current direction which is similar to that of the Phra Wihan Formation. Hahn (1982 a) considered the Phu Phan Formation as a typical fluvial sediments.

The Khok Kruat Formation

The redbeds overlying the Phu Phan Formation represent the Khok Kruat Formation. It consists predominantly of sandstone with some siltstone and claystone. The fluvial environment is suggested and the deposition took place in an arid climate. Gypsum nodules and lenses were observed. The fossil found in its equivalent beds, the Ban Na Yo Formation, points to the Upper Cretaceous age (Kobayashi, 1968).

The Maha Sarakham Formation

This formation is thought to rest unconformably on the underlying Khorat strata (Japakasetr and Workman, in print) thus, raising the problem about its status. This rock unit consists of the Lower, Middle and Upper

Rock Salt with 2 units of claystone in between. The unconformity does not show a strong discordance, thus a disconformity is suggested (Japakasetr and Workman, in print). The depositional basin, is quite similar in shape to that of the older Khorat sediments. The Khorat and Sakon Nakorn basins were the same basin at that time. The age of this formation is inferred as the Upper most Cretaceous.

The Phu Tok Formation

This informal formation was mapped by Sattayarak and Sutheetorn (1979). It consists of two sandstone types, one with very large-scaled crossbedding and the other with small wavy structures. The sandstone was described as a red-coloured, fine-grained, well sorted and friable rock. The gross characteristics of this formation resembled an eolian deposits. The strata are found above the Khok Kruat Formation, but, correlation with the Maha Sarakham Formation is not conclusive. It was probably deposited contemporaneously, but in different environment, with the rock salt. This formation, on the other hand, is possibly younger than the Maha Sarakham Formation as it lies unconformably on the latter.

The Upper Claystone

The sequence consists typically of brick red-coloured claystone, siltstone and sandstone with gypsum and anhydrite lenses and/or nodules. This unit rests unconformably on the Maha Sarakham Formation (Japakasetr and Workman, in print). Its age is likely to be Tertiary more than Mesozoic. Furthermore, the sandstone resembled that of the Phu Tok Formation. If this is true, the two units would be of the same age but with a slightly different environment of deposition. This unit cropped out in the central part of the Plateau. It was probably accumulated in two separated basins, the Khorat and Sakon Nakorn basins, after the Himalayan orogeny built up the Phu Phan anticlinorium.

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