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A REVIEW OF THE TERTIARY SEDIMENTARY ROCKS OF THAILAND

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INTRODUCTION

Tertiary sedimentary rocks in Thailand were previously reviewed by Nutalaya (1975), Bunopas (1976), Gibling and Ratanasthien (1980), Snansieng and Chaodumrong (1981), and Sae Leow (1982). In this present review the paper is divided into three parts, i.e., the general review of the Tertiary rocks of Thailand, the review of previous works, and the stratigraphic details of some Tertiary basins.

There are many small intermontane basins and some larger regional basins with Cenozoic sedimentary deposits in Thailand (Fig. 1). Some large basins consist of a connected set of sub-basins.

Tertiary sedimentary rocks are known in isolated basins of limited extents in 6 main regions. In the northern and the western part of Thailand, the Tertiary sediments consist predominantly of lacustrine and fluviatile carbonaceous shale, coal bed, oil shale, claystone, sandstone and fresh water limestone. In the central basin of Thailand, the area is located within a broad structural depression which was filled by non-marine strata of several thousand feet thick. They are overlain by deltaic sediments of Pleistocene age. In the peninsular Thailand, isolated Tertiary basins contain fossiliferous marine limestone and marlstone with interbedded sandy shale, carbonaceous shale and coal bed. In the Gulf of Thailand, the sediments are predominantly alternating beds of sand and shale with some lignitic layers. These sediments were laid down under the deltaic and fluviatile conditions in the northern part of the basin, while marine incursions were from the south. In the Khorat Plateau, the uppermost part of the Maha Sarakham Formation may represent some upper Cretaceous to lower Tertiary sediments in enclosed basins.

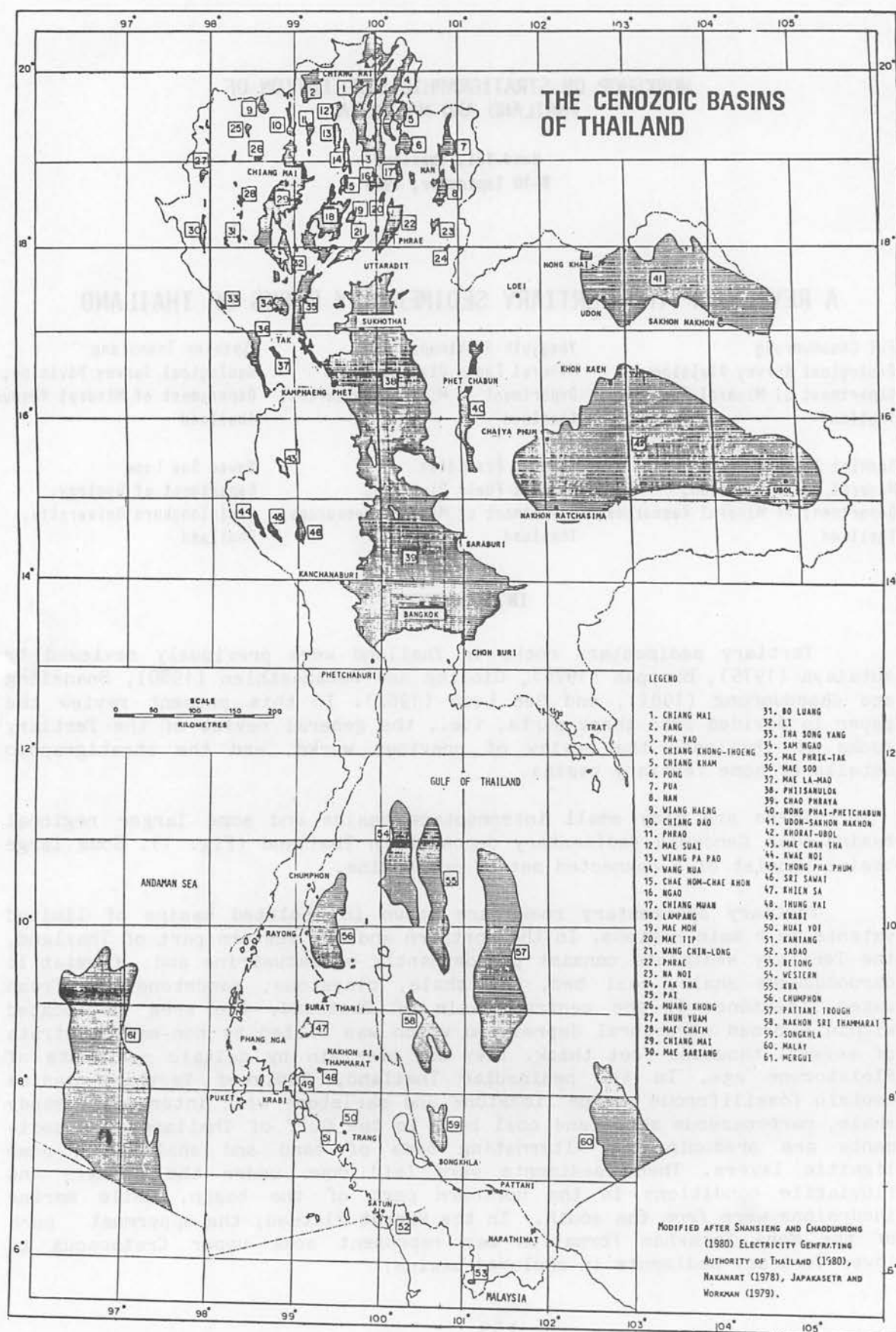


Fig. 1. The Cenozoic Basins of Thailand.

Tertiary basins are mainly fault - bounded grabens and/or half grabens formed by reactivation of basement structures. The shape and trend of the basins are elongated following the regional strike of the older formations, which were also controlled by subsequent faulting. The Tertiary strata rest unconformably on Mesozoic and older rocks and are commonly overlain unconformably by Quaternary, coarse terrigenous strata (Mae Taeng Group). Palynological analyses of well cuttings in the Gulf of Thailand indicate a major unconformity in late Miocene age. This unconformity is also found in the central basin of Thailand and can be traced to the Sundaland area of Southeast Asia.

Paleontological studies of fauna and flora from some of the Tertiary sequences in the Northern Thailand indicated that their ages range from upper Eocene to Pliocene. In the Gulf of Thailand, palynological studies indicated that the oldest rock is Oligocene. Five floral zones were found. Although in most of the studies, the fossils were taken from a limited stratigraphic interval but they represent the age range of each basin. Table 1 shows the summary of the age of rocks in the Thai Tertiary basins.

The topographic elevation of the Tertiary basins, varies from below sea level in the Gulf, to just above the sea level at Krabi basin in the south, to 1000 m above the mean sea level at Boluang basin, in the North. These elevation differences are probably the result of subsequent tectonic movements.

The thickness of Cenozoic strata in Northern Thailand is nearly 3000 meters thick as indicated by drilled holes. Results of geophysical survey suggested that the sediments in the Central basin may reach the thicknesses of 7000 meters in Phitsanulok basin and 3500 meters in the Chao Phraya basin. In the Gulf of Thailand, the study of the seismic and exploration wells data indicated that the Tertiary sequences are up to 8000 meters or more in thickness.

Coal beds are common in the Tertiary basins. Coals occur as seams up to 35 meters thick. They are interbedded with massive mudstone/claystone. Seven coal mines (lignite to high volatile C bituminous) were exploited in five basins. Natural gas is being piped from the Gulf of Thailand. Petroleum is found in the Phitsanulok basin and in Fang basin. Major oil shale deposits are found in the Mae Sot basin and diatomite deposits are in the Lampang basin.

REVIEW OF PREVIOUS WORKS

The Tertiary deposits in Thailand was first reported by Lee (1923). He recognized five basins in the Peninsula of Thailand. These basins were considered by Lee to be either simple synclinal folds or were caused by faults. Brown et al. (1951) named Krabi Series and Mae Sot Series for the Tertiary rocks found in the South and the North of Thailand, respectively. They also reported eight Tertiary basins in the South and six basins in the North. Gardner (1967) described a type section of Tertiary rocks using data from outcrop and bore holes in the vicinity of the Mae Moh mine.

Table 1 Summary of the ages of Tertiary basins (Basin numbers in brackets are referred to Fig. 1)

Region	Basins		Ages	References
Northern Thailand	Mae Soon (Fang - 2)		Oligocene-Miocene	Buravas (1975)
	Lampang (18) (Mae Ta)		Miocene-Pliocene	Pariwatvorn (1962) Ingavat (1981)
	Mae Moh (19)		Miocene-Pliocene	von Koenigswald (1959), Buravas (1973), Ingavat (1981)
	Li (32)	Pa kha	U.Eocene-Miocene	Buravas (1973), Endo (1964, 1966), Ingavat (1981)
		Nam Long	Miocene	Ingavat (1982)
		Na Sai	Miocene	Ingavat (1983)
	Mae Sot (36)		Miocene-Pliocene	Brown et al. (1951), Endo and Fujiyama (1965), Uyeno (1969), Buravas (1973)
	Phayao (3)		Miocene	Baum et al. (1970)
Peninsula	Krabi (49)		Paleocene-Miocene	Hedlund (1972) in Achalabhuti (1975)
	Klong Wai Lek (Krabi mine)		Miocene	Ingavat (1982)
Gulf of Thailand	Gulf of Thailand		? Oligocene-Pliocene	Achalabhuti (197), Woollands and Haw (1976), Paul and Lian (1975)
	Northern Malay (60)		Miocene-Pliocene	Woollands and Haw (1976)
Central Plain	Chao Phraya		? Oligocene-Pliocene	

His Mae Mo formation (also spelled Mae Moh) was later used to represent stratigraphic sequence in many adjacent basins. Piyasin (1972) named the Mae Mo Group for the Tertiary rocks found in Northern Thailand. Javanaphet (1969) and Suensilpong et al., (1979) chose the term Krabi Group to represent all of the Tertiary beds in Thailand. They also divided the Tertiary beds in the North into two formations, namely Mae Mo and Li formations. Buravas (1973), in his study on the geology of the Fang and Chiang Mai basins showed the sequence of Tertiary - Quaternary strata in that area. The formation described are Nam Pat (Paleocene), Li (Oligocene), Mae Mo (Miocene), Mae Sot (Pliocene), Mae Fang (Pleistocene), and Chao Phraya (Recent) formations. Garson et al. (1975) named the Krabi formation for Tertiary rocks within Phuket, Phangnga and Takua Pa areas. Gibling and Ratanasthien (1980) divided the Cenozoic sediments into three facies. The coarse terrigenous association consists predominantly of sandstone and some mudstone, conglomerate and coal. Sandstone is very fine to very coarse grained with horizontal lamination, cross stratification and graded bedding of fluvial origin. The fine terrigenous association consists predominantly of massive mudstone and coal beds. Minor oil shale, diatomite, carbonate and gypsum occurs locally. This fine terrigenous unit represents shallow lacustrine environment of deposition in the North and fluvial, coastal swamp and sublittoral deposits in the South. The last association, fine terrigenous -carbonate association consists of mudstone and/or carbonate, sandstone, oil shale and gypsum. Table 2 shows a comparative classification of the Tertiary rocks of Thailand by various workers.

Tertiary Basins in the North

Snansiang and Chaodumrong (1980) divided the Tertiary intermontane basins in Northern Thailand and the Central Plain into 31 basins. Some of these larger basins consist of a connected set of subbasins. The sediments in these basins tend to be similar and are composed mainly of carbonaceous shale, coal beds and oil shale of lacustrine and fluvial origins.

Fang Basin (2)

The Fang basin occupies the area around Amphoe Fang, about 150 km north of Changwat Chiang Mai. Fang basin is the structural basin bounded by faults in the west. From the studies of structural, seismic and gravity surveys, the Fang basin can be divided into three sub-basins which were separated by the saddles of older rocks. (Pompilian and Vasile, 1981). The maximum thickness of the sediments at the middle sub-basin is 2800. meters. Six structural oil fields were recognized by Piyasin and Kulasing (1981), namely, Chai Phra Karn, Mae Soon, Pong Nok, Haui Born, Pha Dang, and Pha Ngew structures. Petroleum accumulation have been discovered in the first four structures. Other structures are under detailed investigation. Brown et al. (1951) reported the occurrence of semiconsolidated fluvial and lacustrine deposits of probably late Tertiary or Quaternary ages. According to Buravas (1973), Fang basin consists of two formations, i.e., Mae Fang (Pleistocene) and Mae Sot formations (also spelled Mae Sod - Pliocene). These formations are separated by an unconformity. The Mae Sot formation consists interbedded sand and argillaceous sediments. The sandy beds are predominant in the lower part and changed into clay in the upper part. In

the middle part of the formation clay is predominant with intercalation of sands and lignite beds. *Viviparus* sp. key beds are also recorded. Buravas (1973) reported six genera of pollen and spore remains embedded in shale cores from Mae Soon oil field. They were identified by Bunyananond as the following: *Microhenrici*, *Henrici*, *Coruphaeus*, *Salix*, *Pollenitescfallax*, and *Pinus hapoxylon* of Oligocene age. Palynological investigation on the lignite at Fang basin by Baum et al. (1970) indicated Miocene-Pliocene age.

Chae Hom Basin (15)

Chae Hom basin is located in the area of Amphoe Chae Hom, Changwat Lampang. Exploratory holes were drilled by the Oil Shale Project, of the Department of Mineral Resources. The stratigraphic sequences from the base to the top are: thick sequences of gray claystone and mudstone, overlain by lignite seam about 7 m thick, and followed by the sequence of oil shale about 15 m thick. The fossiliferous beds and laminated shale were found at the top. In Mae Pan basin west of Amphoe Chae Hom the Tertiary beds are similar to those of the Chae Hom basin. The top section consists of sand and gravel beds which were underlain by shale containing fossil woods, insects, and fresh water mollusks (Piyasin, 1972).

Chae Khon Basin (15)

Chae Khon basin is located in Amphoe Chae Hom, about 86 kilometers north of Changwat Lampang. Seventy four cored holes were drilled by the National Energy Administration for coal exploration. The thickness of the Tertiary rocks estimated from the bore hole data is about 80 meters. In the lower part, the sediments consist predominantly of brown to reddish brown clay stone and mudstone, followed by the strata of coal seam with *Viviparus* sp. Fragments of insect and plant remains are common. The strata overlying the coal seam are carbonaceous shale, gray to dark gray shale with gastropod and insect fragments. The uppermost unit is light gray claystone with some thin layer of coal beds and fresh water sandy limestone (Universal Engineering Consultants, 1982). Jitapunkul (1980), in his studies on the environment of deposition in Chae Khon area by using 47 bore holes data, concluded that the sediments were deposited in sapropel of dystrophic permanent lacustrine environment and can be compared with the Mae Sot Series of Brown et al. (1951). The Universal Engineering Consultants (1982) used the term Mae Mo Group to represent the rocks in this area.

Lampang Basin (18)

Lampang basin is one of the largest basins in the North. Surface geology was previously outlined by Brown et al. (1951), Piyasin (1972), and Snansiang et al. (1982). Exploratory drillings in this area were done by the Defense Energy Department for petroleum exploration, Mineral Fuels Division and Economic Geology Division of the Department of Mineral Resources for oil shale and diatomite exploration respectively, and the Electricity Generating Authority of Thailand for coal exploration. It can be summarized that the Tertiary strata from the base to the top are composed of thick sequence of gray to olive claystone and mudstone

Table 2 A comparative classification of Tertiary rocks of Thailand

	Neogene		Palaeogene		
	Pliocene	Miocene	Oligocene	Eocene	Paleocene
Brown, et al., 1951	Krabi Series (South) Mae Sot Series (North)				
Javanaphet, 1969	Krabi Group				
	Mae Mo Formation		Li Formation		
Gardner, 1969	Mae Mo Fm.				
Piyasin, 1972 1975	Mae Mo Group				
Buravas, 1973	Mae Sot Fm.	Mae Mo Fm.	Li Fm.	Nam Pat Fm.	
Suensilpong, et al., (1978)	Krabi Group				
	Mae Mo Fm.	Li Fm.			
Others	Tertiary sequence or geographic names of each basin				

interbedded with carbonaceous shale, and coal beds exceeding 300 meters thick. They are overlain by the sequence of diatomaceous clay, claystone and oil shale, about 35 meters thick, and the top layers are diatomite and diatomaceous clay about 29 meters thick. Diatomite deposits occur locally in the southeastern part of the Lampang basin. Coal beds and oil shale are closely associated and are found in the southern part of Amphoe Ko Ka, Amphoe Mae Tha, and Amphoe Serm Ngam. Pariwatvorn (1962) identified the diatoms as; *Melosira granulata*, *Frustulia* sp., *Anomoconcis* sp., *Cocconcis* sp., *Synedra* sp., and *Navicula* sp. These fossil assemblages indicate fresh water species of Pliocene to Recent age. Ingavat (1981, unpublished report) identified fish fossils collected from claystone of lowermost sequence, as cypriniforms and siluriforms. These fossils indicate lacustrine environment, and Miocene age.

Mae Moh Basin (19)

Tertiary rocks of the Mae Moh (formerly spelled Mae Mo) have been known for several years and the first coal is mined at the Mae Moh lignite mine. This mine has been operated by the Electricity Generating Authority of Thailand. The Mae Moh basin consists of three sub basins separated the structural highs. The Tertiary strata are overlain unconformably of surficial deposits probably of Pleistocene age. Tertiary strata commence with a sequence at least 250 m. and probably up to 470 m. thick of grayish calcareous mudstone with abundant fossil beds and minor lignite beds, and followed by the Q and K lignite seams, their thicknesses are 10-30 m and 15-30 m respectively. These seams are quite uniform along the strike for several kilometers. Between the upper, K and lower Q lignite seams is a thin layer of gray to olive calcareous mudstone 10-30 m thick. Overlying the K seam is a thick sequence of massive to thickly bedded mudstone with occasional siltstone, calcareous mudstone, fresh water limestone and low grade oil shale. The uppermost unit is a thin to thick (in excess of 300 m.) layer of reddish to brown soft to firm clay and weathered claystone, clayey siltstone and some discontinuous thin seams of lignite. Sithiprasasna (1959) reported the occurrences of teeth of mastodon, fish remains, turtle ribs and back plate, fossil wood and gas, and end part of a fish tooth in the Mae Moh basin. The teeth of mastodon which were collected from the upper part of the K seam were identified by Von Koenigswald (1959) as *Stegolophodon Praelatidens* of lower to middle Pliocene age. Chaodumrong collected fossils from the mining pit section. They were identified by Ingavat (1981) as *Paludina* sp., *Viviparus* sp., *Physa* sp., *Melanoides* sp., *Planorbis* sp., fish remain of cypriniforms and siluriforms and fragments of amphibian. The fish fragments were found throughout the Tertiary sequences. Gastropod of *Paludina* sp. occurred predominantly at the lower part, *Physa* sp. and *Melanoides* sp. are predominantly in the upper part of the sequences. These fossil assemblages indicate the fresh water lacustrine environment and Miocene age.

The lignite was probably originated in peat swamps of herbaceous plants with few woody plants such as ordinary trees (Gardner, 1967). The studies of lignite in thin sections shows no recognizable tissue at all (Sundharovat, 1964). From field evidence, only monocotyledon leaf remains were found in the coal seams, while dicotyledon leaf remains were found in the mudstone above and below the coal seams.

Gibling and Ratanasthien (1980) studied the fossil assemblages in the mudstone at Mae Moh mine. A mudstone 6 m thick contains fish fragments below, with gastropods, fish and plant fragments above, and is overlain by coal. The study shows cyclicity of regressive type, i.e., the environment of deposition changed from bodies of open water to swamps and to peat bogs.

Mae Tip Basin (20)

The Mae Tip basin is located in Tam Bon Mae Tip, Amphoe Ngao, Chang Wat Lampang, about 80 km northeast of Amphoe Muang Lampang. The basin is 3 km wide and 10 km long.

In 1972, Piyasin reported that the bedrock surrounding the basin of Mae Tip consists of Permo-Triassic volcanics, and shale, sandstone and limestone of the Lampang Group, and within the basin, thin coal beds intercalated with shale are observed along Nam Mae Tip.

Coal mines were opened on the western margin of the Mae Tip basin during 1975 - 1980, but neither exploratory drilling was performed to find out the detail information, nor was the estimate of coal reserves made.

The exploratory survey and drilling of coal bearing formations were performed during 1980 - 1981 by the Mineral Fuels Division's team. The report on these explorations (Ukakimapan, 1980 and Ukakimapan et al., 1981) described the Cenozoic sequence around this area and classified it into 5 units, as shown in Table 3.

Regarding the depositional environment of these Tertiary units, Gibling (1981) described that Unit 3 represented a swamp-to-swamp-margin transition, while Units 2 and 4 are shallow - lake deposits.

Fossils preserved in this Tertiary sequence consist of fish, leaf, gastropod and bivalve fragments. They are commonly found scattered in shale, oil shale, lignite clay and coal bed in Unit 3 and 4 (Ukakimapan et al., 1981). A gastropod bed with a thickness of upto 50 cm. was found in an oil shale bed (Ukakimapan et al., 1982). The age of these fossils have not been determined.

At present, coal in the Mae Tip basin has been continuously mined since the end of 1982, about 180,000 tons of subbituminous coal has been produced 600,000 tons of proven reserves and 5,000,000 tons of possible reserves have been established.

Chiang Mai Basin (29)

The Chiang Mai basin is a large Tertiary basin in the North. It covers an area of more than 2,500 km². The basin is about 100 km long and 25 km wide, and underlies the floodplain of Mae Nam Ping. The stratigraphic section of the Tertiary sequence in this basin was not defined until 1970.

During 1970 - 1973, petroleum exploration in this basin was carried out by the Defence Energy Department. Five exploratory wells reaching the depth of more than 4,000 ft were drilled in different parts of the basin.

Table 3 Stratigraphy of the western margin of the Mae Tip basin
(Data from Ukakimaphan et al., 1981)

Unit No.	Lithology	Thickness (m)
ALLUVIUM (? QUATERNARY)		
5	Gravel, pebbly sand, muddy sand, sandy clay (semi-consolidated). Clasts of quartz, quartzite, chert, rhyolite, tuff (10 cm max.) Light gray to brown.	up to 72.6 + commonly 4 - 10
-----EROSIONAL SURFACE-----		
COAL-BEARING SEQUENCE (? TERTIARY)		
4	Mudstone (fissile), oil shale, minor marlstone, Mudstone brown, oil shale dark brown - yellowish brown. Fish, leaf and gastropod fragments.	up to 33.5 +
3	Coal, carbonaceous mudstone, minor oil shale Dark brown - black. Fish fragments.	0 - 17.5 commonly 8 - 12
2	Mudstone, siltstone, sandstone. Light gray. Limestone pebbles/ nodules in sandstone.	13.9 - 45 +
1	Limestone, argillaceous to arenaceous limestone, calcareous sandstone and mudstone. Medium gray.	25 +

Table 4 The Cenozoic stratigraphic section of Chiang Mai Basin
(after Buravas, 1973)

Thickness (ft)	Rock Unit		Description	Age
> 500	?		Unconsolidated gravel, sand and clay	Upper Pleistocene
> 2500	Mae Fang Formation		Sand, sandy clay, clay, minor gravel bed, semi - unconsolidated	Lower Pleistocene
≈ 300	Transitional zone of Mae Sod Formation		Clay, sandy clay, brown with a few beds of thin bedded sand with appearance of oil show	Mio - Pliocene
600-700	Mae Sod Formation	Mae Sod clay	Alternation of clay, claystone, brown compact, trace of oil show	
≈ 100		Chaipra- karn sand	Sandstone of various origins	
> 800			Pebble, cobble beds of rocks derived from Doi Ti-Doi Sked Formations, compacted, overlying on alternated beds of sand- stone and black shale	Cretaceous

The stratigraphic section derived from the interpretation of the lithologic logs of these exploratory wells is shown in Table 4.

Results of the exploratory drilling show that the oldest unit of the Tertiary sequence of Chiang Mai basin is the Mae Sod Formation of Mio - Pliocene age. The total thickness of the Cenozoic sequences is more than 5,000 ft. The top of the Tertiary sequence is generally covered by the upper Pleistocene gravel beds and the alluvium of Mae Nam Ping. The outcrops of Tertiary sequence is rarely exposed.

Meesook et al. (1979) reported the occurrence of about 40 m thick sequence of the Tertiary rocks at Doi Noi, Amphoe Chom Thong. The rocks consist of alternated sequence of sandstone and conglomeratic sandstone. Sandstone is white to light gray, poorly sorted and cross - bedded. The framework of conglomeratic sandstone consists predominantly of quartz, shale, mudstone and chert.

Li Basin (32)

The Li basin is located in the area around Amphoe Li, about 80 kilometers south of Changwat Lamphun. Geology of the Li basin was discussed briefly by Bunopas (1964), Poothai and Chana (1969), German Geological Mission (1972), Jabaketr, et al. (1973), Piyasin (1975), Gibling and Ratanasthien (1981) and Chaodumrong et al. (1982). Most of these reports were concerned with the Ban Pa Kha sub-basin. At least four sub-basins were recognized by Chaodumrong et al. (1982) according to their depositional environments. The four sub-basins are: Ban Pa kha, Ban Pu, Ban Na Sai and Mae Long sub-basins. In 1982, scout drillings with geophysical loggings in the Li basin were made by the Electricity Generating Authority of Thailand, but their results are not available.

The Ban Pa Kha sub-basin is located in the southeast rim of the Li basin. Strata are well exposed in the coal mine operated by the National Energy Administration. The lower unit rests unconformably on the Mesozoic and older rocks, and are predominantly of sandstone and shale. It is overlain by the upper and lower coal seams, the average thicknesses are 8 m and 6 m respectively. Between these coal seams is the sequence of oil shale, gray shale and mudstone about 30 m thick. The underclay are also found beneath the coal bed. The uppermost Tertiary strata are massive mudstone and claystone with some coal lenses. These strata are overlain unconformably by gravel and coarse sand of fluvial origin. Endo (1964) identified plant fossils from the lignite and oil shale as *Alnus thaiensis* new species, *Sequoia longsdorfii*, *Taxodium thaiensis* new species, *Sparganium thaiensis* new species, and *Carpinus* (?) sp. The association of these plants were considered by Endo to be upper Eocene age and the climate in which it flourished was warm temperate. In 1966 a new collection of plant remains were identified by Endo as *Glyptostrobus europaeus*, *Sequoia longsdorfii*, *Ficus eowightiana*, *Alnus thaiensis*, *Alnus thaiensis* (?), *Fagus feroniae*, *Quercus lanceaefolia*, *Quercus cf. protoglauca*, *salix* ? sp. These new collections also confirm the Palaeogene age. Gibling and Ratanasthien (1981) collected a block of a dark carbonaceous mudstone above the upper coal seam. They classified fossils into six assemblages which indicated the environment of deposition from swamp to shallow lake. According to

Gibling and Ratanasthien (1980), Ban Pa Kha sub-basin is a fine terrigenous association.

The Ban Pu sub-basin is located at Ban Pu east of Amphoe Li. Five bore holes were drilled in the vicinity of World Fuel Mine indicated a thick major coal seam (sub bituminous coal-ASTM) upto 200 feet thick. The major coal seam is underlain by sandstone and shale, and is overlain by gray to olive claystone/mudstone. The tree stump which was found at the lower part of the coal seam indicated the authochthonous origin of the plants.

The Ban Na Sai sub-basin is located at the south rim of the Li basin. Twelve bore holes were drilled by National Energy Administration in this area. The sediments in this sub-basin were deposited in swamp under a calcium rich environment. The rocks at the coal mine consist of coal seam in the lower part. The overlying strata are predominantly massive and laminated claystone/mudstone. Fish fragments and dicotyledon leaves are common. The Gastropod bed of *Viviparus* sp., *Melanoides* sp. were found overlying the coal seam indicating the Miocene age. The Tertiary formation was covered with gravels and sands of the Mae Taeng formation.

Ukakimapan (1981) collected the fragments of bones some of which resemble - *Legomericidae*. Others are turtle plates, snake's vertebrae, fish's vertebrae, fish's jaws and teeth and other fish remains (probably cat fish) from the Mae Long sub-basin. The lower to middle Miocene age of these fossils were given by Ingavat (1982).

Mae Tun Basin

The Mae Tun basin is located in the area around Ban Ko Lo Hae, Tam Bon Mae Tun, Amphoe Mae Ramat, Chang Wat Tak, about 70 km northwest of Amphoe Muang Tak. The basin is 1.5 km wide and 10 km long, and elongates along the NW-SE direction.

Since 1976, the outcrops of Tertiary coal have been found along the Mae Tun River, and a small coal mine belonging to a private company has been established. The exploratory survey and drilling to work out the details of the Tertiary coal-bearing formations were done during 1978 - 1979 (Ukakimapan and Supertipanitch, 1978, 1979). The Mae Tun basin is an intermontane fault block basin. The surrounding horsts are sandstone and limestone of Cambro-Ordovician age. These reports divided the Cenozoic formations into 2 units. They are shown in Table 5.

The fossil leaves and plant fragments were found in the shale and oil shale beds of the Lower Unit. Dating of these fossils have not been done.

The coal in the Mae Tun basin is classified as being in a range of high volatile C to high volatile B bituminous, and the average seam thickness is about 4.50 m. 1,200,000 tons of proven and 5,300,000 tons of possible reserves are estimated.

Table 5 Cenozoic sequence of Mae Tun basin

Stratigraphic Unit	Description	Thickness	Age
Upper Unit	Coarse-grained strata, consisting of conglomerates, conglomeratic sandstones with some lenses of lignite sand and lignitic clay unconformity	100 m.	Quaternary?
Lower Unit	Fine - grained strata, consisting of sandstones, shales, mudstones, lignitic shales and coal seams	100 m.	Tertiary

Mae sot Basin (36)*

The Mae Sot basin is located in the area of Amphoe Mae Sot, Changwat Tak, about 85 km to the west of Amphoe Muang, Changwat Tak. The basin which is 15 km wide (along east-west direction) and 45 km long (along north-south direction) covers an area of 675 sq km. The basin is a fault-block basin. The bounding horsts consist of limestone, sandstone, and shale of Triassic age.

In 1947, Buravas and others divided the Cenozoic sequences in the Mae Sot basin into 6 units as shown in Table 6. He estimated the reserves of oil shale in this basin at about 2,790 million tons.

Chana (1964) indicated that the oil shale of the Mae Sot basin was deposited alternately with shale, marlstone, sandstone and limestone of Tertiary age.

In 1978, the exploration team of the Mineral Fuels Division, Department of Mineral Resources divided the Tertiary formation of the Mae Sot basin into 4 units as shown in Table 7. The thickness of the formation is more than 2,000 m. The formation overlies the basement rocks of Permian and Triassic ages. This report indicated that the Tertiary formation of the Mae Sot basin was deposited in fluvial and lacustrine environments.

According to the oil shale reports of the Mineral Fuels Division (1978, 1979). They showed that fossils of fresh water mollusks, insects, fishes and snakes were found in the Tertiary sequence. The fresh water mollusks were identified as *Viviparus* sp. and *Turritella* sp. of Late

* Summarized by Surapon Thanomsub, Mineral Fuels Division, Department of Mineral Resources, Thailand

**Table 6 The Cenozoic sequence in the Mae Sot Basin
(after Buravas, et al., 1947)**

<div style="display: flex; flex-direction: column; align-items: center;"> Top ↑ <div style="border-left: 1px solid black; border-right: 1px solid black; height: 200px; margin: 0 5px;"></div> ↓ Bottom </div>	Unit no.	Description	Thickness (m)
	6	Semiconsolidated alluvial cobbles, pebbles and sands	?
		unconformity	
	5	Marlstone, sandy marl and marly sandstone	> 20
	4	Oil shale	10 - 112
	3	Marlstone	≈ 20
	2	Sandy marl, marly sandstone	≈ 80
	1	Basal impure limestone	> 400

**Table 7 The Tertiary sequence of Mae Sot basin
(after the Mineral Fuels Division Report, 1978)**

<div style="display: flex; flex-direction: column; align-items: center;"> Upper ↑ <div style="border-left: 1px solid black; border-right: 1px solid black; height: 200px; margin: 0 5px;"></div> ↓ Lower </div>	unit no.	Description	Thickness (m)
		Quaternary gravel bed	
		unconformity	
	4	Shale, grayish green interbedded with mudstone and oil shale	300
	3	Sandy shale, sandy marl interbedded with oil shale	> 500
	2	Marlstone, mudstone interbedded with shale and oil shale	> 900
	1	Sandstone, siltstone, reddish brown and fossiliferous limestone	> 600
		unconformity	
		Basement rocks	

Tertiary age (Ingavat, 1978). The reserve of oil shale in this basin was estimated at about 18,000 million tons (Mineral Fuels Division Report, 1979).

The Central Basin

The Central basin, located in the central part of Thailand, is the largest onshore Tertiary basin in Thailand. The basin is divided into Phitsanulok basin (or North Central basin) and Chao Phraya basin (or South Central basin) by the NW-SE trending Chainat Ridge, which is a zone of outcropping Palaeozoic rocks.

The intracratonic Central basin was probably formed in early Tertiary by block faultings along N-S and NW-SE trends. Results of geophysical survey suggested that the basin fills may reach the thickness of 7000 meters and 3500 meters in the Phitsanulok basin and Chao Phraya basin, respectively.

Drilling for petroleum in the Chao Phraya basin was commenced in 1957. Up to present, five wells, three of them were shallow wells, were drilled by the Royal Department of Mines and the Gulf Oil Company. However, geological information of these wells are very limited. In the Phitsanulok basin, no petroleum-exploration well was drilled before 1981, and geological data of the wells which were subsequently drilled by the Thai Shell Exploration and Production Ltd. are still confidential. Hence, detailed description of stratigraphy of the two basins is quite impossible. However, broad lithology, environment of deposition and age of sediments can be summarized and described from previous published materials and studies.

The Chao Phraya basin was predominantly filled by fluvial and flood plain clastics of probably Oligocene to Recent age. Influence of marine transgression in the basin was negligible, therefore, the sequence of the deposits in the basin may entirely contain non-marine sediments. Broad lithostratigraphic descriptions are given in Table 8.

By analogy the stratigraphy of the Chao Phraya basin and other onland Tertiary basins in Thailand are quite compatible. The middle and lower Mae Mo of the Chao Phraya basin are similar and probably equivalent to the lacustrine beds underlying the oil field of Mae Soon and oil-shale beds of Mae Sot. Lacustrine deposits were very significant in the Tertiary basins of the northern part of the country. Hence, the sequence of the Phitsanulok basin may also comprise and alternation of fluvial sands, gravels and finer-grained deposits of the flood plain (Mae Taeng Group), and lacustrine and fluvio-lacustrine deposits (Mae Mo Group).

Prominent unconformities in the Central basin and other onland Tertiary basins are the Pleistocene-Pliocene and late middle Miocene unconformities. The Pleistocene-Pliocene unconformity lies between the Mae Taeng Group and Mae Mo Group, but the late middle Miocene unconformity is in the Mae Mo Group.

Table 8 Stratigraphic summary of the Chao Phraya basin

Geological Age	Formation and Group		Lithology	Depositional Environment
Recent	Mae Taeng Group	Upper	Riddish series of gravel and sand	Fluvial channels
Pleistocene	(700 m.) unconformity	Lower	Reddish series of sand, clay with minor gravel	Fluvial channels Flood Plain
Pliocene	Mae Mo Group	Upper	Reddish series of claystone with some grey claystone, minor sandstone and siltstone	Flood Plain Fluvial channels
Late Mid. Miocene ? Oligocene	(1000m.)	Middle unconformity	Grey series of claystone, shale with sandstone siltstone, occasional limestone, coal with gastropod fragments.	Flood Plain, Fluvial channels and Lacustrine
		Lower	? same as the grey series	

Tertiary Sedimentary Rocks in the Northeast

Tertiary sediments in the Khorat Plateau, were found in two areas, The Khorat - Ubol basin in the south and the Udon - Sakhon Nakhon basin in the north. These basins are separated by the Phu Phan uplift or anticlinorium trending east - west across the plateau.

Chonglakmani et al. (1979), in the compiled geological map of Changwat Udon Thani and Vang Viang Quadrangle, divided the Khorat Group into eight formations. The top two formations of the Khorat Group are the Maha Sarakham formation at the base and the Phu Tok formation at the top. According to Chonglakmani, et al. (1979) these formations are of lower Tertiary age. The Exxon company identified the ages of spores and pollens which were collected from drilled cores of the Maha Sarakham formation as Jurassic to Miocene, and they concluded that these samples belong to Albian-Cenomanian (Middle Cretaceous) (Sundharovat, 1978). Subsequently Sundharovat (1978) reported that these pollens and spores might be transported from the underlying formation, the Khok Kruat formation whose fossils were dated as upper Cretaceous (for more details see A Review of the Khorat Group). Exxon also reported that abundant Miocene pollens were found in drilled core at

a depth of 310 feet in the area around Changwat Nakhon Rachasima. In 1978, Thiramongkol suggested that the rock salt of Maha Sarakham formation was deposited in an inland sea or lagoonal environment in upper Cretaceous to lower Tertiary time and was later uplifted by epeirogenic movements such as warping and block faulting. He also suggested that the gypsum at Nakhon Sawan and Phichit areas were probably originated during the Tertiary period.

The Maha Sarakham formation is composed of reddish brown to brick-red mudstones, claystones, shales, siltstones with fine-grained sandstones in the upper part. The thickness is generally in the range 50 to 300 m and the sequence is usually predominantly of claystone. The evaporite, reddish brown claystone with green mottles, and some siltstone are found in the lower part. These two members are separated by an unconformity. Japakasetr and Workman (1981) proposed that the beds overlying the uppermost rock salt of the Maha Sarakham formation should belong to another formation, younger than the Maha Sarakham formation. This formation probably belongs to the Tertiary age. According to Chonglakmani et al. (1979), the Phu Tok formation is composed predominantly of brick red sandstone, fine to medium grained, thick bedded to massive with very large scale crossbedding and small scale wavy structured beds. This formation is considered to be lower Tertiary in age without any direct evidence, but superposition.

Tertiary Basin in the West

Mae Chan Tha Basin *

The NNW trending Mae Chan Tha basin is located in the southern part of Amphoe Umphang, Changwat Tak. It lies between the latitudes 15°25'N to 15°35'N and longitudes 98°45'E to 98°50'E. This intermontane basin, comprising an 80 sq km area, is bounded on all sides by mountainous terrain with a maximum altitude of about 1000 m above the mean sea level. The basin, approximately 7 km wide and 20 km long, has an average elevation of 280-320 m above the mean sea level. There are two main rivers, viz., Mae Chan River and Mae Klong River which flow in NNW and NE directions, respectively.

Almost all of the Tertiary sequence in the basin was found along the creek of Huai Kroeng Kho, a NE-SW tributary of Nam Mae Klong. The outcrops are exposed along the creek for a distance of approximately 1 km. Some sections are intermittently covered by stream sediments. The upper part of the Tertiary sequence consists predominantly of medium to well-cemented conglomerate and pebbly sandstone whereas both the middle and lower parts consist mainly of fossiliferous mudstone with coal beds, especially in the latter.

Sandstone lenses are frequently observed in the conglomeratic unit. Limestone pebbles are predominant framework of the conglomerate and calcium carbonate is the cement. Fossiliferous pale brown and yellowish-

* Summarized by Chaiyan Hinthong, Assanee MeeSook, Varavudh Sutheethorn, Sunya Sarapirome and Srun Jindasute, Geological Survey Division, Department of Mineral Resources, Thailand

brown mudstone and claystone showing pencil-like weathering with occasionally laminated and highly calcareous layers characterized the middle part of this Tertiary unit. Lithologic similarity and fossil assemblage of plant remains, *Viviparus*, gastropods and bivalves are also recognized in the lower part. Three separated coal beds are found at the base of the sequence. The three coal beds have the thickness of, from top to bottom, 23, 10 and 16 cm respectively. Bedding of the coal beds generally strike 230° and dip 22° - 25° NW.

Laboratory determination of the coals revealed that they vary slightly in quality from bed to bed. The coals from the top two beds fall within Subbituminous rank with the heating values of 10,028 and 9,819 Btu/lb, respectively. Unidentified fauna and flora, particularly fish scales are observed in the calcareous mudstone throughout the sequence.

Tertiary Basins in the Peninsula

Krabi Basin (49)

The Krabi basin is located between the eastern part of the town of Krabi and the Khao Chong granite hill.

The basement rocks of the Krabi basin are the Phuket Group, Ratburi Group and Ko Yao Formation (Garson, et al., (1975). The Tertiary beds assume steep dips as the results of minor faults and gravity movements rather than any major tectonic events (Garson, et al., 1975). According to Longworth CMPS Engineers (1980) the basin axis trends NNW and the northwest part of the basin shows a shallow inlet channel deposition.

Ratanasthien, et al. (1982) studied the petrography of coal at the Krabi Lignite Mine. They suggested that the depositional environment of the coal was brackish water. They also reported the stratigraphy of the Krabi basin.

The stratigraphy of the Krabi basin based on borehole logging, geophysical logging and seismic profiles indicated three cycles of deposition.

Cycle 1: The strata underly the coal seams and form the basal unit of the Tertiary sequence. The rocks are composed of white sandstone and white claystone. The sandstone is well rounded well sorted with some marine fossils. Gastropods and pelecypods are preserved in this unit.

Cycle 2: The strata consist of coal seams and greenish gray claystone. The total thickness of the coal seams are about 20 m. The coal seams are interbedded with greenish gray claystone and are overlain by greenish gray claystone whose thickness varies between 100-150 m. Thin layer of gray limestone is also found in some parts of the basin.

Cycle 3: The strata are composed of conglomerate, gray sandstone and gray claystone all of fluvial origin. The grain size decreases upward. Conglomerate and sandstone are thinly bedded and are overlain by thick

layers of claystone. Total thickness of the strata is 50-100 m.

Based on the stratigraphy, the depositional environment could be discerned as follows: In the Early Tertiary the beach sand and clay were deposited under marine and transitional environments. Then with the regression of the sea level, the environments were changed to brackish environments and the basin were turned to mangrove swamps. Organic materials were deposited, and were subsequently changed to coal by coalification. While the organic materials were deposited, the low velocity stream sediments were also deposited, so the coal seams were interbedded with greenish gray claystone. In some parts of the basin condition was right for limestone to be deposited. Then the basin was uplifted, and the environments were changed to fluvial and lacustrine. Folding and faulting took place in late Tertiary to early Quaternary and the entire sequence was folded and faulted.

Sadao Basin (52)

The Sadao basin is the Cenozoic basin which extends into the northern part of the States of Perlis and Kedah of Malaysia. The part of this basin which is located in the Thai territory lies in between the latitudes $6^{\circ}31' - 6^{\circ}45'N$ and longitudes $100^{\circ}18' - 100^{\circ}30'E$ covering an area of about 200 sq km around the western part of Amphoe Sadao, Changwat Songkhla.

Scrivenor (1913) reported the discovery of thin coal seams in the pits on the slopes of Bukit Tingi and Bukit Arang (on the Thai Malaysian border near Boundary Pillar 18A).

In 1920, three coal seams ranging from 15 to 30 cm were reportedly found in exploratory holes near Bukit Arang. Drilling was done by the Federated Malay States Railway Department (Willbourn, 1926).

In 1941 exploratory drilling to the depth of 600 ft. was performed by the Geological Survey Department of Malaysia. Alexander (1946) reported that the formations consist of semi-consolidated clay, sand and gravel. No coal seam of any sequence was encountered, and only small quantities of coal fragments were found.

During 1957-1959, exploratory pitting was conducted by C.R. Jones west and southwest of Bukit Arang. Results from 19 exploratory pits reaching down to 20 ft, indicated that the Cenozoic strata in this area consist of loose to semiconsolidated gravel, sand and clay alternately. These rock and sediment strata spread over a major portion of the areas northwest of the State of Perlis (Jones, 1958).

During 1981-1982, in an attempt to search for the coal deposits along the Thailand-Malaysia border area, exploratory drilling and surveying were performed by the Geological Survey Department of Malaysia. By means of these exploratory activities, details of the Tertiary sequences around this area were obtained and reported by Aw (1982), as summarised in Table 9.

In line with the Thai-Malaysian cooperation to determine the potential




**Table 9 The description of Cenozoic sequence in area of Bukit Arang
(after Aw, 1982)**

1. Areal extent	75 km , excluding the area on the Thai side
2. Stratigraphy	<ul style="list-style-type: none"> - Boulder-gravel beds Thickness > 90 m. <li style="text-align: center;">?? - Alternate layers of clay and sand with or without thin coal seams. Thickness > 130 m.
3. Lithification	<div style="text-align: center;">----- unconformities -----</div> <ul style="list-style-type: none"> - Non-consolidated, at best semi-consolidated
4. Coal grade	Probably similar to that of the coal at Batu Arang
5. Coal reserve	Unknown
6. Age	No evidence

of coal deposits along the common border, in mid 1982 a Thai exploratory team reported on its preliminary coal investigation of Sadao District that the Cenozoic basin in this area covered more than 200 sq km, and was divided into 2 minor basins, one in the east another in the west, by a ridge of Carboniferous rocks. Surface geological surveys indicated that the Cenozoic sequence consist of semi-unconsolidated gravel, sand and clay alternately. No coal outcrop was located (Ukakimapan and Maneeprapan, 1982).

Exploratory drilling was carried out by the Department of Mineral Resources's team from November 1982 to March 1983. Results from 5 drilled holes across the trends of the 2 minor basins indicated that the thickness of the Cenozoic sequence in the western basin is more than 300 m. The sequence consists of an alternation of semiconsolidated sand and clay with some thin coal seams and thin lamination of lignitic clay. The top layers are semi- to unconsolidated gravel beds lying unconformably. On the other hand, the eastern basin is much shallower than the western counterpart, with the absence of thick sand and clay bed. Only thick gravel beds were found lying unconformably on the Carboniferous basement. Correlation of sequences in the drilled holes indicated that the Cenozoic sequences in the Sadao basin were deposited in a transition of fluvial and lacustrine environments with pronounced facies changes. The fragments of gastropods and bivalves were found in some clay beds. However the dating of these fossils was not done (Ukakimapan, Maneeprapan and Krobbuaban, 1983).

Table 10 Generalized stratigraphic section of the Gulf of Thailand
(modified after Achalabhuti and Oudom-Ugsorn, 1978; Paul and Lian, 1975)

MAJOR LITHOLOGIC UNITS (THICKNESS* m.)	HC ZONES	FLORAL ZONES	ENVIRONMENTAL PHASES			AGE	TERTIARY
LIGHT GRAY TO GRAY - BROWN CLAYS, SILTY WITH LIGNITE INTERBEDS (126)		<i>Podocarpus</i>	INNER SUBLITTORAL			QUATERNARY	
LIGHT GRAY CLAYS WITH SANDS AND LIGNITE INTERBEDS (268)		<i>Dacrydium</i>	COASTAL SWAMP	LITTORAL	SUB-LITTORAL	PLIOCENE	
GRAY CLAYSTONES AND SHALES WITH SANDSTONE, LIGNITE, AND COAL INTERBEDS (759)		<i>Florschuetzia meridionalis</i>	COASTAL SWAMP	LAGOONAL	COASTAL PLAIN	LATE MIDDLE MIOCENE	
VARIGATED SHALES WITH SANDSTONE AND COAL INTERBEDS (1187)		<i>Florschuetzia levipoli</i>	FLOODPLAIN	COASTAL PLAIN	LAGOONAL	MIDDLE MIOCENE	
		<i>Alnipollenites verus</i>	COASTAL PLAIN	LITTORAL	INNER-SUBLITTORAL	EARLY MIOCENE	
DARK GRAY SHALE WITH SANDSTONE INTERBEDS (957 +)		<i>Florschuetzia trilobata</i>	LITTORAL	INNER SUB-LITTORAL		OLIGOCENE	

* From UNION-SEAPEC Well 13-1, a typical of wells drilled in Pattani Trough

Other Tertiary rocks in the peninsula were reported by Muenlek and Meesook (1981) who studied the rocks at Khuan Khuha, Amphoe Betong, Chang-wat Naratiwat. They proposed the name the Khuan Khula Formation to represent the Tertiary rocks consisting predominantly of reddish fluviatile conglomerate with clasts of sandstone, chert and quartzite in this area. It is 120 m. thick.

Udomratn and Dhammasuddee (1980) reported the Tertiary section of Amphoe Kantang. It consists of sandstone, siltstone, conglomerate, lignite and mudstone with total thickness exceeding 125 meters.

Gulf of Thailand

The basins in the Gulf of Thailand were developed during late Cretaceous-early Tertiary times by block faulting along a north-south trend. The north-south trending Ko Kra Ridge divided basins in the Gulf into two areas. To the west of the ridge, there are several small, narrow, north-south elongate basins and grabens. To the east of the ridge, there are two large, elongate basins the north-south trending Pattani Trough and the northwest-southeast trending Malay Basin (Woollands and Haw, 1976).

The Tertiary sedimentary sequences are well developed in the Pattani Trough and Malay Basin with the maximum thickness of more than 8,000 m in the deepest part of the Malay basin in Thai waters (Woollands and Haw, 1976). The oldest sedimentary rocks in the Gulf were reported as Oligocene (Paul and Lian, 1975; Woollands and Haw, 1976; Achalabhuti and Oudom-Ugsorn, 1978). However, no well has not yet penetrated the entire sedimentary sequences.

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