

Cenozoic Stratigraphy, Sedimentation and Tectonic Setting, Onshore Peninsular Malaysia: A Review

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ABSTRACT

Cenozoic sediments in Peninsular Malaysia occur along the western and eastern part of the Peninsular as onshore basins and in the South China Sea and the Straits of Malacca as offshore basins. The study is about reviewing the stratigraphy, sedimentation and tectonic pattern of the onshore Cenozoic basins/sediments, Peninsular Malaysia. This is with the aim of updating and establishing missing information and proposing future research direction. The Cenozoic sediments occupy 20 percent of the landmass of Peninsular Malaysia, with Quaternary deposits dominating. The Tertiary rocks/basins, which are Eocene to Oligocene in age, occur as pull-apart basins in seven localities (Batu Arang, Bukit Arang, Kampung Durian Chondong, Enggor, Layang-Layang, Lawin and Kluang-Niyor). Siliciclastic sedimentary rocks (conglomerates, sandstones, siltstone and shales/mudstones) are the dominant rock types in the Tertiary stratigraphy. Coal seams especially the low-grade types have been reported in these Tertiary basins. The basins are half graben or isolated circular depression aligned to major fault zones. Quaternary sediments occupy east and west coastland with minor occurrences within river valleys onshore. They consist of unconsidered boulders, gravels, sand, silts and clays. The Quaternary formations (Simpang, Kempadang, Gula and Beruas) are distributed in and around North Kedah and Perlis, South Kedah and Penang, Perak, Kinta Valley, Selangor, Kuala Lumpur, Negeri Sembilan and Malacca, west, east and central Johor, Terengganu and Kelantan. These basins are tectonically stable with only minor fault movements, uplift and local deformations. In general, Cenozoic basins are associated with continuous adjustment by transtensional and/or transpressional wrench faulting, rifting and thermal subsidence.

Keywords: Cenozoic, peninsular Malaysia, stratigraphy, sedimentation, transtensional, transpressional

1. INTRODUCTION

Peninsular Malaysia is the South-East Asian part of Eurasian Plate [1,2]. It is an elongate NW trending southern tip of the Malay-Thai Peninsular that forms part of Sundaland. Other major Sundaland's continental blocks include the SW Borneo block, South China block, the Sibumasu terrane, the Indochina block, West Burma block and West Sumatra block [3] (figures 1 and 2). These blocks were derived from Gondwana supercontinent in three episodes of tectonism as three successive ocean basins; the Palaeo-Tethys (Devonian-Triassic), Meso-Tethys (Permian– Late Cretaceous) and Ceno-Tethys (Late Triassic–Late Cretaceous) opened and subsequently closed [3-6]. Peninsular Malaysia, together with southwestern Borneo, forms part of the continental terrane that once formed a major landmass during Mesozoic and Cenozoic times [7]. Geologically, the Peninsular is divided into Western, Central and Eastern belts based on stratigraphic and structural difference as well as variation in geologic/geophysical signatures. The NNW-structural trends of the Peninsular is defined by lithologic/bed strikes and fold axes/planes. The Peninsular, which has been emergent throughout the Cenozoic, is tectonically stable. However, there is still limited tectonic activities in form of fault movement, uplift and tilting and some local gentle downwarps affecting the area [8,9]. The Bentong-Raub suture zone (figures 2 and 3) which is a 15-20km NS

trending suture is the major geologic structure in Peninsular Malaysia. Other major faults systems include the Lebir, Bok Bak, Kuala Lumpur, Mersing, Lepar, Ma'Okil and Bukit Tinggi faults.

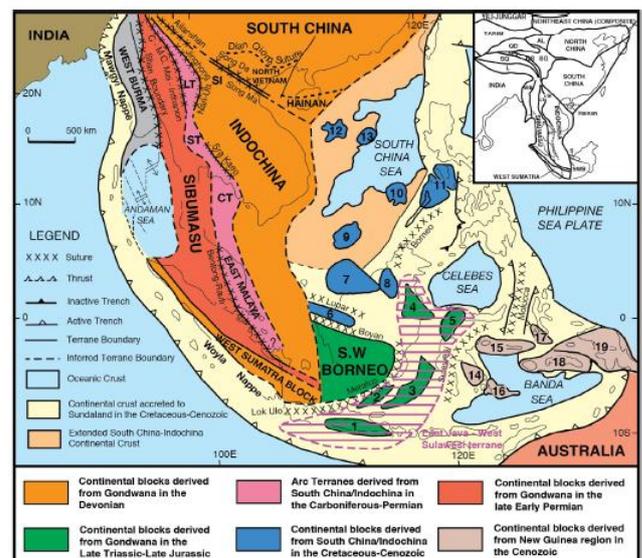


Figure 1 Map showing the main continental terrain of the mainland Southeast Asia [3,11]

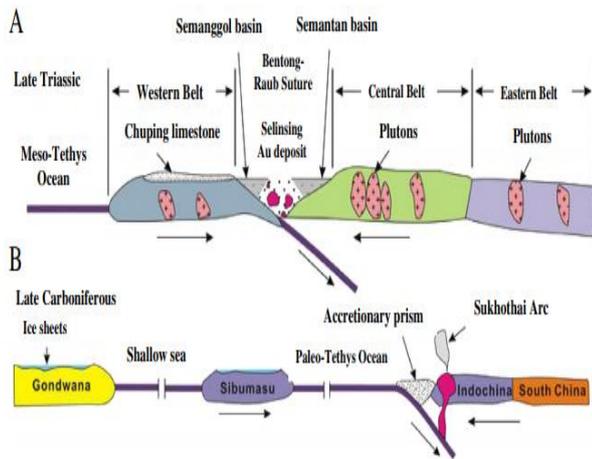


Figure 2 Cross-sections showing tectonic setting (A) In the Late Triassic, Indochina and Sibumasu terranes collided, forming the Bentong-Raub Suture Zone and the granitoids emplacement in the Malay Peninsula. (B) In the Late Carboniferous, the Sibumasu terrane drifted away from Gondwana across the Palaeo-Tethys Ocean, creating an accretionary wedge above the subduction zone [12]

Onshore Peninsular Malaysia basins are generally terrestrial extensional basins throughout their histories [10] and are characterized by high surface heat flow with a thermal anomaly beneath the basins. Peninsular Malaysia has played a vital role in the history of Malaysia's mineral (tin and gold) and energy (oil and gas) resources that have been mined respectively in the onshore and offshore Cenozoic basins [2].

Paleozoic, Mesozoic and Cenozoic sediments are widely distributed in the onshore Peninsular Malaysia. Paleozoic sedimentary rocks outcrop over 25%, with more than forty-two (42) formations [13-15] that are distributed in all the three geological zones [16]. Mesozoic rocks have twenty-eight (28) onshore formations distributed in Central belt and Northwest domain; with the Eastern belt having few formations [14]. Mesozoic sediments are flysch-type marine and continental deposited during Triassic and Jurassic-Cretaceous respectively [17]. These Mesozoic rocks form a continuous north-south trending belt in the Central belt and extended beyond the Jurong and Gua Musang formations in the south and north respectively [14]. Cenozoic sediments occupy 20 percent of the landmass of Peninsular Malaysia, with Quaternary deposits dominating. Tertiary sediments/basins, onshore Peninsular Malaysia consist of conglomerates and sandstones; soft shales, coal seams and rare calcareous shale and limestone which are of fluvial and lacustrine origin. They have flat topography, basin/depression structure and dip at 30° – 40°. They lie unconformably on folded and metamorphosed Paleozoic to Mesozoic rocks. Quaternary basins consists of continental and marine sediments of Pleistocene and Holocene age. Suntharalingam [18], has reported ash deposits, basaltic

lava flows, and residual deposits (bauxite and laterites) of Quaternary age.

An updated review of the Cenozoic basins, onshore Peninsular Malaysia is vital for understanding sedimentological and stratigraphic characteristics of the various formations within these basins, as well as understanding their tectonic setting. Only few detailed studies have been carried out especially in the onshore Tertiary basins. There are recently exposed outcrops of both Tertiary and Quaternary age that were covered by thick forest in the past. Extent of the Tertiary basins has not been established. For instance, the extent of the presumed tertiary sediments in Kluang-Niyor basin is poorly known. In addition, geochemical data is lacking on these tertiary basins. The main aim of this paper is therefore to review the stratigraphy, sedimentation and tectonic setting of the onshore Cenozoic basins/sediments, Peninsular Malaysia, with a view to summarising the published and unpublished data/studies, establish missing information and propose future research direction.

2. LOCATION AND GEOGRAPHY OF PENINSULAR MALAYSIA

Peninsular Malaysia (figure 3), with total land area of 130,268km², is in the southern segment of the Malay Peninsula (Southeast Asia). It forms part of Sundaland (together with Borneo, Java, Sumatra, and intervening shallow seas with several small islands) [19]. It is located between latitude 6° to 1° N and longitude 100° to 105° E. It is bordered by Thailand to the north, by Singapore to the south and to the southwest, across the Strait of Malacca, by the island of Sumatra in Indonesia. Peninsular Malaysia has a tropical climate with two monsoon seasons with average annual precipitation of 100 inches. Humidity is high throughout the year and average temperature ranges from 72°F to 90°F and in the mountainous region temperature from 55°F to 80°F. Peninsular Malaysia is marked by mountainous terrain, consisting of eight ranges that are aligned longitudinally from west to east [20]. These are the Nakawan, Keda-Singgora, Bintang, Kledang, Main, Benom, Tahan and East Coast ranges. Tropical humid climate, a series of approximately NNW-SSE trending mountain ranges and sub-aerial exposure gives the Peninsular a distinctive drainage pattern. The longest river is the Sungai Pahang with catchment area of 29,137km² [21]. Tributaries of main rivers flow east west at right angles to the mountain ranges. Generally, the rivers are slow moving and have ill-defined channels, with marshes and swamps extending inland from the coast [22].

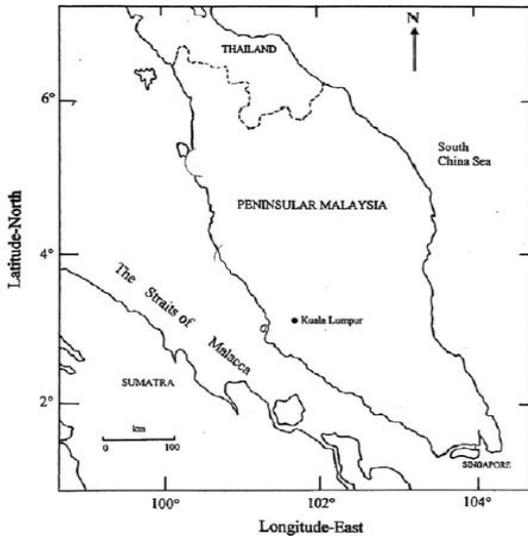


Figure 3 Location Map of Peninsular Malaysia

3. GEOLOGY, STRUCTURAL AND TECTONIC SETTING, ONSHORE PENINSULAR MALAYSIA

Hutchison and Tan [23] have provided detailed review of the geology of onshore Peninsular Malaysia. The Peninsular Malaysia's sedimentary basins' outline, except for Jurassic and younger sediments, have been affected and thus distorted by tectonism, granitic intrusions and continuous denudation [24]. Geologically, there are three main belts in Peninsular Malaysia; Western, Central and Eastern belts (figure 4). The Bentong-Raub Suture separates the Western from the Central belts. This main Palaeo-Tethyan suture (the Bentong–Raub) is thought to be extending north to the Chiang Rai–Sra Kaeo suture (Chiang Mai or Inthanon suture; [25]), with the Nan-Uttaradit suture of north Thailand thought to be a back-arc basin [25-27]. The Bentong–Raub suture zone contains Devonian to Triassic well-dated cherts and deep marine sediments [25,27,28]. In the Western Belt, clastic and carbonate sediments dominate, with scattered volcanics. The belt is characterized by granitic bodies of Triassic age in the Main Range and Paleozoic continental margin sequence that was attached to the NW Australian part of the Gondwanaland until the early

Permian [29]. Paleozoic sediments are found in most of the areas with Mesozoic rocks distributed in Kedah and northern Perak, which were deposited prior to the granitic intrusion. Silurian to Permian carbonate limestones are found in the Kinta Valley while lower Paleozoic limestones and metasediments are found in other localities which are separated from the upper sediments such as Kodiang Limestone, and deep marine Semanggol Formation by an unconformity [24]. Batu Arang, Lawin and Enggor Tertiary basins are found the Western belt. The Triassic granitic intrusions are found in the Kedah, Perlis, Selangor and western part of Melaka and Negeri Sembilan. Within the Western belt, a Northwest Domain contains shallow marine Mahang Formation and deep marine Setul Limestone as well as coarse-grained deltaic peralic Machinchang Formation; deposited during Lower Paleozoic period.

In the Central Belt, which is an extensional graben bounded by Bentong-Raub suture zone to the west and the Lebir Fault Zone to the east, the dominant rocks include the Paleozoic and Triassic deposits with minor occurrences of Jurassic and Cretaceous formations/rocks [30,31]. These deposits include marine carbonate sediments, shales, volcani-clastic and andesites [32,33]. Permian to Lower Triassic shallow marine sediments dominated the northern part of the belt while the younger Triassic beds are found in the southern part [24]. The Paleozoic rocks include marine Permian strata belonging to the Raub Group, Gua Musang Formation, Aring Formation and Kepis Beds [34], and the Mesozoic rocks include Carbonaceous Semantan Formation, Koh Formation, Tembeling Group, Ma'Okil Formation, Bertangga Sandstone and red coloured siliciclastic Paloh Formation [33]. The Tertiary Durian-Chondong basin belongs to this Belt.

The Eastern Belt has two major depocenters; the Permian clastic marine sediments to the south of WNW-ESE striking Lepar fault and the Carboniferous metasediments to the north [35]. Deformed Paleozoic sediments that unconformably overlie by Jurassic-Cretaceous continental deposits [36] dominate the belt. The dominant rock groups are the shallow marine Carboniferous sediments (Kuantan Group, Kamning and Seri Jaya beds) and Permian conglomeratic sediments (Lingui and Dohol formations). Mesozoic witnessed deposition of Badong Conglomerate and its overlying Lotong Sandstone of the Gagau Group (a thick continental sequence outcropping along the SE corner of Kelantan border as a prominent upland [37].

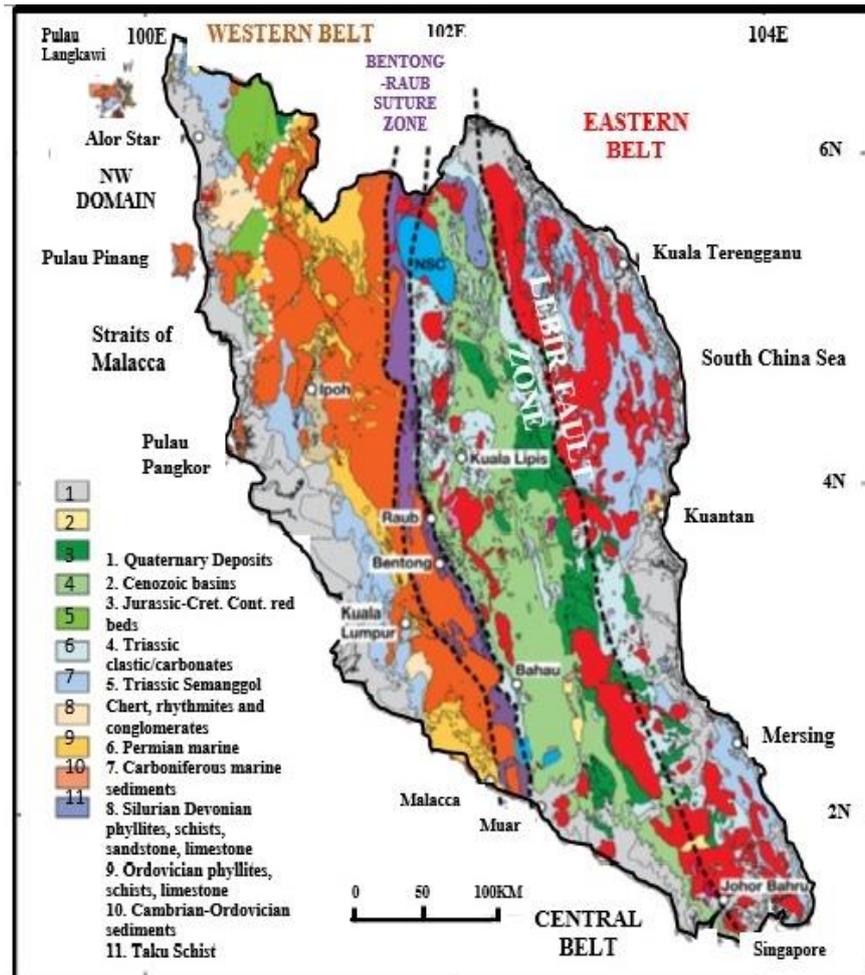


Figure 4 Geologic map of the peninsular Malaysia, showing geologic belts. Modified from Metcalfe [3]

The onshore Peninsular Malaysia has four main structural domains: Northwest, West, Central and East. The Northwest structural domain has NE striking structures, contact aureole and continuous deposition throughout the Paleozoic [16,38]. In the Western domain, the structural trend is in the NNW and N with dominant tectonic transport being westward [36] while in the Central domain, the structural grain varies between North and NNW [24]. The Central extensional graben is bounded by Bentong-Raub line to the west and the Labir Fault zone to the east [30]. In the Eastern domain, regional structural trend is in NW to NNW. The beds here are deformed and tilted regionally to the south with characteristic folds and reverse faults [24]. The NNW-structural trends of the Peninsular is defined by lithologic and beds strike as well as fold axial traces and planes, with complex tectonic evolution spanning between Cambrian to Recent times [39]. During the Triassic Indosian Orogeny, western part (Sibumasu) collided with eastern part (Indochina continental block) along the Bentong-Raub suture line as the collision suture zone [28]. The Bentong-Raub suture zone (Figure 3 and 4) which is a 15-20km width NS trending suture is a major structure in Peninsular Malaysia. Bentong-Raub Suture zone has been

regarded as Late Triassic [40-42] but an Early Triassic age has been proposed by Mitchell [43] based on the recognition of a probable Early Triassic age for olistostromes in the Raub area and structural data from the Peninsula [44]. The Bentong-Raub Suture was first discovered in the southwards part area of Ceroh, through the Raub and Bentong and towards the Kuala Pilah. The suture line separates the Western from the Central Belt [28] and this lineament is characterized by isolated serpentinite rocks associated with schist, chert, mélangé/olistostrome and conglomerates. The East Tectonic Zone is another important zone that separate the Central domain from the East domain, and it runs north south. This zone has associated fault system including the Lebir, Cini and Lepar. Other major faults systems include Lebir, Bok Bak, Kuala Lumpur, Mersing, Lepar, Ma'Okil and Bukit Tinggi Faults [34,36] (Figure 5). Zaiton Harun [45] studied the anatomy of major faults system in Peninsular Malaysia.

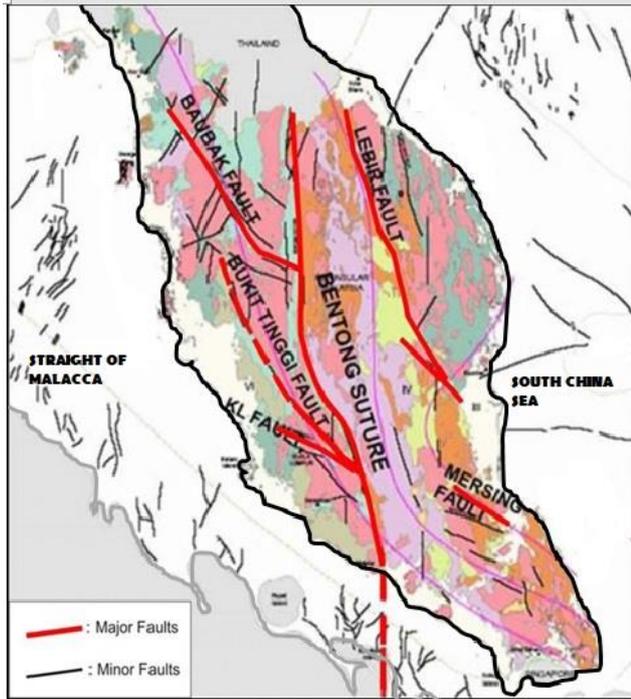


Figure 5 Map of Peninsular Malaysia showing major and minor faults [24,36]

4. STRATIGRAPHY AND SEDIMENTATION OF CENOZOIC BASINS

Cenozoic basins/deposits comprise seven Tertiary sedimentary basins and four Quaternary formations. The earliest work on the onshore Tertiary sedimentary basins have been conducted by Scrivenor [20]; Renwick and Rishworth [46]; Stauffer [8] and Suntharalingam [18]. Thickness of these Cenozoic sediments varies but Malay Basin's sediments have an average of 10,000m [47]. Raj *et al.*, [48] had evaluated the published and unpublished literatures and conducted field investigation on these basins. Sediments in the Tertiary basins are fluvial and lacustrine with significant lignite and coal seams. Conglomerates, sandstones, siltstone and shales/mudstones are the dominant rock types. Suntharalingam and Teoh [49], Suntharalingam [18], Kamaludin [50] and Lee *et al.*, [14], have reported quaternary sediments in Peninsular Malaysia. Quaternary sediments consist of unconsolidated boulders, gravel, sand, silts and clays that occupy the west and east coastal lowlands with minor occurrences in the river valleys. The Cenozoic sediments in the Peninsular Malaysia have been listed in the stratigraphic lexicon [14], table 1 (C1 – C14) and figure 6. Figure 7 shows the Cenozoic correlation chart for the onshore-offshore west and east coast, Peninsular Malaysia.

Table 1 Cenozoic rock formations, Onshore Peninsular Malaysia (modified from Lee *et al.*, [14])

PENINSULAR MALAYSIA (Cenozoic Formations)		
No.	Name	Age
C1	Batu Arang	Late Oligocene to Early Miocene
C2	Enggor	Tertiary (Neogene)
C3	Bukit Arang	Tertiary (? Miocene)
C4	Kluang-Niyor	Late Tertiary
C5	Kampung Durian Chondong	Late Tertiary (? Late Miocene)
C6	Layang Layang	Pliocene to Pleistocene
C6.1	Badak Shale Member	Pliocene to Pleistocene
C6.2	Pengeli Sand Member	Pliocene to Lower Pleistocene
C7	Lawin Basin	Late Tertiary
C8	Boulder Beds	Early to Middle Pleistocene
C9	Old Alluvium	Early to Middle Pleistocene
C10	Simpang Formation	Pleistocene
C11	Kempadang Formation	Pleistocene
C12	Young Alluvium	Holocene
C13	Gula Formation	Holocene
C13.1	Matang Gelugur Member	Holocene
C13.2	Port Weld Member	Holocene
C13.3	Parit Buntar Member	Holocene
C14	Beruas Formation	Holocene
C14.1	Pengkalan Member	Holocene
C14.2	Matang Timbul Member	Holocene

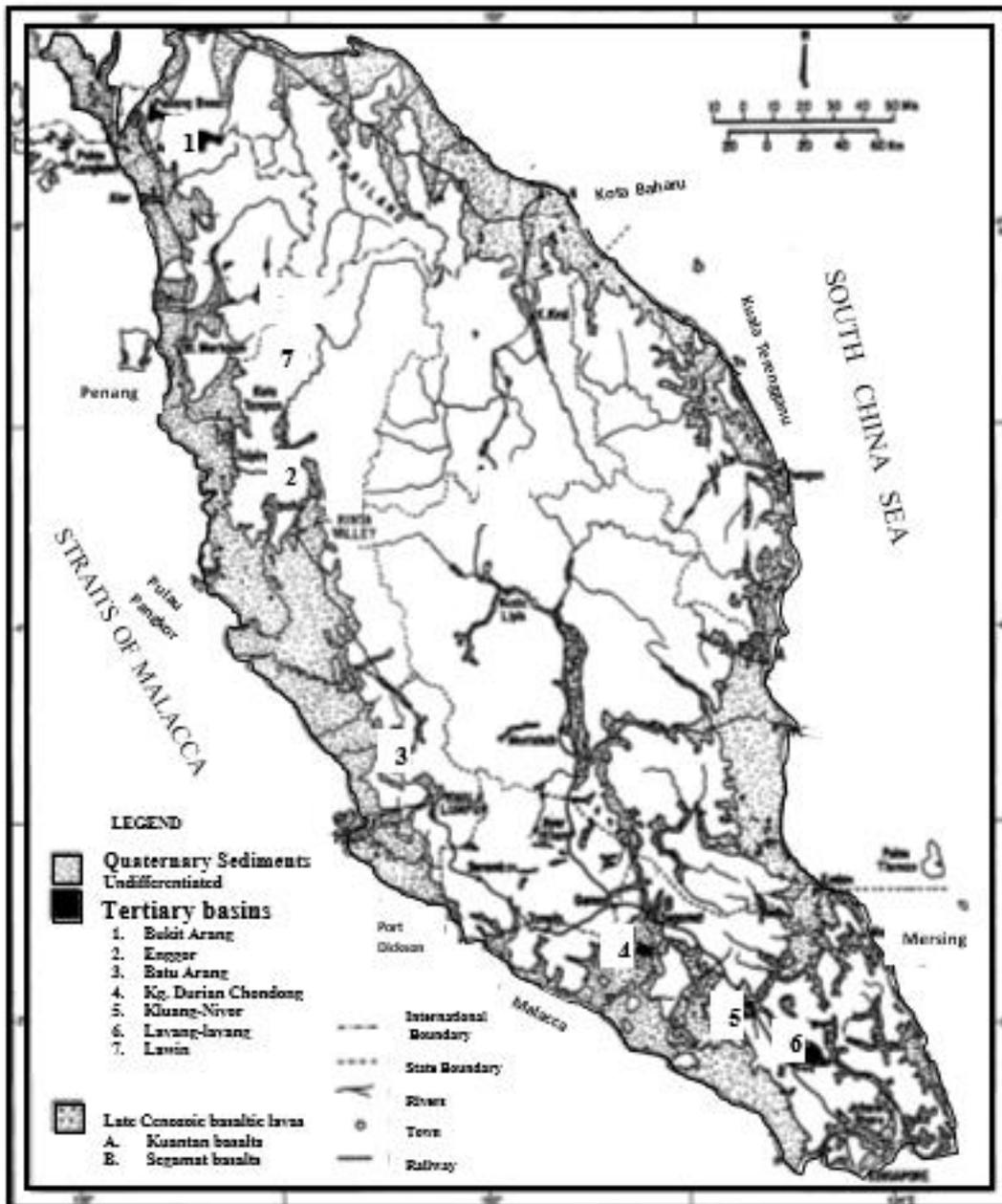


Figure 6 Map showing onshore Cenozoic rocks (modified from Raj, [51])

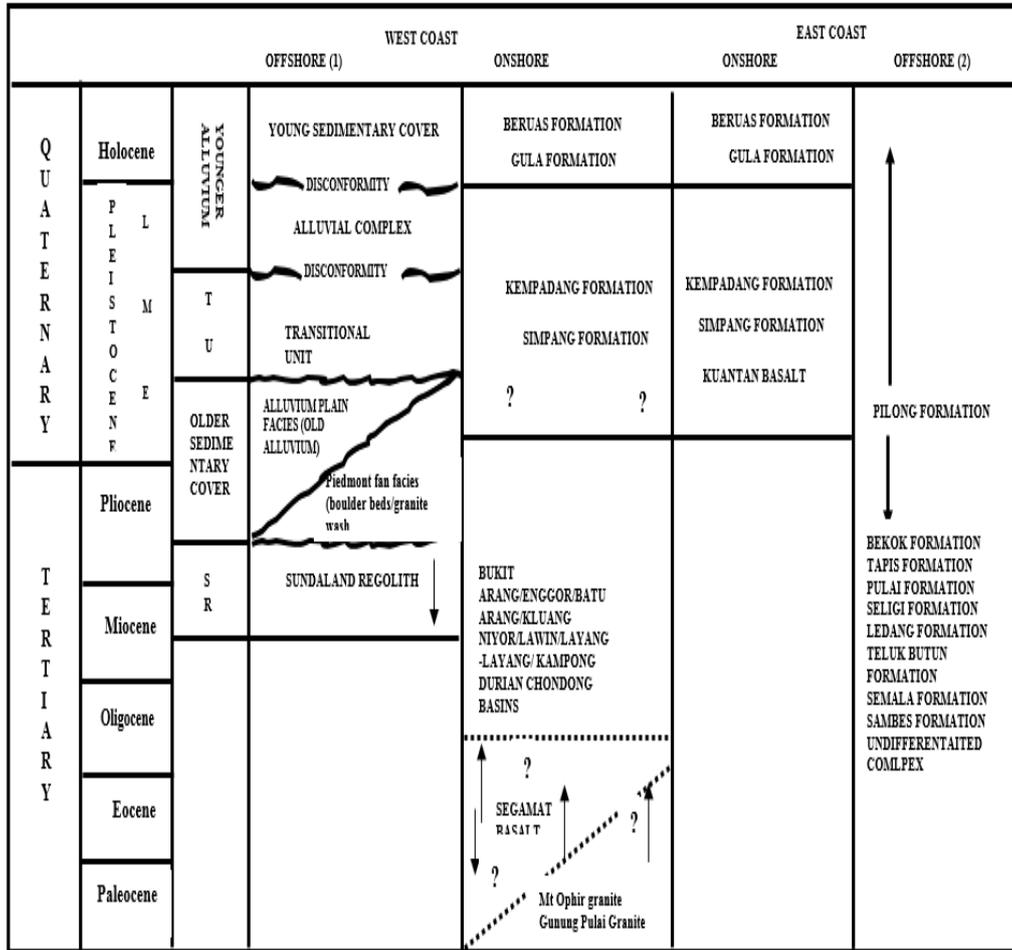


Figure 7 Simplified correlation chart for Cenozoic formations, onshore and offshore Peninsular Malaysia (Redrawn and modified after Suntharalingam, [18])

4.1. Onshore Tertiary Stratigraphy and Sedimentation

Tertiary sediments occur as isolated basins between the Peninsular Malaysia Main Range and the west coast or they underlie the Quaternary sediments in offshore and coastal areas [18]. The geologic (stratigraphy, sedimentological and tectonic) characteristics of these basins are summarized in table 3. The basins' stratigraphy and sedimentology are discussed below.

4.1.1. Bukit Arang Basin

The Bukit Arang basin is located near the Malaysia-Thailand border in Perlis and north Kedah. The basin has a lobe shape with an estimated length of about 8 km and width of 3.5 km wide. Recent gravity data of the Bukit Arang has shown that the basin thickness ranges from 200 m up to 800 m in some places [52]. Sediments here are loose and semi consolidated but in general, highland areas consists of gravels and lowland areas have abundant clays within

stream valleys [53]. The sediments are in a synclinal basin with moderate bedding dips less than 35°. The upper part consists of poorly sorted fluvial conglomerates and sandstones in a sandy to clayey matrix deposits while the lower part/sequence consists of lacustrine sand and clay with coal seams of limited lateral extent [48]. The upper and lower parts are separated by an unconformity. Bukit Arang basin has been dated as Late Tertiary based on the similarities of its coal layers and rock types to that of the Batu Arang. Although no fossil record reported in the basin, Ukakimapan *et al.*, [54] reported fragments of bivalves and gastropods form the clay beds of nearby Sadao Basin (Thailand) but no age determination was conducted. Low quality coal seams were reported but is was not of economic importance. Oil shows and small amount of cassiterite were reported in the shales and sands respectively [52].

4.1.2. Enggor Basin

The Enggor basin (earlier known as Enggor coalfield, Enggor coal beds, Enggor coal deposits) is located near Kuala Kangsar, Perak. It consists of thin layer of surface wash [48], which unconformably overlies the strongly folded sediments of the Devonian to Permian Salak Baharu

Bed [55]. The beds dip at 10° towards 330° . Stratigraphic section of about 63 m thick has been reported in this basin consisting of a thick upper sequence of sandy shale and sandstone and a lower sequence of grey shale, two layer of coal seams separated by a thin shale, black shale and calcareous shale [14]. The upper and lower coal seams of 0.75 to 1.8 m and 0.3 to 1.2 m thick respectively, separated by a 0.45 m thick shale containing organic matter, were previously mined in this area [48,56,57]. A simplified stratigraphic succession of Enggor is presented in table 2. Enggor Tertiary beds have been correlated with other basins of Tertiary age, based on plant fossil flora in some carbonaceous shales [57].

Table 2 Simplified Stratigraphy Sequence of Enggor Basin [55]

Upper thick layer of sandy shale and sandstone
Thin zone of grey shale
First coal seam – 0.75 to 1.8 m thick
Oil bearing shale – 0.45 m thick
Second coal seam – 0.3 to 1.2 m thick
Black shale and calcareous shale – About 9 m thick
Folded Upper Paleozoic Strata-Salak Baharu Beds

4.1.3. Batu Arang

The discovery of two coal seems in the Batu Arang area in the 90's made it the most extensively studied onshore Tertiary basin. Mahendran *et al.*, [58] described Batu Arang basin as a NW-SE trending roughly oval-shaped basin consisting of two (2) sedimentary sequences; the Boulder Beds upper sequence and the Batu Arang Beds/Coal Measures, separated by an unconformity.

The upper boulder beds are made up of boulders of sandstone, cherts, shale and coal fragments with no records of fossils. Paleocurrent studies using available sedimentary structures such as pebble imbrication and channels deposits indicates that the Boulder Beds exhibit a multi directional flow. The deposits are believed to have been accumulated as subaerial debris flow and deposited as alluvial fans under semi-arid or tropical conditions [59]. The Boulder Beds are divided into three units, based on colour variation, composition and clast shapes; Unit A – reddish unit with angular to rounded boulders of sandstones, shales and some metasediments, Unit B - greyish unit with subangular to angular, pebble to boulders of sandstone, shale and metasediments and Unit C - greyish unit with sub rounded, pebble to boulders of sandstone, quartzite, shale, and polymict conglomerate [51]. The Boulder beds upper sequence is Late Miocene to Pliocene [59].

The lower sequence (Coal Measures) consists of sandstone with shale and clay intercalation facies, shale facies, coal bed facies and sandstone facies with shale, clay and conglomerate intercalation [59]. Raj [51] summarized the characteristics of these different facies. The sandstone facies consists of fine-grained sandstones and coarse-grained sandstone lenses, sandy to silty shales and structureless clay beds as well as thin beds and another

coarser grained sandstone lenses and some low-grade coal seams. The shale facies has fine-grained sediments that include well-laminated and fissile shales and structureless clays with abundant carbonaceous matter. The coal bed facies contain dark shales. Two thick coal seams, an upper and a lower seam of 15 m and 8 m thick respectively were reported in the eastern part of this basin. The interbedded sandstones facies consists of small-scale cross-bedded, fine to coarse-grained sandstones intercalated with shale, clay and conglomerates. The organic matter in this basin contains coaly materials and plants fragments. The Coal Measures is Early Miocene [58] or Eocene-Oligocene [60] in age.

4.1.4. Kampung Durian Chondong Basin

The Kanmpung Durian Chondong Basin is located in Northwest Johor, 10 km to the east of Gunung Ledang. It consists of clastic sand, silt and clay as well as volcanic ash layers with clay lenses [61]. Soils and Pleistocene or Pliocene sandy alluvium covers these strata unconformably [62]. In the early 90s, coals seams of varying thicknesses, shales with plant remains, oil shales and coal, calcareous fossil-shells in shales and hard grey impure limestone were exposed at some parts of or near Kampung Durian Chondong after several pits were sunk at various depth [48]. The reported volcanic ash was at a depth of 190m with its top dipping ESE at 6° [57]. Several gastropods fossils shells, which were sometimes well preserved with some of their colour ornamentation, were seen in grey shales samples at depth of 26.8 to 44.2m [63]. Raj *et al.*, [63] reported trace fossils and some small fish teeth in the shales. The presence of fossils species *Vivaparus wilhourni* is an indication of non-marine and probably lacustrine environment [63]. Plant fossils from coals were reported from the nearby Bukit Serampang [57].

4.1.5. Kluang-Niyor Basin

The Kluang-Niyor Basin, located at the norther part of Johor, ranges from Kluang to Niyor south (approximately 8 km) and from Kluang to the west and south-west (over 9.5 km). The basin may extend for several kilometers across due to the variable dip directions and rapid lateral change in thickness [8]. Sequence of shale and clays as well as lignite are the major sediments in this basin. The shale ranges in colour from pale grey to black compact, fine grained. Raj *et al.*, [64], also reported some hard, red mottled sandy clay and fine sands. Natural exposures are not very common in this basin. However, [64] reported the occurrences of exposures along the Kluang and Niyor rail milepost 413.25–417.25, where a dominantly grey and pink, slightly iron-stained alluvium consists of mainly of sub-angular quartz grain was observed. A pale grey compact fine-grained shale was exposure beneath the alluvium in milepost 414.25. In addition, Poor-quality low-grade coal seams dipping NE bedded with alluvium at milepost 471.75 [64]. Sands, shale, sandy clay and clays were encountered at shallow depth from several borehole drillings in the Kluang rail station. A

borehole discovered a 4.5-m-thick shale contains plant fossil and little oil shows at the deeper part of the borehole (10.7 m) [48]. Recent work by Meng *et al.*, [65] discovered two new outcrops of Tertiary ages, which belong the Kluang-Niyor basin. These two outcrops are located at Kluang town in Taman Saujana and Sri Permai. The main lithology is unconsolidated, grey to light-coloured poorly sorted medium- to very coarse-grained sandstone/conglomerate. The outcrops have clear channel features with a fining upward pattern typical of fluvial environment.

4.1.6. Layang-Layang Basin

Layang-Layang basin, which lies between the towns of Layang-Layang and Bandar Tenggara, is the southernmost of the known Tertiary basins in Peninsular Malaysia [66]. The basin is a half-graben bounded by listric normal fault to the northeast with a throw of just 1km [66]. Rajah [67] considered the basin to be probably of Pliocene-Pleistocene age and sub divided it into a lower Badak Shale Member and an upper Pengeli Sand Member. The Badak Shale Member consists of finely laminated greyish shale overlain by poorly consolidated grey to yellow brown sandy clay. The Upper Pengeli Sand Member is composed of sand, sandy clay, clay of varying colours and clayey sand. Badak Shale Member was deposited in intermontane or lacustrine environment while fluvial to deltaic environment was assigned to Pengeli Sand Member [67].

4.1.7. Lawin Basin

Lawin Basin, which is located in North Perak, consists of poorly graded sand, grit and pebble beds/sediments. The sediments were deposited as alluvial fans and have thickness of >300 m [48]. The sediments are feldspathic in composition and appear to be of granitic origin. Quartz grains, altered feldspar and occasional biotite with a certain amount of silty and ferruginous material were reported [68]. The basin lithology and structure are comparable to other late Tertiary basin sediments in the Peninsular. However, there is absence of lignite seams [68]. The beds are not affected by folding and therefore depositional. Bedding and horizontal disconformity of strata are very common. The likely environments of deposition are fluvial, deltaic, lacustrine or a combination of them [48]. Although no fossil record has not been found in the Lawin basin, Late Tertiary age has been assigned to the basin due to the partially consolidated nature of the sediments and similarities in lithology and structural disposition with other Tertiary basins such as the Bentong Basin in south Thailand and Enggor basin in Perak [68].

4.2. Onshore Quaternary Stratigraphy and Sedimentation

The four stratigraphic units/formations that constitute the onshore Quaternary are Simpang, Gula, Kempadang and Beruas formations. These formations are mainly of continental and marine origin, and were deposited during Pleistocene and Holocene time.

4.2.1. Simpang Formation

The formation consists of complex unconsolidated sands and gravels, silt and clay that overlies the bedrock [64]. It is divided into a Lower Sandy Member and an Upper Clayey Member. Stauffer [8] placed the Formation to be Lower to Middle Pleistocene in age. Simpang Formation deposits have been reported in the Kinta Valley consisting of grey to brown sandy clay with sand and gravel intercalation [69] having lenticular and discontinuous beds of fluvial origin [64]. In addition, in the Tanjong Duabelas area of Selangor, sediments of Simpang Formation consist of coarse-grained channel deposits and overbank deposits with thickness of 35 m and 6 m respectively [64]. Muhammed [70] reported tin placer deposits in the Kuala Lumpur area belonging to Simpang Formation. Thick sequence of continental gravel and sand of about 30-45 m thick Simpang Formation sediments have also been reported in the Kuantan area in Pahang [71].

4.2.2 Kempadang Formation

The Formation consist of Pleistocene marine sediments [71]; marine clays with shales and sands with cassiterite recorded in the sand fraction [18]. Sediments of Kempadang Formation were first observed from borehole samples in Pahang (Kuantan south) and subsequently were also mapped in Perak (Lumut area). In the Lumut area, 20 m thick sediments of marine origin and 8 m thick sequence of fluvial sediments were reported [72].

4.2.3 Beruas Formation

Beruas Formation is Holocene in age. The Formation refers to the fluvial-estuarine-lacustrine sediments that consist of sandy clay, sandy gravel, clay, silt and peat [73]. Two members have been identified; the Pengkalan Member consisting of inland freshwater swamp clay, peat and silt and the Matang Timbul Member, consisting of poorly sorted gravelly sand to clay [64]. Maximum thickness reported for this formation is 10 m. Raj [74] reported the occurrence of Beruas Formation sediments (sand and sandy clays) in South Kedah and Penang. In South Perak, the formation consists of sediments deposited by Sungai Perak and its tributaries [64] and in Batu Gajah, [75] documented the occurrence of fluvial sedimentary structures such as lenticular bedding, channels and trough cross bedding. A sequence of medium stiff-to-stiff clay is found at Keper [74] and greyish orange mottled sandy clay of swampy peat and

Table 3 Geological signatures of Tertiary basins, Onshore Peninsular Malaysia

References	Basin/ Formation	Location	Sedimentology	Stratigraphy	Age	Depositional environment	Structural geology/ Tectonism	Coal seams
Raj et al. [48] Lee [53]	Bukit Arang	Perlis and Kedah (Malaysia Thailand boarder)	Gravel and boulders within sandy to clayey Clay and sand layers	Boulder beds unconformable over Lower Sequence	Late Tertiary	Fluvial (boulder beds) and lacustrine (Lower sequence)	Synclinal, bounded by normal faults striking NS	Thin lignite of limited lateral extent and low quality
Foo [55] Raj et al. [48]	Enggor	Perak, near Kuala Kangsar	Quartzite Pebbles in sandy matrix, shale sandstone and clays	Surface wash sediments over coal strata	Late Neogene or Quaternary	Fluvial (boulder beds) and lacustrine (Lower sequence)	Dips 10 ⁰ towards 330 ⁰ , overlie folded Salak Baharu Beds	1 m thick lignite and poor quality seams of 1.5m
Raj [51] Raj et al. [48] Mahendran et al. [57]	Batu Arang	Selangor, Darul Ehsan	Gravel and boulders within sandy matrix Shale sandstone and clays	Boulder beds unconformable over coal measures	Late Oligocene to Late Miocene	Alluvial fan deposit (boulder beds), lacustrine (Lower sequence)	Synclinal structure plunging southward, half-graben shape, NW-SE faults	Two thick coal seams
Cox [62] Raj et al. [48]	Kg Durian Chondong	Near Kepong, NW Johor	Sand, clays Shale, volcanic ash and clays	Alluvium unconformable over lower sequence	Late Tertiary	Fluvial (boulder beds), lacustrine (Lower sequence)	Fractures/ faults of Gunung Ledang area led to structurally controlled basin	Few lignite seams
Raj et al. [48]	Kluang-Niyor	Central Johor	Sand and clays Shales and some clays	Alluvium unconformable over lower sequence	Late Tertiary	Fluvial (boulder beds), lacustrine (Lower sequence)	NW-SE linear trends of some rivers (evidence of Pengeli fault extension)	Few lignite seams, with limited lateral extent
Rajah [66] Raj et al. [48] Vijayan [65]	Layang-Layang	South Johor	Pengeli: sand, clayey sands and clays Badak: mudstone and shale	Pengeli sand member conformably over Badak Shale member	Miocene	Fluvial deltaic (Pengeli), lacustrine (Badak)	Half-graben bounded by listric normal fault to the northeast with a throw of just 1km	Not reported by likely at depth
Jones [67] Raj et al. [48]	Lawin	Gerik Area, Perak	Grit sand and pebble beds	Boulder beds	Tertiary	Fluvial fan deposits	Depositional (not affected by folding)	Absence of lignite seams

organic clay [76] in South Selangor. In the coastal areas of Negeri Sembilan and Malacca, Beruas Formation consists of soft brown grey clay and silt deposited in mangrove environment. Raj *et al.*, [64] also reported unconsolidated fluvial sand, silt and clay in Batu Pahat, West Johor and levee and flood plain deposits in the Pahang area.

4.2.4. Gula Formation

Gula Formation consists of greenish-grey to grey estuarine and marine clay and subordinate sand of Holocene age [49]. Littoral zone and estuarine to shallow marine have been interpreted as the environment of deposition based on the lithology and fossil content [50]. Suntharalingam [18] proposed the term 'Port Weld Member' for the brown grey to green clay with abundant mangrove and riverine nipah deposits and 'Matang Gelugor Member' for the sand occurring as beach ridges along the coastal areas. Sediments of Gula Formation are distributed in North Kedah and Perlis as bluish or greenish marine clays, in North and Central Perak, in South Perak as estuarine and coastal shallow marine deposits. In Selangor, Negeri Sembilan and Malacca, the Matang Gelugor Member deposits are found as infilled valleys underlying the entire coastal area. In Johor area, marine clays of the Gula Formation have been divided into an upper subtidal clay and a lower intertidal clay [74].

5. DISCUSSION

5.1. Sedimentology and Stratigraphy

Continental Cenozoic basins occur in the west and east coast of Peninsular Malaysia. They consist of Tertiary and Quaternary sediments. Tertiary basins are seven (7) in number. They are Batu Arang, Bukit Arang, Kluang-Niyor, Enggor, Lawin, Layang-Layang and Kampung Durian Chondong. These Eocene to Oligocene sedimentary basins were deposited in pull-apart basins. The sedimentology and stratigraphy of the basins can be summarized using Stauffer [8] work. The basins consist of conglomerates and sandstones; soft carbonaceous shales; low-grade coal seams; and rarely calcareous shale and limestone. The basins' stratigraphy shows facies associations of continental, lacustrine, paludal and fluvial sediments. Stratigraphically, all the Tertiary basins, with the exception of Lawin basins, are divided into an upper sequence/boulder beds/alluvium (mainly fluvial) and a lower sequence (mainly lacustrine), separated by an unconformity. In Layang-Layang basin, the upper sequence is called Pengeli Sand Member while the lower sequence is called Badak Shale Member. Their thicknesses vary, generally more than 100m with Batu Arang (470m) being the maximum highest thickness reported. Their topography is generally flat lying, with dips of 30° – 40°. These basins lie on folded and metamorphosed Paleozoic to Mesozoic rocks unconformably.

Quaternary sediments consist of unconsolidated boulders, gravel, sand, silts and clays. These sediments have been considered as "alluvium" with some having colluvial, littoral and marine origin [64]. Suntharalingam and Teoh [49] have developed stratigraphic scheme for the onshore Quaternary sediments in Peninsular Malaysia. They based their finding using lithology, heavy mineral content and paleoenvironment. The four stratigraphic units/formations that constitute the onshore Quaternary are Simpang Formation, Gula Formation, Kempadang Formation and Beruas Formation. Quaternary sediments have been named based on two approaches [14]. Quaternary sediments could be differentiated into Boulder beds, Old and Young alluvium based on the outcrop characteristics and exposures of the Kinta Valley in Perak, while Simpang Formation, Gula Formation and Beruas Formation were classified based on the subsurface signatures of the formations especially in the lowland areas of Perak (Beruas and Taiping); and that of Kempadang Formation from Pahang (Kuantan) area. The continental Simpang Formation and Beruas Formation are the equivalent to the "Older Alluvium" and the "Young Alluvium" of Walker [77] respectively.

5.2. Tectonic and Structural Setting

Peninsular Malaysia basins are generally terrestrial extensional basins throughout their histories [10] and are characterized by high surface heat flow with a thermal anomaly beneath the basins. This may be due to thinning of the lithosphere during their formation [78]. Tectonic activities in the Peninsular Malaysia were regarded at minimal level, but recent works by, for examples (Raj [79]; Tjia, [80,81]; Mustafa [39]), showed that the Cenozoic deformations of Sundaland occurred in the numerous offshore sedimentary basins and onshore basins alongside elevated highlands.

The evolution of Cenozoic basins, Peninsular Malaysia could be linked to the development of Sumatran Paleogene grabens and half-grabens that developed due to back-arc extension during Late Eocene to Early Oligocene. The basins development was initiated due to the variations in Sumatra Trench subduction rates as the collision between India and Eurasia plate led to the development of the extensional tectonic setting in these basins [82,83]. According to Hutchison [84] the SW margin of Eurasia Plate was believed to have been deformed to its present configuration since 55 Ma; and this extensional tectonic regime affected the western zone thereby experiencing extension which led to development of Tertiary Basins in Sumatra.

Cenozoic basins were formed within the vicinity of regional fracture zones and major fault zones, as these major zones of weaknesses were reactivated [85]. Their locations is in the marginal belts of semi-cratonic continental crust as onshore basins and their development show that thermal subsidence, rifting and changes by transpressional and/or transtensional strike slip (wrench) faulting are the tectonic processes that operate on depressions underlain by

continental crust [86]. Basement fractures were reactivated by wrench faulting which led to the development of pull-apart basins. Inverted structures are the rule, as are reversals of slip sense on the wrench faults.

The Tertiary sedimentary basins formed in transtensional zones within Baubak-Batang Kali-Kuala Lumpur-Endau fault zone as a result of stresses released from the east by Malay and Penyu basins and from the west by the Sumatran Basins. The Tertiary basins are aligned to major fault zones. These Tertiary basins had experienced sinistral movement along the fault system/zone during the Eocene [87]. This zone is the major zone of structural activity in the Peninsular during the Tertiary period. The Tertiary basin at Batu Arang is a fault-controlled basin [88]. Stauffer [8] also suggested that structural adjustment during Late Tertiary time involved faulting at the Batu Arang area. The stresses from the Malay and Penyu basins in the east and Sumatra basin in the west released through the Baubak-Batang- Kali-Kuala Lumpur-Endau fault zone was responsible for sediments infill that formed the onshore Tertiary pull apart basins [89].

Raj [79] has observed that, an outcrop 13 km northwest of Karak, along the Kuala Lumpur - Karak Highway provides a good evidence of tectonic movements during the Quaternary of Peninsular Malaysia. This outcrop is located along the road cut of a terrace consisting of upper unconsolidated deposits and overlying schist bedrock. On this outcrop, presence of a normal fault that cuts across the unconsolidated deposits and bedrock suggested the Quaternary age for the fault. Offset of the unconsolidated deposits and underlying bedrock was clearly noticed, indicating a normal fault with a dip slip of about 1.5m and a linear fault plane. The fault plane is stained with secondary iron oxides and strikes of north south with a dip of 55 towards the east [79]. However, Tjia [90] argued that the above interpretation might be wrong. He [90] agreed that the fault might be Quaternary but that the Quaternary tectonic movement has not yet been demonstrated for the Sunda Platform to which the Peninsular Malaysia belongs; he added that the geology of the area points to the tectonic stabilization of the platform. Since then only epeirogenic movements appear to have affected the cratonic region [8,9].

5.3. Limitation and Constrain

Most of the previous works on onshore Cenozoic basins had been on the Quaternary sedimentary basins, with Tertiary basins been less studied. There is insufficient data/research work carried out in the onshore Tertiary basins.

In addition, sedimentology and stratigraphy work need field data, and these could be sourced from quality outcrops. However, the available outcrops for such studies are very limited and if available, are affected by the climate (chemically weathered) and/or covered by the very thick plantation. This thick vegetation hinders detailed field studies.

5.4. Recommendation for Future Work

Understanding of integrated sedimentology and stratigraphy, including geochemical studies of the Cenozoic basins, especially the Tertiary basins is still lacking. Based on this review, it is recommended that detailed sedimentological and stratigraphy studies be carried out, to establish stratigraphic schemes especially for the Tertiary basins.

Detailed study of basins' structures and depth should also be conducted. This study will help in identifying and mapping the extent of these sedimentary basins, which may help for possible hydrocarbon potential, especially on the Tertiary basins. This is because most of the hydrocarbon basins of the region developed during the Tertiary period. New outcrops have just been exposed as a result of excavation for road construction. Such outcrops (Figure 8) need to be studied in details.



Figure 8 Newly exposed outcrop of Tertiary age, Taman Sri Permai (Kluang-Niyor Basin)

Palynological data is lacking in these basins, especially in the Tertiary sediments (except for Layang-Layang and Batu Arang basins). Ages of other basins are still doubtful, as their ages are inferred based on similarities with other Tertiary basins [55]. This calls for detailed paleontological studies to determine the absolute age of the basins.

6. CONCLUSION

The onshore Cenozoic basins, Peninsular Malaysia are in the marginal belts of semi-cratonic continental crust. They comprise sediments of Tertiary and Quaternary ages. The Tertiary sediments/basins consist of conglomerates and sandstones, soft carbonaceous shales, lignite and rarely calcareous shale and limestone that are of continental fluvial and lacustrine origin. They have flat-lying topography, with dips of 30° – 40° and with basin shapes in some areas. They lie unconformably on folded and

metamorphosed Paleozoic to early Mesozoic rocks. The Quaternary sediments consist of unconsolidated boulders, gravel, sand, silts and clays. These sediments mainly occupy the west and east coasts lowlands and minor occurrences in the river valleys. In general, the Southeast Asia Cenozoic basin development is associated with thermal subsidence, rifting, and transtensional and/or transpressional wrench faulting modification. These tectonic processes operate on depressions and basins underlain by continental crust. Peninsular Malaysia sedimentary basins has played important role in the history of Malaysia's mineral (tin and gold) and energy (oil and gas) resources that been mined in the onshore and offshore Cenozoic basins respectively. Availability of gravel, sand and clays in the Cenozoic basins could be used for industrial and other purposes.

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