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Tertiary basins of inland Peninsular Malaysia: review and tectonic evolution

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Abstract: Sedimentary rocks of Tertiary age have been reported from several areas of inland (or onshore) Peninsular Malaysia, though a review of published data indicates that only some of them are known, or likely, to be so (Table A).

In the known and likely localities, which occur as a series of small basins along the West Coast, are found partly consolidated gravels and sands inter-bedded with soft, often carbonaceous, shales, clays and lignite seams, as well as rare limestone, calcareous shale and volcanic ash. The sediments are entirely continental deposits and mostly gently dipping, though dips of 30° to 45° occur with a synclinal or basinal structure shown by some of them. The sediments mostly unconformably overlie, much older, Palaeozoic to early Mesozoic, generally folded and partly metamorphosed, rocks. The sediments have been considered to have been of a more extensive distribution than they presently are, for in places dipping beds are truncated, at the surface, or along an unconformity, though it is doubtful if they ever formed a connected sheet.

At Bukit Arang in Perlis and Kedah, the Tertiary strata form two broad, gently northward plunging, synclinal basins with moderate bedding dips (< 35°). The strata consist of an upper sequence of poorly sorted gravels and boulders in a sandy to clayey matrix (Boulder Beds) that unconformably overlies a lower sequence of sand and clay layers with a few thin coal seams. The lower sequence has a minimum thickness of 130 m and was deposited in a lacustrine environment, whilst the Boulder Beds with a total thickness of some 90 m were deposited under fluvial conditions.

At Enggor in Perak, the Tertiary strata form a small, circular, basin with a thin layer of surface wash sediments overlying a sequence of shales, sandstones and clays with two coal seams. The coal-bearing strata, which dip 10° towards the NW, have a minimum thickness of 65 m and unconformably overlie folded, Upper Palaeozoic sedimentary rocks.

At Batu Arang in Selangor, the Tertiary strata form a broad, gently southwestward plunging, synclinal basin with moderate dips (< 45°). The strata consist of an upper sequence of pebble to boulder sized clasts in a sandy to gravelly matrix (Boulder Beds) that unconformably overlies a lower sequence of shales, structureless clay layers and sandstones with some thin to thick coal seams. The lower sequence, which is of an Eocene to Oligocene age, has a maximum known thickness of 265 m and was deposited in a lacustrine environment, whilst the Boulder Beds with a minimum thickness of 300 m were mainly developed as alluvial fan deposits.

At Kampung Durian Chondong in Johore, Tertiary strata lie under a cover of soil and Older Alluvium that is at least 5 m thick. The Older Alluvium, of a probable Pliocene to Early Pleistocene age, consists mainly of fluvially deposited sands and unconformably overlies a sequence of shales, clays and volcanic ash with some thin to thick coal seams. The coal-bearing strata, which dip some 20° westwards, have a maximum known thickness of 195 m and were deposited in a lacustrine environment.

At Kluang-Niyor in Johore, the Tertiary strata consist of a sequence of shales and clays with some lignite seams that unconformably underlie Older Alluvium of some 5 m thick. The Older Alluvium consists mainly of fluvially deposited sands, whilst the Tertiary strata, which show gentle (< 20°) dips, have a maximum known thickness of 67 m and were deposited in a lacustrine environment.

At Layang-Layang in Johore, the Tertiary strata (Layang-Layang Formation) consist of an upper sequence (3.5 m thick) of sands, clayey sands and clays unconformably overlying a gently dipping sequence of clay-shales and mudstones with a minimum thickness of 95 m. The upper sequence (Pengeli Sand Member) is equivalent to the Older Alluvium and was deposited in a fluvial to deltaic environment, whilst the lower sequence (Badak Shale member) is of a probable Miocene age and was deposited in a lacustrine environment.

At Lawin in Perak, the Tertiary sediments only consist of inter-stratified sand, grit and pebble beds that gently dip inwards to form a basin. The sediments are likely to be more than 300 m thick and were most likely deposited as alluvial fans.

The development of the Tertiary basins has not been discussed by most workers, except for Stauffer (1973) who postulated that they were produced by Late Tertiary structural adjustments mainly involving

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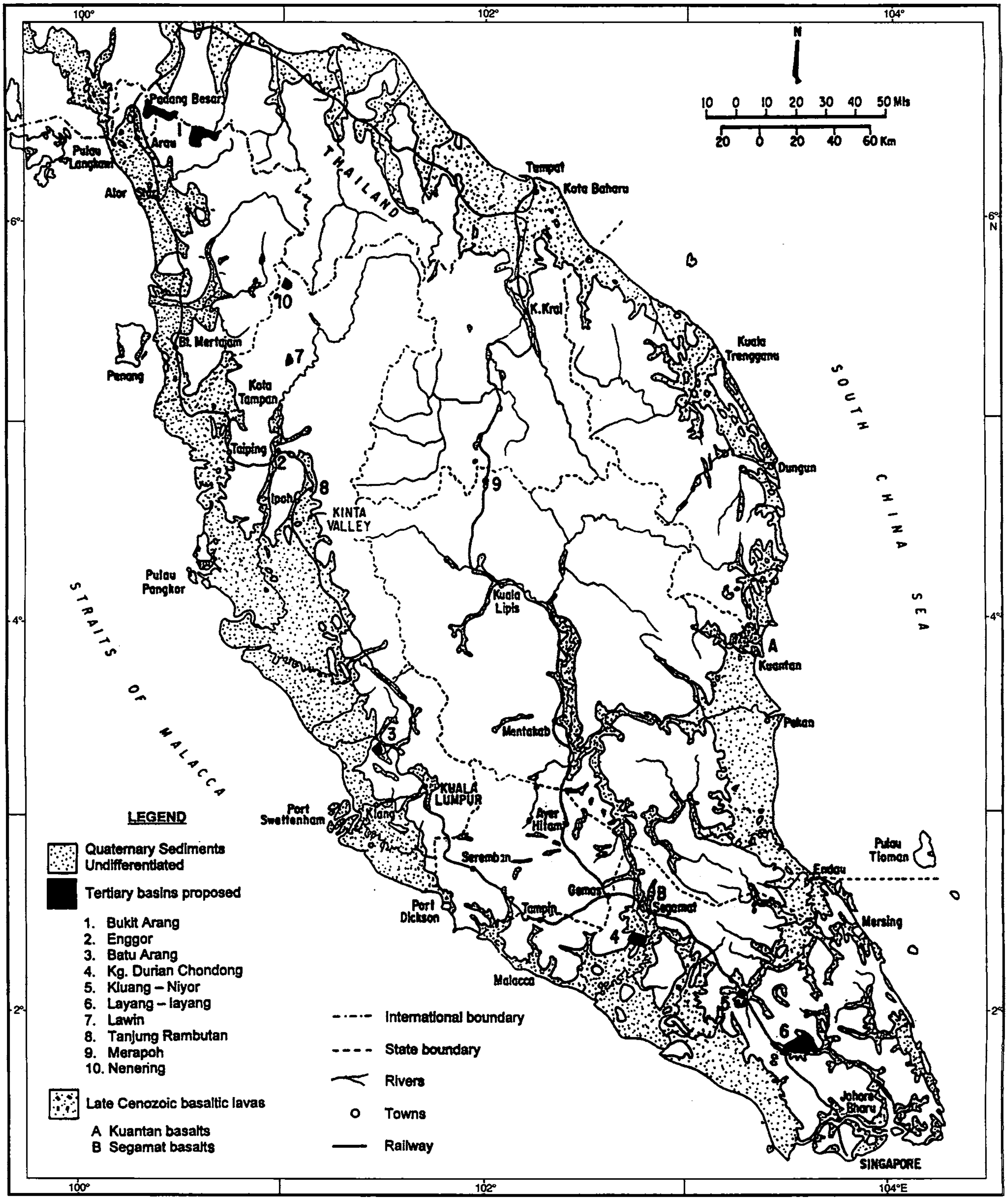

Figure 1. Tertiary sedimentary strata of inland (or onshore) Peninsular Malaysia.

faulting, as several of the basins were located on the trends of major structural lineaments. Raj *et al.* (1989) enlarged on this postulation and considered that sinistral displacements along NW-SE trending faults were initially responsible for development of the basins; later normal faulting resulting in deposition of the Boulder Beds in some basins.

Evaluation of published data and limited field investigations, show the coal bearing strata at the Bukit Arang, Enggor, Batu Arang, Kg. Durian Chondong, Kluang-Nyior, and Layang-Layang, localities to have been deposited in pull-apart basins formed during the Late Eocene to Early Oligocene. These basins developed as a result of left-lateral displacements along pre-existing NW-SE trending faults; the regional tectonic setting arising from the E-W orientated maximum horizontal component of the regional stress field that developed when the Indian Plate collided with the Eurasian Plate at about 50 Ma. Deposition in swampy, alluvial flood-plain to lacustrine environments within the basins, then led to the coal-bearing strata. Continued northward movement of the Indian Plate led to a progressive clockwise rotation of Peninsular Malaysia, and of the regional stress field, and resulted in mild folding and uplift of the coal-bearing strata during the late Early Oligocene. During the late Middle Miocene to Pliocene, concomitant with, or following, uplift of the Barisan Mountain Range in Sumatra, there occurred an extensional tectonic setting in the Peninsula which led to normal faulting and the deposition of the Boulder Beds at Bukit Arang, Batu Arang and Lawin. During this same period, or during the Pliocene to Early Pleistocene, the Older Alluvium was deposited over the coal-bearing strata at Kg. Durian Chondong, Kluang-Niyor and Layang-Layang. Rifting in the Andaman Sea during the Pliocene to Pleistocene has led to faulting in some of the Tertiary basins.

Table A. Proposed localities of Tertiary sedimentary rocks in Peninsular Malaysia

	Known localities
1.	Bukit Arang, near the Thai border in north Perlis and north Kedah
2.	Enggor, near Kuala Kangsar in central Perak
3.	Batu Arang, near Rawang in central Selangor
4.	Kg. Durian Chondong, near Kepong in northwest Johore
5.	Kluang-Niyor, in central Johore
6.	Layang-Layang, in south Johore
	Likely locality
7.	Lawin, near Grik in north Perak
	Proposed, but untenable localities
8.	Tanjung Rambutan, near Ipoh in central Perak
9.	Merapoh, in north Pahang
10.	Nenering, near Klian Intan in north Perak

INTRODUCTION

There is a lack of literature on the Tertiary sedimentary rocks of inland (or onshore) Peninsular Malaysia; there only having been published an early review by Scrivenor in 1931, and two more comprehensive reviews by Renwick and Rishworth in 1966, and Stauffer in 1973. No other reviews have since been published except for a very brief one by Suntharalingam in 1983. Over the years, however, new geological data has been made available on some of the Tertiary basins, whilst new concepts have been presented and published on the tectonic evolution of the Sundaland craton. As such, this presentation aims to provide an up to date review of all available data on the Tertiary sedimentary strata of inland (or onshore) Peninsular Malaysia (Fig. 1), as well as discuss their evolution with reference to the tectonic history of the Sundaland craton.

Scrivenor (1931), in discussing the post-granitic rocks of Peninsular Malaysia, identified four localities where shales and coals of possibly younger than Miocene age were present (Table 1). In view of the absence of definite palaeontological data, Scrivenor based his age estimation on mainly physical properties of the strata, i.e. high moisture content of the coals, the proximity of impure limestone under coal at Enggor, and the compactness of the shales and their content of a little oil.

Renwick and Rishworth (1966) in their study of the fuel resources of Peninsular Malaysia identified a total of five areas (with a total outcrop area < 256 km^2) where Tertiary sediments with coal deposits were found (Table 2). They noted that these rocks were difficult to date accurately and were of the opinion that even if new Tertiary deposits were

Table 1. Localities of Tertiary sedimentary rocks in Peninsular Malaysia according to Scrivenor (1931).

1.	Bukit Arang, near the Thai border in north Perlis and north Kedah
2.	Enggor, near Kuala Kangsar in central Perak
3.	Batu Arang, near Rawang in central Selangor
4.	Kluang-Niyor, in central Johore

Table 2. Localities of Tertiary sedimentary rocks in Peninsular Malaysia according to Renwick and Rishworth (1966).

1.	Bukit Arang, near the Thai border in north Perlis and north Kedah
2.	Enggor, near Kuala Kangsar in central Perak
3.	Batu Arang, near Rawang in central Selangor
4.	Kampung Durian Chondong, near Kepong in northwest Johore
5.	Kluang-Niyor, in central Johore

Table 3. Localities of known and probable Tertiary sedimentary rocks in Peninsular Malaysia according to Stauffer (1973).

Known localities	
1.	Bukit Arang, near the Thai border in north Perlis and north Kedah
2.	Enggor, near Kuala Kangsar in central Perak
3.	Batu Arang, near Rawang in central Selangor
4.	Kampung Durian Chondong, near Kepong in northwest Johore
5.	Kluang-Niyor, in central Johore
Probable localities	
6.	Lawin, near Grik in north Perak
7.	Tanjung Rambutan, near Ipoh in central Perak
8.	Layang-Layang, in south Johore

discovered in areas not yet mapped, they would not be reliably dated and accurately plotted for some time. They also noted that "it was possible that there were Tertiary beds underlying some of the larger tracts of Pleistocene and Recent alluvium, though the indications obtained from widespread boring for cassiterite" suggested that this was not the case. They concluded that coal prospecting in the Peninsula must be limited to evaluation of the known potentially ligniferous Tertiary localities for the existing palaeontological evidence indicated that most of the "Tertiary beds were laid down in swamps, lakes, estuaries or possibly shallow gulfs". They also concluded that economic coal deposits could not be found in the Quaternary alluvium, though there were several occurrences of seams and veins of brown and black lignite, as well as layers of organic mud or peat, in the alluvial deposits of the Kinta Valley.

Stauffer (1973) in discussing the Cenozoic of Peninsular Malaysia identified a total of eight areas where known and probable Tertiary sediments were to be found in a series of small basins between the Main Range and the west coast (Table 3). He noted that the sediments consisted of partly consolidated gravel and sand, soft, often carbonaceous, shale, low-grade coal seams and rare calcareous shales and limestone, with total thickness in the order of a few hundred feet. He considered these sediments to be mainly, and probably entirely, continental deposits, i.e. lacustrine, paludal and fluvial sediments. He noted that the strata were generally almost flat-lying, though dips of 30° to 40° occurred, with a synclinal or basinal structure being shown in some basins. He also noted that these Tertiary sediments unconformably overlay much older Palaeozoic to early Mesozoic rocks that were generally folded and partly metamorphosed. Stauffer (1973) considered the Tertiary sediments to have been of a more extensive distribution than they presently are, though he doubted that they ever formed a connected sheet. He also pointed out that the nature of the deposits suggested discrete basins of sedimentation and postulated that the scattered basins were "produced by late Tertiary structural adjustments mainly involving faulting and that, although other basins that have been eroded away or lie yet undiscovered may have formed, they probably were always a series of discrete and isolated downwarps, possibly far from the coast but probably low lying".

Suntharalingam (1983) in his paper on the "Cenozoic stratigraphy of Peninsular Malaysia" agreed with the eight localities of Tertiary basins identified by Stauffer (1973) and also briefly discussed the Cenozoic sediments offshore the West and East Coasts of the Peninsula. He considered the onshore Tertiary sediments to be of a Miocene to Pliocene age and noted that they were not localized beneath Quaternary sediments, but more extensive and difficult to differentiate from the Quaternary deposits.

REVIEW OF PROPOSED LOCALITIES WITH TERTIARY ROCKS

Bukit Arang, North Perlis and North Kedah

Small coal seams on the slopes of Bukit Tinggi and Bukit Arang in north Perlis were first reported by Scrivenor (1917) who considered them to be of a Tertiary age by correlation with the coal bearing beds at Batu Arang in Selangor. Between 1919 and 1921, three boreholes were drilled in the area and two coal seams of 0.15 m thick, as well as one of 0.3 m thick, reported in two of the holes. A 0.6 m thick limestone bed was also reported from one of the boreholes which passed through clays with some hard stone (Wilbourn, 1926). A deep borehole in 1941 encountered a total of 8 major bands of stiff clay as well as fragmentary traces of coal from 5 horizons and a definite 0.51 dm thick coal band just before the bottom (Alexander, 1946). Nineteen pits sunk in the general area in 1958 did not reveal any coal, but exposed sequences of loose and semi-consolidated gravels, sands and clays which indicated a further southwestward extension of the deposits (Jones, 1981).

Seventeen boreholes to depths of between 24 m and 85 m, drilled in the late 1970's furthermore, did not reveal the presence of any coal seams. The most recent investigations in the area involving field mapping and the drilling of 3 Bangka drillholes (to a maximum depth of 20 m) as well as 2 rotary boreholes (to a depth of 158 m) have led to the conclusion that the coal potential of these sediments is poor; there only being present thin coal seams (from traces to 0.3 m thick) of limited lateral extent (Aw, 1982).

The Tertiary sediments here underlie an area of rolling terrain some 60 m above sea-level with occasional hummocks rising to 120 m and are surrounded by undulating to hilly terrain developed over shales, siltstones and sandstones of the Late Devonian to Triassic Kubang Pasu Formation (Jones, 1981). Boreholes show the Tertiary sediments to overlie an uneven basement topography developed over the Kubang Pasu Formation, though the presence of limestone in one borehole suggests that the Chuping Formation (time equivalent to the Kubang Pasu Formation) may also be present (Aw, 1982).

Surface mapping and borehole data show the Tertiary sediments to outcrop in the form of two broad, gently northward plunging, basins that cover an area of some 60 km^2 in Perlis and about 15 km^2 in Kedah. The sediments strike either NE or NW with northward dips of 10° to 35° and can be separated into an upper sequence known as the Boulder Bed which unconformably overlies a lower sequence comprising alternate layers of clay and sand, with occasional thin coal seams (Aw, 1982).

The loose to weakly consolidated Boulder Bed, with a total thickness of about 90 m, consists of poorly-sorted gravels and boulders of mainly quartzite and vein quartz as well as occasional hornfels and decomposed granite, in a sandy to clayey matrix with some clay and sand lenses (Jones, 1981). Some of the sand layers are also cemented by secondary iron oxides and hydroxides (Aw, 1982).

The lower sequence has a minimum total thickness of 130 m and consists of mainly soft clay, and sand, layers with a few thin coal seams as well as thin gravel and laterite bands. Authigenic limestone grains of up to 4 mm in size as well as intact and broken, bivalve and gastropod shells are also present, as are framboidal pyrite grains (Aw, 1982).

From the gastropod shells (identified as *Stenothyra* sp. and *Pseudovivipara* sp.), which almost "certainly lived in either fresh water or possibly a brackish, but low salinity, area", a Cenozoic age (likely late Neogene or even Quaternary) has been assigned to these sediments (Aw, 1982). The lower sequence was probably deposited in a lacustrine environment, that was either fresh or brackish; rivers bringing in sediments from areas of clastic rocks, limestone and granite. The upper sequence or Boulder Bed, however, was deposited under fluvial conditions.

To the immediate north, and forming extensions, of the Tertiary basins in north Perlis and Kedah, are found in the Sadao area of Peninsular Thailand, two small Cenozoic basins separated by a ridge of Carboniferous rocks. These basins cover an area of more than 200 km^2 with surface outcrops indicating that they consist of alternating layers of semi-consolidated, gravel, sand and clay, similar to the sediments at Bukit Arang. Five boreholes, drilled across the trends of the basins, show the Cenozoic sequence in the western basin to exceed 300 m thickness and consist of an alternation of semi-consolidated sand and clay with some thin coal seams and thin laminations of lignitic clay. Unconformably overlying these sediments are loose to semi-consolidated gravel beds. The eastern basin, however, is much shallower with an absence of thick sand and clay beds and consists of thick gravel beds unconformably overlying the Carboniferous basement. Correlation of sequences in the boreholes shows that the sediments of this Sadao Basin were deposited in a "transition of fluvial and lacustrine environments with pronounced facies changes" (Chaodumrong *et al.*, 1983). Fragments of gastropods and bivalves have been found in some of the clay beds, though they have not been dated.

Enggor, Central Perak

Coal was first reported from a shallow well in agricultural lot 1701 on the south slope of Sungai Enggor in 1917 and subsequent investigations showed a stratigraphic section some 63 m thick with two 1.22 m thick coal seams (Scrivenor, 1917). In 1925, Enggor Coal Syndicate Ltd. prospected and began mining the area, both by underground and opencast methods. The mine was taken over by Osborne and Chappel in 1927, but closed down in June 1928, with a total output of some 21,533 tons of sub-bituminous coal between the years 1925 and 1927. Two coal seams of limited lateral extent were apparently mined; an upper seam, some 0.75 to 1.8 m thick, of similar quality as the coal mined at Batu Arang and a lower seam, some 0.3 to 1.2 m thick, of poor quality that contained clay partings parallel to bedding. These two seams were separated by a 0.45 m thick oil-bearing shale, whilst the roof of the upper seam was composed of soft shale and necessitated heavy timbering as well as the leaving of large pillars of unworked coal (Renwick and Rishworth, 1966). In 1941, the area was rebored, with a total footage of 537 m in 25 boreholes of which the deepest ended in decomposed granite at 31.6 m. Four of the boreholes did not penetrate the Tertiary strata, whilst six of the boreholes reached coal of varying thickness at varying depths, and the remaining boreholes did not find any coal. At this time, it was considered that there was too little coal left at Enggor to warrant further mining (Renwick and Rishworth, 1966). In summarizing past reports and records, Foo (1990) has noted the stratigraphic succession shown in Table 4.

The strata here are located at an elevation of between 46 m and 76 m above sea-level, though their exact outcrop area is somewhat uncertain, as the most recent work (Foo, 1990) places the area some 2 km further to east than earlier work (Renwick and Rishworth, 1966; Stauffer, 1973). The Enggor Tertiary beds, which have been reported to be dipping 10° towards 330°, unconformably overlie an undulating surface developed over strongly folded, grey to black, carbonaceous shales, siltstones and sandstones of the Devonian to Permian, Salak Baharu Beds (Foo, 1992).

The definite age of the strata is uncertain, though all workers agree on a Tertiary age. Fossil flora in some carbonaceous shales, including both monocot and dicot leaves, show a marked resemblance to present-day flora and do not appear to indicate the presence of a great variety of floral genera (Foo, 1990). Foo (1990) has also correlated these strata with the strata of the other Tertiary Basins of the Peninsula identified by Renwick and Rishworth (1966) and has considered them to represent remnants of Tertiary basins which were probably at one time much more widespread.

Table 4. Stratigraphic succession at Enggor (after Foo, 1990).

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 & calcareous shale — About 9 m thick
Folded Upper Palaeozoic Strata-Salak Baharu Beds

Batu Arang, Selangor

The most intensely studied and best known of the Tertiary deposits is the one at Batu Arang in Selangor where coal was first reported in 1908. Subsequent prospecting between 1909 and 1912, proved the existence of two thick coal seams that extended over an area of about 4.8 km radius; an Upper Seam some 15.3 m thick that dipped about 15° and a Lower Seam, some 7.3 m thick (Renwick and Rishworth, 1966).

Coal mining was started in 1915 and continued till 1960 with both surface and underground methods being employed; the choice of method influenced by demand and the limitations posed by a thick overburden (Mackie, 1938; Roe, 1940). The coal was mined from two main seams that were some 60 m stratigraphically apart; the Upper Seam (about 15 m thick) and the Lower Seam (about 8 m thick). Where the seams outcropped at the surface, they were extracted by open-cast methods, though underground workings were employed when the open-cast methods were not economically feasible. A total of 5 open-cast workings on the Lower Seam, and 8 on the Upper Seam, have operated at various times, whilst 11 underground mines have operated at different times, though only 1 of them was in operation in the late 1950's.

A variety of sedimentary and meta-sedimentary rocks as well as Holocene sediments are found in the area; the Holocene deposits being restricted to the flat-bottomed valley floors of the larger streams. The Tertiary rocks cover about 15 km^2 and are found within an elliptical, trough shaped depression that is surrounded by undulating to hilly terrain developed over meta-sedimentary bedrock. The meta-sediments also unconformably underlie the Tertiary strata and consists of quartzites, schistose quartzites, phyllites and indurated shales with rare cherts of the Lower to Middle Permian, Kenny Hill Formation (Roe, 1951; Mahendran, 1990).

The meta-sedimentary strata generally strike NNW-SSE with very steep to vertical dips and are moderately to strongly jointed with closely spaced joint planes and thin quartz veins of variable orientations (Law, 1961; Raj, 1995). To the southwest, fault breccia, sheared strata and variations in bedding all point to a major NW-SE trending fault that appears to form the southern boundary for the Tertiary basin. No evidence of faulting is, however, seen along the other sides of the basin, though this may be due to weathering and the absence of outcrops in the generally low-lying terrain. Steep dips of Tertiary strata in the northwestern part of the basin furthermore, suggest the presence of a fault there. A gravity survey by Mahendran (1990) shows the Tertiary strata to be located within a half-graben; the basin being delimited to the southwest by the afore-said NW-SE trending fault.

Field mapping and interpretation of borehole logs have allowed the Tertiary strata at Batu Arang to be separated into two sequences; an upper sequence known as the Boulder Beds which unconformably overlies the lower sequence known as the Coal Measures (or Batu Arang Beds) (Roe, 1951; Stauffer, 1973).

Boulder Beds

The Boulder Beds form hilly country within the basin and consist of angular to rounded, pebble to boulder sized clasts of mainly quartzite, sandstone and vein quartz and lesser chert, phyllite, schist and shale, as well as rare coal fragments, embedded in a sandy to gravelly matrix (Law, 1961). The clasts range from 0.07 to 0.7 m in size, though a few are up to 1.7 m in diameter. A few thin beds of sand and sandy clay are also inter-stratified with the gravel beds, whose individual bed thickness can exceed 30 m. The Boulder Beds show variable colours and this, together with differences in the composition and rounding of clasts, has allowed for differentiation of three inter-fingering sequences (Intan, 1998).

The Boulder Beds are horizontal or nearly so in the centre of the basin, though at the edges they show inward dips of 20° to 45° (Law, 1961). The beds rest unconformably on the underlying rocks which are Tertiary shales, sandstones and coal, in the east and north of the basin, but Permian quartzites and phyllites in the south and west. In the southwest furthermore, quartzite conglomerates comprising quartz pebbles in a sandy matrix with abundant secondary iron oxide stains and concretions mark the base of the Boulder beds. The Boulder Beds are more than 300 m thick in the centre of the basin and are cut by several normal faults that are likely to be syn-depositional with throws of only a few feet (Roe, 1951). A number of post-depositional, sinistral wrench faults with displacements of up to 1 m, are also to be seen.

No fossils have been found within the Boulder Beds that were considered by Roe (1951) to be of a Pleistocene age. Raj (1998), however, has suggested that the Boulder Beds are of a likely late Middle Miocene to Pliocene age and deposited, concomitantly with, or following, uplift of the Barisan Mountain Range in Sumatra.

Sedimentary structures, including pebble imbrications and channel fills, show multi-directional palaeo-current flow directions within the Boulder Beds, though a general SW to NE flow direction is indicated by an increase in roundness of clasts, as well as a decrease in their size (Mahendran, 1990). The clasts have all been derived from nearby areas and deposited by alluvial fans in a seasonal, semi-arid to tropical climate through erosion of steep, fault produced slopes (Stauffer, 1973; Batchelor, 1979).

Coal Measures (Batu Arang Beds)

The Coal Measures (or Batu Arang Beds as termed by Stauffer, 1973) underlie the Boulder Beds and consist of the following facies arranged in the stratigraphic order shown (Roe, 1951):

a) Sandstone, with intercalations of shale and clay;
b) Shale;
c) Coal beds, comprising two main coal seams, shale and sandstone; and
d) Sandstone with intercalations of shale, clay and conglomerate.

The Coal Measures have a maximum recorded thickness of 265 m in the centre of the basin, but are only some 183 to 244 m thick along the eastern and western sides where the beds outcrop. The sediments consist mainly of silty to sandy shales that are commonly carbonaceous, structureless clay layers and fine grained sandstones as well as thin beds and lenses of coarser grained sandstones and some lignite seams. In the northern edge of the basin, a semi-consolidated, poorly sorted, pebbly sandstone bed consisting predominantly of angular, pebble sized vein quartz clasts in a fine to medium sand matrix appears to mark the base of the Coal Measures. This pebbly sandstone, which dips some 25° westwards, is more than 10 m thick and unconformably overlies folded, fine to medium grained sandstones and shales that generally strike E-W with moderate to steep dips.

The Coal Measures show a southwestward plunging, synclinal structure, though this is considered to reflect the basin of deposition, rather than tectonic activity (Roe, 1951). The strata show an average dip of 14° towards the centre of the basin, though local variations are common especially towards the NW corner, where the coal seams dip as much as 40° close to the quartzite beds, and in the south where dips of 25° or more are not uncommon (Law, 1961). In the NW corner furthermore, the coal seams appear to be bent or folded for their strike shows a sudden change.

The coal occurs mostly as thin laminae or streaks in dark shales, but also builds thicker layers of more than 30 cm thick. In the eastern part of the basin, two thick coal seams are found as well as some thin beds of coal and coaly shale. The two seams are some 60 m stratigraphically apart; the Upper Seam attaining a thickness of up to 15 m, and the Lower Seam averaging 8 m in thickness. The seams are, however, not laterally extensive; the Lower Seam being restricted to the northern part of the basin and thinning out southwestwards, whilst the Upper Seam similarly thins out and is not seen in boreholes drilled in the centre of the basin (Roe, 1961).

The Coal Measures have yielded thin-shelled, fresh-water gastropods, leaves and leaf impressions which have suggested that these beds are of a probable Upper Miocene or even Pliocene age (Roe, 1951). The plant fossils have also suggested that a drier climate, or higher altitude, than present prevailed at the time of deposition (Scrivenor, 1931).

Pollen analysis has suggested an Late Oligocene to Early Miocene age for the Lower Coal Seam (Mahendran, 1990), though more recent work utilizing palynomorph assemblages, indicates that the coals are of an Eocene to Oligocene age and deposited in a lacustrine environment under somewhat seasonal climatic conditions (Ahmad, 1993).

Scrivenor (1931) considered the coal seams to be "drift-formed" ones that probably developed in swampy lakes within a roughly elliptical shaped depression. Roe (1940) also noted that variations in the beds suggested formation in a lake, with disturbed zones representing channels of rivers that drained the swamps where vegetable matter was accumulating. Renwick and Rishworth (1966) furthermore, pointed out that various features, as shale partings and lenses in the seams, as well as washouts of fine sand and clayey sand, suggested formation of the coal seams through accumulation of drifted vegetation in a fresh-water (or perhaps estuarine) environment.

On the basis of organic petrological and geochemical studies, Wan Hasiah (1997) has interpreted the Coal Seams to be peat-swamp deposits within an alluvial flood plain setting. Shales (with TOC < 20%) were interpreted to be deposited in a freshwater lacustrine setting and carbargillite (TOC 20 to 49%) deposited within smaller ponds or flood basins in the swampy alluvial plain where the peats that formed coals accumulated.

Kampung Durian Chondong, Northwest Johore

In 1934, following the discovery of some oil-shale, a shaft was sunk close to Kampung Durian Chondong and revealed a somewhat broken-up, coal seam, about 0.15 m thick. In 1935, several pits were sunk to various depths in the general area and exposed shales containing plant remains as well as small amounts of oil and some coal. In 1936, Malayan Collieries Ltd. sank a number of deep boreholes, all of which were apparently in rocks of the coal bearing strata and did not pass into more ancient rocks. Apart from a hard, grey, impure limestone, as well as calcareous fossil-shells in shale, it was noted that no coal seams of economic value had yet been found. Volcanic ash was also reported at a depth of 190 m in one borehole; its top dipping at about 6° towards ESE (Renwick and Rishworth, 1966). In 1955, some 29 pits were dug to depths of between 5.8 and 18.0 m to the west of Kampung Durian Chondong with six of them showing coal seams. In 1956, eight pits were dug to depths of between 3.7 and 11.3 m to the northwest of Kampung Durian Chondong and 4 of them showed coal seams of about 1.2 m thick, whilst one showed a seam some 6.4 m thick. Burton (in Renwick and Rishworth, 1966) inspected these pits and reported that although there was thick coal in the area, it was only of a very limited extent. He also noted that the coal bearing strata dipped 20° to 25° towards the west and showed rapid changes in thicknesses. Ulu Muar Ltd. apparently started mining of the coal in the nearby Bukit Serampang area in 1957, though no details of subsequent development are known.

The coal bearing strata here are nowhere exposed at the ground surface for they lie under a cover of soil and alluvium in an gently undulating area located some 15 m above sea-level. Pits and boreholes show sandy alluvium to unconformably overlie the coal bearing strata, though both show a westerly dip of about 20°, with the base of the alluvium being an irregular one that contains coal fragments (Burton, 1964). The coal bearing strata have been mapped as the 'Durian Chondong Formation' by Loganathan (1981) which is described as being layers of sand, silt, clay and volcanic ash with low-quality coal lenses.

Cox (1937) reported that the numerous gastropod fossil shells seen in borehole samples of grey, marly shales, from depths of 26.8 to 44.2 m, were mainly more or less crushed, but sometimes well preserved and even retained traces of their colour-ornamentation. A few obscure plant impressions and some small and indeterminate fish teeth were also reported in the shales. All the shells, with one exception, were of a single species called *Viviparus willbourni*, whose presence proved that the deposit was non-marine and probably of a lacustrine origin. In view of the long range of the genus, however, no distinct date could be assigned to the shales, though the fairly fresh state of preservation of the shells suggested an age not older than Upper Tertiary (Cox, 1937).

Blocks of coal from the nearby Bukit Serampang area were furthermore, found to contain both macroscopic and microscopic plant fossils of Tertiary age (Renwick and Rishworth, 1966). The age of the unconformably overlying alluvium is also not known, though Burton (1964) has suggested an Early Pleistocene or even Pliocene age.

Kluang-Niyor, Central Johore

In 1910, rocks exposed at railway cuttings in the vicinity of Niyor were thought to resemble the Tertiary rocks of Indonesia and prospecting for coal was proposed. In 1929, examination of all cuts along the Kluang-Niyor railway line between mile-posts 413.50 and 418.00 showed exposures of grey and pink, sightly iron-stained alluvium containing many subangular quartz grains at mile-posts 413.25, 415.75 and 417.25. At mile-post 417.75, however, poor quality lignite with a northeastward dip was seen bedded with alluvium, but considered of no economic significance. To the south of Niyor Station, at mile-post 414.25 furthermore, pale grey shales of a compact, fine grained nature containing numerous concretions of similar material were exposed beneath alluvium. These shales dipped northwards at about 20° and were considered to be probably Tertiary in age as they did not show any resemblance to the older sedimentary strata of the Peninsula. In 1930, a borehole drilled by Malayan Collieries Ltd. at the Niyor Station passed through 65.5 m of clays before it was abandoned unbottomed. Two pits sunk to depths of 10.4 and 9.1 m on either side of the cut at the 414.25 mile-post encountered no coal and passed through red mottled, sandy clay, white clay and stony wash. Two other boreholes drilled in 1930 near Kluang Station also did not encounter any coal and passed through some 17.5 m of hard, red mottled, sandy clay, before encountering about 14.3 m of tight, fine sand. A third borehole drilled in a cut near Kluang Station encountered a 0.45 m thick shale containing much fossil vegetation and a little oil at a depth of 10.7 m. A fourth borehole, drilled some 16.8 m south of the third hole, encountered a 2.1 m thick layer of soft coaly material. In 1930, at a new well to the immediate WSW of Kluang Station was exposed 3.1 m of black shale and lignite below a hard, mottled clay of about 6.1 m thick. The black shale and lignite, which dipped about 15° towards 190°, showed a planar top surface, indicating that erosion had occurred before deposition of the clay. In another well in the same area, a lignite seam some 9.1 m thick was encountered at a depth of 5.8 m and overlay clay and sandstone. A borehole drilled some 3.85 km WSW of this well, however, struck 'rock' (granite) at 28.7 m and was stopped at 46.1 m, whilst another borehole, some 0.53 km SSE of the first hole, encountered volcanic rocks at a depth of 38.1 m. Two other boreholes sunk to the southwest and west furthermore, bottomed at 15.2 m on granite and at 37.2 m on quartzite (or tuffs). There are no records of further activity in the area, and it is quite clear from their poor quality and limited extent, that the known lignite deposits area will never prove to be workable (Renwick and Rishworth, 1966).

The Kluang-Niyor area, is a low-lying one mostly between 30 and 75 m above sea-level and as there are only a few natural exposures, the extent of the presumed Tertiary sediments is poorly known. Their reported occurrences, however, range from Niyor south to Kluang (over a distance of about 8 km) and from Kluang to the west and southwest over some 9.5 km. In view of this, and in view of the variable dip directions as well as rapid lateral changes in thickness and depths to older bedrock (granitic and volcanic rocks), it has been suggested that the basin of deposition was probably several kilometres across and was not a simple one (Stauffer, 1973).

Other than unidentified plant fragments, no fossils have been reported from these sediments which are definitely older than the alluvium that unconformably overlies them. The sediments are generally similar to those at Batu Arang and in the other Tertiary Basins of West Malaysia and a similar Late Tertiary age is thus likely (Stauffer, 1973). Burton (1964), however, has mentioned the possibility of a Quaternary age for these sediments, though he considers the unconformably overlying alluvium to be of an Early Pleistocene or even Pliocene age.

Layang-layang, South Johore

Burton (1964) first reported the occurrence of grey to grey-brown partly consolidated clays underneath Quaternary 'Older Alluvium' near Layang-Layang on the railway line to the south of Kluang and considered them to be of a Late Tertiary age by analogy with the stratigraphy at Kluang-Nyior and Kampung Durian Chondong. These sediments, which have been mapped by Rajah (1986) as the Layang-Layang Formation in the Gunung Belumut area, cover an area of about 61 km^2 and have given rise to a low-lying, gently undulating terrain that rises to some 95 m above sea-level. In the adjoining Kluang area to the west, however, equivalent sediments have been mapped as the Older Alluvium of a probable Pleistocene age (Loh, 1980).

The basin in which the Layang-Layang Formation is found is surrounded on all sides by the Middle Triassic Belumut Granite, except to the east where Lower Cretaceous sandstones with minor siltstone, mudstone, shale, and conglomerate, intercalations of the Tebak Formation are found. A gravity survey shows that the Layang-Layang Tertiary Basin has a half-graben structure that is bounded to its northeast by a 'listric normal fault with a minimum throw of 1 km' (Vijayan, 1990).

The Layang-Layang Formation, is generally flat-lying or gently dipping with inclinations of < 15° and has been separated by Rajah (1986) into the Badak Shale Member and the apparently, conformably overlying Pengeli Sand Member. The Badak Shale Member underlies an area of about 8 km^2 and consists essentially of finely laminated, grey to greyish brown and black, clay-shales, that often contain well preserved plant remains, leaves and stems, that are overlain by semi-consolidated to poorly consolidated grey to yellowish brown, sandy clay and clay loam with layers of grey clay and minor orange-yellow clay. The Pengeli Sand Member, which apparently conformably overlies the Badak Shale Member, though no actual contact has been seen, consists of unconsolidated to semi-consolidated, quartzo-feldspathic sands, sandy clay, clayey sand and clay, ranging in colour from white through cream to grey. The Pengeli Sand Member merges into Recent sediments and has been considered by Rajah (1986) to be homologous with the Older Alluvium mapped by Burton (1964) in Johore. The maximum exposed thickness of the Layang-Layang Formation is estimated to be about 95 m, though it could be thicker as its basal boundary was nowhere exposed. The Badak Shale Member was considered by Rajah (1986) to have been deposited in an intermontane or lacustrine basin, whilst the Pengeli Sand Member was deposited in a fluvial to deltaic environment.

The Layang-Layang Formation was considered to be of a probable Pliocene-Pleistocene age by Rajah (1986) in view of Pliocene-Pleistocene plant remains in the Badak Shale member, and possibly middle or late Pleistocene plant leaves in the Pengeli Sand Member. The Pengeli Sand Member, which was mapped as the Older Alluvium by Burton (1964) is of an Early Pleistocene or even Pliocene age. More recent palynological work on mainly greyish mudstones from the Badak Shale Member near Bandar Tenggara shows abundant, well preserved palynomorphs that could have been sourced from a freshwater swamp plant community and thus suggest deposition of the mudstones in a lacustrine environment. The presence of a few index fossils suggests a Miocene age (Ahmad Munif *et al.*, 1994).

Lawin, Upper Perak

Along the Sungai Lawin and Sungai Puchong Babi, to the west of Lawin in Upper Perak, are found a number of exposures of semi-consolidated, inter-stratified sand, grit and pebble beds (Jones, 1970). These sediments underlie an area of some 2.4 km diameter and are also exposed in slope cuts within FELDA Lawin Utara. The sediments underlie the low undulating terrain of a depression at the foot of the Bintang Hills and rest unconformably over Mesozoic granite in the west, but over quartzites and tuffs of the Ordovician to Early Devonian, Baling Group in the east. In the eastern and central parts, the strata dip westwards at 20° to 30°, whilst in the western part, they dip eastwards more steeply at 45°.

A probable thickness of more than 300 m has been estimated for the sediments in view of the basinal structure. The attitudes of the beds are furthermore, thought to be depositional, rather than due to subsequent folding; deposition having occurred in a N-S trending, trough-like basin (Jones, 1970).

The Lawin Basin deposits comprise a sequence of poorly graded sediments ranging through sand, grit, gravel and boulder beds. Much of this material is strongly feldspathic and appears to be essentially of granitic origin, though there are some pebbles and boulders of a red proto-quartzite that outcrops in the vicinity. The sand and grit horizons consist of angular grains of quartz, altered feldspar and occasional flakes of chloritized biotite with a certain amount of silty and ferruginuous material which acts as a bonding agent. Small amounts of detrital cassiterite are also recorded (Jones, 1970).

The strata are semi-consolidated and friable with poorly defined bedding, though current bedding and lateral disconformity of individual horizons are common features. Deposition appears to have taken place in either a fluviatile, deltaic or lacustrine environment, or more likely a combination of these, and there is evidence that certain parts of the sequence accumulated under torrential conditions.

No fossils have been found, though Jones (1970) proposed that deposition occurred during the late-Tertiary or Pleistocene, rather than sub-Recent times, due to the partially consolidated nature of the deposits. Jones (1970) also suggested a possible correlation between the Lawin Basin sediments and the other known occurrences of Late Tertiary rocks in the Peninsula in view of their structural disposition, i.e. the Lawin Basin, the Betong Basin, some 50 km to the north in south Thailand, and the Enggor Basin, some 65 km to the south in Central Perak, all located along an almost straight line parallel to the regional structural elements of the area. These "similarities in lithology and structural disposition, however, do not constitute conclusive proof of contemporaneous deposition, and it is still possible that the Lawin Beds are of Pleistocene age" (Jones, 1970, p. 96).

Tanjung Rambutan, Central Perak

In the Rambutan Ltd. Mine at Tanjung Rambutan, Scrivenor (Scrivenor and Jones, 1919, p. 82) reported the occurrence of a compact and homogenous lignite seam that was of "a marked lenticular shape and seemed to consist of the remains of modern jungle plants. The colour was brown and the woody structure distinctly preserved. This also is the only seam that I have seen likely to be useful as a fuel, but it was very limited in extent". Stauffer (1973, p. 151), however, described this locality as "an occurrence of dipping beds of shale, sand and lignite, unconformably capped by later deposits" and considered them to be of a Late Tertiary age on the basis of pollen analysis that indicated "a Miocene or possibly younger age".

Although there is some confusion over the description, it is more likely that the sediments here are of a Quaternary age, as noted by Renwick and Rishworth (1966). To quote Scrivenor furthermore, "Immediately above the clays and boulder-clays of the Siputeh and Pusing neighbourhood and also elsewhere — e.g., Lahat and Tanjung Rambutan — one frequently finds seams of brown and sometimes black lignite with a great deal of sand and often quantities of fairly well preserved timber. The last seems to indicate that these beds are of recent origin, a probability that is not contradicted by the presence of the lignite ..." (Scrivenor and Jones, 1919, page 82).

Nenering, Upper Perak

In north Perak, along the Kampung Ayer Panas to Kampung Lalang road, is exposed a sequence of moderately dipping (15° to 24°), mudstones and sandstones with minor conglomerates that unconformably overlie steeply dipping to vertical, N-S striking, quartzites of the Silurian, Baling Formation. The unconformity plane dips 20° towards 210° and is cut by an interpreted, normal fault with an estimated throw of 30 m.

The mudstones are brownish to bluish in colour, whilst the medium grained sandstones are lenticular to tabular in shape with minor conglomerate bands. The strata, referred to as the Nenering Beds, have been considered to be of a Tertiary age on the basis of their lithology, degree of consolidation and structures. Field observations and the interpreted fault also indicate that they have suffered some degree of normal faulting after deposition (Ibrahim Abdullah *et al.*, 1991; Teh and Sia, 1991; Teh, 1992).

Lithology, bedding shape and forms as well as sedimentary textures and structures suggest that these sediments were deposited by fast-flowing but short lived (ephermal) streams/gullies on the foot slopes of recently uplifted terrain. Grain and clast composition suggests that the materials making up the sedimentary sequence were derived mainly from erosion of granitic terrain; sedimentary terrain only constituting a minor provenance. Pre-existing northeast-southwest trending faults in the area were active during deposition of the sediments (Ahmad Jantan *et al.*, 1993).

Palynological analyses of some sixty-two samples (mainly dark grey carbonaceous sandstone and shale) from eleven localities along the Kampung Lalang to Kampung Air Panas road and border road, show that the palynomorph assemblage is not comparable with Tertiary or Early Cretaceous palynomorph assemblages. The presence of Aptian-Albian age pollen furthermore, indicates that the Nenering Beds are of a Late Cretaceous age and deposited during a warm climate due to the dominance of fungal spores (Uyop Said and Che Aziz Ali, 1997).

Merapoh, North Pahang

In the Merapoh area of north Pahang, a thin sequence of sedimentary rocks inter-bedded with coal seams and unconformably overlying limestones of the Permo-Triassic, Gua Musang Formation was proposed to be of a Tertiary age in view of its similarity to the known Tertiary beds of the Peninsula. This sequence, termed the Merapoh Tertiary Bed, is only some 4 to 5 m thick and consists of a basal thin bituminous siltstone (< 0.1 m thick) followed by a coal seam of about 2 m thick and a layer of structureless clay of some 0.5 m thick. In places, a thin carbonaceous shale (< 0.05 m thick) occurs between the coal seam and the structureless clay layer, whilst in other places, a smaller coal seam (some 0.12 m thick) occurs above and parallel to the thick coal seam. Unconformably overlying this sequence are alluvial deposits (Old Alluvium) that are some 0.5 m to 10 m thick, with a thick basal layer of gravels and cobbles in a matrix of clay, silt and sand. Occasional lenses of clay, peat and partly lignitised wood fragments are also found within this upper layer. The Merapoh Tertiary Bed has in places slumped into sinkholes

Table 5. Proposed localities of Tertiary sedimentary rocks in Peninsular Malaysia.

Known localities	
1.	Bukit Arang, near the Thai border in north Perlis and north Kedah
2.	Enggor, near Kuala Kangsar in central Perak
3.	Batu Arang, near Rawang in central Selangor
4.	Kampung Durian Chondong, near Kepong in northwest Johore
5.	Kluang-Niyor in central Johore
6.	Layang-Layang, in south Johore
Likely locality	
7.	Lawin, near Grik in north Perak
Proposed, but untenable localities	
8.	Tanjung Rambutan, near Ipoh in central Perak
9.	Merapoh, in north Pahang
10.	Nenering, near Klian Intan in north Perak

in the underlying limestones where occur blocks of coal intermixed chaotically with clay, siltstone, shale and alluvial deposits (Tan and Lim, 1990).

It is to be noted that the strata here have also been considered to be of a Tertiary age by Jones *et al.* (1970), though Stauffer (1973) regards them to be more likely of a Quaternary age in view of the very young appearance of the deposits in the field and the non-diagnostic character of rather poorly preserved plant material.

CORRELATION AMONGST PROPOSED TERTIARY BASINS

From the above review, it is clear that strata of Tertiary age are not found at the proposed localities of Tanjung Rambutan in central Perak, Nenering in north Perak and Merapoh in north Pahang (Table 5). To date therefore, it can be considered that sedimentary rocks of known, or likely, Tertiary age are only to be found at seven localities in the Peninsula (Table 6 and Fig. 1).

When the main geological features of the first seven (known and likely) localities are compared furthermore, several similarities and a few differences are to be seen (Table 6). In all the localities, with the exception of Lawin, are found two sequences of sediments; an upper sequence which unconformably overlies a lower sequence. At Layang-Layang, Kampung Durian Chondong and Kluang-Niyor, the upper sequence consists of Older Alluvium of an Early Pleistocene or even Pliocene age (Burton, 1964), whilst at Enggor, a thin layer of surface wash forms the upper sequence. At Lawin, Batu Arang and Bukit Arang, however, the upper sequence consists of Boulder Beds. Boulder Beds of probably a similar age and origin, have also been reported from the Kinta Valley in Perak, near Kangar Pulai, Kahang and Ulu Choh in south Johore (Burton, 1964) and some inland valleys as Kanching in Selangor (Stauffer, 1973). All these Boulder Beds are of an unknown age, though Raj (1998) has suggested a late Middle Miocene to Pliocene age for the Boulder Beds at Batu Arang by correlation with regional tectonic events. The temporal relationship between the Boulder Beds and the Older Alluvium is also not known, though Burton (1964) has suggested that they are time equivalent strata. Such a temporal relationship is likely in view of the fact that both the Boulder Beds and the Older Alluvium were deposited under semi-arid to seasonal climatic conditions (Batchelor, 1979). Differences in topographic settings could furthermore, account for differences in textures and other features between the Boulder Beds and the Older Alluvium.

The lower sequence, which is not found at Lawin, however, consists of shales, clays and sandstones that show differences in their degree of consolidation as well as variations in thickness of their intercalated coal seams. The strata at Bukit Arang are semi-consolidated at best and contain thin coal seams, whereas the strata at Batu Arang are weakly consolidated to consolidated and contain some thick lignite seams. Lignite seams have also not been reported from the Layang-Layang area, though this is more likely due to the absence of natural exposures and the absence of subsurface investigations. In view of this, it is considered likely that the strata at Layang-Layang are much older than the reported Miocene age (Ahmad Munif *et al.*, 1994) which is based on outcrop samples of younger strata. In all the localities furthermore, the sediments of the lower sequence have been deposited in a lacustrine environment. Strata of the lower sequence also show differences in bedding dips and orientations with the strata at Batu Arang in Selangor and Bukit Arang in Perlis and Kedah forming synclinal basins. Bedding dips are, however, mostly gentle (< 20°), except close to faults.

When the localities of the known and likely Tertiary basins are compared with regional geological structures in the Peninsula furthermore, a interesting relationship is seen with the basins all located close to, or aligned parallel with, major faults; a relationship emphasized by Stauffer (1973).

In the case of the Batu Arang Tertiary Basin,

Table 6. Geological features of known and likely Tertiary basins in inland (onshore) Peninsular Malaysia.

LOCALITY	Bukit Arang, North Perlis & Kedah	Enggor, Central Perak	Batu Arang, Selangor	Kg. Durian Chondong, Northwest Johore	Kluang-Niyor, Central Johore	Layang-Layang, South Johore	Lawin, North Perak
GENERALIZIED STRATIGRAPHY	Boulder Bed uncon-formable over Lower Sequence	Thin layer of surface wash sediments over Coal Bearing Strata	Boulder Beds unconformable over Coal Measures	Alluvium uncon-formable over Lower Sequence	Alluvium uncon-formable over Lower Sequence	Pengeli Sand Member conformable over Badak Shale member	Boulder Beds
DETAILS OF LITHOLOGY & STRATIGRAPHY	**Boulder Bed** • Poorly sorted gravels and boulders in sandy to clayey matrix • Loose to weakly consolidated • About 90 m thick • Deposited under fluvial conditions • Gently dipping towards N • Age not known	**Surface Wash Layer** • Quartzite pebbles in sandy matrix • Unconsolidated • Some 1.2 m thick • Deposited under fluvial conditions • Bedding horizontal • Age not known	**Boulder Beds** • Poorly sorted gravels and boulders in sandy to gravelly matrix • Weakly consolidated to semi-consolidated • At least 300 m thick • Deposited by alluvial fans • Dipping 20 to 45° towards basin centre • Age not known	**Alluvium** • Mainly sand with some clay • Unconsolidated • At least 5 m thick • Deposited under fluvial conditions • Dipping 20° to 25° towards W • Pleistocene (?). Same as Older Alluvium	**Alluvium** • Mainly sand with some clay • Unconsolidated • At least 5 m thick • Deposited under fluvial conditions • Bedding horizontal • Pleistocene (?). Same as Older Alluvium	**Pengeli Sand Member** • Sands, clayey sands and clays • Unconsolidated • At least 3.5 m thick • Deposited fluvial to deltaic environment • Bedding horizontal • Pleistocene (?). Same as Older Alluvium	**Boulder Beds** • Poorly graded, grit, sand and pebble beds • Weakly consolidated to semi-consolidated • At least 300 m thick • Deposited by alluvial fans • Dipping 20 to 45° towards basin centre • Same age as Boulder Beds at Batu Arang
	Lower Sequence • Layers of clay and sand, with or without thin coal seams • Weakly consolidated to semi-consolidated • Minimum thickness of 130 m • Strike NE or NW with dips of 10° to 35° towards N • Deposited in lacustrine environment • Late Neogene or Quaternary age	**Coal Bearing Strata** • Shales, sandstones and clays with some lignite seams • Weakly consolidated to semi-consolidated • Maximum known thickness of 63 m • Reported dipping 10° towards NW • Same age as Coal Measures of B. Arang	**Coal Measures** • Shales, sandstones and clays with some lignite seams • Weakly consolidated to consolidated • Maximum known thickness of 265 m • Strike E-W to N-S with dips of 10° to 40° towards S and W • Deposited in lacustrine environment • Eocene to Oligocene	**Lower Sequence** • Shales, volcanic ash and clays with some lignite seams • Weakly consolidated to semi-consolidated • Maximum known thickness of 195 m • Dipping 20° to 25° towards W • Deposited in lacustrine environment • Late Tertiary	**Lower Sequence** • Shales and clays with some lignite seams • Weakly consolidated to semi-consolidated • Maximum known thickness of 67 m • Dipping 6° to 20° towards N & S • Late Tertiary	**Badak Shale Member** • Mudstones and clay-shales • Weakly consolidated to semi-consolidated • Maximum exposed thickness of 95 m • Dips of < 15° • Deposited in lacustrine environment • Miocene - Likely to be older	
COAL SEAMS	Thin lignite seams of limited lateral extent	One 1 m thick lignite seam and another of poor quality 1.5 m thick	Two thick coal seams • Upper Seam 15 m • Lower Seam 8 m Sub-bituminous to Lignite	A few lignite seams of limited lateral extent; one up to 6 m thick	A few lignite seams of limited lateral extent, one up to 10 m thick	No lignite seams seen or reported, but likely to be found at depth	Total absence of lignite seams

Raj (1998) has proposed that it developed as a half-graben basin due to sinistral displacements along two NW-SE trending faults. Faults of similar trends are seen close to, or aligned parallel with, the other likely Tertiary basins. For instance, at Layang-Layang, there is the NW-SE trending Pengeli Fault, which may form in part the eastern boundary for the Tertiary sediments there. When the Pengeli Fault is extended northwestwards furthermore, it passes through the Tertiary sediments of the Kluang-Niyor area, though no such fault has been mapped (Loh, 1980). Such an extension of the Pengeli fault is, however, strongly indicated by the NW-SE linear trends of some large rivers in the Kluang area. A southeastward extension of the NW-SE trending Bukit Tinggi Fault Zone that cuts through the Main Range of Peninsula Malaysia will furthermore, pass close to the Tertiary strata at Kampung Durian Chondong where NW-SE trending faults have been mapped by Loganathan (1981).

The Lawin Tertiary basin is also located close to the approximately NW-SE trending Bok Bak Fault Zone (Jones, 1970), whilst the Tertiary sediments at Enggor are aligned with approximately NW-SE trending faults that occur in the Main Range and in the Taiping area (Foo, 1990). The Bukit Arang Basin, however, trends N-S and does not appear to be related to any NW-SE trending faults, though faults have been mapped in neighbouring areas (Jones, 1981).

TECTONIC EVOLUTION OF TERTIARY BASINS

The tectonic evolution of the Tertiary Basins has not been discussed by most workers, though Scrivenor and Jones (1919) suggested that the Tertiary sediments at Batu Arang were deposited in a fault controlled basin. Stauffer (1973) furthermore, pointed out that rapid lateral wedging of the deposits at Batu Arang argued for local down-warping at the time of deposition and that in fact controlled deposition. Stauffer (1973) thus postulated that the Tertiary Basins of the Peninsula were produced by Late Tertiary structural adjustments mainly involving faulting as several of them are located on the trends of major structural discontinuities. Raj *et al.* (1989) enlarged on the postulation of Stauffer and proposed that sinistral displacements along NW-SE trending faults were initially responsible for formation of the Tertiary basins as 'pull apart' basins; later normal faulting resulting in deposition of the Boulder Beds in some basins.

In terms of regional tectonic evolutions, it is pertinent to note that in Sumatra, on the SW margin of Sundaland, there are found several sub-parallel, approximately N-S aligned, Palaeogene grabens and half-grabens. These grabens and half-grabens are separated by basement highs into five groups of basins known (from north to south) as the North, Central and South Sumatra Basins, the offshore Southeast Sumatra (Sunda) Basin and the Northwest Java Basin. The grabens and half-grabens, which are all now infilled with any remaining surface expression largely obscured by recent sediments and/or recent movements (Moulds, 1989), have been widely considered to have developed during the Late Eocene to Early Oligocene in response to 'back-arc extension'. The extensional tectonic setting required for development of the basins being differences in subduction rates along the Sumatra Trench as a result of India colliding with Eurasia (Davies, 1984; Daly *et al.*, 1987). Hutchison (1993), however, has suggested that the southwestern continental margin of the Eurasia Plate was progressively oroclinally bent into its present configuration since 55 Ma; the outer *extrados* western zone having experienced considerable stretching and pull-apart leading to the Sumatran Tertiary Basins.

In a related paper (Raj, 1998) has proposed that sinistral movements along pre-existing NW-SE trending faults led to a 'pull-apart', half graben structure in the Batu Arang area during the Late Eocene to Early Oligocene; the basin filling in with the sediments mapped as the Coal Measures (or Batu Arang Beds). In the light of more recent published work (Huchon *et al.*, 1994), the extensional tectonic setting required for the displacements is likely to result from the E-W orientated maximum horizontal component of the regional stress field that developed when the Indian and Eurasian Plates collided at about 50 Ma. Continued northward movement of the Indian Plate led to a progressive, clockwise rotation of Peninsular Malaysia, and of the regional stress field (Huchon *et al.*, 1994) resulting in mild folding and uplift of the Coal Measures during the late Early Oligocene. During the late Middle Miocene, concomitant with, or following, uplift of the Barisan Mountain Range in Sumatra, there developed an extensional tectonic setting at Batu Arang which led to uplift of surrounding areas, and the creation of steep scarps. Rapid erosion of the uplifted areas and scarps led to deposition of the Boulder Beds in a subsiding basin with syn-depositional faulting during the Late Miocene to Pliocene. A compressional tectonic setting during the Pliocene, associated with rifting in the Andaman Sea, then led to minor wrench faulting and possible warping of all the Tertiary strata at Batu Arang. During the Late Pliocene and Quaternary, there was isostatic uplift of the Tertiary strata with subsequent erosion and development of the present-day topography.

A similar evolutionary history is also envisaged for the other Tertiary basins, particularly when it is considered that they are also all located close to, or aligned with, similar NW-SE trending faults. There will, however, be some differences that reflect local environmental and tectonic controls, as the presence of Boulder Beds or Older Alluvium.

CONCLUSION

On the basis of the above review and discussion, it is concluded that sedimentary strata of Tertiary age are presently only found at seven localities in Peninsular Malaysia, all of them located on the West Coast. In view of the relationship between these localities and NW-SE trending faults, it is concluded that the sediments were deposited in individual, discrete basins and never formed a continuous sheet. It is also concluded that as yet undiscovered Tertiary Basins (if any) will only be found on the West Coast close to, or aligned with, major NW-SE trending faults.

It is also concluded that the Tertiary strata were deposited in pull-apart basins that developed during the Late Eocene to Early Oligocene as a result of sinistral displacements along pre-existing NW-SE trending faults. During the late Middle Miocene to Pliocene, concomitant with, or following, uplift of the Barisan Mountain Range in Sumatra, there occurred normal faulting and deposition of Boulder Beds at Bukit Arang, Batu Arang and Lawin. At about the same time and extending into Early Pleistocene, occurred deposition of Older Alluvium in Kg. Durian Chondong, Kluang-Niyor and Layang-Layang areas. Rifting in the Andaman Sea during the Pliocene to Pleistocene has led to minor faulting in some of the Tertiary basins.

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