

Timing of Cenozoic basin formation in northern Sundaland, Southeast Asia

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Abstract: Continental wrench shear basins and back-arc basins are developed on the present stable northern Sundaland. Different basin geometries and structural patterns among Cenozoic basins in northern Sundaland indicate different origins and/or timing of basin formation. Wrench faulting has played a significant role in the formation of these Cenozoic basins. The collision of the Indian Subplate with the Eurasian Plate during early Cenozoic has caused a redistribution of stress within this region. Zones of weakness have been reactivated or created by these stress field changes, thus initiating the subsidence of these basins. The episodic initiation of Cenozoic basins may have begun as early as Jurassic and continued in Eocene-early Oligocene and Late Miocene.

INTRODUCTION

Tjia (1991) defined Sundaland as a geological designation for a semi-cratonic region of the southern South China Sea and the Java Sea. This geological province includes the land areas of the Thai-Malay Peninsula, a narrow strip of eastern Sumatra, the tin islands and a triangular patch of Borneo enclosing West Kalimantan and western-most Sarawak (Fig. 1 insert). This area was cratonised in Late Triassic (Hutchison, 1989). In this paper, the study area of northern Sundaland extends from the Strait of Malacca in the west to the hingeline of the Malay Basin in the east. The northern and southern boundaries of the study area are near latitudes 7°N and 1°N respectively (Fig. 1).

Tertiary basins of different geometries and structural patterns have been mapped in this region. Most of the Tertiary basins in the study area are half grabens or small depressions aligned to major fault zones. The kinematics and timing of the formation of these basins are relatively unknown. Hence, the purpose of this paper is to investigate the possible kinematics and timing of Cenozoic basins formation within the study area in northern Sundaland.

STRATIGRAPHY

Cenozoic sedimentation of the basins/depressions began from ?Jura-Cretaceous to Upper Oligocene (Fig. 2). The stratigraphic schemes of offshore basins in northern Sundaland are well documented by oil companies operating in these

areas whereas those onshore have not been studied in-depth. Based on the sedimentation history, the study area is divided into three areas: Strait of Malacca, Peninsular Malaysia and west-central Malay Basin.

Stratigraphic schemes (Fig. 2) utilised by the operator in the Strait of Malacca are similar to those of the North Sumatra Basin (for PM 1) and the Central Sumatra Basin (for PM 15). It is believed that sedimentation within both blocks is related to these greater basins. The Tertiary basement is interpreted to be Upper Oligocene. Tertiary sedimentation in PM 1 (north western margin area) began in a terrestrial environment with lacustrine to lagoonal rich shales (Bampo formation). Holomarine to inner neritic conditions (Belumai formation) were established during Lower Miocene with carbonate reefs buildup on existing structural highs. Influx of coarse clastics in the middle Miocene marked the deposition of the Baong formation. The top of Baong formation is the Upper Miocene unconformity. Regional transgression has resulted in Post Baong sedimentation within a shallow marine environment (Murray, 1991). Within PM 15 grabens, three major stratigraphic sequences are identified: (1) Early graben fill which comprises lacustrine sediments (Pematang equivalent) (2) middle to late graben fill of fluviolacustrine deltaic sediments (Sihapas equivalent) and, (3) post graben fill (Petani/Minas equivalent) with sediments of marine influence. They are separated by unconformities (Wong, 1990, 1991).

The stratigraphic scheme of Tertiary basins on Peninsular Malaysia has not been established. These basins have been mapped by the Geological

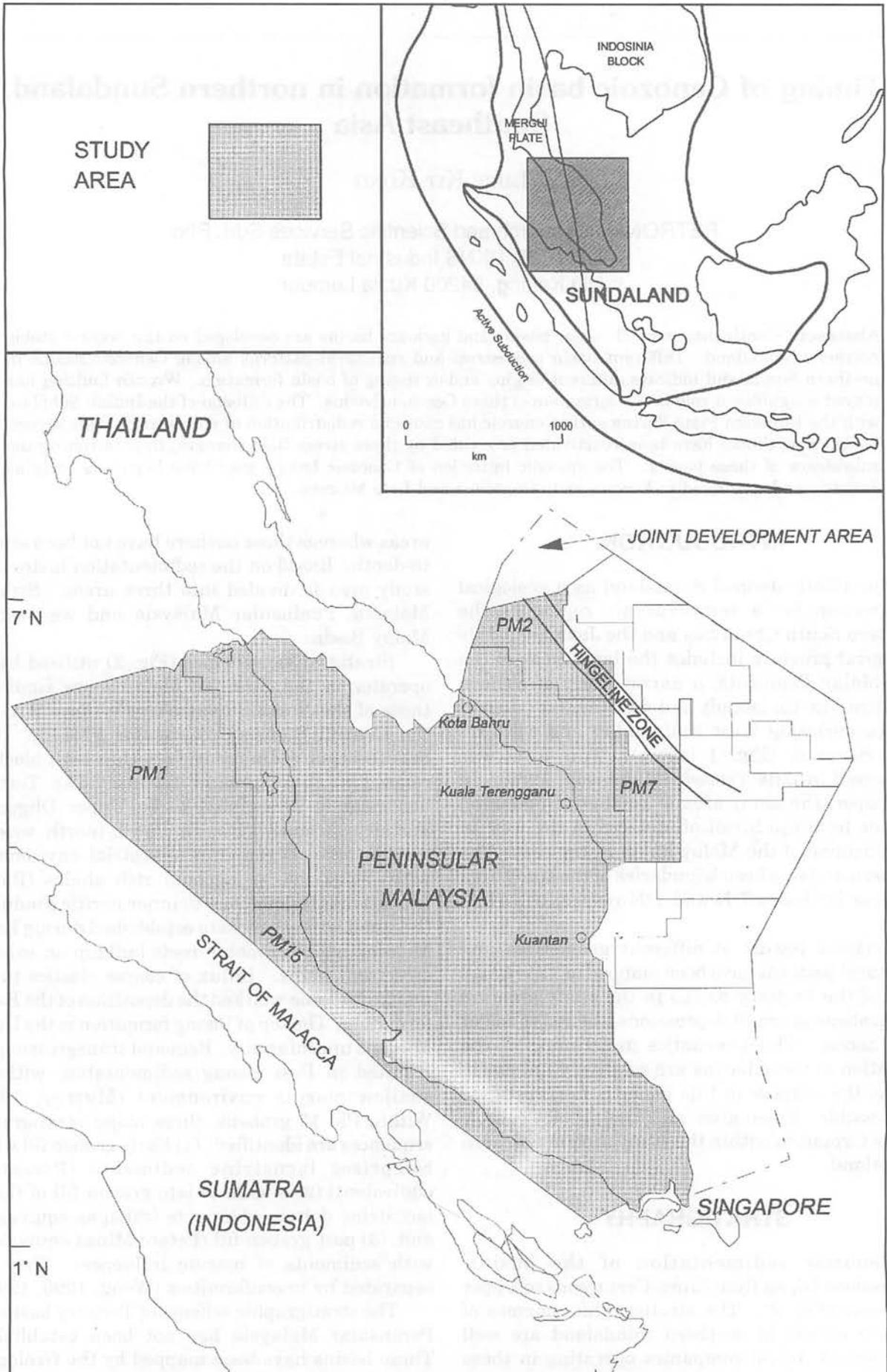


Figure 1. Location of the study area. Inset is the area of Sundaland (Adapted from Tjia, 1991). Pre-Cenozoic tectonics domains of Sundaland consists of Mergui Plate and Indosinia Block.

M.Y	AGE	WEST STRAIT OF MALACCA				PENINSULAR MALAYSIA	EAST		
		PM 1		PM 15			WEST-CENTRAL MALAY BASIN		
		Formation	Sedimentary Environments	Formation	Sedimentary Environments		Sedimentary Environments	Seismic Sequence	Sedimentary Environments
10	Pleistocene	Post Baong	Coastal to Inner neritic	Minas Equivalent	Shallow marine to Lower coastal plains	T E R R E S T R I A L	4	Holomarine	
	Pliocene		Middle neritic	Petani Equivalent	Lacustrine to Fluvio-Deltaic				
			Inner-neritic						
	Miocene	Upper	Baong	Coastal to Inner neritic	Sihapas Equivalent		RED	Littoral	
		Middle		Coastal to Inner neritic			GREEN 2C Local	Coastal Plain	
		Lower	Belumai	Holomarine Inner neritic	Pematang Equivalent		YELLOW 2B	Lower Coastal Plain	
	30	Oligocene	Upper	Continental at the base and marine towards the top	Pematang Equivalent		Lacustrine	ORANGE	Upper Coastal Plain
			Lower	Parapat				PURPLE 1B	
	40	Eocene	Tampur	Uncertain	Basement (Undifferentiated)		Basement (Undifferentiated)	1A	Alluvial Plain
								Pre-Oligocene rift infill (possibly Cretaceous)	
60	Paleocene	Basement (Undifferentiated)	Basement (Undifferentiated)	Basement (Undifferentiated)	Basement (Undifferentiated)	Basement (Undifferentiated)	Basement (Undifferentiated)		

Figure 2. Generalised stratigraphic schemes of the study area. Compiled from Murray (1991), Wong (1991), and Lasmo Oil (1990).

Survey of Malaysia. These Tertiary deposits appear to be fully continental; they show facies association of lacustrine, paludal and fluvial origin. Geological Survey of Malaysia (1985) interpreted these basins as isolated continental basin deposits of Late Tertiary age (?Late Miocene). Recent study on the Tertiary palynomorphs of Batu Arang suggested that the initiation of Batu Arang basin is probably Eocene to Oligocene (Ahmad Munif, 1993). Stauffer (1973) concluded that the nature of the continental deposits suggested that each basin has a discrete sedimentation history. The rapid lateral wedging of the deposits, e.g. Batu Arang, indicated that local downwarp controlled deposition.

A joint regional study by Petronas, Lasmo and Carigali on the northwest Malay Basin has proposed a new stratigraphic system for the area (Lasmo Oil, 1990). This system is based on seismic sequence stratigraphy (Fig. 2). Seismic sequence 1 (Purple to Basement isochron: ?Lower Oligocene to Middle Upper Oligocene) is divided into two parasequences separated by a local angular unconformity. Sediments of this sequence were laid down under alluvial to upper coastal plain conditions. Seismic sequence 2 (Green to Purple isochron: mid Upper Oligocene to lower Middle Miocene) is divided into three subsequences: Subsequence 2A was deposited under lower coastal plain conditions with alluvial plain dominated by braided and meandering channels. Subsequence 2B indicated the onset of coastal conditions and subsequence 2C recorded the onset of marine conditions. Seismic sequence 3 (Red to Green isochron: lower Middle Miocene to Upper Miocene) was deposited under predominantly lower coastal plain conditions (low energy estuarine conditions) with widespread coastal swamp dominated by mangrove and a network of low sinuosity distributary channel. Coastal conditions are prevalent at the base of Seismic sequence 4 (above Red horizon; ?Upper Miocene to present) with progressively more marine conditions up section. Localised channelling appeared in this sequence.

GRABENS IN THE STRAIT OF MALACCA

Within the basement of the Strait of Malacca, northerly trending grabens have been mapped at discrete locations. These grabens can be grouped into (1) Bengkalis Trough related grabens, (2) Pematang-Balam Trough related grabens, (3) Asahan Arch-Kepulauan Aruah Nose related grabens, and (4) Tamiang-Yang Besar High related grabens. These northerly trending graben groupings are situated between regional highs (Fig. 3). The maximum depth of these grabens range from 2,700 ft to 13,000 ft (Table 1).

Bengkalis Trough related grabens include Johor Graben and Kukup Graben. These grabens are situated about 60 km east of the N-S trending Bengkalis Trough. Both grabens are aligned in the NNE direction. Tjia (1988,1989a) suggested that in late Cretaceous-early Tertiary time, the Bengkalis segment of the Bentong-Bengkalis suture experienced normal faulting that created the depression. Lateral faulting occurred in the Oligocene(?) and the Miocene. Pleistocene NW striking reverse faults have superimposed upon earlier trends. Wong (1990) believed that the Johor Graben is genetically related to the Bengkalis Trough in Central Sumatra. This graben could have developed as a side graben of Bengkalis Depression (Moulds, 1989).

Pematang-Balam Trough related grabens are Port Klang Graben, Angsa Graben and Sabak Graben. These grabens are situated north of the N-S trending Balam Trough and Pematang Trough and could be the northern ?extension of the Troughs. Kepulauan Aruah Nose is situated west of these grabens. These grabens are aligned in a NNW direction. Port Klang Graben and Sabak Graben are northerly elongated grabens whilst Angsa Graben which is situated between these two grabens is oval in shape.

Grabens located between the Asahan Arch and the Kepulauan Aruah Nose are Central Grabens, Southern Graben, Eastern Graben, West Penang Graben, North Penang Graben and East Penang Graben. Collectively, these grabens are aligned in the NNE direction. Major bounding faults for these grabens are situated on the western margin of these grabens (except Central Graben).

Grabens that are situated north of the N-S Tamiang and Yang Besar High are Northern Graben, MSS-XA Graben, Thai Border East and Thai Border West. The Northern and MSS-XA Graben which are situated on the southern part of this graben grouping are aligned in NNE direction. Thai Border West and Thai Border East are aligned in N-S direction. There is no preferred sloping direction of these grabens.

The Asahan Arch is a northerly trending regional high that separates the North Sumatra Basin from the Central Sumatra Basin (Fig. 3). This arch probably extends to the west of Central Graben. Based on sediment fill within the grabens, Murray (1991) interpreted that grabens east of the Asahan Arch are associated with Central Sumatra Basin and those west of the arch are associated with North Sumatra Basin. In this paper, Northern Graben and Port Klang Graben are used as representative for North Central Basin and Central Sumatra Basin respectively.

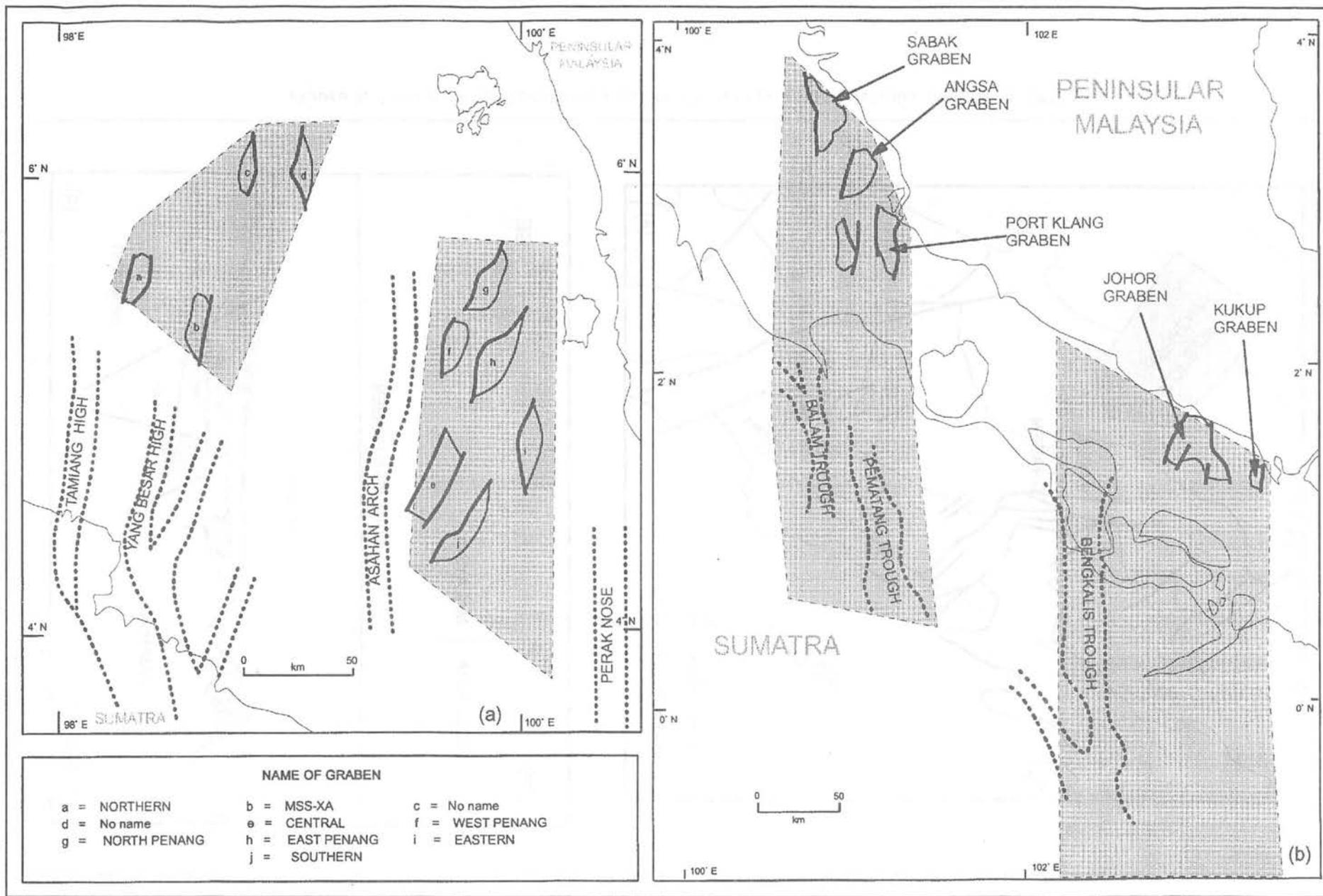


Figure 3. (a) Location of graben groupings with regional elements. Note the orientation of graben groupings with regional elements. Modified from Sosromihardjo (1988) and Dyer *et al.* (1991). (b) Location of graben groupings with regional elements. Note the alignment of the Balam-Pematang Trough related grabens with both Troughs. Johor Graben and Kukup are east of the Bengkalis.

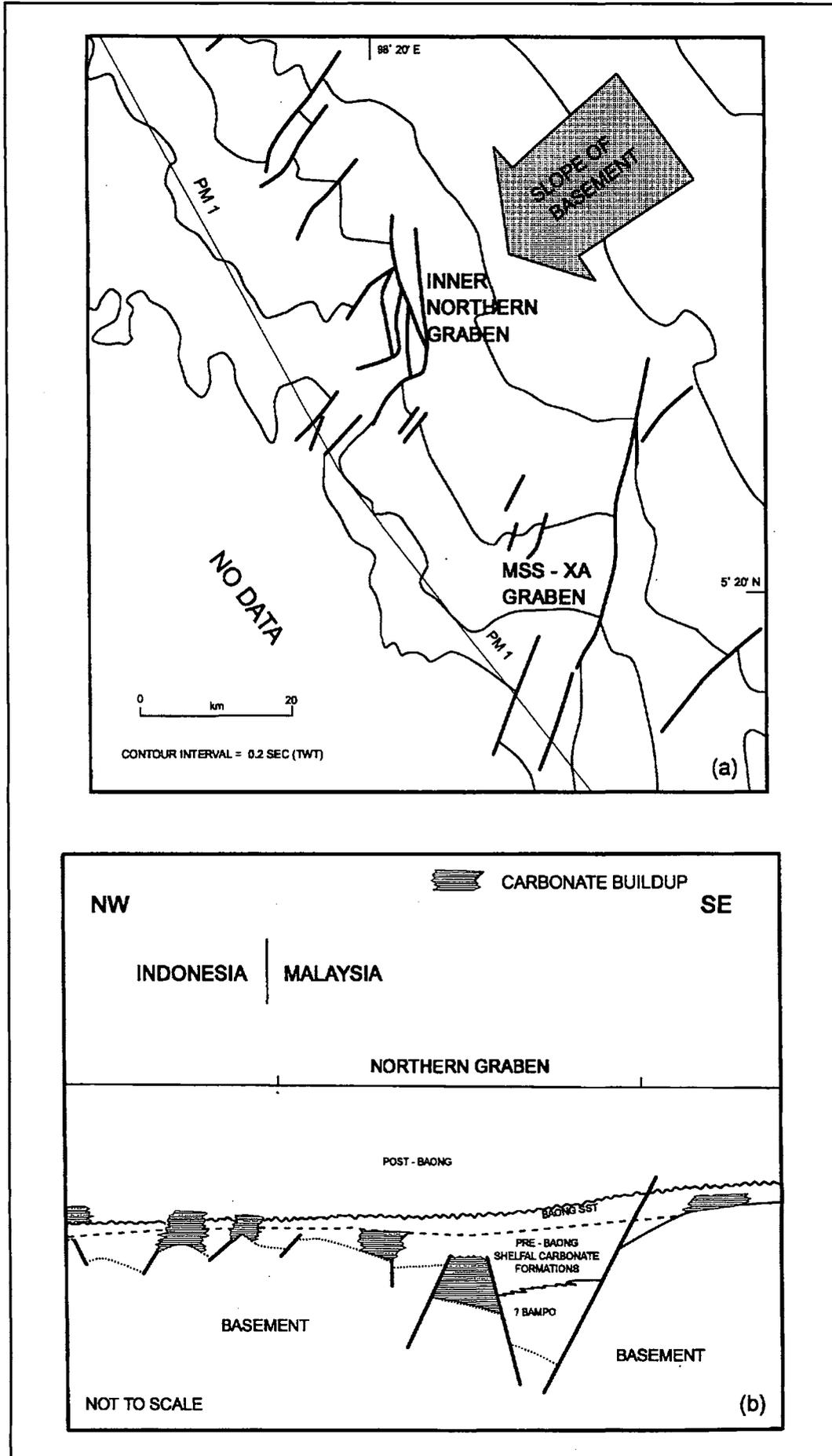


Figure 4. Location of Northern Graben and its schematic geosection. Adapted from Wong (1990).

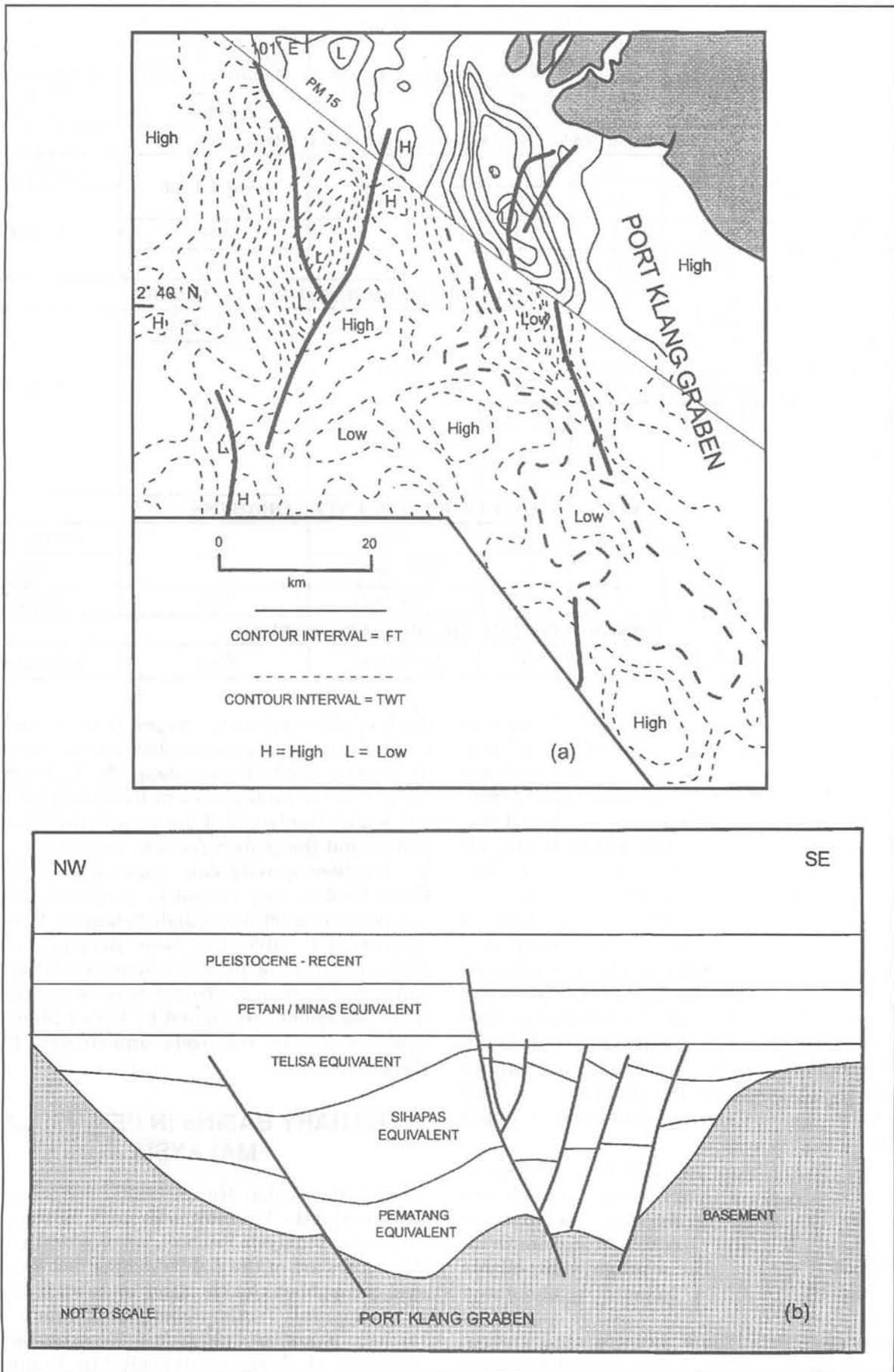


Figure 5. Location of Port Klang Graben and its schematic geosection. Adapted from Wong (1991).

Table 1. Summary of the geometry of the grabens/depressions in the Strait of Malacca (Malaysian waters).

GRABEN	DEPTH (maximum)	SIZE (approx.)		ORIENTATION	Location of Major Bounding Fault Relative to Graben	ELONGATION of Graben
		Length (km)	Breadth (km)			
TAMANG-YANG BESAR HIGH RELATED GRABENS						
Northern	8,100 ft	20	10	NNE-SSW	West & East	?Curvilinear
MSS-XA	8,500 ft	40	15	NE-SW		Linear
No Name 1	2,700 ft	30	10	N-S	West	
No Name 2	3,700 ft	30	10		East	
ASAHAN ARCH-KEPULAUAN ARUAH NOSE RELATED GRABENS						
Central	13,000 ft	60	20	NE-SW	West & East	Linear
North Penang	9,400 ft	35	12		West	
East Penang	4,600 ft	55	16			
Southern	7,600 ft	50	20			
Eastern	3,200 ft	35	10	N-S	West	
West Penang	2,600 ft	20	8			
PERMATANG-BALAM TROUGH RELATED GRABENS						
Sabak	8,000 ft	35	15	N-S	West	Curvilinear
Angsa	12,000 ft	25	25	NNE-SSW		Oval
Port Klang	12,000 ft	80	15	NNW-SSE	East	Linear
BENGKALIS TROUGH RELATED GRABENS						
Johor	11,000 ft	15	10	NNE-SSW	East	?Curvilinear

The NNE elongated Northern Graben is situated near the western margin of PM 1 Block and near the Malaysia/Indonesia international boundary. Basement contour deepens towards SW. Faults mapped in this graben trend north and NE, and are interconnected. Most major faults are located on the eastern flank of this graben. The size of this graben is estimated to be 20 km x 10 km. The maximum depth of this graben is 8,100 ft (Fig. 4). Cross section shows that the basement of this graben generally tilts towards southeast. Structural overprint on the basement topography is evidenced by the presence of a number of fault blocks within the grabens. Carbonate buildups are found on local highs within the graben. Unconformity is above the Boang Sandstone. This shows that structural modification peaks at Upper Miocene.

The NNW-SSE elongated Port Klang Graben is situated southwest of Pulau Lumut. The axis of this graben extended across the Malaysia/Indonesia international boundary, reaching a length of approximately 80 km. The average width of this graben is 15 km. The NNW-SSE elongated depocentre is approximately 12,000 ft deep. N-S faults have transacted the depocentre of this graben. Normal faults have been mapped on the eastern and western flanks of the graben. The eastern

flank of this graben is steeper than the western flank. Higher curvature is observed on contours of the western flank of the graben. The high linearity of the contour on the eastern flank suggest that a major fault has bounded the eastern margin of this graben and the graben deepens towards east (Fig. 5). Offshore gravity data suggest that the Port Klang Graben may extend in northeast direction into the islands offshore Kuala Selangor. Basement topography is altered by later structural events. Wrench faulting with flower structure is observed in this graben (Fig. 5). This structural modification of the basement terminated by Upper Miocene as indicated by the relatively undisturbed Petani/Minas sediment.

TERTIARY BASINS IN PENINSULAR MALAYSIA

Tjia and Zaiton Harun (1985) suggested that by the end of the Mesozoic or in early Tertiary time, Peninsular Malaysia has become tectonically stable. The main part of the country remained above sea level throughout the Cenozoic and small outcrops of continental Tertiary sediments mark minor basins. Stauffer (1973) has summarised the existence of Tertiary deposits in Peninsular Malaysia. The Tertiary deposits (Fig. 6) known at

that time include Bukit Arang-Betong, Enggor, Batu Arang, Kepong and Kluang-Nyior. The other probable sites are Lawin, Tanjung Rambutan and Layang-Layang. Recently, Tertiary basins are identified in Pengkalan Hulu, Perak (Nenering Tertiary Basin; Ibrahim *et al.* (1991), Teh and Sia (1991), Teh (1992), Teh and Rushdan (1994) and Che Aziz Ali *et al.* (1994)) and Lenggong, Perak (Lenggong Tertiary Basin; Teh and Rushdan, 1994.). Generally, these small Tertiary deposits are situated on the western side of the Peninsula, and most are less than 50 km from the Strait of Malacca. Coincidentally, these basins (except Layang-Layang) lie on the west side of Peninsular drainage divide (Tjia, 1973). The Tertiary sediments have been interpreted to be more extensive than now as dipping beds are truncated at the surface or along an unconformity. Tertiary grabens in the Strait of Malacca have been mapped to extend onto the west

coast of Peninsular Malaysia by Sun Malaysia Petroleum Co.

The geological map of Peninsular Malaysia (Geological Survey of Malaysia, 1985) indicates six Tertiary basins. These mapped Tertiary basins are Bukit Arang, Lawin, Batu Arang, Kepong, Kluang-Nyior and Layang-Layang. Tanjung Rambutan Tertiary basin which was postulated by Stauffer (1973) is not in this map. These mapped basins are oval/elliptic in shape. The preferred elongated directions of these basins are north-south (Lawin, Batu Arang and Kluang-Nyior), east-west (?Bukit Arang, Enggor and Layang-Layang) and NW-SE (Kepong). They consist of shale, sandstone, conglomerate and minor coal seams. The larger Tertiary basins are Layang-Layang and Bukit Arang (Table 2). These basins are interpreted to be isolated continental basin deposits of Late Tertiary age (Geological Survey of Malaysia, 1985). Tertiary basins have undergone only mild structural deformation. It is postulated that the scattered Tertiary basins were produced by ?late Tertiary structural adjustments mainly involving faulting. Gobbett (1973) has postulated that some of the Tertiary basins are aligned with the major faults. Enggor, Batu Arang and Kepong are located on the trends of major structural lineaments (Stauffer, 1973).

Two Tertiary basins will be discussed in this paper, namely Batu Arang and Layang-Layang Tertiary basins. The age of these basins have been determined palynologically (Ahmad Munif, 1993; Ahmad Munif *et al.*, 1994). Ages of other basins are still doubtful as paleontological evidence is lacking. Most of these basins are inferred as Tertiary based on their lithological similarity with the Batu Arang Basin (Foo, 1990).

As shown in the geological map of Peninsular Malaysia, the north-south elongated Batu Arang Tertiary basin is surrounded by Carboniferous rocks (southwest), Silurian-Ordovician rocks (east) and Devonian rocks (north). Stauffer (1973) indicated that the age of this deposit is Late Tertiary (?Upper Miocene). Recent palynological study by Ahmad Munif (1993) indicated that the age of this deposit is Eocene. The coal bearing sequence of this basin consists mainly of clay and shale, commonly carbonaceous, and fine-grained sandstone. There are also beds and lenses of coarse sandstone and conglomerate and lignite seams. Depositional environment is interpreted to be fluvio-lacustrine (Mahendran *et al.*, 1991).

Wong (1991) mapped Batu Arang basin as a NE-SW elongated basin with a major NW-trending normal fault delineating the SW boundary of the basin (Fig. 7). Basin deepens towards SW. Deposition in this basin began with fanlomerate

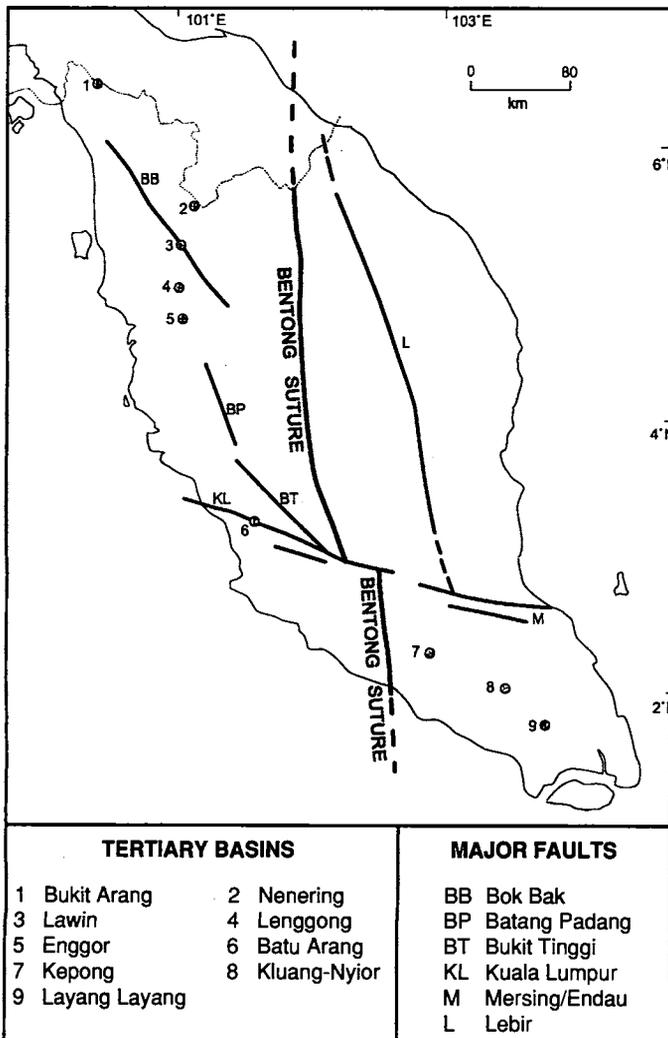


Figure 6. Location of Tertiary basins and major faults in Peninsular Malaysia. Major faults after Tjia (1972,1989b). Tertiary basins adapted from Geological map of Malaysia, 8th edition, 1985.

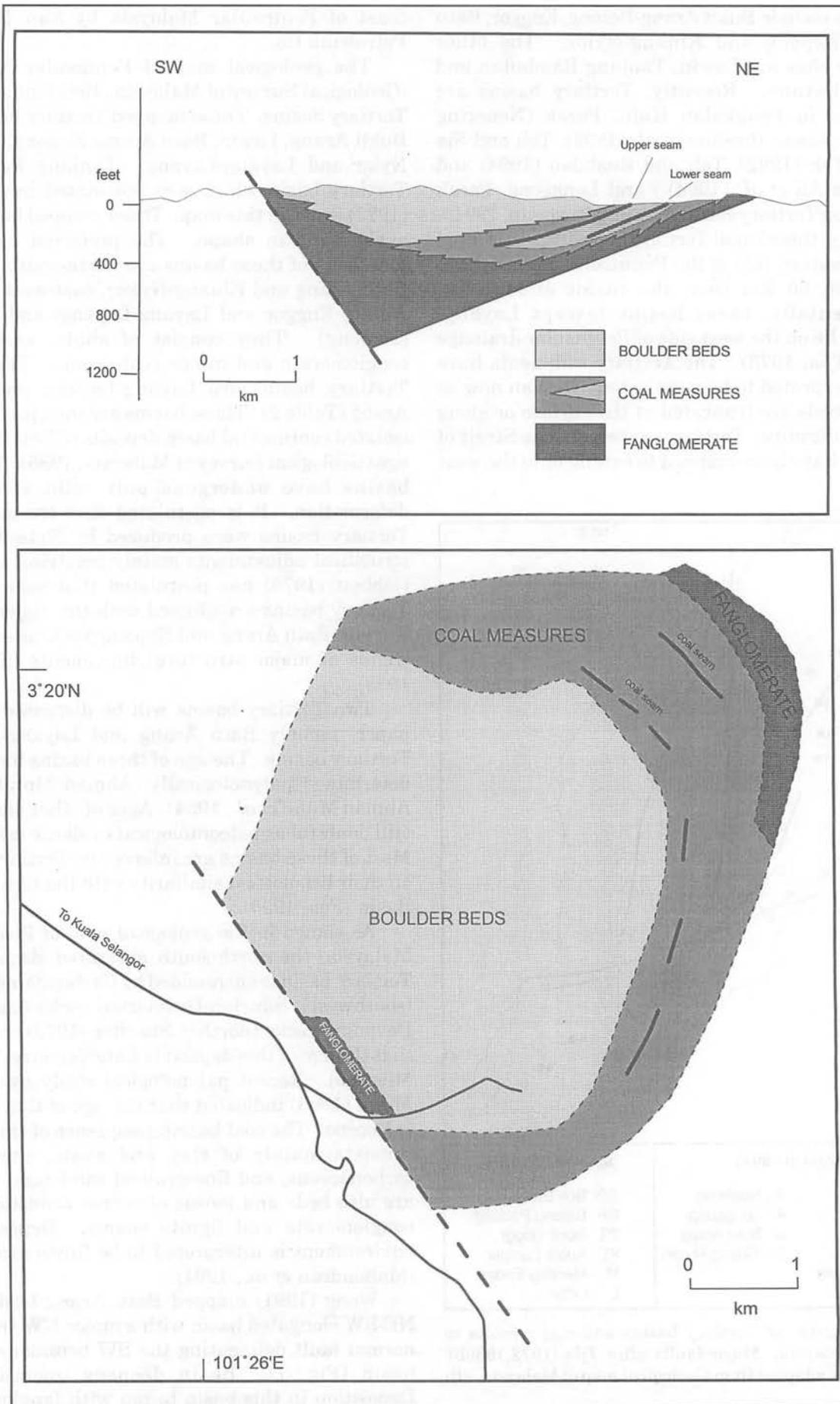


Figure 7. Simplified geological map of Batu Arang Tertiary Basin and its cross section. Adapted from Wong (1991).

Table 2. Geometry of Tertiary Basins in Peninsular Malaysia.

Tertiary Basin	Size (approx.)		Area	Orientation	Elevation (meter) above sea-level	Thickness (meter)	Structural Domain
	Length* (km)	Breadth* (km)					
Bukit Arang-Betong	20	7.5	40 km ²	East-West (?N-S)	60-120	> 180	Northwest
Lawin	3.5	2.5	5 km ²	North-South	~ 170	> 300	
Nenering	?	?	?	?NE-SW	~ 340	?	
Lenggong	?	?	?	?	?	?	West
Enggor	1	0.5	20 ha	East-West	46-76	> 62	
Tanjung Rambutan	Existence doubtful						
Batu Arang	5.5	3.5	15 km ²	North-South	21	> 265	
Kepong	5	2.5	6,000 ha	NW-SE	15	> 194	Central
Kluang-Nyior	2.5	1.5	N/A	North-South	30-75	> 60	East
Layang-Layang	25	10	N/A	East-West	?	?	
Banting Graben	20	10	N/A	North-South	subsurface	> 2,000	? West
Ext. of Sabak Graben	15	10	N/A	NNE-SSW	subsurface	> 1,700	
Ext. of Angsa Graben	?25	?15	N/A	?NE-SW	subsurface	?	
Ext. of Port Klang Graben	?15	?10	N/A	NE-SW	subsurface	?	
<p>Note: Information on area, elevation and thickness of sediments is extracted from Stauffer (1973). Information on size and orientation of basins is measured from geological map of Peninsular Malaysia (1985). * indicate maximum length and breadth. Structural domain is after Tjia and Zaiton Harun (1985). Information on extension of grabens is extracted from Wong (1991).</p>							

which consists of boulders/cobbles of quartzite in sandy siltstone matrix, grading to pebbly sandstone. Progressively upsection, fanglomerate interfingers with coal measures. These coal measures consist of shale and sandstone interbedded with coal seams. In the top section, fanglomerate interfingers with boulder beds. These beds consist of cobbles/boulders of sandstone and claystone in sandy clay matrix.

Lineaments in the vicinity of Batu Arang Basin are absent as surrounding areas are covered with alluvium. Granite in the east shows major lineaments that trended WNW (Geological Survey of Malaysia, 1985). Tjia (1989b) showed that minor lineaments in this area trended north and northeast. The western extension of Kuala Lumpur fault is interpreted to extend to Pulau Jemur (Tjia, 1977). This basin lies within the western extension of Kuala Lumpur fault. The major NW fault bounding the basin could be part of this extension. Mahendran *et al.* (1991) found that this basin is bounded by NW-SE trending faults. They interpreted this basin as a fault-controlled basin. Rapidly deposited boulder beds and fault breccia were found in this basin.

Layang-Layang basin is among the larger Tertiary basins on Peninsular Malaysia. Ahmad Munif *et al.* (1994) determined the age of this basin as Late Miocene. This basin is triangular in shape

and elongated in the east-west direction. It tapers towards west. This basin is surrounded by granite and bordered by Jura-Cretaceous sediments in the east (Fig. 8A). Sediments thicken eastward with major depocentre in the eastern area of the basin. Lineaments in this locality is lacking (Geological Survey of Malaysia, 1985). Tjia (1989b) has mapped major WNW lineaments (Mersing trend) in the eastern area of this basin. The Geological Survey of Malaysia (1985) has mapped north to northwest lineaments in the eastern area of this basin. The Bouguer gravity anomaly (Vijayan, 1990) indicates that Layang-Layang basin is a half graben bounded by a near-linear fault to the south and a listric fault to the northeast with an estimated minimum vertical throw of 1 km.

Jengeli and Pengeli faults that trend northwesterly transect this basin. This northwesterly trend coincides with the trends of boundaries of older formations. A structural map (Fig. 8B) shows that the basin is surrounded by normal faults. Left stepping *en echelon* normal faults are mapped on the southwest part of the basin. These faults may indicate right lateral movement along the southern margin of the basin during its inception. Supported by high linearity of gravity contours on this margin, the east-west boundary between the granite and the basin may

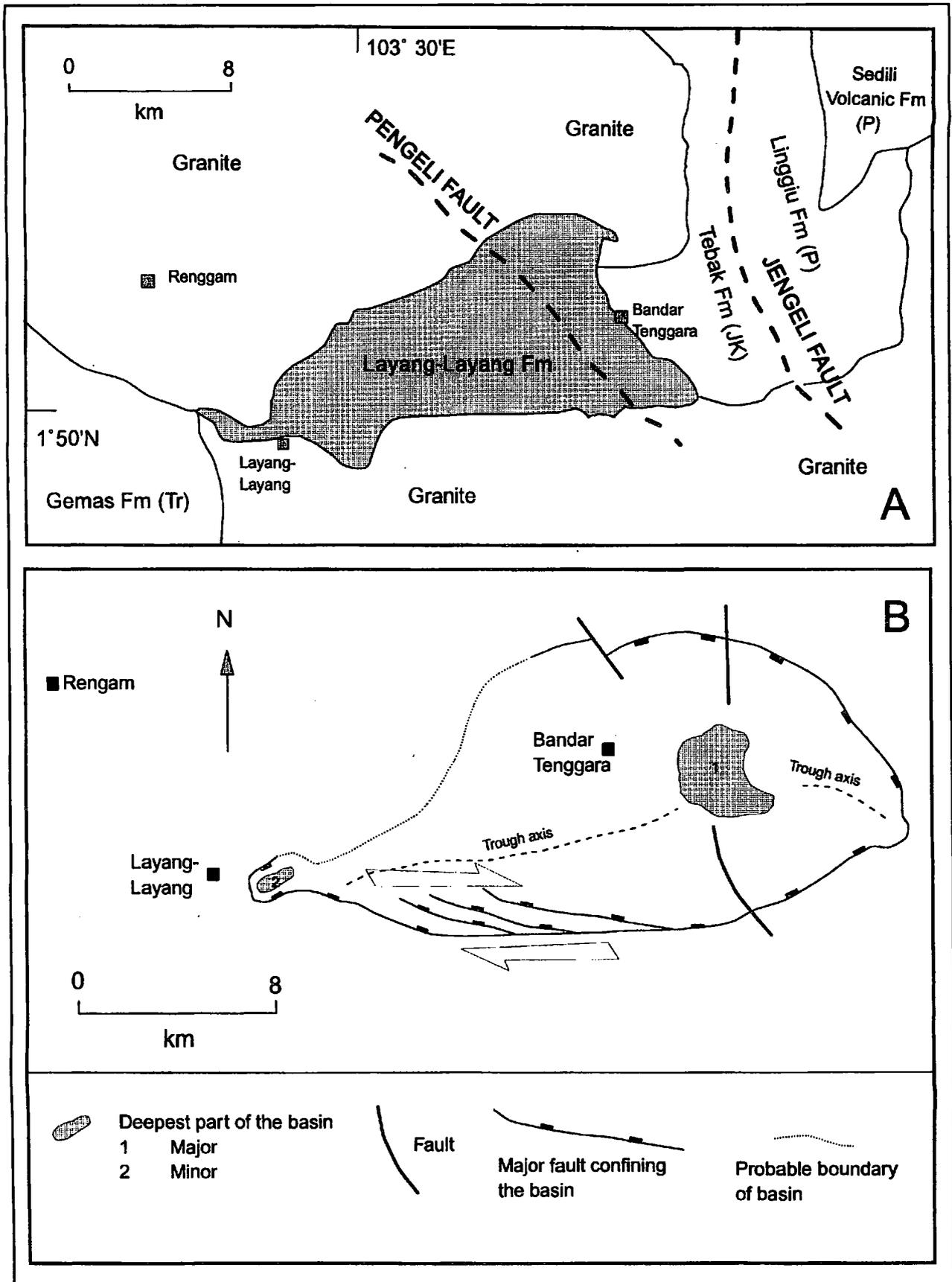


Figure 8. (A) Simplified geological map of Layang-Layang Tertiary basin. Adapted from Geological map of Malaysia, 8th edition, 1985. (B) Structural map of Layang-Layang Tertiary basin. After Vijayan (1990).

represents a major controlling fault in the development of this basin. In short, northwesterly faults within this basin represent older fault trends within the basement (parallel to Mersing Fault). This trend is responsible for the narrowing of the basin towards west. The basin maybe separated into several subbasins by these faults. The east-west faults controlled the elongation of the basin. These faults may represent zones of weakness within ?pluton/pluton interfaces developed within the granite (Syed Sheikh Almashoor, 1989). East-west faults/fractures are activated during Tertiary and a transtensional stress regime is created within this area. This initiated the subsidence of Layang-Layang Tertiary basin.

In Peninsular Malaysia, Tertiary basins are in proximity with the Baubak-Batang Kali-Kuala Lumpur-Endau fault zone. The Kuala Lumpur-Endau fault zone represents a prominent line of dislocation that extends from Kuala Lumpur to Ulu Endau in southeast Pahang. In this fault zone it appears that the east-southeast striking faults are discontinuous and the southeast striking faults are the major fractures (Gobbett and Tjia, 1973). The Kuala Lumpur fault zone is about 15 km wide and has several 280°–300° strike lineaments in the Kuala Lumpur region. Total left lateral displacement of this fault is estimated to be 20 km. This fault zone has been structurally mapped to extend to Pulau Jemur. Many parts of the Kuala Lumpur fault zone are filled with quartz dykes (e.g. Klang Gates and Tekali quartz dykes). The Mersing or Endau fault zone is represented by a number of 290° striking shear zones of ?left lateral displacement in northwest Johore. This fault zone is 30 km wide and extends for a distance of about 100 km. The youngest known fault movement was of Cretaceous age. Left lateral displacement was in the order of 40 km (Tjia, 1972, 1977; Syed Sheikh Almashoor, 1989). Batu Arang, Kepong and Kluang-Nyior Tertiary basins are located in proximity with the Kuala Lumpur-Endau Fault Zone. The size of these basins decreases as the distance from the fault zone increases. Batu Arang basin, being the largest, is within the fault zone. Kluang-Nyior basin is the smallest and is located the furthest from the fault zone. Could this relationship show that these three basins are genetically related to the Kuala Lumpur-Endau fault zone ?

Gobbett and Tjia (1973) summarised that the Bok Bak Fault (or referred to as the Baubak Fault) is represented by two fault sets, one striking 143° and the other 32°. These sets represent a complementary system of shear faults. This fault zone maybe as wide as 10 km (Tjia, 1972). The Bok Bak fault, the largest fault striking NW, was traced for 75 km. The southern end of this fault can be

traced to Lasah (Syed Sheikh Almashoor, 1989). The northwest faults (325°) and the NNE faults (32°) were interpreted to have left and right lateral movements respectively. The recognisable lateral movements were probably during the upper Triassic-lower Jurassic. Vertical movement during Tertiary was indicated by the tilted Tertiary gravel deposits of Lawin (Tjia, 1972). Lawin, Nenering, Enggor and Lenggong lie in proximity with the Baubak fault zone. This fault zone could have initiated the formation of these Tertiary basins. Lawin basin is within the northwest fault set (325°) of the Baubak fault zone whereas Nenering is within the second set of faults (32°) of the Baubak fault zone.

GRABENS IN WEST-CENTRAL MALAY BASIN

The west-central margin of the Malay Basin comprise a platform area and a hinge fault zone which runs parallel (NW-SE) to the basin margin (Fig. 9). Structurally, this area can be divided into three structural zones based on fault trends and basement contours (Liew, in press). Tok Bidan Graben and Dungun Graben are situated at the northern and southern portion of this margin respectively. Both grabens have rhombic shapes and are elongated in the NW-SE direction. Faults in the vicinity of Dungun Graben trended northwesterly. This trend progressively change to northerly northward. Tok Bidan Graben is surrounded by northeasterly faults on the west and northwesterly faults on the east. Major faults within this margin are parallel to major faults on Peninsular Malaysia such as Lebir Fault, Lepar Fault and Terengganu Faults. To illustrate the formation of basins/depressions in this margin, Tok Bidan Graben and Dungun Graben are discussed.

The NW elongated Tok Bidan Graben is located about 50 km north of Pulau Perhentian Besar. This graben is flanked by a NNE plunging basement high to the west and a NNW plunging basement high to the east (Fig. 10b). The basement of this graben has a rhombic shape. There is a large NW striking fault bounding the southwest margin of this graben with a length of 30 km and vertical throw reaching 800 msec. This fault is connected with the NNW faults on the western margin of the graben. These faults demarcate the length of the graben. The northeast margin of this graben is bounded by SE striking step faults downthrowing to SW. These faults are connected with SSE striking faults on the eastern margin of the graben. The basement deepens towards south-west. There are two NW-SE elongated depocentres in this graben.

The geosection of the Tok Bidan Graben (Fig.

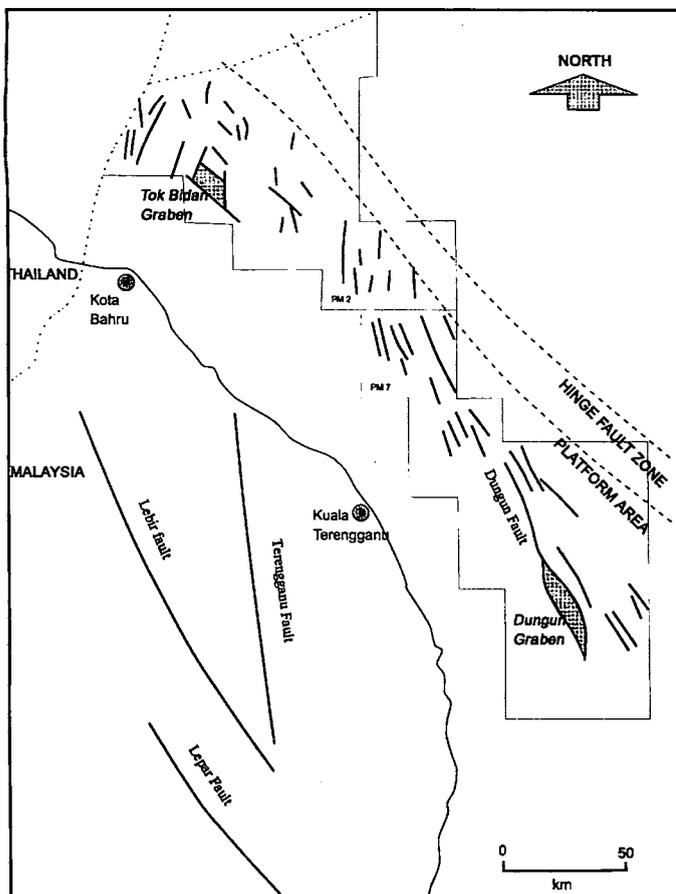


Figure 9. Location map of the west-central margin of the Malay Basin. Majority of the faults trended northwesterly to northerly. Adapted from Liew (in press).

10a) shows that the basement faults have been active since Jura-Cretaceous. The east dipping faults are relatively more active than the west dipping faults as the Permo-Carboniferous basement inclined is westward. Jura-Cretaceous sequence has sagged in the middle of the graben due to rifting or pull apart of the graben. Progressively towards Lower Oligocene, only the east dipping faults remain active. This continued activation of east dipping faults has further inclined the Permo-Carboniferous basement westward. During Lower Oligocene, the Tok Bidan Graben continues to rift or pull apart. This is shown by the sagging of Lower Oligocene sequence. An angular unconformity separated Lower Oligocene sequence from Upper Oligocene sequence. After the angular unconformity period, east dipping faults are reactivated again. No faults are seen affecting Miocene sequences. This geosection demonstrates that there is three episodes of subsidence within the graben. These episodes terminate with unconformities: Jura-Cretaceous, Early Oligocene and Late Oligocene. In other words, the formation of this graben began in Jura-Cretaceous with episodic renewal in Early Oligocene and Late

Oligocene.

The rhombic Dungun Graben is situated northwest of the Tenggol Arch. This graben has a NNW-SSE elongation (Fig. 11). This graben is at least 3 km deep and occupies an area of about 200 km². This graben comprises regional northwest-southeast trending faults interconnected by north-south diagonal faults. The basement deepens towards northeast. A major NNW fault demarcate the northeast boundary of this graben. This fault reaches a length of more than 40 km with a vertical throw of 2,200 msec and a heave of 1.8 km. The southwest portion of this graben is characterised by numerous NW striking step faults and its highly faulted compared to its northeast counterpart. The NNW-SSE plunging basement high within the southwest portion of this graben suggests compression within this portion of graben (Fig. 11). Extending northwesterly from Dungun Graben are three smaller fault-bounded and sediment-filled depressions. These depressions represent the southern part of the Dungun fault: the Dungun fault is a splay from the Hinge Fault Zone. Based on these features, Tjia (1993a) has interpreted a right lateral displacement of 16 km along the northeast boundary of the Dungun Graben.

Rainey Exploration (1992) interpreted that the paleoenvironment sequences within Dungun Graben have changed progressively from lacustrine to deltaic and to fluvial sediments. The basement is probably entirely of metamorphic or crystalline origin. The oldest sequence boundary is interpreted to be 36.0 Ma (Lower Oligocene). Hence, the formation of this graben could be as early as upper Eocene.

KINEMATICS AND TIMING OF BASIN FORMATION

The three areas in northern Sundaland show distinct structural patterns: Grabens in the Strait of Malacca trend northerly; Tertiary basins in Peninsular Malaysia align to major fault zones; Grabens in west-central margin of Malay Basin have NW-SE elongation (Table 4).

Grabens in the Strait of Malacca are located in northerly regional fracture zones. These fracture zones represent N-S depressions between N-S regional highs. The Bengkalis Trough related grabens, Pematang-Balam Trough related grabens, and Asahan Arch-Kepulauan Aruah Nose related grabens are extensions of the Troughs of the Central Sumatra Basin. Tamiang-Yang Besar High related grabens are probably extension of lows within the Tamiang-Yang Besar High. If the formation of the first three graben groupings are associated with the Central Sumatra basin, then the earliest

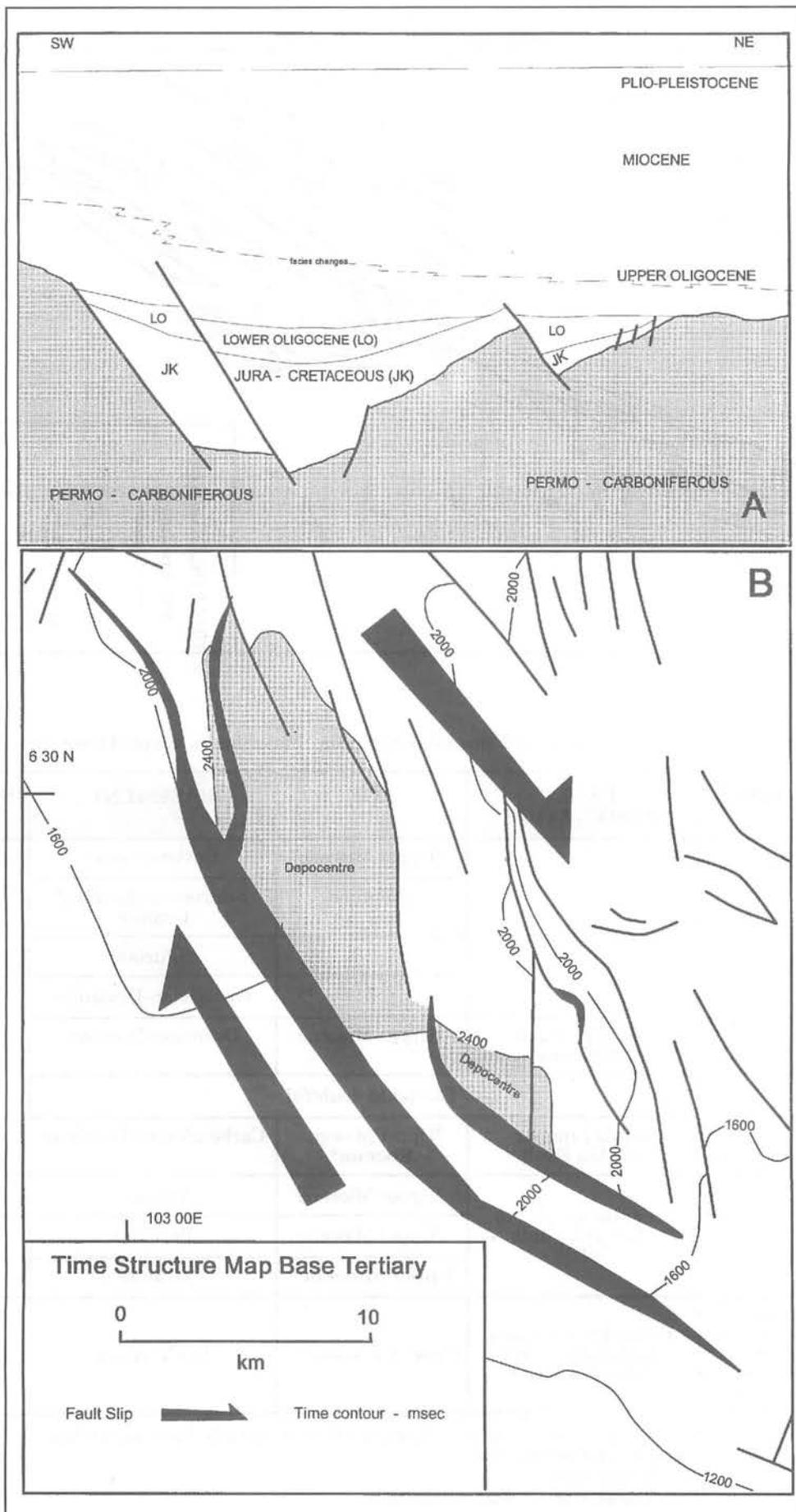


Figure 10. (A) Geosection of Tok Bidan Graben. (B) Rhombic Tok Bidan graben that is elongated in the NW-SE direction. Adapted from Lasmo Oil (1990).

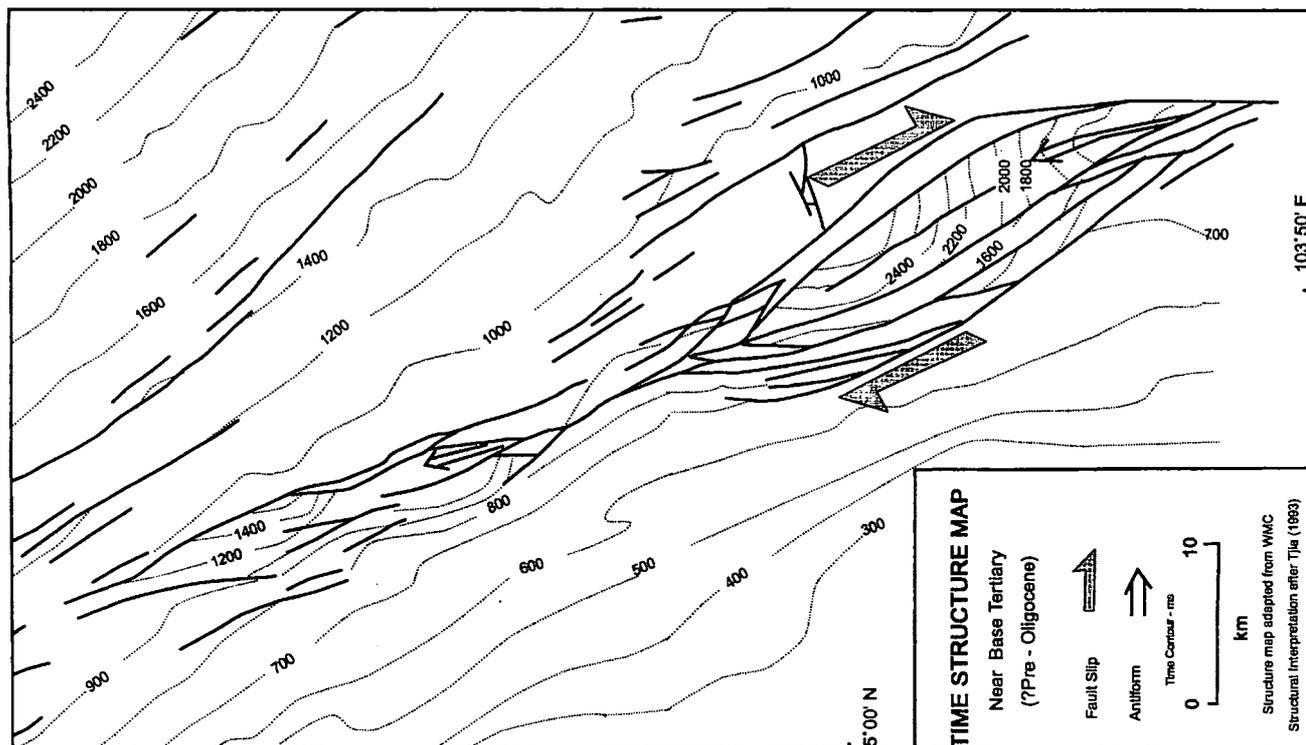


Figure 11. Time structure map of Near Base Tertiary showing Dungun graben and its associated grabens. Extracted from WMC (1990).

Table 3. Major faults and Tertiary basins in Peninsular Malaysia. Major faults adapted from Tjia (1972, 1989b).

TERTIARY BASIN	FAULT ASSOCIATION	AGE	BASEMENT	STRUCTURAL DOMAIN
Bukit Arang-Betong	?Baubak Fault	?Upper Miocene	Carboniferous	Northwest
Lawin		?Miocene	Silurian-Ordovician/ Granite	
Nenering		?	Silurian	
Lenggong		?	Ordovician-Devonian	
Enggor	?Baubak Fault/ Batang Padang Fault	?Upper Miocene	Devonian-Permian	West
Tanjung Rambutan	Existence doubtful			
Batu Arang	Kuala Lumpur- Endau Fault	?Upper Miocene Eocene*	Carboniferous/Devonian	
Kepong	?Faults parallel to Mersing Fault (WNW)	?Upper Miocene	Triassic	Central
Kluang-Nyior		?Upper Miocene	Permian	East
Layang-Layang		Upper Miocene*	Granite	
Ext. of Sabak Graben	Related to northerly faults of Central Sumatra Basin	Upper Oligocene **	Pre-Tertiary	?West
Ext. of Angsa Graben				
Ext. of Port Klang Graben				

Note: Age of Tertiary basin is from Stauffer (1973) and various district memoirs of Geological Survey Malaysia.
* age by Ahmad Munif (1993, 1994).
** age by Wong (1991).
Structural domain is after Tjia & Zaiton Harun (1985).

Table 4. Summary of the kinematics of Cenozoic basin formation in northern Sundaland.

REGION	STRUCTURAL PATTERNS	KINEMATICS OF FORMATION	COMMON FEATURES
STRAIT OF MALACCA	Northerly grabens at four northerly regional fracture zones	E-W extension of northerly fracture initiated by right-lateral movement in the NW-SE direction	TERTIARY BASINS ARE FORMED WITHIN OR IN PROMIXITY WITH MAJOR FAULT ZONES REACTIVATION OF ZONE OF WEAKNESS
PENINSULAR MALAYSIA	Isolated basins aligned to major faults	Transtensional bends within major fault zones	
WEST-CENTRAL MARGIN OF MALAY BASIN	NW rhombic grabens parallel to prominent fault trends	Pull apart depressions in the NW direction	

Cenozoic structural development is the Eo-Oligocene rifting along old basement breaks of N-NNE strike and reactivation of WNW trending regional basement arches (Heidrick and Aulia, 1993). If the Tamiang-Yang Besar High related grabens are related to North Sumatra Basin, then these depressions were developed during the Late Oligocene through Early Miocene as tensional horst and graben structures formed between reactivated dextral wrench faults (Davies, 1984).

The average horizontal spacing between these graben groupings is 150 km. If these graben groupings represent regional fracture zones, then they depict a left-stepping *en echelon* array. Right-lateral movement in the NW-SE direction could have caused the E-W transtension initiating these grabens. This right-lateral movement maybe caused by the relative movement between relatively stable Peninsular Malaysia and mobile Sumatra during Tertiary times. The possible dynamics is the northward progression of the Indian-Australian plate into the edge of Eurasian plate (Sundaland) during Tertiary.

Tertiary basins in Peninsular Malaysia can be linked together by the Baubak-Batang Kali-Kuala Lumpur-Endau fault zone that had experienced left lateral motion during Eocene (Tjia, 1972). If development of Tertiary basins could be used as a structural barometer during Tertiary, then this zone was the major zone of structural activity or weakness in Peninsular Malaysia during Tertiary. It is evidenced by the concentration of Tertiary basins along this zone. Though, this zone has the greatest structural activity, it only experienced minor structural adjustment along existing faults. Strata in these basins experienced mild deformation ($< 10^\circ$).

Sites of Tertiary basins are ?extensional bends of the Baubak-Batang Kali-Kuala Lumpur-Endau fault zones. These bends led to local subsidence.

Fractures within the granite could also play a role in the development of the Tertiary basins. If Kuala Lumpur-Endau fault zone and Baubak fault zone are ?active during Tertiary, then fractures in the vicinity of these fault zones could also be active. These ?active fractures would be parallel or subparallel to the fault zones. Syed Sheikh Almashoor (1989) suggested that structural accommodation within the granite after Late Triassic-Early Jurassic would be within the ready-made weak linear zones. These zones are represented by pluton/pluton interfaces, the interpluton metasedimentary screens, and the batholith's interface with the metasedimentary terrain. Tertiary basins such as Layang-Layang, Enggor and Lawin are within these ready-made weak linear zones within the granite. Therefore, the orientation of the granite bodies indirectly influences the configuration of some Tertiary basins. Though the formation of these Tertiary basins have a common cause, each basin is discrete and requires its own stratigraphic and structural analysis. Older structures influence the configuration and development of these basins. They are developed as ?local phenomena (reactivation of major faults).

Structural elements in west-central margin of the Malay Basin trend NW to NNW. The orientation of the two grabens as well as major faults are parallel to this trend. The geometry of the two grabens is rhombic with elongation in the NW direction. This configuration suggests that these two grabens are formed as pull-apart basins. Their initiations were by right lateral wrenching in the NW-SE direction. The description of these grabens indicates that Cenozoic sedimentation of Tok Bidan Graben is through reactivation of old basement faults within Jura-Cretaceous sediments whereas Dungun graben is contemporaneous with the formation of Malay Basin during pre-Oligocene. Tjia and Liew (1993) suggested that during Late

Table 5. Alternative hypotheses for timing of Cenozoic basin formation in northern Sundaland.

AGE	SINGLE			EPISODIC		
	Strait of Malacca	Peninsular Malaysia	West-central margin of Malay Basin	Strait of Malacca	Peninsular Malaysia	West-central margin of Malay Basin
PLIO-PLEISTOCENE						
MIOCENE	Upper				Layang-Layang	
	Middle					
	Lower					
OLIGOCENE	Upper					Tok Bidan
	Lower					Tok Bidan/Dungun
EOCENE					Batu Arang	?Dungun
PALEOCENE						
JURA-CRETACEOUS						Tok Bidan

Oligocene, Dungun fault with Dungun graben and Ping-Teris faults with Tok Bidan Graben (Tjia, 1993b) acted as wrench-fault boundaries between tectonic domains in this part of the Malay Basin. In other words, basins/depressions in the west-central margin of the Malay Basin are formed within major fractures zones.

The Cenozoic basins in this area are formed within or in proximity with major faults zones or regional fracture zones. The reactivation of major zones of weakness is the main cause of the initiation of the Cenozoic basins. The difference in geometry between basins/depressions in the Strait of Malacca and west-central margin of the Malay Basin is attributed to the difference in pre-Tertiary basement of these two regions; the former is developed on Gondwana whereas the latter is on Cathaysia. Bentong Suture is the divider of these two pre-Tertiary tectonic plates (Tjia, 1989a).

Peninsular Malaysia could be the buffer zone to the stresses from Malay Basin and Penyu Basin (in the east) and Sumatran Basins (in the west). Stresses from these two regions are released partially through Baubak-Batang Kali-Kuala Lumpur-Endau fault zone and Tertiary basins are formed in transtensional sites within this zone. In other words, Peninsular Malaysia can be divided into two major structural domains during Tertiary. These domains are delineated by Baubak-Batang Kali-Kuala Lumpur-Endau fault zone. Structural domain west of this zone experienced stress from Sumatran Basins whereas that east of this zone

from the Malay Basin and Penyu Basin.

The depth of Tertiary basins in the Strait of Malacca (Malaysian waters) and west-central margin of the Malay Basin is of the order of 10^3 metres (Liew, 1993; Liew, 1994) whereas those in Peninsular Malaysia is of the order 10^2 metres. If subsidence rate of the Tertiary basins is a function of the movement of major fault zones, then the magnitude of fault movements in Peninsular Malaysia during Tertiary is lower than its adjacent areas. The main reason for the above inference is that regional subsidence is low, while local subsidence is mainly controlled by fault movement and basins are formed almost contemporary.

The timing of the basin formation is debatable as there is a lack of biostratigraphic markers within the oldest Tertiary sediments drilled and most of the wells did not penetrate the basement. Wells that penetrated the basements are on regional highs or basin margin and may not represent the oldest sediments in the basin. The oldest Tertiary sediments within these Cenozoic basins are believed to be of terrestrial origin. Biostratigraphic markers recovery from these environment is very poor. As there is a lack of good biostratigraphic evidence, the author proposes two hypotheses for the timing of the Cenozoic basin formation in northern Sundaland (Table 5). The hypotheses are single event hypothesis and episodic events hypothesis.

The single event hypothesis proposes that during Cenozoic, basin formation in northern Sundaland concentrated in Eocene-early Oligocene

(Table 5). The oldest Tertiary palynomorph recovered in the study area is dated as Eocene in Batu Arang basin in Peninsular Malaysia (Ahmad Munif, 1993). In North Sumatra Basin, the oldest Tertiary sediment is the Tampur formation which is Eocene (Fig. 2). If the formation of Sumatran basins are genetically related to the grabens in the Strait of Malacca, then the oldest possible Tertiary sediment in the latter grabens could be Eocene. As for the Malay Basin, study by EPIC indicated the existence of older sediments than N (Lower Oligocene). The age of the reddish Jura-Cretaceous sediments in Tok Bidan Graben is based on its lithological similarity to the continental deposits in Peninsular Malaysia (Gagau Group; Rishworth, 1974). These Jura-Cretaceous sediments have not been determined biostratigraphically. They maybe Eocene terrestrial sediments. As for late Miocene palynomorph recovered from Layang-Layang, it can be argued that the older Tertiary sediment is situated deeper in the section and is not exposed. Vijayan (1990) interprets that Layang-Layang basin as a closed one comprising both Tertiary and Pre-Tertiary sediments.

The episodic event hypothesis suggests that there are at least two major episodes of basin formation in northern Sundaland during Cenozoic; Eocene-early Oligocene and Late Miocene (Table 5). Some basins are formed during Eocene-early Oligocene (e.g. grabens in Strait of Malacca, Batu Arang Basin, Dungun Graben and Tok Bidan Graben). Most of the Tertiary basins in Peninsular Malaysia are formed during Late Miocene (Table 3). Some of these basins (e.g. Layang-Layang Basin and Tok Bidan Graben) are formed on Jura-Cretaceous sequences: reactivation of Jura-Cretaceous faults caused the initiation of these Cenozoic basins.

The author is inclined to favour the episodic events hypothesis as the model for the timing of the Cenozoic basin formation in the study area (Fig. 12). The pre-Tertiary basement in northern Sundaland experienced compression in Eocene-early Oligocene (Peninsular Malaysia, Tjia, 1972; Malay Basin, Tjia, 1993a; Strait of Malacca, Liew, 1994). This compression created tensional stress systems at some segments of major zones of weakness in this region. Basins/depressions in the Strait of Malacca, west-central Malay Basin, and some basins in Peninsular Malaysia are initiated by this stress system. At some places, this stress system reactivated Jura-Cretaceous faults. Thus, Cenozoic basins developed on Jura-Cretaceous sequences. Major stress reversal in Late Miocene is recorded in sediments of Malay Basin (Tjia, 1993a) and Strait of Malacca (Wong, 1991). This Late Miocene stress system is responsible for majority of the Tertiary

basins developed in Peninsular Malaysia (e.g. Layang-Layang).

The model forwarded is only a proposal as more studies are required to determine the ages of the Cenozoic sediments and the kinematics of the formation of individual Cenozoic basin. The present biostratigraphic data as well as the known stress systems within this region supported the episodic events model for the timing of Cenozoic basin formation in northern Sundaland.

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REFERENCES

- AHMAD MUNIF KORAINI, 1993. Tertiary palynomorphs from Batu Arang, Malaysia. *Geological Society Malaysia, Annual Geological Conference 1993. Abstract of Papers.*
- AHMAD MUNIF KORAINI, AZMI MOHD. YAKZAN AND UYOP SAID, 1994. Palynological study of outcrop samples from Layang-Layang Formation, Bandar Tenggara, Johor. Malaysia. *Geological Society Malaysia, Annual Geological Conference 1994. Abstract of Papers.*
- CHE AZIZ ALI, AHMAD Jantan, Ibrahim Abdullah and Juhari Mat Akhir, 1994. Kehadiran paleosol di dalam jujukan sedimen kebenuaan di Nenering serta implikasi iklim kuno. *Geological Society Malaysia, Annual Geological Conference 1994. Abstract of Papers.*
- DAVIES, P.R., 1984. Tertiary structural evolution and related hydrocarbon occurrences, North Sumatra Basin. *Proceedings 13th Ann. Conv. Indonesian Petroleum Association*, 19-49.
- DYER, J., FINLAY, A., MOHD. GHAZALI AND WONG, D., 1991. Report on the geophysical and geological re-evaluation of contract area PM 1, Malacca Straits, Malaysia. Sun Malaysia Petroleum Co. (unpublished).
- FOO, K.Y., 1990. Geology and mineral resources of the Taiping — Kuala Kangsar area, Perak Darul Ridzuan. *Geological Survey Malaysia Map Report 1*, 145p.
- GEOLOGICAL SURVEY OF MALAYSIA, 1985. Geological map of Peninsular Malaysia, 8th edition, 1:500,000. Kuala Lumpur, 2 sheets.
- GOBBETT, D.J. AND TJIA, H.D., 1973. Tectonic History. In: Gobbett, D.J. and Hutchison, C.S. (Eds.), Chapter 10, *Geology of the Malay Peninsula West Malaysia and Singapore*, New York, Wiley-Interscience, 305-334.
- HEIDRICK, T.L. AND AULIA, K., 1993. A structural and tectonic

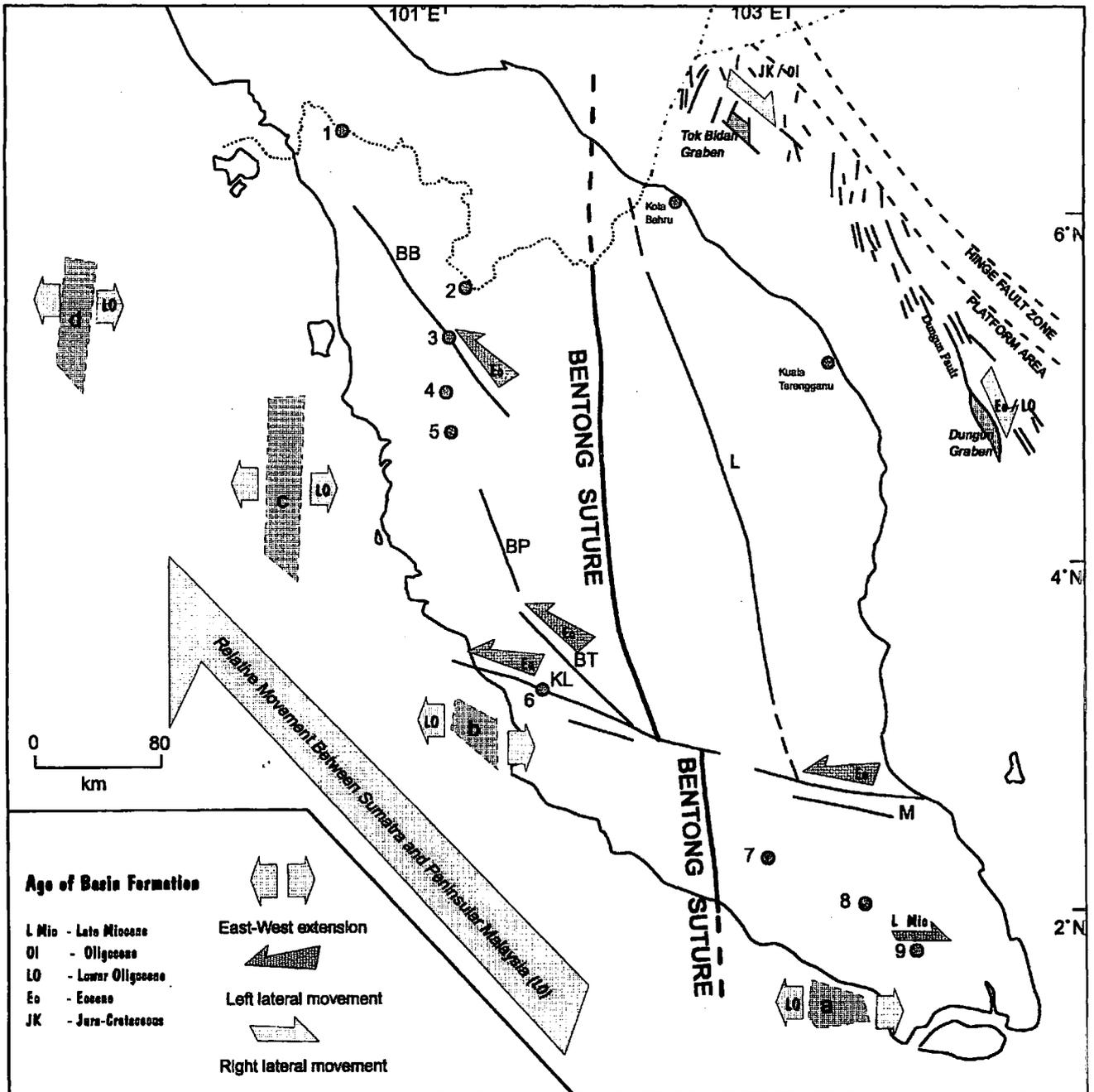


Figure 12. Kinematics and timing of Cenozoic basin formation in northern Sundaland. (a) Bengkalis Trough related grabens, (b) Pematang-Balam Trough related grabens (c) Asahan Arch-Keulauan Aruah Nose related grabens and (d) Tamiang-Yang Besar High related grabens. Numerical 1 to 9 indicate locations of Tertiary basins in Peninsular Malaysia (refer to Fig. 6). Capital letters BB to L refers to major faults in Peninsular Malaysia (refer to Fig. 6).

- model of the coastal plains block, Central Sumatra Basin, Indonesia. *Proceedings 22nd Ann. Conv. Indonesian Petroleum Association*, 285–317.
- HUTCHISON, C.S., 1989. *Geological Evolution of South-East Asia*. Oxford Monographs on Geology and Geophysics no. 13. Oxford Science Publications.
- IBRAHIM ABDULLAH, JUHARI MAT AKHIR, ABD. RASID JAAPAR AND NOR AZLAN HAMZAH, 1991. The Tertiary Basin in Felda Nenering, Pengkalan Hulu (Kerah), Perak. *Warta Geologi*, 17(4), 181–186.
- LASMO OIL (MALAYSIA) LTD., 1990. North west Malay Basin Joint Study. PETRONAS-LASMO-CARIGALI Joint Study (unpublished).
- LIEW, K.K., 1993. Structural development of the west-central margin of the Malay Basin (basement of blocks PM2 and PM7). *Geological Society Malaysia, Annual Geological Conference 1993. Abstract of Papers*.
- LIEW, K.K., 1994. Structural patterns within the Tertiary basement of Strait of Malacca. *PETRONAS Research and Scientific Services, Project 123/92, Report No. RP5-94-02*. (unpublished).
- LIEW, K.K., in press. Structural development at the west-central margin of the Malay Basin. *Bull. Geol. Soc. Malaysia*.
- MAHENDRAN, G., MUSTAFFA, K.S. AND RAJ, J.K., 1991. The stratigraphy of the Batu Arang area. *Geological Society Malaysia, Annual Geological Conference 1991. Abstract of Papers*.
- MOULDS, P.J., 1989. Development of the Bengkalis Depression, Central Sumatra and its subsequent deformation — A model for other Sumatran Grabens? *Proceedings 18th Ann. Conv. Indonesian Petroleum Association*, 217–245.
- MURRAY, C., 1991. Review of the prospectivity of Block PM-1, Straits of Malacca, Malaysia. Sun Malaysia Petroleum Co. (unpublished).
- RAINEY EXPLORATION, 1992. Seismic Stratigraphy of the Dungun Graben PM 7 (unpublished).
- RISHWORTH, D.E.H., 1974. The Upper Mesozoic terrigenous Gagau Group of Peninsular Malaysia. *Geol. Sur. Malaysia Special Paper 1*.
- SOSROMIHARDJO, S.P.C., 1988. Structural analysis of the North Sumatra Basin — with emphasis on synthetic aperture radar data. *Proceedings 17th Ann. Conv. Indonesian Petroleum Association*, 187–209.
- STAUFFER, P.H., 1973. Cenozoic. In: Gobbett, D.J. and Hutchison, C.S. (Eds.), Chapter 6, *Geology of the Malay Peninsula West Malaysia and Singapore*. New York, Wiley-Interscience, 143–176.
- SYED SHEKH ALMASHOOR, 1989. The role of Peninsular Malaysia's main range batholith in fault developments. *Sains Malaysiana* 18(1), 3–11.
- TEH, G.H. AND SIA, S.G., 1991. The Nenering Tertiary deposit, Keroh, north Perak — A preliminary study. *Warta Geologi*, 17(20), 49–58.
- TEH, G.H., 1992. The Nenering Tertiary sedimentary basin, Keroh (Hulu Perak), Perak. *Geological Society Malaysia, Annual Geological Conference 1992. Abstract of Papers*.
- TEH, G.H., 1992. Field Relationships of rock units along the Malaysia-Thai border, Nenering, Ulu Perak. *Geological Society Malaysia, Annual Geological Conference 1992. Abstract of Papers*.
- TEH, G.H. AND RUSHDAN ABDUL LATIF, 1994. Occurrence of Tertiary deposit in the Lenggong area, Perak — its implication. *Geological Society Malaysia, Annual Geological Conference 1994. Abstract of Papers*.
- TJIA, H.D., 1972. Strike-slip faults in West Malaysia. *24th International Geological Congress, Montreal, Canada, Section 3 Tectonics*, 255–262.
- TJIA, H.D., 1973. Geomorphology. In: Gobbett, D.J. and Hutchison, C.S. (Eds.), Chapter 2, *Geology of the Malay Peninsula, West Malaysia and Singapore*. New York, Wiley-Interscience, 13–24.
- TJIA, H.D., 1977. Western extension of the Kuala Lumpur fault zone. *Bull. Geol. Soc. Malaysia*, 8, 123–125.
- TJIA, H.D., 1988. Tectonic history of the Bentong-Bengkalis Suture. *Geological Society of Malaysia, Petroleum Geology Seminar 1988. Abstracts of Paper*.
- TJIA, H.D., 1989a. Tectonic history of the Bentong-Bengkalis Suture. *Geol. Indon.*, 12(1), 89–111.
- TJIA, H.D. 1989b. Major faults of Peninsular Malaysia on remotely sensed images. *Sains Malaysiana* 18(1), 101–114.
- TJIA, H.D., 1991. Geological structures and tectonics workshop. PETRONAS PRI (unpublished).
- TJIA, H.D., 1993a. Inversion tectonics in the Malay Basin: Evidence and timing of events. *PETRONAS Research and Scientific Services, Project 123/92, Report No. RP5-93-04*.
- TJIA, H.D., 1993b. Northerly striking regional faults of Terengganu. *PETRONAS Research and Scientific Services, Project 123/92, Report No. RP5-93-05*. (unpublished).
- TJIA, H.D. AND ZAITON HARUN, 1985. Regional structures of Peninsular Malaysia. *Sains Malaysiana*, 14(1), 95–107.
- TJIA, H.D. AND LIEW, K.K., 1993. Changes in tectonic stress field in the northern Sunda Shelf basins. *PETRONAS Research and Scientific Services, Project 123/92, Report No. RP5-93-06* (unpublished).
- VIJAYAN, V.R., 1990. Gravity survey of the Layang-Layang Tertiary Basin in Johor, Peninsular Malaysia — A preliminary report. *Bull. Geol. Soc. Malaysia*, 26, 55–70.
- WONG, D., 1990. Hydrocarbon potential of PM-15 grabens (overview). Sun Malaysia Petroleum Co. (unpublished).
- WONG, D., 1991. Review of the prospectivity of PSC block PM-15 (Post Port Klang-1), Strait of Malacca. Sun Malaysia Petroleum Co. (unpublished).

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