

Structural history of Hinge fault system of the Malay Basin

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Abstract: The curvilinear Hinge fault system demarcates the western boundary of the Malay Basin: it trends northerly in the north and this direction changes progressively to WNW-ESE in the south. This 20-kilometre wide fault system is traceable for more than 450 km. Based on the trends and structural styles, this fault system can be subdivided into five major segments: northerly trending Ular-Kuda fault segment, northwest-southeast trending Kabut-Tembikai fault segment, WNW-ESE trending Angsi-Duyong fault segment and NNW-SSE Dungun fault segment.

During Late Eocene-Early Oligocene, this fault system experienced right lateral movement. In this wrenching period, strings of rhomboid pull-apart grabens were developed within its northern segments. The fault system was probably active until Late Middle Miocene. During Middle Miocene, reversal of wrench movement (left lateral) produced transpressional anticlines within the pull-apart grabens. Based on the abundance of faults and sedimentation rates within the fault segments, it is interpreted that the dominant activities within this fault system shifted progressively northwards from Early Miocene to Late Miocene. This system may represent a major fault system in the western margin of the Malay Basin since Triassic.

INTRODUCTION

The northwest-southeast trending Malay Basin is 500 km long and 200 km wide. This basin is asymmetrical with the western margin much steeper than the eastern margin. The area bounding the western margin of this basin is commonly known as the (western) hinge zone of the Malay Basin (Fig. 1). Numerous hydrocarbon accumulations have been discovered in several parts of this hinge zone. There is a dearth of published information regarding the characteristics of this zone. This zone is known to represent a flexure zone in the western flank of the basin: the gradient of the basement slope changes from gentle to steep within this zone. In 1994, PETRONAS Carigali Sdn. Bhd. (PCSB) and Esso Production Malaysia Inc. (EPIC's study) have completed their regional studies on the Malay Basin (and also Penyu Basin by PCSB). Results of these studies are presented in several volumes of texts, several portfolios of compiled maps, a database of both basins, and new findings about the petroleum systems of the basins. Structure and fault maps of these two studies revealed that a major fault system lies within the (western) hinge zone of the Malay Basin. This paper attempts to describe this Hinge fault system and its structural history.

PCSB's regional study and EPIC's study have produced four and ten regional structure maps of the Malay Basin, respectively. The structures and faults in the maps by EPIC and PCSB are depicted

differently, though both showed quite similar regional trends. PCSB's maps tend to depict simplified versions of the fault trends. The presence of faults (or fault zones) is indicated by a single continuous line. EPIC's maps provide more detail accounts of the fault zones. They are more descriptive: major and minor faults within fault zones are shown. In this paper, PCSB's maps are mainly used to show the prominent fault zone in their geological development whereas EPIC's map are used as base to describe the fault zones.

HINGE FAULT SYSTEM

The curvilinear Hinge fault system demarcates the western boundary of the Malay Basin. This fault system trends northerly in the north and changes progressively to WNW-ESE direction in the south. The average width of this fault system is 20 kilometres. The width of the fault system becomes progressively more narrow towards the south. This fault system is traceable for more than 450 km. There are five major segments in this fault system: Ular-Kuda fault segment, Kabut-Tembikai fault segment, Angsi-Duyong fault segment, Dungun fault segment, and Sotong fault segment (Fig. 2).

The naming convention of the fault segment is by the name of the wells located at the two ends of the fault segment, except Sotong and Dungun fault segments. The naming of the Sotong fault segment is based on the Sotong field which is situated in the

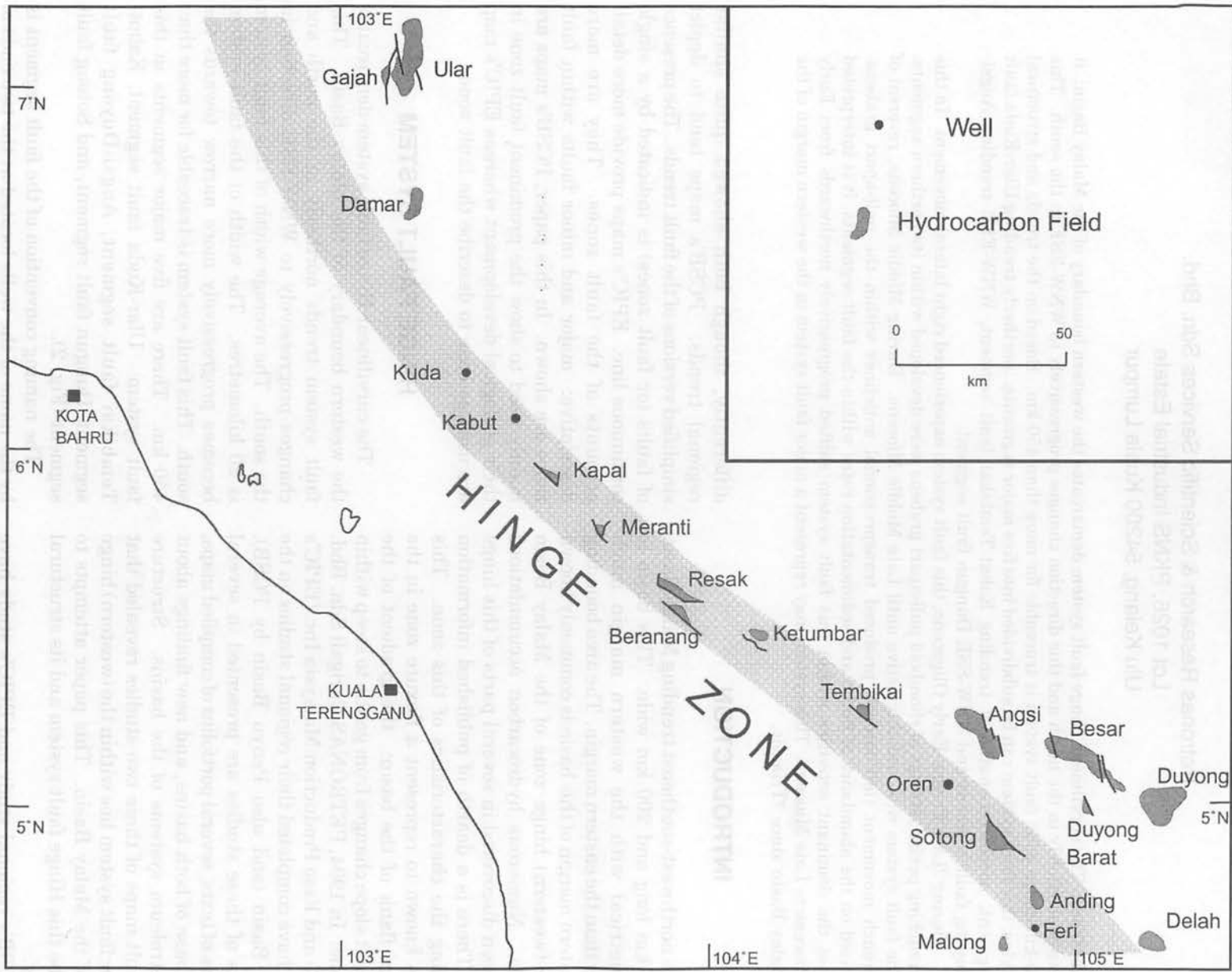


Figure 1. Location map of the (western) hinge system of the Malay Basin and its associated hydrocarbon accumulations. The shaded area is the approximate extend of the hinge zone.

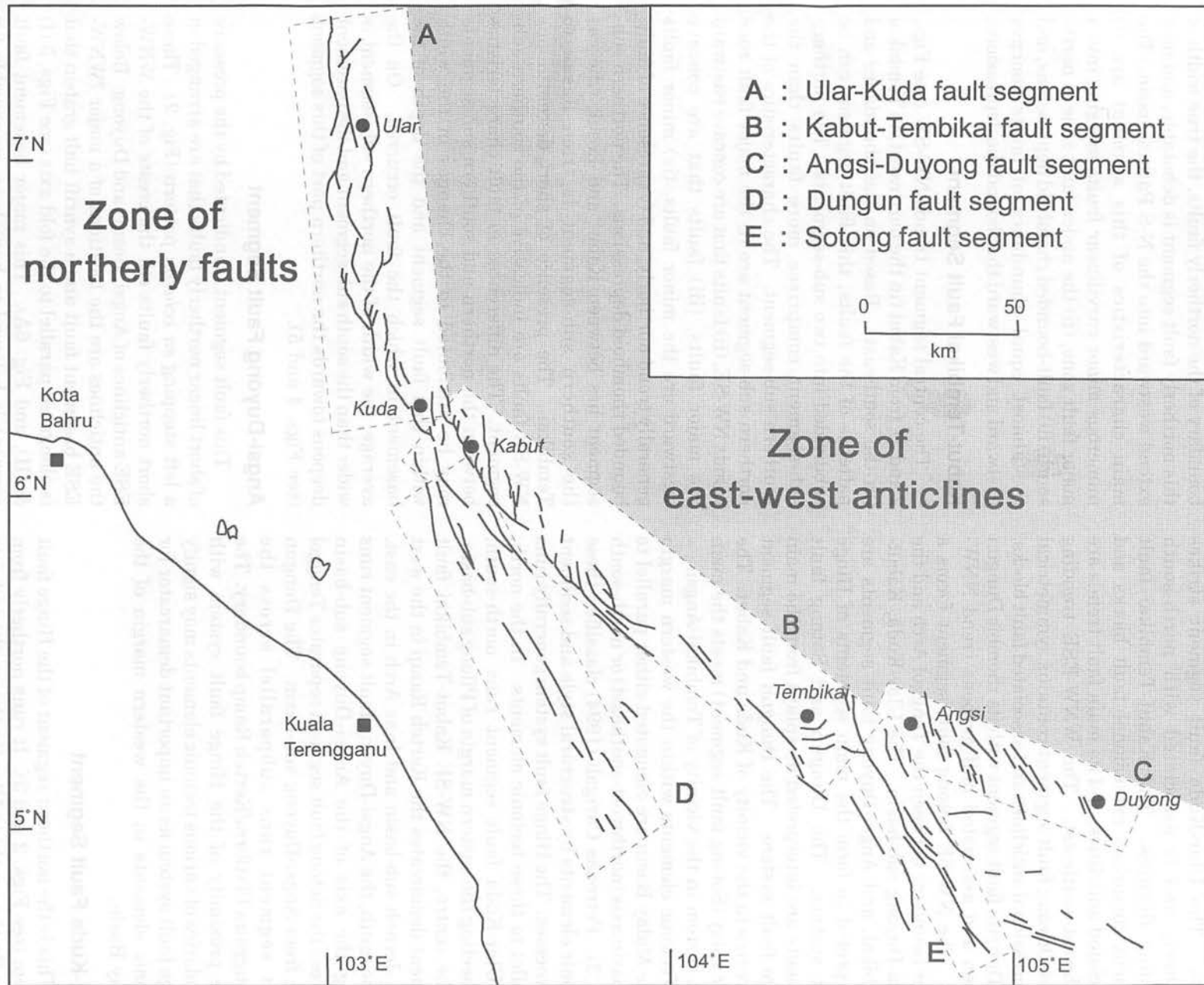


Figure 2. The five major segments of the Hinge fault system. Note that this fault system separates the northerly faults in east from the east-west anticlines in the west. The locations of the wells (with names) signified the ends of the fault segments. Structures were adapted from EPIC 1994 study.

centre of this fault segment. Dungun Graben is situated at the southern end of the Dungun fault segment; the basis of the name of this fault segment.

The segmentation of the Hinge fault system is based on the trends and structural style of the faults. The Ular-Kuda fault segment strikes northerly and is associated with north-south trending flexures. The Kabut-Tembikai fault segment comprises extensional fault blocks and associated anticlines, and its main fault trends are northwest-southeast. The WNW-ESE trending Angsi-Duyong fault segment contains symmetrical compressional anticlines and associated fault blocks. The Dungun fault segment with its rhombic Dungun graben and associated half grabens trend NNW-SSE. The NW-SE Sotong fault segment forms a major boundary between the Tenggol Arch and the Angsi-Duyong sub-basin. The Ular-Kuda, Kabut-Tembikai, and Angsi-Duyong fault segments are interpreted to form the main segments of Hinge fault system. The Dungun and Sotong fault segments are interpreted as splays from the main Hinge fault system. The Dungun fault segment bifurcates in the vicinity of Kuda and Kabut. The other splay (Sotong fault segment) meets the main fault system in the vicinity of Tembikai-Angsi.

Tectonic elements within the western margin of the Malay Basin are elongated either parallel to the basin axis (northwest-southeast) or north-south (Fig. 3). Petronas Carigali (1994) classified these tectonic elements by structural style and sediment thicknesses. The Hinge fault system generally runs parallel to these tectonic elements. In the north, the Ular-Kuda fault segment runs north-south, transecting the eastern margin of Piling sub-basin. In the centre, the NW-SE Kabut-Tembikai fault segment demarcates the Kerteh Ramp in the west from Jerneh sub-basin and Inas Arch in the east. In the south, the Angsi-Duyong fault segment runs along the axis of the Angsi-Duyong sub-basin whereas the Sotong fault segment separates Tenggol Arch from Angsi-Duyong sub-basin. The Dungun fault segment runs subparallel across the Terengganu Platform/Kerteh Ramp boundary. The close proximity of the Hinge fault system with boundaries of various tectonic elements may signify Hinge fault system as an important demarcator for tectonic elements in the western margin of the Malay Basin.

Ular-Kuda Fault Segment

This is the northern segment of the Hinge fault system (see Figs. 2 and 3). It runs northerly from Kuda (in the south) to Ular (in the north) and cuts through the eastern margin of the Piling Sub-basin. Situated in the eastern margin of the zone of northerly faults, this segment is the western

boundary of the zone of east-west anticlines. Based on the extrapolation from the central segment of the Hinge fault system, the width of this fault segment is interpreted to be about 25 kilometres. However, as this fault segment forms the eastern boundary of the northerly faults, the true width of this northerly fault segment is debatable, and may extend westward into the N-S Pattani basin. The main characteristics of this segment are (i) numerous minor curvilinear faults merging into a major fault zone, (ii) the major fault zone is north-south (iii) fault-bounded rhomboid depressions, and (iv) almost equal abundance of faults concave eastward and westward that bound the depressions.

Kabut-Tembikai Fault Segment

The central segment trends NW-SW (see Figs. 2 and 3), from Kabut (in the northwest) to Tembikai (in the southeast). Based on the abundance and patterns of the faults, this fault segment can be subdivided into two sub-segments. The northern sub-segment comprises more faults than the southern sub-segment. The characteristics of the northern sub-segment are (i) the major fault zone trends NW-SE, (ii) faults that are concave eastward are major faults, (iii) faults that are concave westward are the minor faults, (iv) minor faults generally trend northerly, and (v) presence of fault-bounded rhomboid depressions. The northern sub-segment lies between Kabut and Resak whereas the southern sub-segment is from Resak to Tembikai. The presence of short discontinuous NW-SE faults are indicative of the southern sub-segment. The differences in fault characteristics between the northern and southern sub-segments may be attributed to the changes in the width within this fault segment and the depth of the basement in which the fault occurred. On the average, the width of the northern sub-segment is wider than the south sub-segment and the basement deepens towards the northern part of this segment (see Figs. 4 and 5).

Angsi-Duyong Fault Segment

This fault segment is indicated by the presence of short linear northerly faults that are arranged in a left stepping *en echelon* pattern (Fig. 2). These short northerly faults cut the crests of the WNW-ESE anticlines of Angsi, Besar, and Duyong. Below the anticlines are the locations of a major WNW-ESE basement fault and a synrift half graben that is elongated parallel to the fold axis (see Figs. 5 (I) & (II), and Fig. 6A). This major basement fault segment is believed to have been responsible for the creation of the synrift half graben. It should be noted that synrift half grabens in the axes of the Malay basin are elongated east-west (see Tjia, 1993)

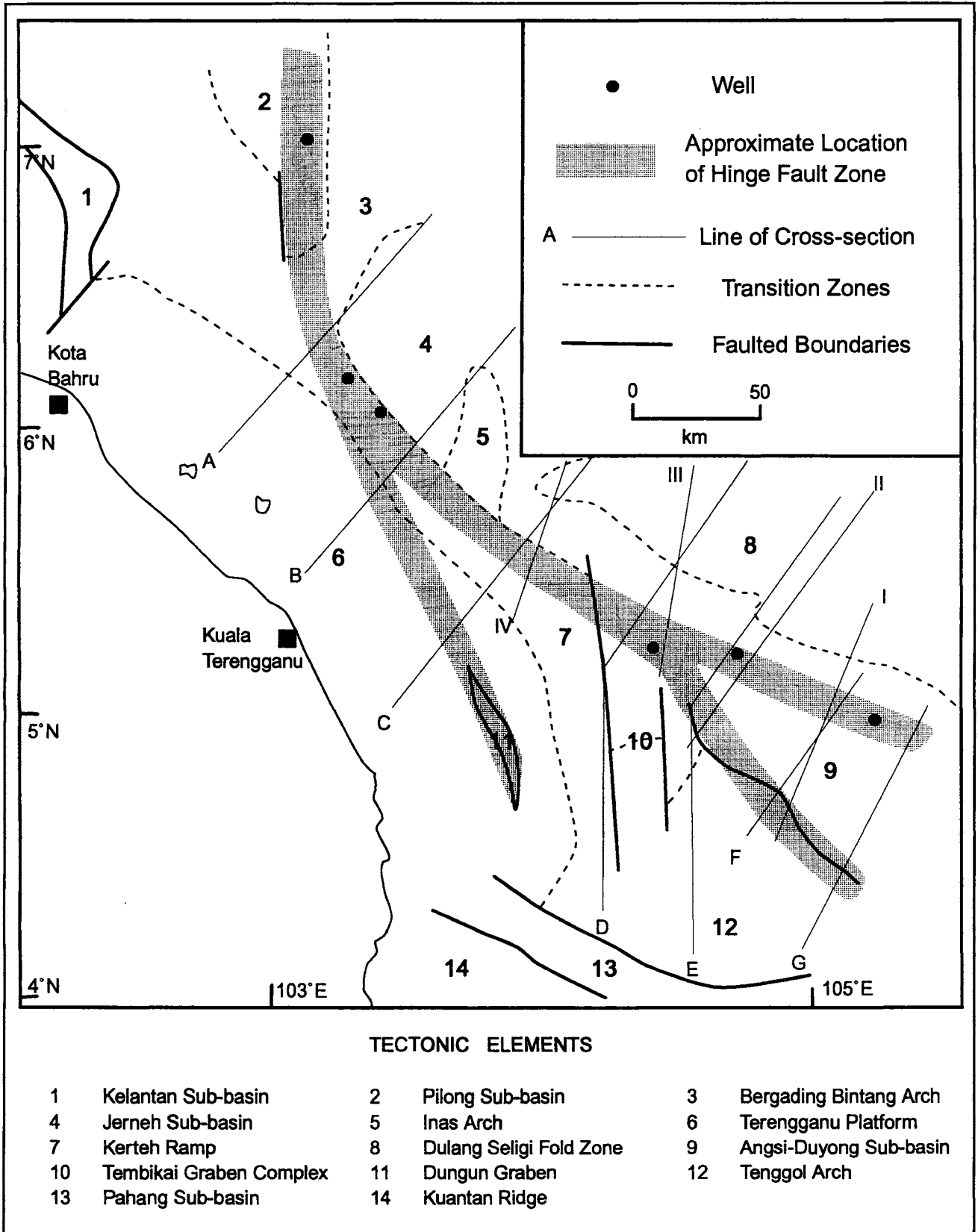


Figure 3. The thirteen tectonic elements within the western margin of the Malay Basin. Tectonic elements were adapted from PCSB regional study 1994.

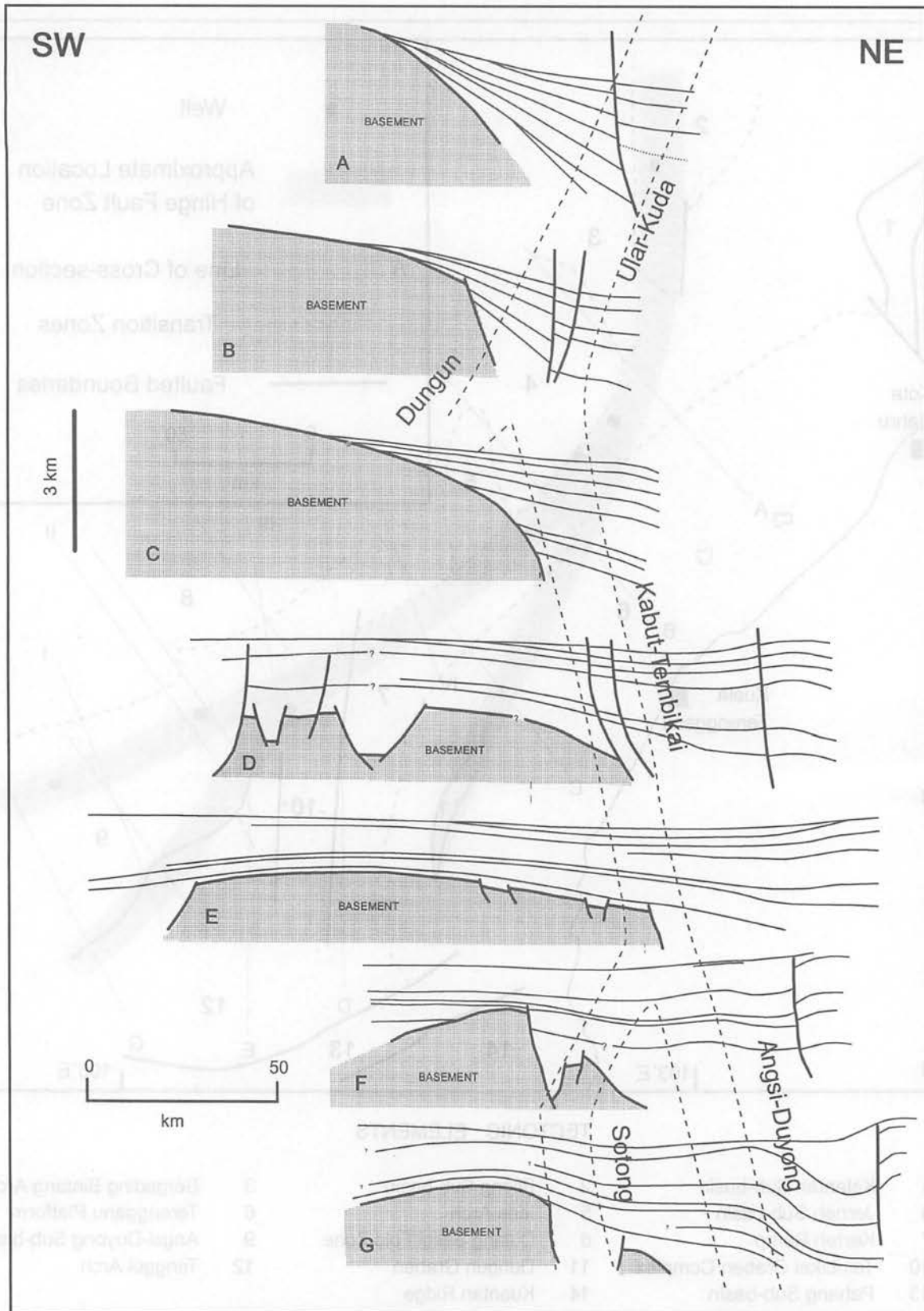


Figure 4. Cross-sections across various parts of the Hinge fault system. The locations of the cross-sections, A to G, are referred in Figure 3. The cross-sections are not represented in their true geometrical relationship with one another. The dotted lines indicated the approximate location of the fault zones within the basement. The cross-sections are modified from PCSB regional study 1994.

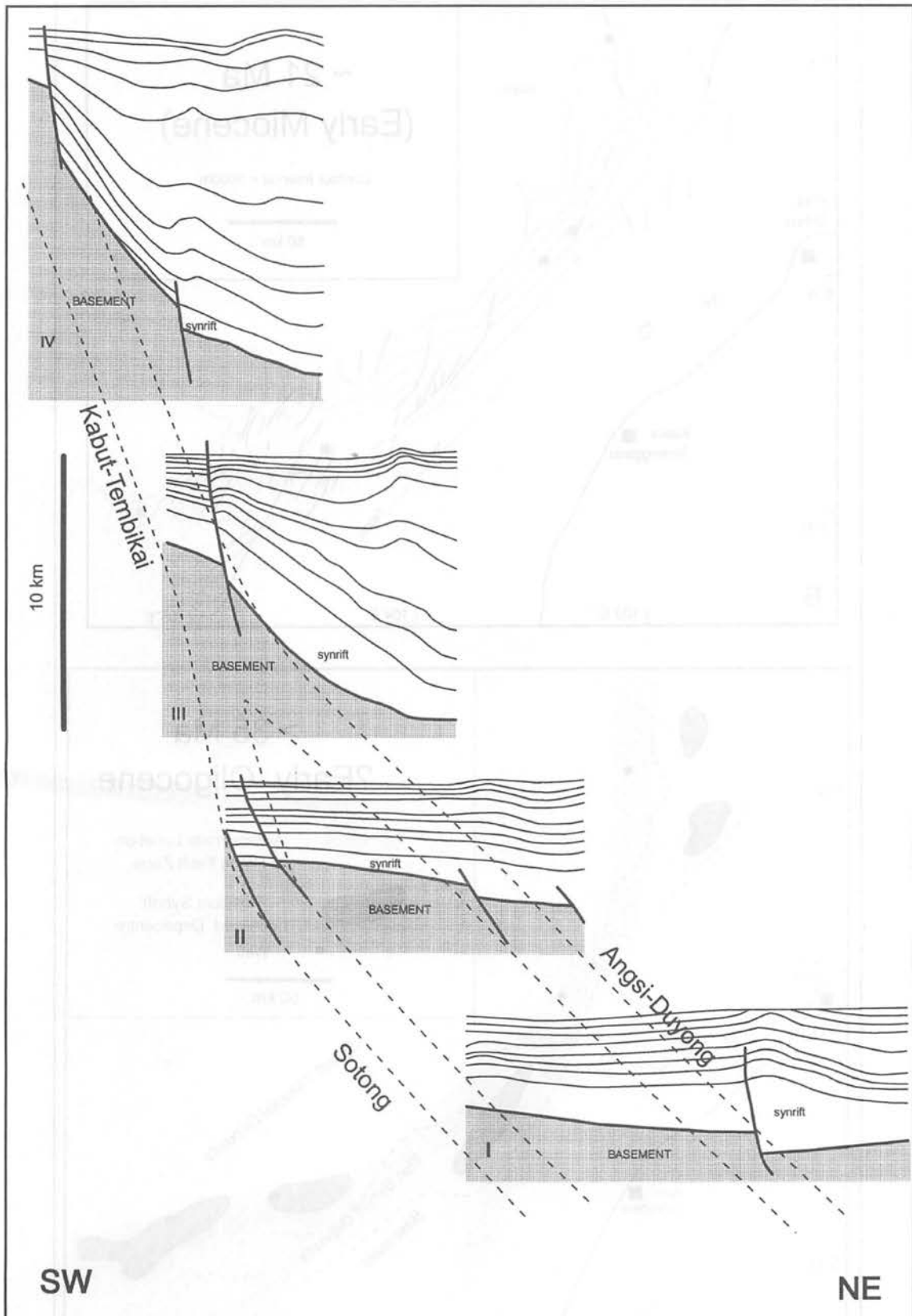


Figure 5. Cross-sections across various parts of the southern part of the Hinge fault system. The locations of the cross-sections, I to IV, are referred in Figure 3. The cross-sections are not represented in their true geometrical relationship with one another. The dotted lines indicated the approximate location of the fault zones within the basement. The cross-sections are modified from EPIC 1994 study.

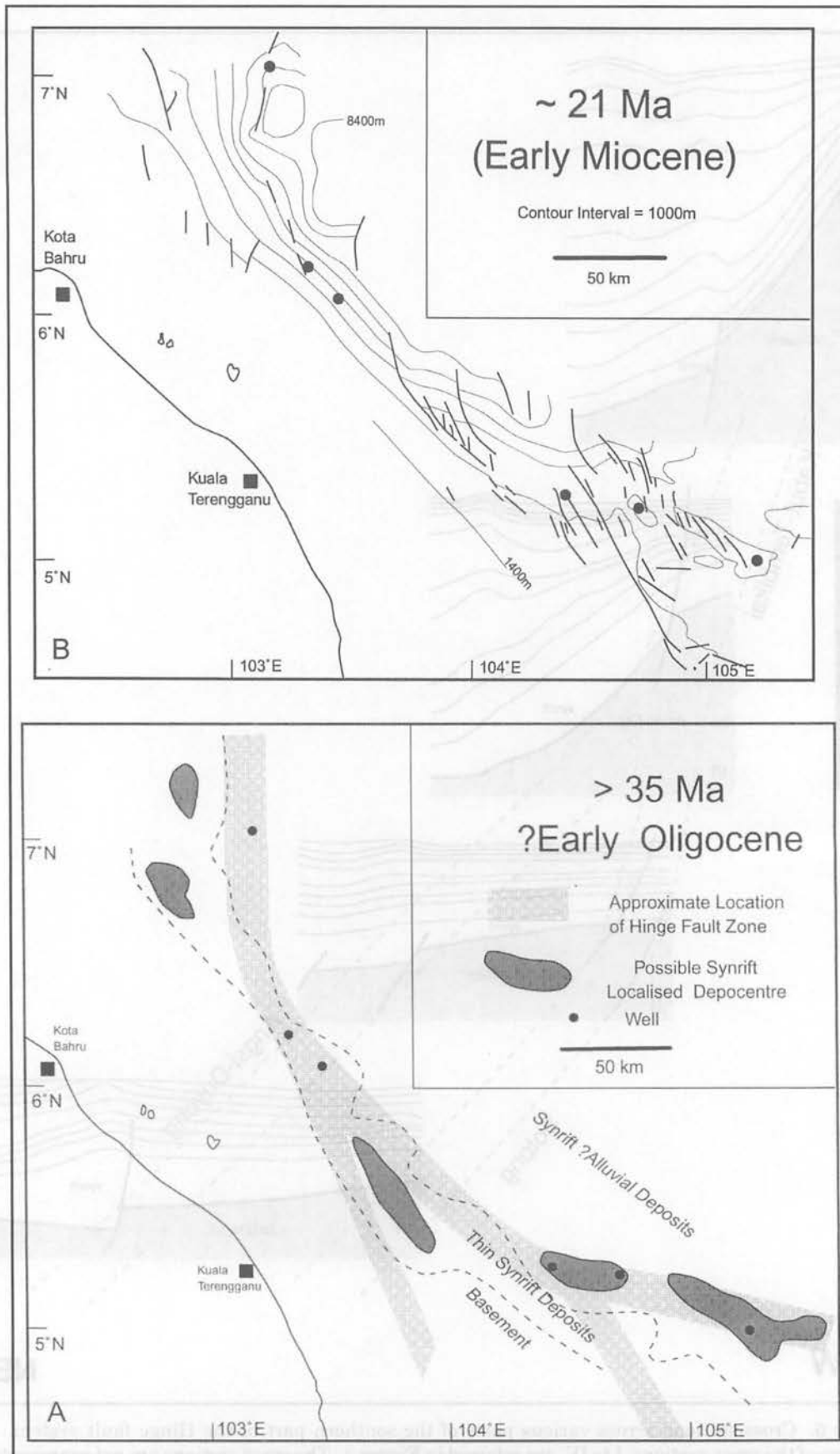


Figure 6. (A) Approximate location of synrift half grabens that are in proximity with the Hinge fault system during ?Lower Oligocene. (B) Structures in the 21 Ma horizon. Adapted from EPIC 1994 study.

whereas this graben is elongated WNW-ESE. Based on the trends, the synrift half grabens within the axis of the Malay Basin and the synrift half graben here are not genetically related. Angsi-Duyong fault zone may be one of the major bounding faults of the synrift half graben here. This fault segment is interpreted to run WNW-ESE within the basement, below the axis of the anticlines. The interpretation of the major southward extension of the Hinge fault system is debatable. Tjia (1993) recognised the Sotong fault segment as part of the (western) Hinge fault zone and did not mention Angsi-Duyong fault segment. If the presence of long distinct faults is used as a criterion to determine whether a segment is major or minor, then the Sotong segment is a major segment. However, the author is inclined to interpret the Angsi-Duyong fault segment as one of the main fault segments because it separates main structural styles within the western margin of the Malay Basin.

Dungun Fault Segment

Among the fault segments, the NNW-SSE Dungun fault segment is the least mapped fault zone (Fig. 2). Both PCSB and EPMI mapped this fault segment as a band of discontinuous faults striking NNE-SSE and only appeared in older horizons (see Fig. 8A). Tjia (1993) and Liew (1993a) provided brief accounts of the main features of this fault segment. This segment is about 6 kilometres wide and 45 kilometres long. The northwest end of this fault segment has been interpreted to merge with the main segments of the Hinge fault zone in the vicinity of Kuda-Kabut. This fault segment terminates in the southeast with the rhomboid Dungun Graben. Three half grabens straddle this fault segment, just northwest of the Dungun Graben. The maximum heave of this fault segment is 1.8 kilometres and its throw is about 2 kilometres. Movement of this fault segment is interpreted from the geometry of the Dungun Graben. The rhomboid shape of Dungun Graben is indicative of a dextral wrenching origin. NNW-striking drag folds and right-stepping *en echelon* faults in younger sequences (?Miocene) within the graben suggested later sinistral wrenching (Liew, 1993b; Tjia, 1993). In short, this fault segment is interpreted to have experienced right lateral movement earlier and a later reversal of lateral movement.

Sotong Fault Segment

A 100-kilometre long continuous fault accompanied by a band of short discontinuous faults characterises the NW-SE Sotong fault segment. This major fault segment separates the Tenggol Arch from Angsi-Duyong sub-basin (Figs. 2 and 3). There are two major faults in this fault segment.

One is situated in the northwest and the other in the southeast. Ng (1987) named the 100 kilometre long fault that is situated in the southeast part of this fault segment as the Tenggol fault. The major northwest fault in this fault segment is the Sotong fault. This fault is the northeast bounding fault for the Sotong structure. The Sotong fault is less than 40 kilometres long. Within these two major faults is a band of discontinuous faults. In this paper, the two major faults together with the band of discontinuous faults is named the Sotong fault segment. The average width of this fault segment is 15 kilometres. The northern end of this fault segment can be interpreted either to merge with the main segment of Hinge fault system in the vicinity of Tembikai and Angsi or to continue northward as the N-S Laba-Mesah fault zone (see Tjia, 1993).

Characteristic Differences Among Fault Segments

The descriptions of the various segments of the Hinge fault system suggest that this fault system manifests itself differently in various parts of the basin. The fault system can be indicated by the presence of curvilinear faults forming rhombic depressions, long continuous linear faults or short *en echelon* faults. Along the main segments of the Hinge fault system, only the Ular-Kuda fault segment and the northern sub-segment of the Kabut-Tembikai have rhombic depressions. The width of the fault segment may play a role in the formation of the rhombic depressions within the fault system (Tjia, pers. comm.). There must be a critical width for the formation of rhombic depressions. On the average, the northern part of Hinge fault system tends to be wider.

The depth of the basement may also be a contributory factor for the differences in characteristic among the fault segments. The basement tends to deepen northwards. Figure 4 and 5 depict the various cross-sections across different parts of the Hinge fault system. The fault system transects the basement of different topographic characteristics. In the north, (Figs. 4A to 4C), the basement slope tends to steepen in the proximity with the fault system. Basement in the southern segment of the fault (Figs. 4D to 4G, Figs. 5I to 5IV) is more highly faulted than that of the north. The fault system tends to transect through the faulted edge of the basement. The long continuous Sotong fault segment cuts across the basement of relatively shallow depth (Figs. 4F and 4G). The presence of the northerly left stepping *en echelon* faults on the crests of the Angsi-Duyong anticlines may indicate right lateral movement of the basement fault during structural inversion.

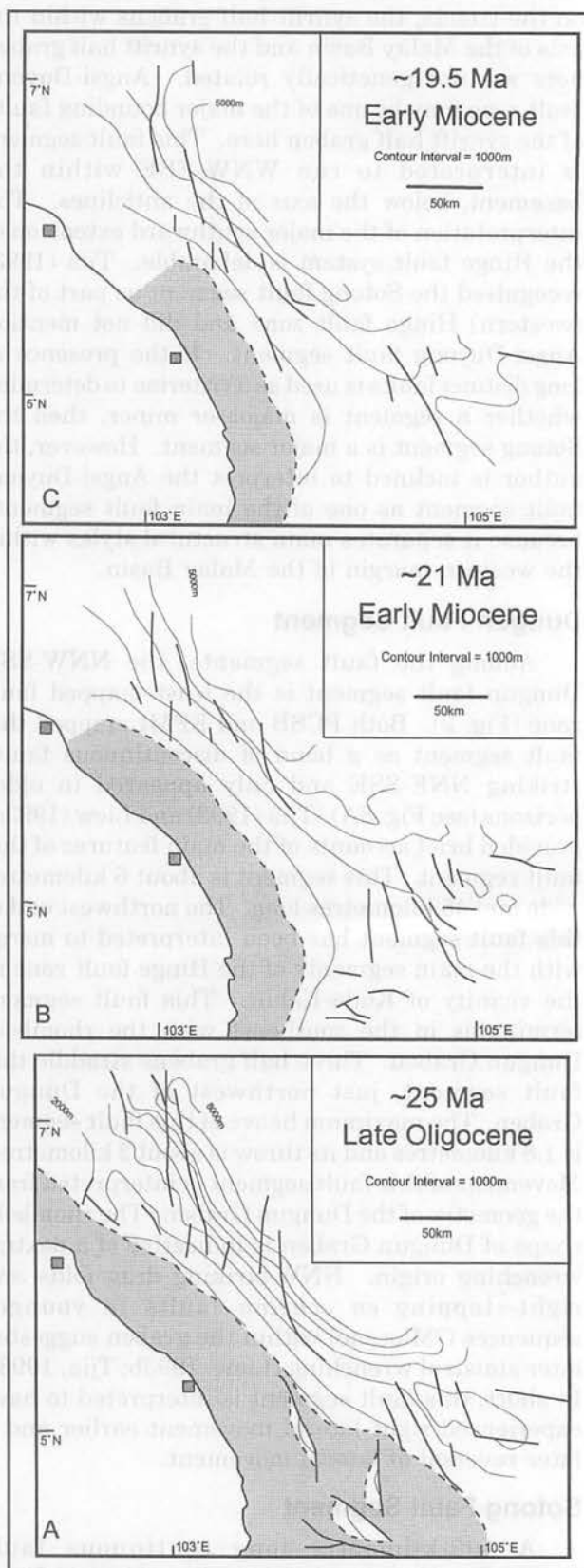
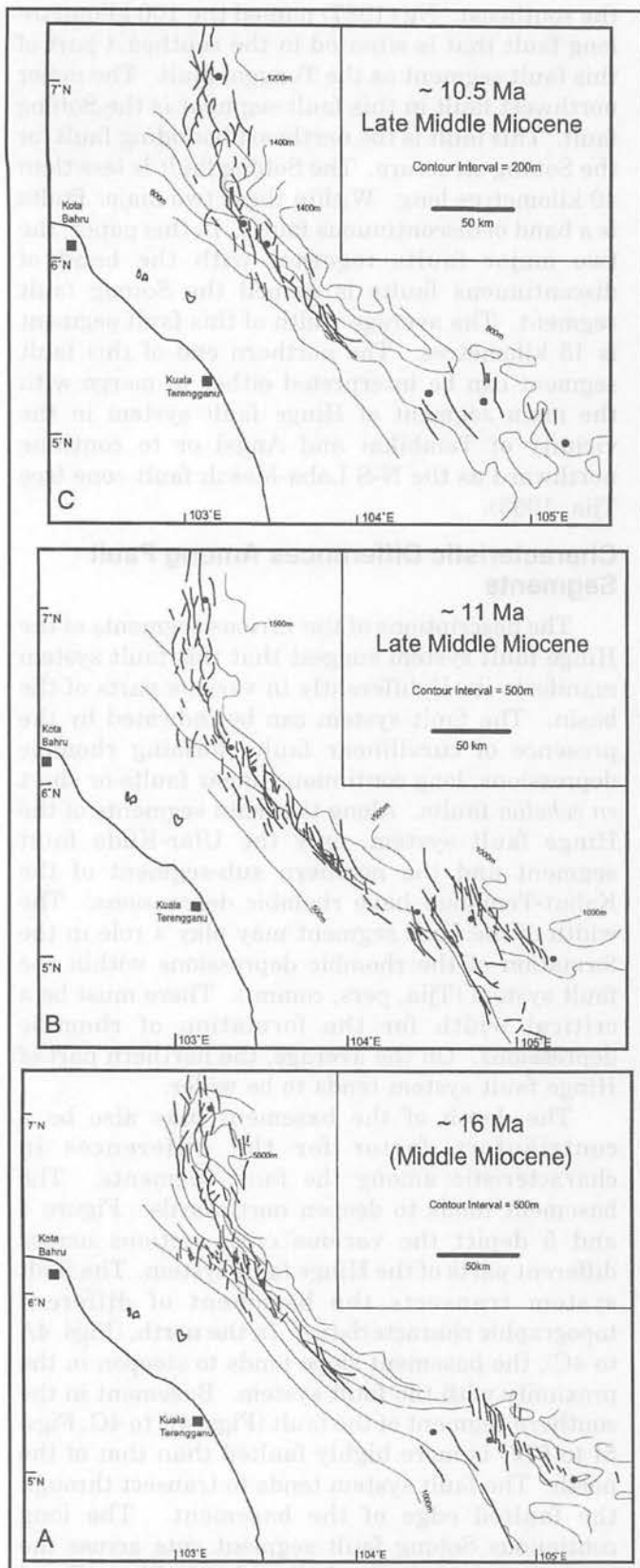


Figure 7. (A–C) Structures of the Hinge fault system at various structural horizons. Adapted from EPIC 1994 study.

Figure 8. (A–C) Structures of the Hinge fault system at various structural horizons. Shaded areas indicated areas of non-deposition during that period. Adapted from PCSB regional study 1994.

Transpressional anticlines are located above the Angsi-Duyong basement fault (Figs. 5I and 5II).

STRUCTURAL HISTORY

The Hinge fault system may have formed contemporaneous with the formation of the Malay Basin. During ?Early Oligocene, the activation of the Hinge fault system may have created synrift half grabens on the western margin of the Malay Basin. Here, the synrift half grabens are elongated either northerly or NW-SE (Fig. 6A). It should be noted that synrift half grabens are also formed in the centre of the Malay basin, but they are elongated in the east-west direction. Based on the orientation of the rhombic depressions and the general strike of the faults in the Ular-Kuda fault segment and northern sub-segment of Kabut-Tembikai fault segment (collectively known as northern segments of Hinge fault system), Tjia (1993) suggested that this part of the Hinge fault system has experienced right-lateral slip before Late Oligocene. Almost during the same period, the Dungun fault segment also experienced right lateral movement (Liew, 1993a; Tjia, 1993). This initial movement of the Dungun fault segment was inferred from the orientation and geometry of the Dungun Graben. Reversal of wrench movement (left lateral) within the northern segments of the Hinge fault system occurred during middle to late Miocene (Tjia, 1993). The evidences provided by Tjia (1993) are the occurrence of anticlines within the Upper Oligocene-Miocene sedimentary fills. The strike of these anticlines are subparallel to the length of the depressions. Using similar evidences for the Dungun Graben, Liew (1993b) and Tjia (1993) suggested that the Dungun fault segment also experienced wrench reversal (left lateral) contemporaneously with the northern segments of the Hinge fault system. During middle to late Miocene, left stepping *en echelon* faults were formed on the crests of the WNW-ESE anticlines of Angsi, Besar and Duyong. If the left-stepping *en echelon* faults are indicative of a right lateral shearing within the basement of Angsi-Duyong, then these *en echelon* faults are extensional fractures developed by reorientation of the maximum principal stress by the wrenching of the basement fault (Tjia, 1972). Hence, it can be inferred that the Angsi-Duyong fault segment underwent right lateral movement during the reversal period. This sense of motion is opposite to the lateral motions of the northern segments during the same period. The lateral movements, if any, of the Sotong fault segment and southern sub-segment of Kabut-Tembikai fault segment cannot be inferred from the information presently available.

During Early Miocene, most of the active faults within the Hinge fault system are located in the southern segments (Fig. 6B) of the Hinge fault system. The faults here generally trend NW-SE whereas those on the northern segments trend N-S. The northern segments have higher topographic relief than the south. The concentration of faults shifted northward to Ular-Kuda fault segment during Middle Miocene (Fig. 7A). During Late Middle Miocene (Fig. 7B), there are many faults in the Hinge fault system. However, the Kabut-Tembikai fault segment shows its prominence during this period. Towards the end of Late Middle Miocene (Fig. 7C), most of the faults are found in the northern segments of the Hinge fault system.

Figures 8 and 9 show the changes in the abundance of faults within different segments of the Hinge fault system from Upper Oligocene to Upper Middle Miocene. During Upper Oligocene, the concentration of the faults are in the northern and southern parts of the fault system (Fig. 8A). The central part is almost devoid of faults. Faults in the northern part are mostly north-south whereas those in the south are NW-SE. Northwesterly and northerly striking half grabens are found close to the southern part of the fault system. During Lower Miocene (Fig. 8B), most of the faults are found in the southern part of the fault system. The concentration of faults shifted northwards to the Kabut-Tembikai fault segment at approximately 19.5 Ma (Fig. 8C). From Middle Miocene to Late Middle Miocene, many faults were found in the Ular-Kuda fault segment (Figs. 9A to 9D).

If the abundance of faults within a fault segment can be regarded as a proxy for the intensity of the fault activity during that period, then it can be seen that the intensity of fault activity within the Hinge fault system has progressively shifted northwards during its structural development (Fig. 10). During Early Miocene, the main activity of the fault system was in the southern part (Sotong & Angsi-Duyong fault segments). From Middle Miocene to Late Miocene, fault activity is mainly concentrated on the northern part (mainly the Ular-Kuda fault segment).

Figure 11 shows the sedimentation rates at various locations of the Hinge fault system from Oligocene to Recent. The maximum sedimentation rates recorded in this fault system is about 500 metres/Ma. The sedimentation rate of an area is influenced by the rates of uplift, subsidence and supply of sediments (Blatt *et al.*, 1980). If subsidence and sediment supply are assumed constant, then sedimentation rate will be a function of the rate of uplift. Rate of uplift for a local area is an indicator for local fault activity. The sedimentation rates within the fault system have a maximum value of

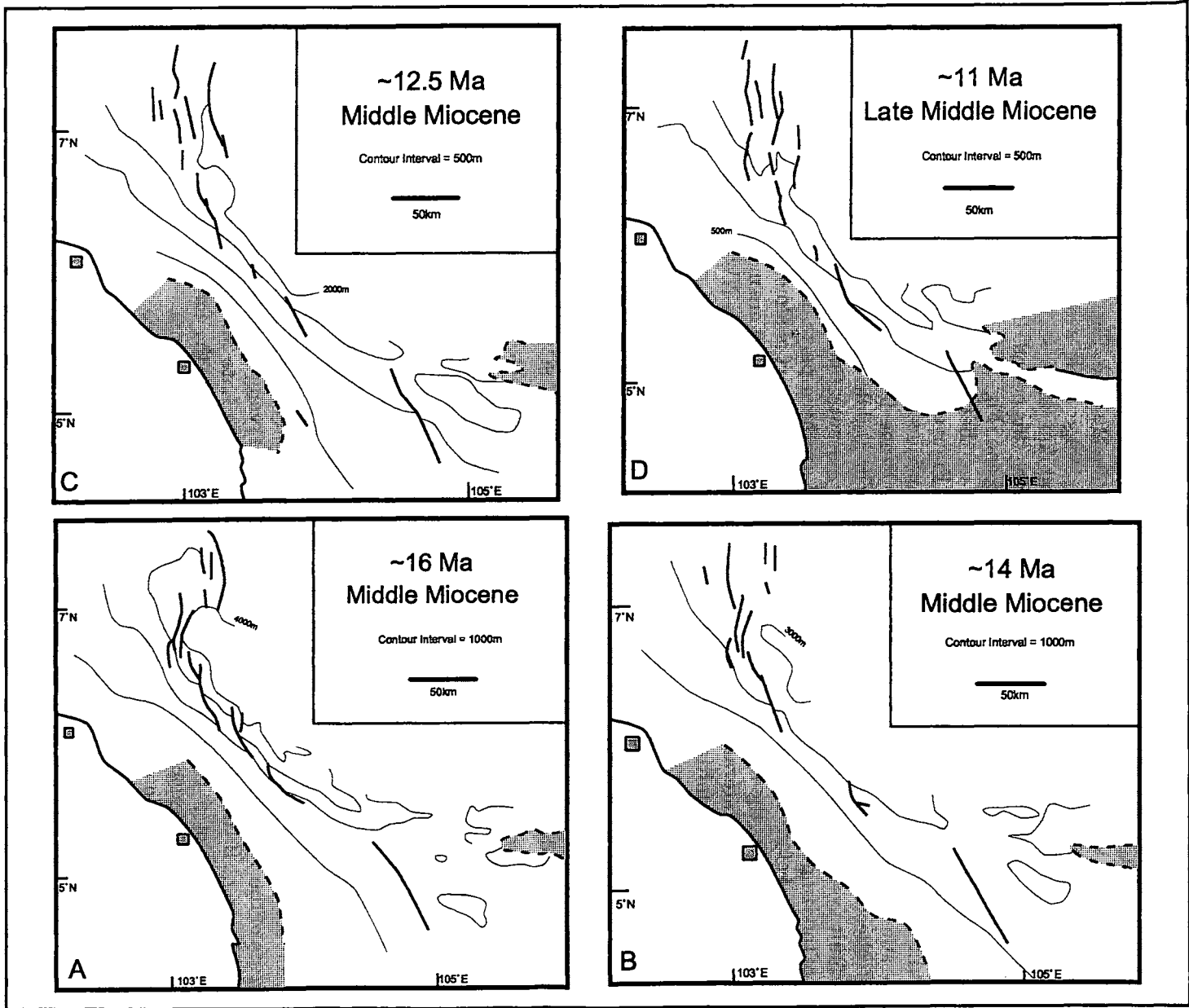


Figure 9. (A–D) Structures of the Hinge fault system at various structural horizons. Shaded areas indicated areas of non-deposition during that period. Adapted from PCSB regional study 1994.

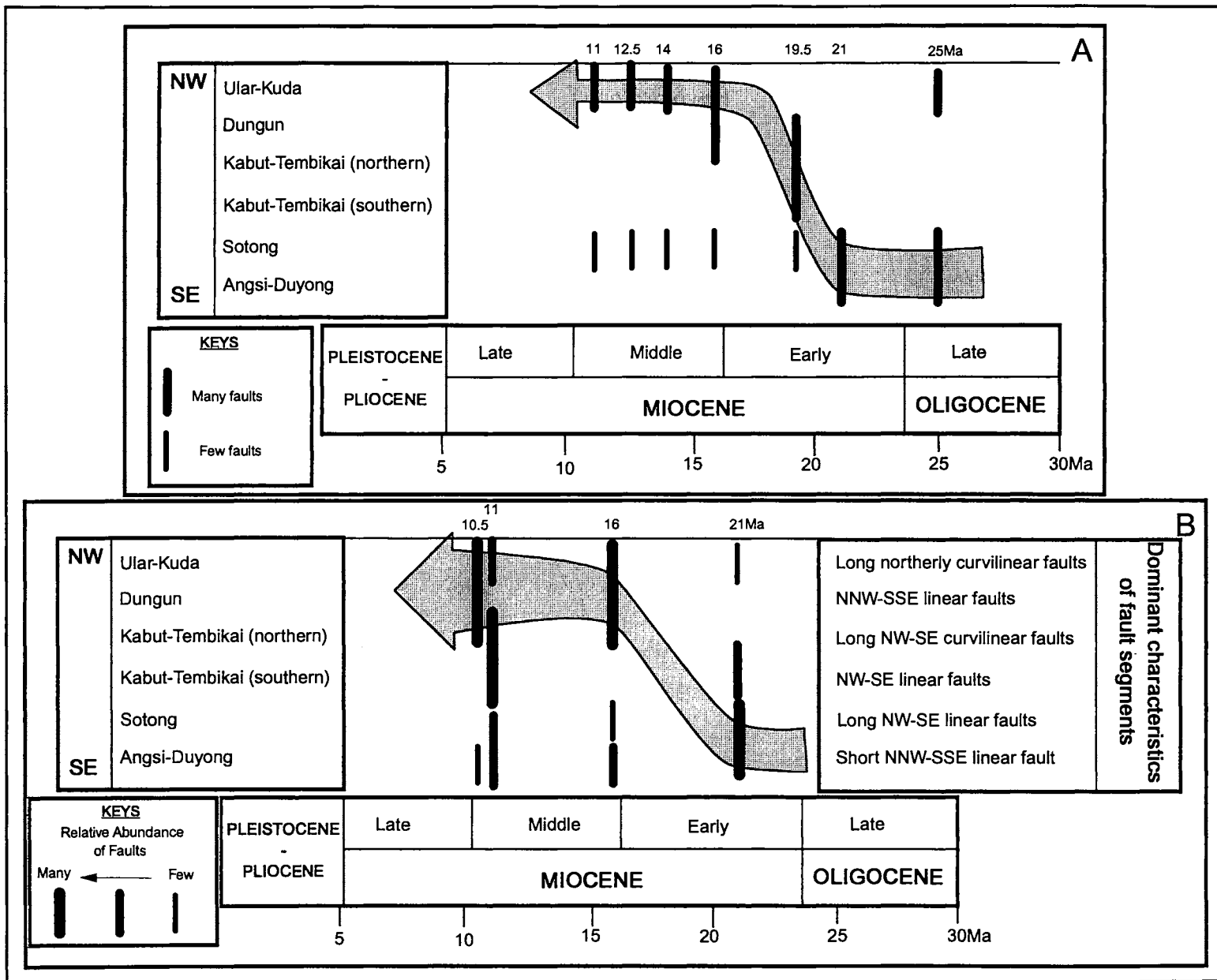


Figure 10. Relative abundance of faults within different fault segments in the Hinge fault system from Upper Oligocene to Upper Miocene. Large arrow showing the northward shift in fault concentration. (A) Information extracted from PCSB regional study 1994. (B) Information extracted from EPIC 1994 study.

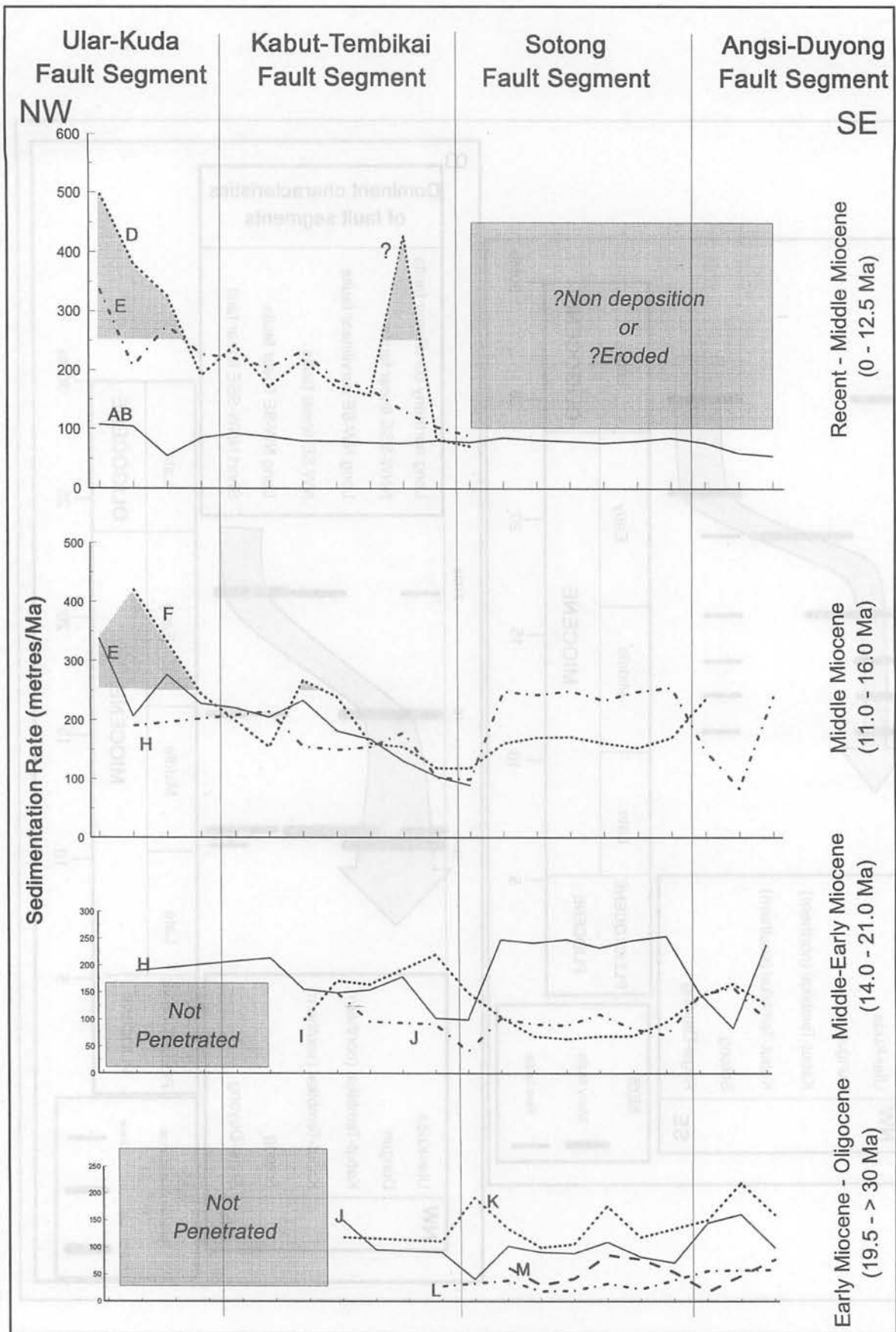


Figure 11. Line graphs depicts the relationship between sedimentation rates and different locations within the Hinge fault system from Oligocene to Recent. The letters AB to M represent the sedimentary sequences within the Malay Basin using EPMI seismo-stratigraphic scheme. The shaded areas represent sedimentation rates more than 250 metres/Ma.

500 metres/Ma. From Oligocene to Early Miocene, the sedimentation rates in different parts of the fault system did not exceed 250 metres/Ma. It can be inferred that the fault activity within the fault system was relatively low during Oligocene to Early Miocene as compared to Middle Miocene to Recent. During Middle Miocene to Recent, sedimentation rates were found to be higher in the northern part of the Ular-Kuda fault segment than in the southern part of Kabut-Tembikai fault segment. There was a gradual increase in sedimentation rates from south to north. This pattern may suggest that faults within the northern segments of the Hinge fault system became progressively more active northward during this period.

REGIONAL SETTING AND IMPLICATIONS

Tjia (1994) proposed that the Malay Basin originated as one of the three aulacogens developed from a Late Cretaceous hot spot. During ?Late Eocene to Early Oligocene, the NW-SE Axial Malay fault moved sinistrally (The Axial Malay fault is interpreted to run through the basin axis of the Malay Basin and is a southeast continuation of the Three Pagodas fault). However, the Hinge fault system that straddles the western margin of the Malay Basin moved dextrally. The difference in lateral movements between these two major faults is due to the differential southeastward movements of the various tectonic slabs within the Malay Basin. The faults act as boundaries for the tectonic slabs. The southeastward movements of the tectonic slabs are caused by the extrusion of southeast Asia by the indentation of Indian subplate into Asia (Tapponnier *et al.*, 1982). Thermal subsidence dominated the tectonic activity of the Malay Basin from Late Oligocene to Early Miocene. A transpressional stress regime prevailed in the Malay Basin from late Early Miocene to Late Miocene. During this period, wrench motions of the major faults in the Malay Basin were reversed from their initial directions; the Axial Malay fault moved dextrally while the Hinge fault system moved sinistrally. Pliocene to Recent has been a period of tectonic quiescence in the Malay Basin.

Figure 12 shows the schematic block diagram of the Hinge fault system and the lateral movements of its various segments during Tertiary. It can be seen that the lateral movements of the Ular-Kuda, Dungun, and Kabut-Tembikai fault segments had been in unison throughout Tertiary; right-lateral slip during ?Early Oligocene and left-lateral slip during Middle to Late Miocene. The lateral movement of Sotong fault segment is unknown due to the lack of horizontal stress indicators. However,

it is assumed that this fault segment experienced the same lateral motion as the rest.

During the synrift period (?pre-Oligocene), it is believed that right-lateral slip has created the half grabens within the basement along the Dungun and Angsi-Duyong fault segments. The lateral slip of the whole Hinge fault system is interpreted to be right-lateral at that time. During the transpressional period, the lateral movement of Angsi-Duyong fault segment may have been influenced by the right-lateral movement of the Axial Malay fault. Structural inversion occurred at Angsi-Duyong fault segment with transpressional anticlines over the synrift half grabens. Left-stepping *en echelon* faults on the crests of the anticlines suggest right lateral movement of the Angsi-Duyong fault segment during this period.

Based on the discovery of Triassic "reefal" limestone in the basement of Sotong well (within Sotong fault segment), Fontaine *et al.* (1990) suggested that pre-Tertiary basement of ages ranging from Lower Carboniferous to Upper Triassic probably exists in the Malay Basin. It is argued that Terengganu state lacks Triassic sequences, suggesting an emergence of that area during this period. They believe that Terengganu state remained as a horst block between two subsiding basins since Triassic. The main fault on the west of the horst block was inferred to be the paleo-Lebir fault. Coincidentally, Jura-Cretaceous sedimentation was also influenced by the this paleo-Lebir fault.

Tjia and Zaiton Harun (1985) recognised the Lebir fault (lineament) as the important boundary that separates the central geological domain from the eastern geological domain in Peninsular Malaysia. This NNW-SSE fault runs through the Lebir valley for almost 200 kilometres. The northern segment of this fault comprise fault strands ranging up to a few tens of metres. The width of this fault system can reach up to a few kilometres. Towards the south, this fault system trends more southerly (Tjia, 1969). One of the major faults in the south of the Lebir fault is the Lepar fault. This fault trends NW-SE and also represents an important geological demarcator; it represents a geological boundary between Carboniferous sediments and Jura-Cretaceous sediments. The combined length of the Lebir and Lepar faults reach up to 420 kilometres, stretching from the Thai-Malaysia border southeastwards to Mersing, Johor. Both the Lebir and Lepar faults are interpreted as left lateral strike-slip faults. The latest movement occurred in Cretaceous (Tjia, 1976; Lee, 1990).

Most outcrops of Jura-Cretaceous age in the central belt of Peninsular Malaysia are situated near its eastern boundary. Presently, these outcrops

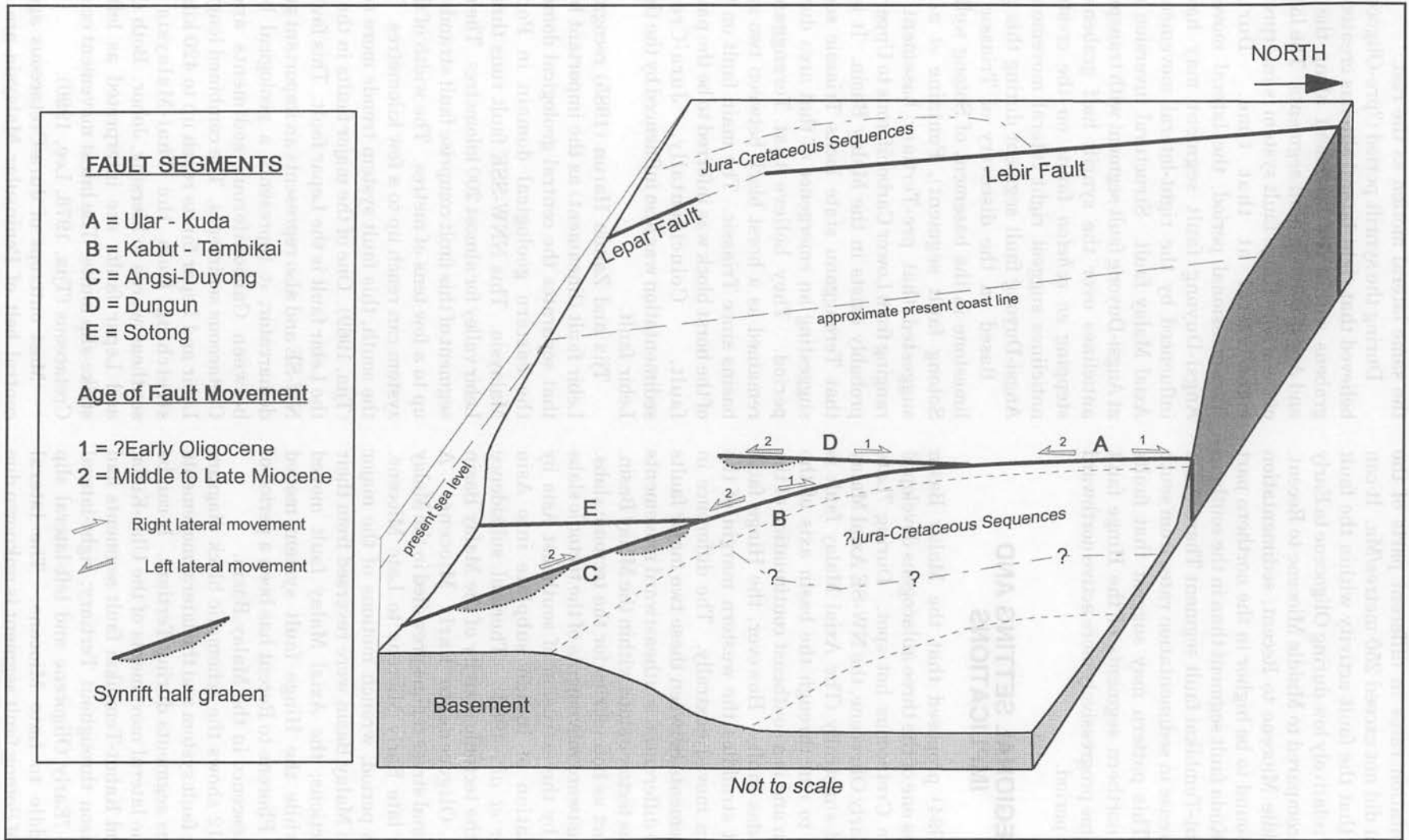


Figure 12. Schematic block diagram depicting movements of the various fault segments of the Hinge fault system during Tertiary.

are separated from one another. Khoo (1983) found that Jura-Cretaceous formations have good lithostratigraphic correlation with one another, suggesting connectivity between different formations during their deposition. The Koh Formation and Tembeling Group (Jura-Cretaceous) are situated west of the Lebir and Lepar faults. Koopmans (1968) suggested that during the deposition of the Tembeling Formation, the clastics originated from the highland areas situated east of the Lebir fault. The close proximity between the Jura-Cretaceous sequences and the Lebir and Lepar faults suggested fault controlled deposition of these Jura-Cretaceous sequences.

With the Lebir fault as the main fault zone in the western boundary of a paleo-horst, one may question the location of the main fault zone on the eastern boundary. The author proposes that the Hinge fault system is the major fault that demarcates the eastern end of the paleo-horst. Though some major northerly faults have been mapped within Terengganu state (see Tjia, 1992), they do not seem to control the Mesozoic sedimentation in Peninsular Malaysia. Recent acquisition of 15 deep regional seismic lines (12 seconds) of the Malay Basin by Petronas Carigali revealed that the SW-NE cross-section of the basement profile does not just resemble an asymmetrical depression with the west side steeper than the east. The asymmetrical depression is only depicted in the basin profile from Upper Oligocene onward. The true basement profile resembles a funnel, i.e., inclined margin at the upper part with a vertical margin at the lower part. Tjia (pers. comm.) interpreted that the vertical margin in the deeper part of the basin to represent the rifted axial zone of the Malay Basin. After seismic reprocessing, layered reflections of several kilometres are found within the axial zone of the Malay Basin. These layered reflections can be interpreted as deposits of pre Upper Oligocene sequence, perhaps Jura-Cretaceous or Triassic. The Hinge fault system can be traced downwards to the vertical margin of the axial zone of the Malay Basin. The vertical margin may be the major paleo-fault that delineated the eastern margin of the paleo-horst during ?Triassic. The Hinge fault system may be the Tertiary manifestation of this paleo-fault. If the Hinge fault system was a boundary fault for the paleo-horst since Triassic, it is highly probably that Jura-Cretaceous sediments were deposited in the area along the eastern side of the Hinge fault system (Fig. 12). In other words, Tertiary sediments within the Kerteh Ramp and its eastern zone may be underlain by Jura-Cretaceous sequences.

CONCLUSIONS

The curvilinear Hinge fault system is a major boundary fault on the western margin of the Malay Basin. Five major fault segments are identified by their differences in trends and structural styles; Ular-Kuda, Kabut-Tembikai, Angsi-Duyong, Dungun, and Sotong fault segments. The expressions of the faults can be in the form of curvilinear faults (mostly in the northern segments), long continuous linear faults (mostly in the southern segments), and short *en echelon* faults (characteristic of the Angsi-Duyong fault segment). Rhombic depressions are only found in the northern segments. The formation of these depressions may be controlled by the width of the fault zone and the depth of the basement. The interpretation of the lateral movements of the fault segments are based on the orientations of the rhombic depressions and its associated anticlines. Right-lateral movements were detected on the northern segments of this fault system from ?Late Eocene to Early Oligocene. The reversal of wrench movement in the northern segments is interpreted to have occurred in Middle Miocene. There is no horizontal stress indicator within the southern segments of this fault system. However, it is assumed that these have experienced similar movements as the northern segments. The Angsi-Duyong fault segment probably experienced different lateral movement during Middle Miocene; the movement of this fault segment is interpreted to have been the same as the movement of the axial Malay fault zone (right lateral). The dominant fault activities within this fault system may have progressively shifted northwards from Early Miocene to Late Miocene. The patterns of abundance of faults and sedimentation rates within the fault segments through time support this inference. On a regional basis, the Hinge fault system may be one of the major zones of weakness in southeast Asia, that facilitated that extrusion of south east Asia during the indentation of Indian subplate into Asia. This fault may have also complemented the Lebir fault in the formation of the paleo-horst in Terengganu state during ?Triassic.

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