GEOSEA '98 Proceedings, Geol. Soc. Malaysia Bull. 43, December 1999; pp. 417-432

Ninth Regional Congress on Geology, Mineral and Energy Resources of Southeast Asia — GEOSEA '98
17 – 19 August 1998 • Shangri-La Hotel, Kuala Lumpur, Malaysia

# Tertiary tectonic model of North-West Borneo

ISMAIL CHE MAT ZIN

Institute of Technology Petronas
31750, Tronoh, Perak
Malaysia

**Abstract:** The recent study on the Sarawak Basin indicated that the formation, sedimentation and deformation of the basin were dominantly controlled by strike-slip tectonism. This finding seems to be inconsistent with the present available regional tectonic models including subduction (James, 1984) and southward thrusting (Untung, 1990) models where acceptance are already on the decline, judging from the recent publications. Although there are several publications on strike-slip lineaments in Sarawak, strike-slip tectonism was not regarded as one of the present tectonic models as the occurrences of strike-slip lineaments in Sarawak were only regarded as local phenomena.

This paper aims to further discuss the geological and geographical evidences for the presence of several major lineaments in the onshore area that could be used as evidences for strike-slip tectonism. Further, this will help in determining whether onshore Sarawak has experienced similar strike-slip tectonism as in the Sarawak Basin. The study has identified nine possible major strike-slip lineaments in onshore Sarawak which could be the extensions of the offshore lineaments.

On the basis of its configuration, it is proposed that north-west Borneo has undergone a series of strike-slip movements which are in NW-SE orientation and gradually changing to eastward direction. The lineaments are progressively younger to the east with several cross-cutting slips. The model with strike-slip movements that are associated with the localised counter clockwise rotation, is proposed to be a new Tertiary tectonic model for the whole onshore and offshore Sarawak.

## INTRODUCTION

The recent study on the Sarawak Basin indicated that the basin formation, sedimentation history and structural deformation of the basin were dominantly controlled by strike-slip tectonism (Ismail, 1997). Five major tectonic lineaments (Fig. 1) have been identified based on the regional seismic data. The geoseismic features across the two lineaments namely west Balingian Line and Mukah Line are shown in Figures 2 and 3 respectively.

Beside the seismic evidences, the subsidence nature of the Sarawak Basin is consistent with the subsidence nature of a strike-slip basin. It is characterised by early rapid subsidence followed by slower rate of thermal subsidence. Many profiles showed polycyclic episodes of deposition and uplift. The evaluation of stretching factor and heat-flow show that the Sarawak Basin is also consistent with the origin of a basin dominated by strike-slip tectonics (Ismail and Tucker, 1997).

This paper discusses the geological evidence for interpreting the onshore lineaments, to determine whether or not strike-slip tectonism model is applicable for the Tertiary tectonic model of north-west Borneo. A model to describe the Tertiary tectonic nature of the north-west Borneo is also generated to facilitate a better understanding on the tectonics of the region.

## PHYSIOGRAPHIC FEATURES

One of the ways to recognise strike-slip lineaments in the onshore area is by identifying the distinctive physiographic features. Several strike-slip faults of heavily vegetated parts of Asia were recognised simply by the great length and linearity of the "rift" topography (Sylvester, 1988). As for onshore Sarawak which is densely forested, the drainage system, mountain range orientations and the linearity of the geological boundaries are the most important indicators of underlying geology.

### Drainage system

The drainage system, that is the flow direction and orientation of the rivers and the orientations of the ridges in onshore Sarawak, provides clues to the occurrence of tectonic lineaments in the area. It is also learnt that the occurrences of most of the identified lineaments in the onshore area between

Igan and Balingian (Fig. 4) coincide with the location of the rivers. The lineaments include the Igan-Oya Line with the Oya River, the Mukah Line with Mukah River and the Lemai Fault with the Lemai River. Similarly the drainage system of onshore Sarawak, is peculiar in that it is characterised by a major river flowing in an E-W direction different from the other smaller rivers.

### Highland ranges

The highland ranges in Sarawak (Fig. 5) are in at least two major orientations. In the SE area, the mountain ranges are sub-parallel in a NW-SE orientation and these ranges are almost perpendicular to the lower hill ranges to the north of the Rajang River which are in a NE-SW orientation and the area near Penembak.

### Boundaries of the geological formations

The boundaries of the geological formations in Sarawak (Fig. 6) also show a great linearity. For example the contact between the Kapit Member (P2) and Pelagus Member (P3pel) of Belaga has been mapped to continue for about 400 km in an E-W orientation. The contacts between other members of the Belaga Formation are almost sub-parallel to the contact between the Kapit and Pelagus Members including the contact between the Belaga Formation and the Oligo-Miocene sedimentary formation to the north, except for the Metah Member and Pelagus Member (P3pel) which is in a NW-SE orientation.

The changes in the physiographic features in onshore Sarawak are believed to be related to the tectonic movements as there is a close interaction between physiographic features and the boundaries of the geological formations. For example, the Rajang River is flowing parallel to the contact between the Kapit Member (P2) and Pelagus Member (P3pel) for about 150 km (Fig. 6). Another example is the Lupar River (Fig. 7), which is one of the biggest in Sarawak, which flows through the Lupar Mélange in the upstream part of the river. In fact, some of the features have already been utilised as evidence for the tectonic elements in proposing the model for the area. For example, the contact between the Belaga Formation and the Oligo-Miocene sedimentary formation was interpreted to represent the Neogene collision caused by the arrival of the Luconia microplate (Hutchison, 1988). The Lupar mélange has been interpreted to represent the Oligo-Miocene subduction zone (Tan, 1982).

## LUPAR MÉLANGE

The location of the Lupar River in Sarawak and is noteworthy for the occurrence of the Lupar mélange (Fig. 8) which is also known as the Lubuk Antu Mélange. This mélange zone marks the boundary between the Belaga Formation (Late

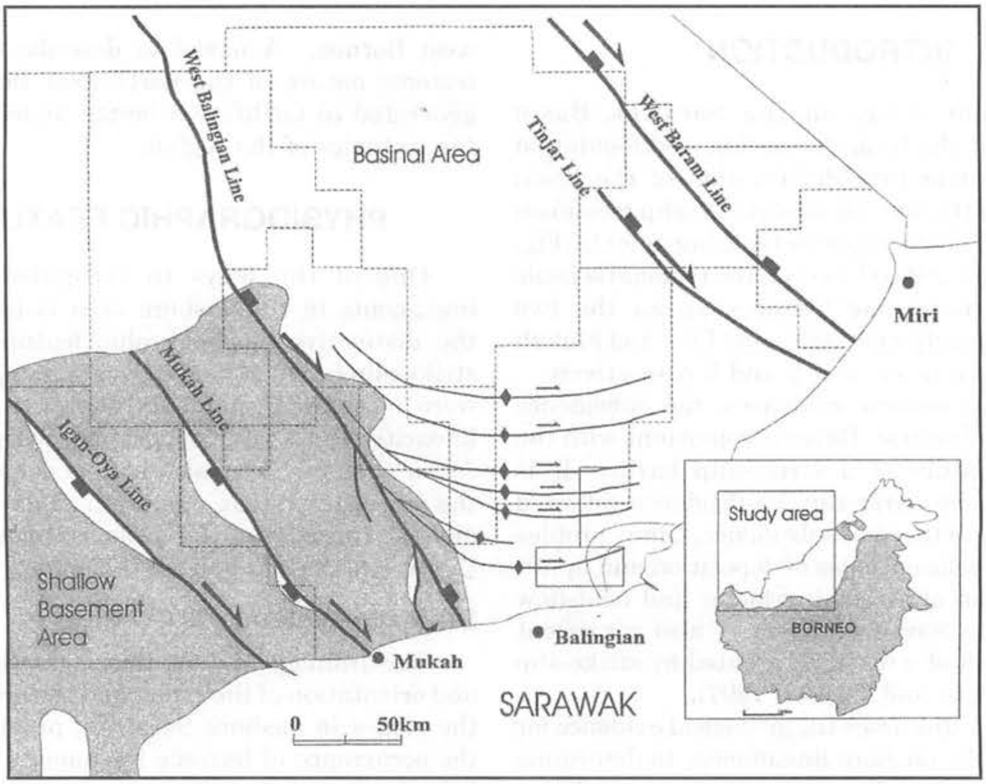


**Figure 1.** Location of major strike-slip lineaments in the Sarawak Basin and the location map of the study area.

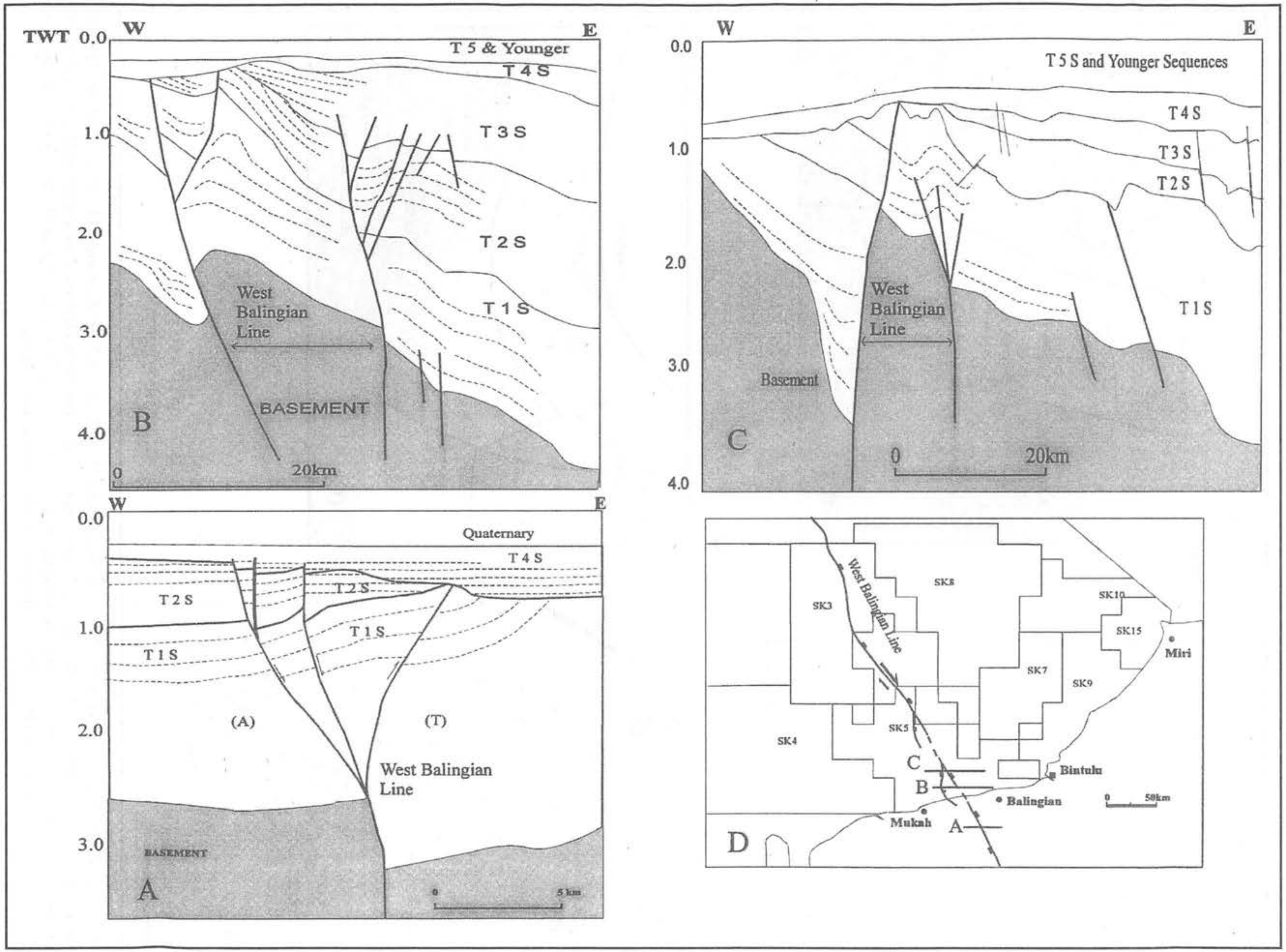


**Figure 2.** (A), (B) and (C) Seismic sections across the west Balingian Line show the nature of the faults within the line. (D) The orientation of the seismic lines.

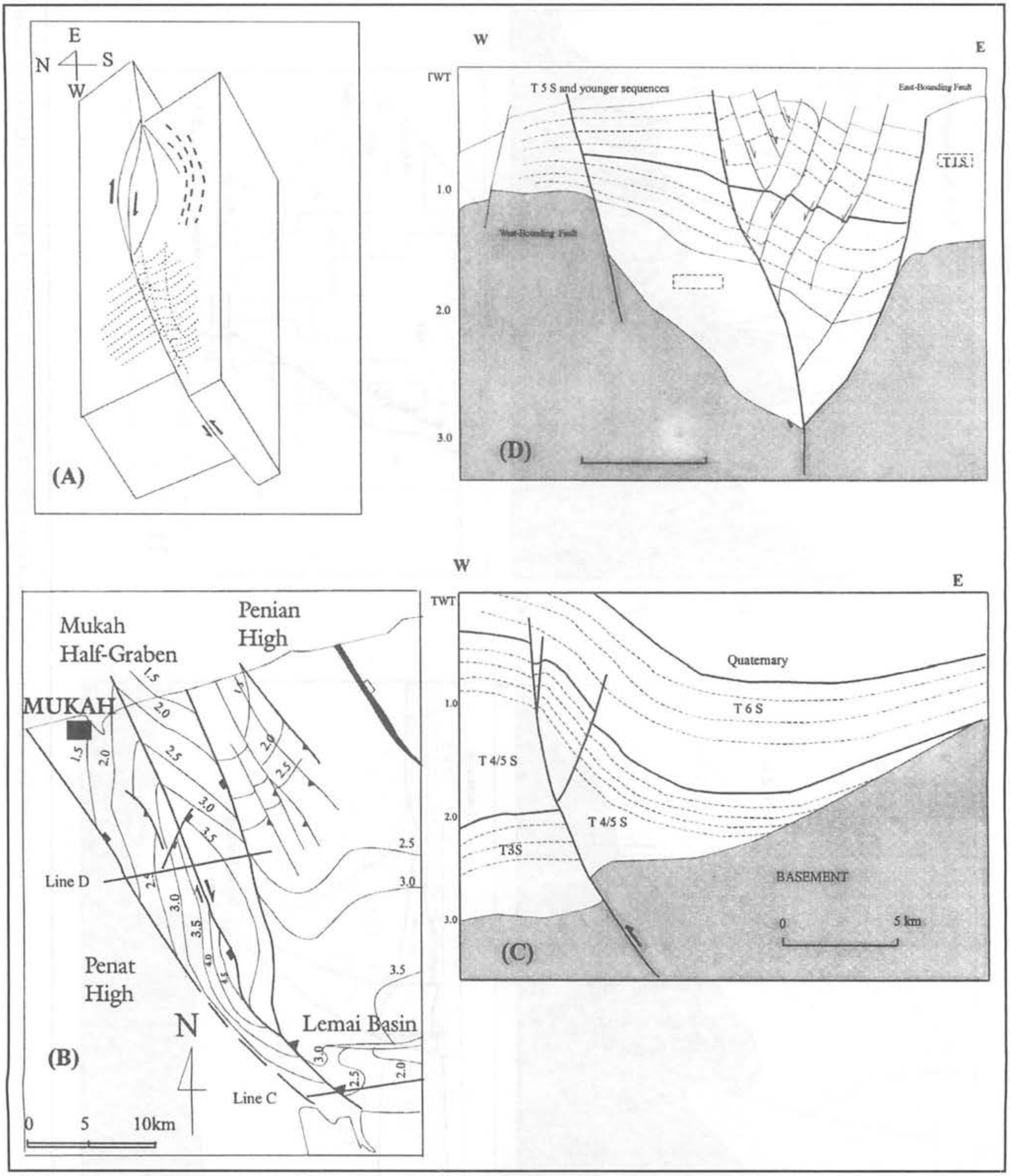


**Figure 3.** (A) Block diagram of Hanmer Basin, formed along Hope Fault in New Zealand. The basin is characterised by transtension and transpression to the west and east respectively. The geometry and kinematics of the Mukah Half-Graben, as shown by the basement map in (B) and the geoseismic sections in (C) and (D), are believed to be analogous to the Hanmer Basin. Refer to (B) for the orientation on the geoseismic sections.

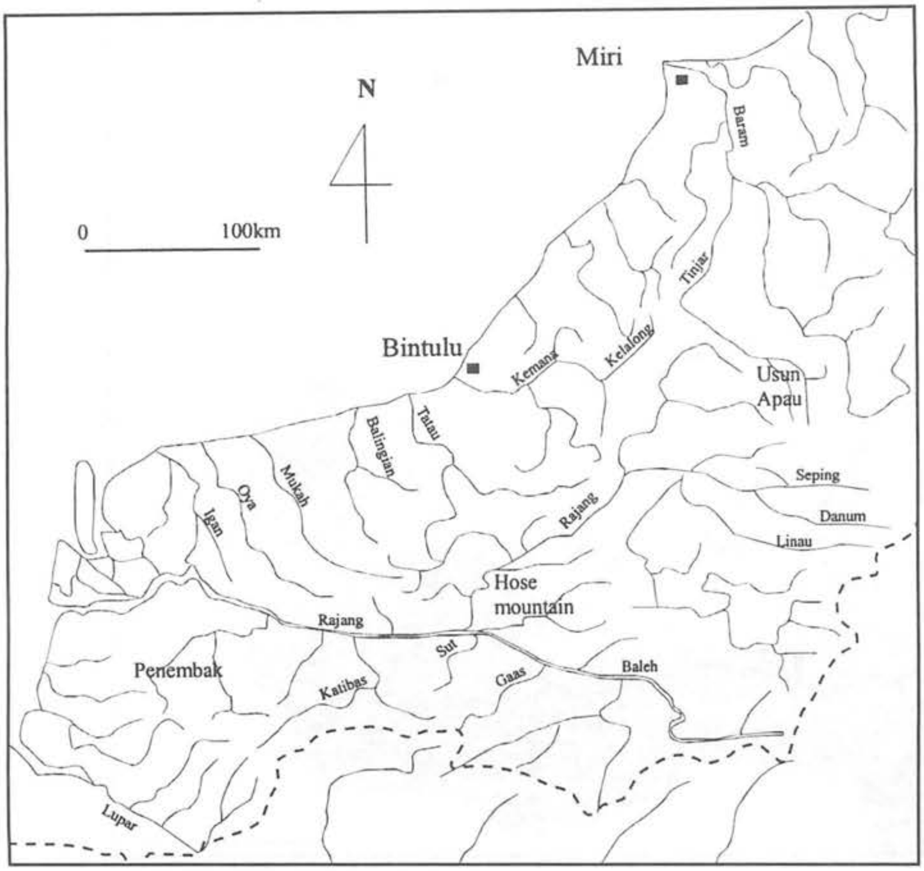


**Figure 4.** River system in Sarawak. Note the changes in the orientation and flow direction of the rivers in the north, south-east and south-west parts of Sarawak.

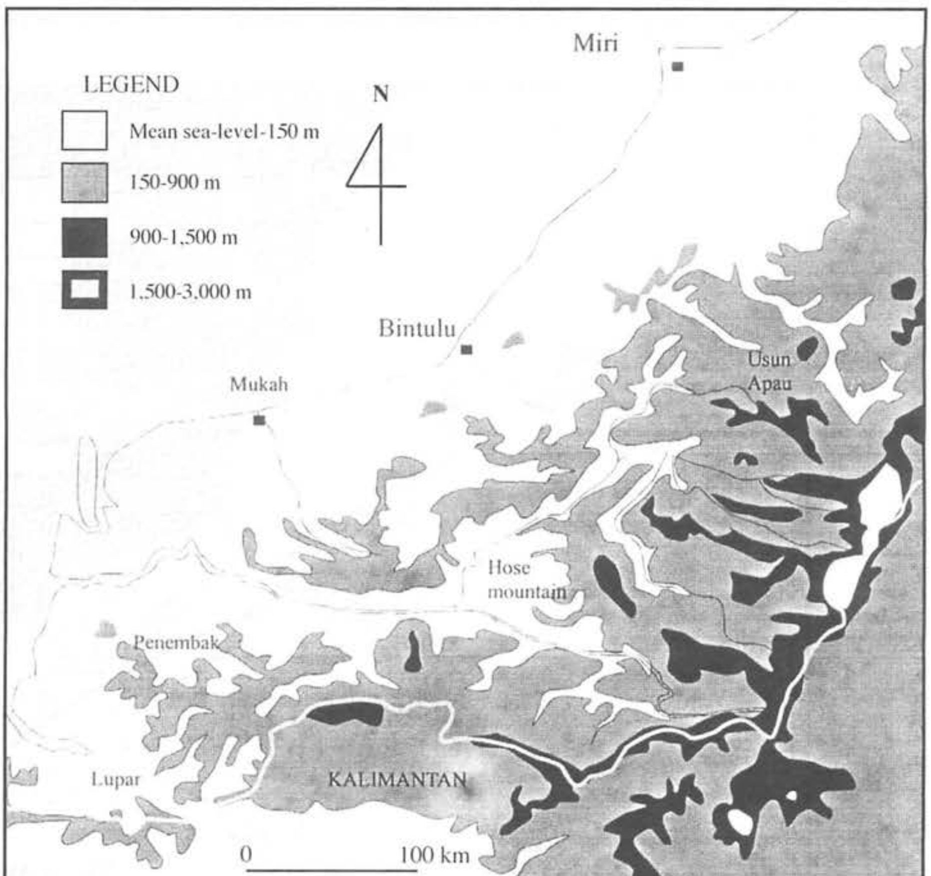


**Figure 5.** Topography map of Sarawak. Note the different orientation of the ridges in the north where the highlands are oriented in an east-west direction, the area near Penembak in the NE-SW orientation and the ranges to the east of Hose Mountain and to the south of Usun Apau are in the NW-SE orientation.

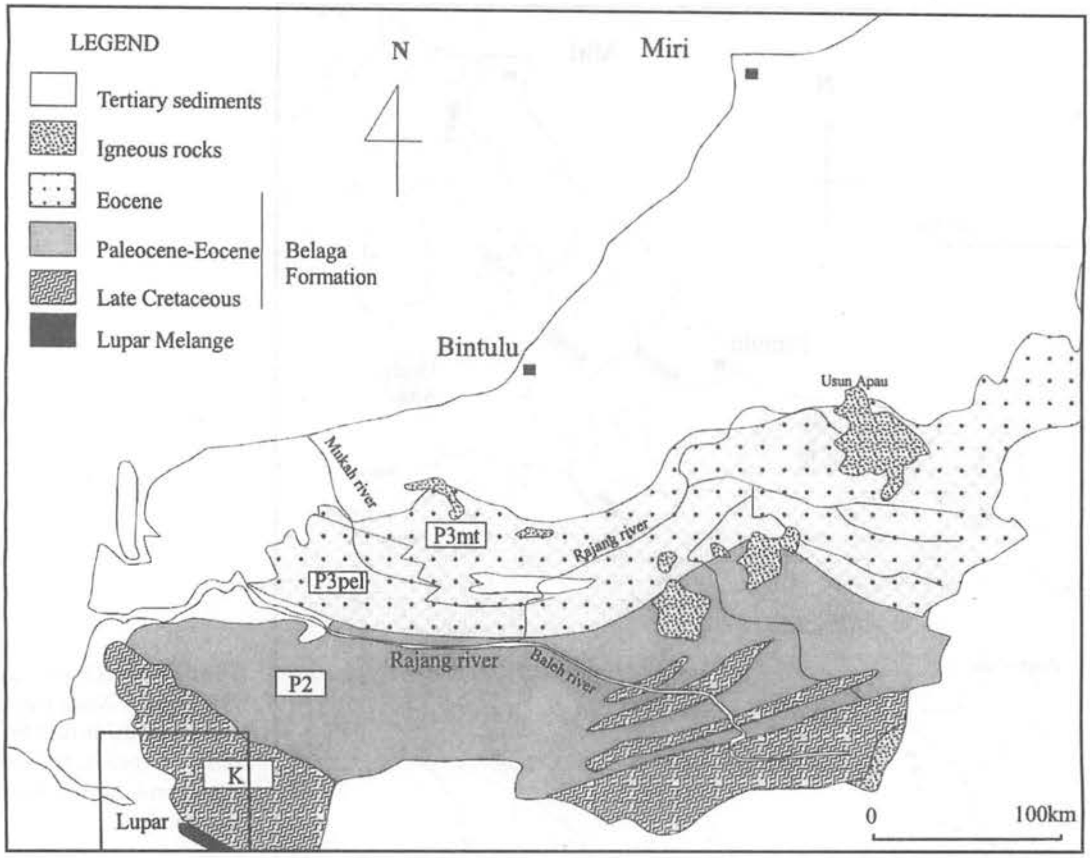


**Figure 6.** The geological map of Sarawak showing the subdivision of the Belaga Formation. The earliest subdivision made by Wolfenden (1960) remained unchanged until present. Map is sketched from Heng (1992). Note also some facies change in the Eocene Belaga Formation between the P3mt and P3pel to the south of Mukah River and the occurrence of Tertiary sediments outcropping within the Belaga formation.

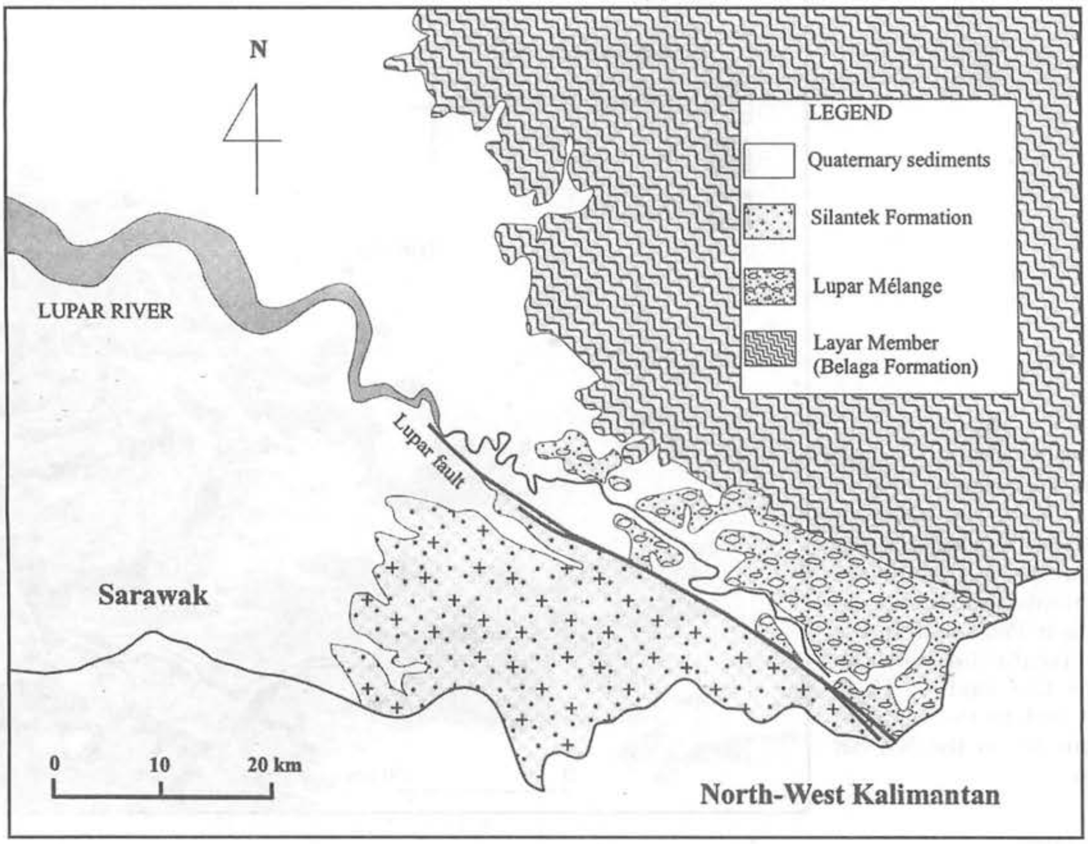


**Figure 7.** Geological map of Lupar area represents the area marked by the square box in Figure 6.

Cretaceous to Eocene) and the Basement complex (Carboniferous-Cretaceous) in the Kuching Area which in places is overlain by the Tertiary sediments known as Kayan and Silantek Formations (Fig. 7).

The Lupar Mélange, with a width of about 20 km, is composed of blocks of mudstone, shale, sandstone, chert, hornfels, basalt, gabbro, limestone and serpentinite in a strongly-cleaved pervasively-sheared chloritised black pelitic matrix (Tan, 1979). The matrix contains foraminifera and nannofossils of Lower Eocene age and the chert contains Lower Cretaceous radiolaria. The chert has not been found in the adjacent Belaga Formation (Tan, 1982).

Jasin and Haile (1993) identified sixteen radiolarian species indicating the age of the Lupar mélange's chert as Albian-Cenomanian (Lower to Upper Cretaceous) which is slightly younger than previously thought. Mahadhir (1994) reported the occurrence of blocks of interbedded shale with thin sandstone laminae which has a lithological resemblance to the Silantek Formation. The age of the Silantek Formation, based on the geological map of Sarawak by Heng (1992), ranges from Eocene to Early Miocene.

According to Tate (1991), the Lupar Mélange extends to NW Kalimantan and is known as the Kapuas complexes. The mélange zone formed as two belts known as the Boyan Mélange and Kapuas Mélange. In the south, the Boyan Mélange extends in an E-W direction for over 200 km in a 5–20 km belt bordered by a prominent fault.

In the offshore area of Kuching (SK19, Fig. 1.2), based on the works of Rapaee (1979) and Ismail (1993), there is a fault-line that appears to be the extension of the Lupar Line characterised by a half-graben filled by Late Miocene sediments (T4S).

Several tectonic models have been proposed by previous workers for the Lupar Line and the occurrence of the mélange rocks, including Holloway (1982), Tan (1982) and James (1984). However, as briefly discussed here, the timing and significance of the Lupar Line to the tectonic models does vary. Among the models that have been proposed are:

1. Holloway (1982) interpreted the Lupar Line as the SW limit of subducting proto China Sea into Borneo during late Cretaceous and

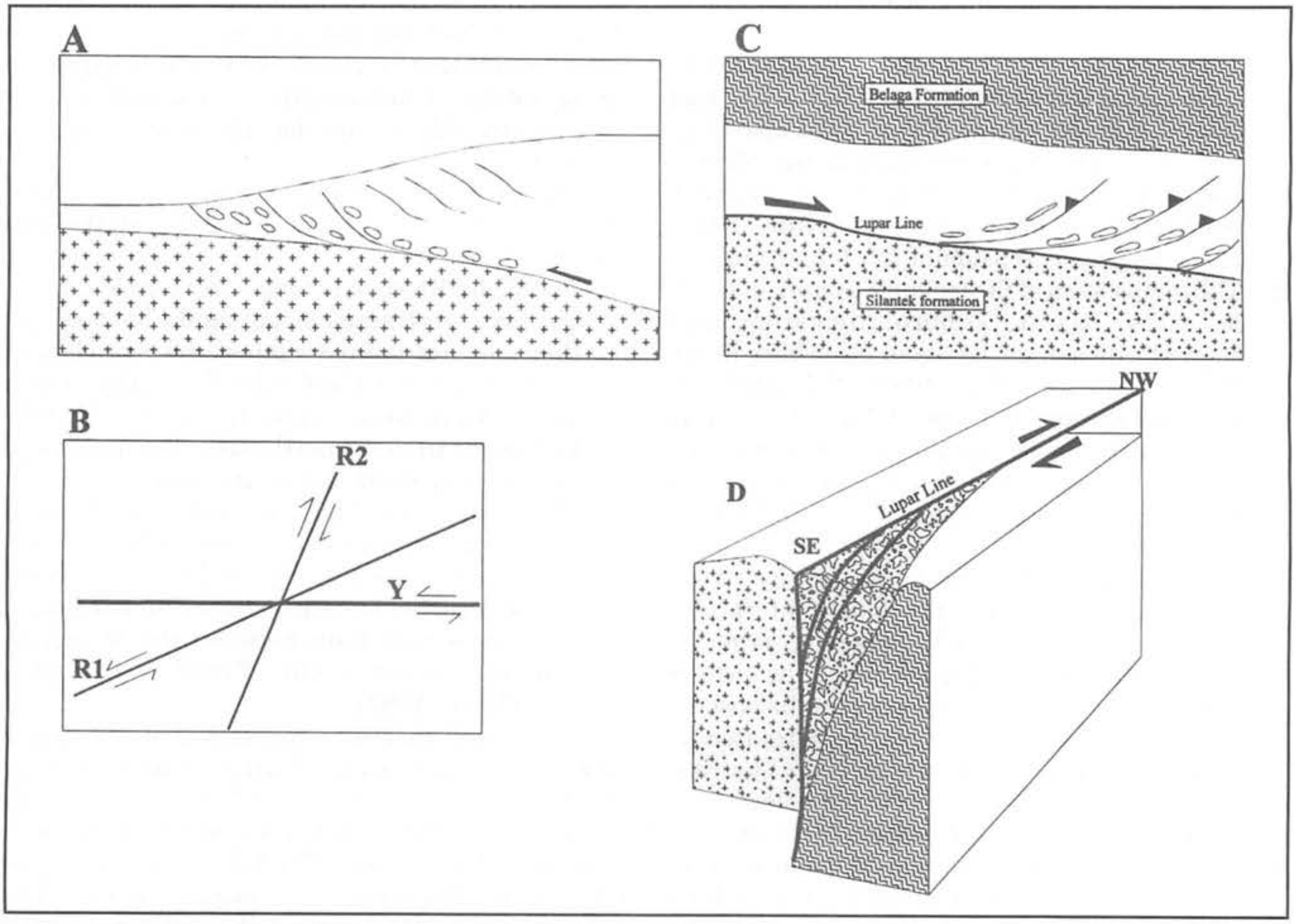


**Figure 8.** (A) The formation of mélange along thrust-fault zones and (B) geometry of secondary structures formed by fracture with Riedel shear fractures around major fault Y. The R1 orientation is of particular interestin this section, based on Needham, 1987. (C) and (D) are the proposed model of strike-slip tectonics along the Lupar Line in two and three dimensions respectively.

terminating during Palaeocene times. This interpretation concurs with those of many workers including Hutchison (1975), Hamilton (1979), Holloway (1982) and Taylor and Hayes (1983).

2. Tan (1982) speculated that the subduction of the northeast oceanic plate and its skin of Lupar Formation (Layar Member of Belaga Formation) and pelagic sediments beneath the southwest continental basement probably took place from very late Cretaceous or Palaeocene to terminal Miocene times. He also interpreted the development of a wedge of deformed "mélange" at the subduction front with incorporated blocks of chert and blocks of Lupar Formation.
3. James' (1984) model proposed that the subduction of the proto South China Oceanic plate was beneath the West Borneo continental basement during Oligocene times. The Rajang accretionary prism that is mainly composed of the Belaga Formation was formed as the result of this subduction.

The observations of the nature of the Lupar Line suggest that the line has characteristics consistent with a strike-slip lineament, on the basis of:

1. The Lupar Mélange is consistently bounded by through-going dominant faults to the SW that extend over 50 kilometres in the Lupar area (Fig. 7). The equivalent rock in the Kapuas complexes in NW Kalimantan is similarly bordered by a prominent fault (Tate, 1991), formed as the extension of the Lupar fault.
2. The composition of the mélange comprises chert, hornfels, basalt, gabbro, limestone and serpentinite cannot be found elsewhere in the Belaga Formation (Tan, 1982). It is similar to the composition and age of Late Jurassic to Late Cretaceous Kedadom and Pendawan Formations that outcrop in the vicinity of Kuching area to the west or NW of the location of Lupar Mélange.
3. The mélange rock could be formed by strike-slip movement, unlike previously interpreted tectonic mélanges which are commonly associated with a subduction zone. The tectonic model cannot satisfactorily explain the absence of volcanics and other features related to subduction. The formation of mélange by strike-slip tectonics is further discussed below.
4. Although there is no publication to the author's knowledge on the formation of mélange rocks by strike-slip tectonics, several workers have reported the occurrence of mélange associated with strike-slip faulting including Sylvester (1988) and Swarbrick (1993). This will be further elaborated below, and are probably analogous to the formation of Lupar Mélange.

In most cases, the formation of tectonic mélanges has been interpreted to be through deformation along fault zones and the association with subduction zones has often been made (Fig. 8a). This does not agree with the conclusions made by Needham (1987). Based on his study of the nature of the mélanges in Japan and Scotland it was concluded that they are characterised by asymmetric extensional structures operating to develop the block-in-matrix structure of this rock type. The secondary zone of displacement has a similar overall geometry regardless of mechanism, fractures being referred to as R1 Riedel shears (Fig. 8b) and structures formed by more plastic processes being variously known as shear bands or extensional crenulated cleavage (Needham, 1987). These structures have been recognised from many different fault zones and shear zones over a wide range of scales and deformation conditions (Tchalenko, 1970 in Plate and Visser, 1980 in Needham, 1987).

On the basis of the above descriptions it is strongly believed that mélange could also be generated by strike-slip faults since the strike-slip movement has similar extensional elements (transtensional of Harland, 1971, which appear to be accumulated dominantly by stepped oblique movement), able to develop the block-in-matrix structure.

The analogous mélange formations to the Lupar Mélange known to be derived by strike-slip movement are;

1. The Violin Breccia (among other terms used for the mixed-rock assemblage, similar to mélange) that now lies faulted against the San Gabriel Fault in southern California (Fig. 3 of Sylvester, 1988) that originated from the Medelo Formation from the north-east. The units were displaced by right slip on the fault zone.
2. The Mamomia complex in south Cyprus which was earlier regarded as a subduction-related mélange, has been interpreted to have formed as the result of sinistral strike-slip movement with high-angle fault between the Mamomia complex against the Troodos Complex (Swarbrick, 1993).

This study therefore suggests that the Lupar mélange was derived by dextral strike-slip along the Lupar Line (Figs. 8c and 8d). The model suggests that these rock components have been transported for about 150 kilometres from the original outcrop location to Lupar Valley. The movement along the line most likely occurred during the Late Cretaceous, on the basis of the age of the rocks that were displaced and formed as matrix and blocks in the Lupar Mélange. The line was possibly reactivated several times until Eocene times.

## OTHER STRIKE-SLIP LINEAMENTS IN ONSHORE SARAWAK

On the basis of physiographic features, the origin of the Lupar Mélange, aerial photographs and geological data from the area, nine major tectonic lineaments (Fig. 9) have been interpreted with some of them already identified by previous workers and a number of them are proposed by this study. The lineaments are:

1. Lupar Line
2. Sarikei Line
3. Rajang Line
4. Igan-Oya Line
5. Mukah Line
6. West Balingian Line
7. Tinjar Line
8. West Baram Line
9. Kemana Line

As the nature and the reasons for the interpretation of Lupar Line being a strike-slip lineament has been discussed earlier, this section will only continue to discuss the other eight lineaments in onshore Sarawak:

### Sarikei Line

The Sarikei Line passes through a small tributary of the Sarikei River and is coincident with the boundary between Late Cretaceous Layar Member (K) and Palaeocene-Eocene Kapit Member (P2) of the Belaga Formation (Fig. 6). The contact between the two members has been mapped as an inter-bedding in the SE direction in the west and more linear to the east. Besides the contact, there is an abrupt change between the ages for the two members. There is also a marked difference in topography and flow direction. The area to the south is characterised by high land with the ridges in a NE-SW orientation (in the Penembak area of Figures 4 and 5) and most of the rivers are flowing either to the SW or to the west. The area to the west of the contact however, is generally characterised by low land with rivers flowing to the NE.

The contact between the Late Cretaceous Layar Member (K) and Palaeocene–Eocene Kapit Member (P2) of the Belaga Formation (Fig. 6) has not been interpreted to be of any geological significance before.

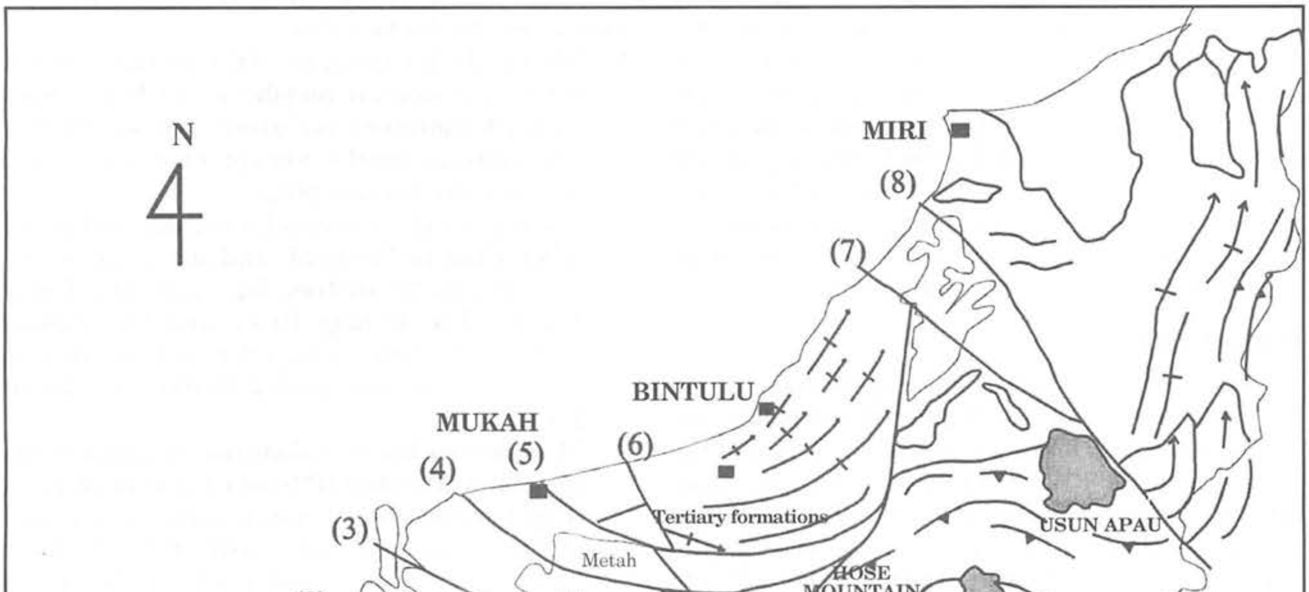


**Figure 9.** Proposed Tertiary Tectonic Model of Sarawak. (1) Lupar Line, (2) Sarikei Line, (3) Rajang Line, (4) Igan-Oya line, (5) Mukah Bukit Mersing Line, (6) West Balingian Line, (7) Tinjar Line (8) West Baram Line and (9) Kemana Line.

Judging from of several peculiar features outlined below, the contact between the Layar Member (K) and the Kapit Member (P2) of the Belaga Formation is interpreted to represent a strike-slip lineament similar to the Lupar Line. Among the characteristics of the contact and the reasoning for the interpretation of a strike-slip origin for the Sarikei Line are:

1. The high in linear nature of the contact which has been mapped to continue for about 400 kilometres. The contact marks the abrupt change in age between the two members of the Belaga Formation and the flow directions of the main rivers.
2. The south-eastward direction of inter-bedded facies can be related to the *en-echelon* array along the strike-slip fault, suggesting dextral movement. The occurrences of Layar Member (K) within the Kapit Member (P2), which are elongated and sub-parallel to the main contact (Fig. 9), could be strike-slip duplexes which brought the older rocks to the surface in the younger member to the north.
3. Judging from the nature of the contact between the two members, including the orientation of the ridges to the north, it is interpreted that the strike-slip movement post-dated the formation of the Layar Member (Late Cretaceous) and pre-dated the end of the Kapit Member (Palaeocene-Eocene). It was probably reactivated several times including Late Miocene time when the half graben structures in the offshore Kuching area (Ismail, 1993) were filled by Late Miocene sediments.

## Rajang Line

The proposed Rajang Line (Fig. 9) passes along the western half of the Rajang River before the river branches to form the upstream section of the Rajang River and Baleh River in central Sarawak (Fig. 4). The line also marks a significant shift in the orientation of the ridges, in the area to the north and south of the Rajang Line. The ridges to the north are trending E-W as compared to the ridges to the south which have a NE-SW orientation and the area to the east of Hose Mountain, where the ridges' orientation is predominantly NW-SE (Fig. 5).

The Rajang Line, however does not exactly coincide with the mapped boundary between the Palaeocene-Eocene Kapit Member (P2) and Eocene Pelagus Member (P3pel) of the Belaga Formation (Fig. 6). The difference in location can be explained since the Pelagus Member (P3pel), located immediately to the north of the Rajang River, forms an antiform, as evident from the topographic map and river's flow direction with most of the small rivers in the area flowing southward toward the Rajang River and the rivers farther north flowing northward. The area between the Rajang River and the southern boundary of the Pelagus Member was eroded, leaving the Kapit Member outcropping in the area (to the north of Rajang River) and the present contact between the two geological members located farther to the north.

The contact between the Kapit Member (P2) and Pelagus Member (P3pel) of the Belaga Formation extends eastward through the Hose Mountain area. The mapped contact passes through two igneous bodies of Pliocene-Pleistocene basalt lava at Hose Mountain to the east (Fig. 9). As for the previous interpretation on the tectonic significance of the Rajang River and the contact between the Kapit Member (P2) and Pelagus Member (P3pel) of the Belaga Formation (Fig. 6), no interpretation has so far been made.

It is strongly believed, however, that the Rajang River in the western half of Sarawak which is parallel to the contact between the Kapit Member (P2) and Pelagus Member (P3pel) of Belaga Formation is geologically significant and has features consistent with a strike-slip lineament. This is due to the fact that;

1. The highly linear nature of the contact between the two geological members which has been mapped continues for about 400 kilometres. The contact marks abrupt changes in age between the two members.
2. The Rajang River is very large compared to any other river in Sarawak and the river is also sub-parallel to another big river, the Lupar River. The Rajang River and the contact between the two geological members are sub-parallel to the interpreted Sarikei and Lupar Lines.
3. Magmatic rock occurs along the contact between the Kapit Member (P2) and Pelagus Member (P3pel) in the Hose Mountain area. Occurrences of magmatism associated with strike-slip have been reported in several places in the world including Vietnam, where the larger (tholeiite) melt fractions were generated within pull-apart basin, while lower (alkali basalt and basanite) melt fractions were associated with a conjugate strike-slip fault (Flower *et al.*, 1993) and the Great Tonolite Sill in southeast Alaska (Hutton and Ingram, 1992).

On the basis of these facts, it is strongly believed that the contact between the Kapit Member (P2) and Pelagus Member (P3pel) of the Belaga Formation that is sub-parallel to the Rajang River in the western half of onshore Sarawak, herein called the Rajang Line, and represents a strike-slip lineament. The movement along the Rajang Line post-dated the formation of the Kapit Member (Palaeocene-Eocene) and pre-dated the end of the Pelagus Member (Eocene); it was probably reactivated for several times during the later times.

## Igan-Oya Line, Mukah Line and West Balingian Line

The Igan-Oya Line and Mukah Line are two new lineaments recognised from the seismic study for the onshore and nearshore Sarawak. The West Balingian Line, however, is an old name used by several workers but restricted in use for the nearshore area of Sarawak, i.e. in SK5 area. This study uses the same name for the same lineament in SK5 and it extends farther offshore from SK5 (Fig. 1) and into the onshore Sarawak area (Fig. 2D).

The Igan-Oya line formed as the boundary between the Pelagus Member and Metah Member of the Belaga Formation (Fig. 9). The boundary between the two members changed in the area further eastward with the boundary of the Metah Member shifted southward closer to the Kapit Member. An outcrop of Nyalau Formation (Tertiary sediment) has an elongate shape parallel to the contact. Farther to the east, the contact between the two members appear to be rather disturbed and they are inter-bedded with each other.

The Mukah Line continues eastward from the south of the Lemai Sub-Basin, along the contact between the Metah Member of the Belaga Formation and the Tatau Formation and Nyalau Formation further eastward. In the vicinity of the contact, several igneous bodies have been mapped including granodiorite at Bukit Piring and andesite and rhyolite lavas at Arip (known as the Arip Volcanic). Farther to the east, an elongated outcrop of andesite at Bukit Mersing has also been mapped.

The location of the West Balingian Line in the onshore area is coincident with the contact between the Pelagus Member (P3pel) and Metah Member (P3mt), when the southern boundary of the Metah Member shifted southward, in irregular contact with the Pelagus Member (Fig. 6).

Although the name of the Igan-Oya and Mukah Line have been proposed by this study, the Mukah Line is believed to coincide with the tectonic lineament called the Bukit Mersing Line which was interpreted to represent the site of the Neogene collision caused by the arrival of the Luconia micro-plate with mainland Sarawak (Hutchison, 1988).

As an alternative interpretation, the three lineaments could represent the major strike-slip lineaments that were possibly active during Eocene to middle Miocene. Other than evidence from seismic data, the information from the onshore area similarly supports the interpretation, which includes:

1. The locations and orientations of the Igan Oya Line and Mukah Line coincide with the changes in the geological formations, i.e. the contact between the Metah and Pelagus Member and the contact between the Belaga Formation and the Tertiary sedimentary formations respectively. The projection of the West Balingian Line also coincides with an irregular facies change between the Metah and Pelagus Members of the Belaga Formation (Fig. 6).
2. A detailed map of the Arip Volcanic (by Wolfenden, 1960) shows it has been dextrally offset; this suggests that not only the intrusion and extrusions of the igneous rocks in the area are associated with the strike-slip tectonism but that they were also subjected to later strike-slip movements. The elongation of the Eocene-Oligocene andesite along the Mukah Line suggests the same.
3. The orientation of the ridges within the Tertiary formations to the north of Igan-Oya and Mukah Lines, swing from east-westerly in the area to the south of Balingian to a NE-SW orientation in the area in the vicinity of Bintulu (Fig. 5). The orientation of the ridges agrees to the interpreted movement along the two lineaments. These lineaments also marked the changes in structural elements between the area to the north of the lineaments and the area to the SE, near the Sarawak-Kalimantan border.

On the basis of these facts, the physiography and geological evidence from the onshore area of Sarawak have further strengthened the interpretation that the Igan-Oya Line, Mukah Line and West Balingian Line are strike-slip. The lines were active during Eocene to middle Miocene and were reactivated several times. The interacted area between the lines and other related movement resulted in severe deformation in this area.

## Kemana Line

The Kemana Line (Fig. 9) is a new proposed name for the line in a NE-SW orientation passing through the upstream part of the Kemana River and farther to SW, along the northern upstream of Rajang River (Fig. 4). The line marked a very distinctive topographic and drainage pattern between the east and the west of the line.

The area to the NW of this line (in the onshore area of Balingian and Bintulu, Fig. 9) is characterised by the ridges in the E-W orientation and gradually changing to NE-SW, with most of the rivers in the area flowing northward. In contrast, the area to the SE of the line is characterised by the rivers such as Seping, Danum and Linau flowing to the NW near the Kalimantan border, merging with the upstream part of the Rajang River and shifting the flow direction to the SW near Hose Mountain (Fig. 4). The flow directions of the rivers in the area are mainly because of the ridge's orientation changes, whereby the hill ridges in the area to the south of Usun Apau are in the NW-SE orientation and the area near the Hose Mountain in the NE-SW orientation.

A sinistral strike-slip line, which is in a N-S orientation extended from Miri, almost the same orientation to the northern part of the proposed Kemana Line has been proposed by Tjia (1994). The line was called the Tubau Line. However, due to a very schematic nature of the drawing, coupled with the unknown location of Tubau, it is decided to propose a new name, Kemana Line which represents the line that is passing through the area mentioned in the above paragraphs.

On the basis of river and ridge offsets, the line is interpreted to be a sinistral strike-slip lineament, and probably formed as the conjugate fault to the West Balingian Line. The age of this line is not certain but it is believed to be younger than Middle Miocene on the basis that the line offsets the Mukah Line (Bukit Mersing Line) that was active until Middle Miocene. Further, the Kemana Line was offset by the Tinjar Line that was active until Late Miocene times.

### Tinjar Line and West Baram Line

The Tinjar Line and West Baram Line marked a significant change in the structural orientation in onshore Sarawak. The area to the east of these two lineaments is characterised by structures with an almost N-S orientation, in the area to the west with structures have predominantly E-W and NE-SW orientations. Both the Tinjar Line and West Baram lines are interpreted to be dextral strike-slip lineaments.

## BLOCK ROTATIONS

As the findings of this study, a total of nine lineaments comprises eight dextral strike-slip and one with sinistral strike-slip have been identified in the onshore Sarawak area. Although the identification of the four lineaments namely the Tinjar, Rajang, Sarikei and Kemana Lines was mainly based on the significant physiographical changes and the geological features, they are coincident with lineaments and it can be substantiated by seismic for their extensions in the offshore area. Further, the interpretations of the nature of the four lines are consistent with the other five lines namely Igan-Oya, Mukah, West Balingian, Tinjar and West Baram Lines whereby the occurrence and the nature of the lines have been confirmed by the most recent regional and exploration seismic lines in the Sarawak Basin, making the interpretations more conclusive.

The tectonic lineaments are generally progressively younger in an eastward direction whereby the age of the Lupar Line is most likely to have been active in Late Cretaceous times and the West Baram Line which the youngest line was active during Pliocene times. The orientations of those lines are sub-parallel and curve southward with a general orientation in the E-W direction, except for the West Baram, Tinjar and West Balingian Lines that are in the NW-SE orientations (Fig. 9).

The effect of block rotation which has been seen to influence the formation of the Rajang Delta depression and structural traps in the nearshore area, suggesting counter clockwise rotation. Several magnetic surveys have been conducted in Sarawak and Sabah including Haile *et al.* (1977) who suggested that Borneo has undergone approximately 45° of counter-clockwise rotation since the Cretaceous and this ended during the Miocene. Paleomagnetic data from Upper Jurassic to Miocene rocks in Sarawak show some 8°–52° of counter-clockwise deflection with declination deflection with age.

### The effect of block rotations to strike-slip faults

The normal strike-slip duplex geometry (Woodcock and Fisher, 1986) and the counter-clockwise rotated geometry (Stone, 1995) are shown in Figures 10 and 11. The orientations of the ridges (Fig. 5) have been compared to the geometry of the rotated duplex, by first assuming the movement along the Lupar Line and the other lines sub-parallel to it, then by the movement along the West Balingian Line. A three-dimension block diagram (Fig. 12) shows the orientation of the ridges and the possible origin of the ridges in relation to the strike-slip duplexes. Whether or not there is sufficient evidence to support the possibility of the above, it is useful to test the observations with the known information about the area.

Based on the constructed 3-D diagram (Fig. 12), the formation of the ridges in the onshore Sarawak can be explained as below:

1. The Kapuas Range in-between the Lupar and the Sarikei Lines, with the orientation of the ridges and the orientations of the rivers dominantly in the NE-SW orientations can be explained as a trailing contractional fan or rotated contractional duplex (Figs. 10 and 11).
2. The ridges to the south of Usun Apau and to

the east of Hose Mountain, with the NW-SE orientation can be explained as a rotated trailing contractional imbricated fan or a thrust fold, probably generated after the formation of the trailing contractional fan in the Kapuas Ridge as a result of the later block rotation.

3. The area to the east of West Baram Line characterised by the NE-SW trending hill ridges with structures thrusting to the NW could also have formed as thrust folds as the result of the strike-slip movement along the line and the later block rotation.
4. The hills and anticline to the north of the Rajang Line including the area close to the shore with the ridges mainly in the E-W orientation and changed directions to NE-SW orientation further eastward and sub-parallel to the orientation of the Igan-Oya and Mukah Lines may represent the *en-echelon* folds and anticlines along the main strike-slip lines.

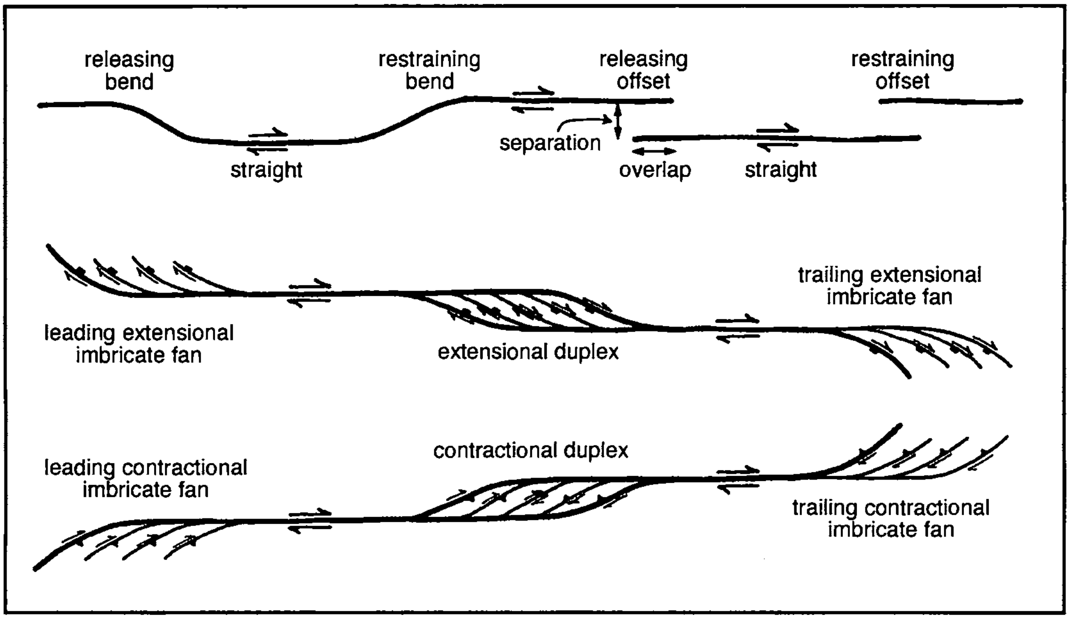


**Figure 10.** Map view of an idealised dextral strike-slip system (Woodcock and Fisher, 1985).

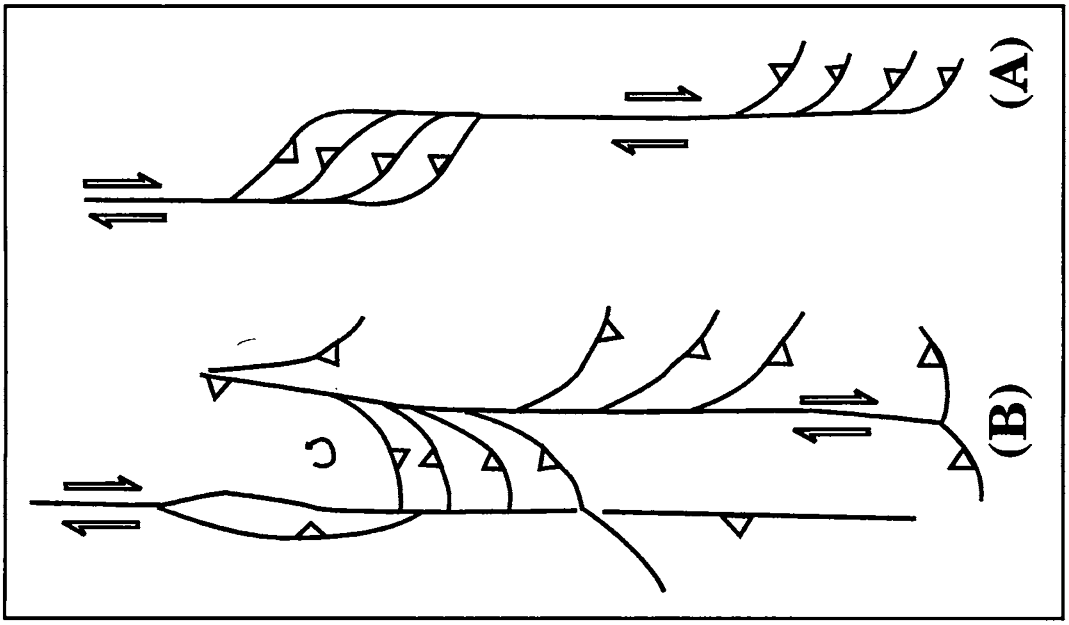


**Figure 11.** (A) Map views of dextral strike-slip system with contractional wrench duplex and trailing contractional imbricate fan. (B) Example from Quealy wrench duplex. The idealised duplex geometry in (A) has been modified by counter clockwise rotation (after Stone, 1995)

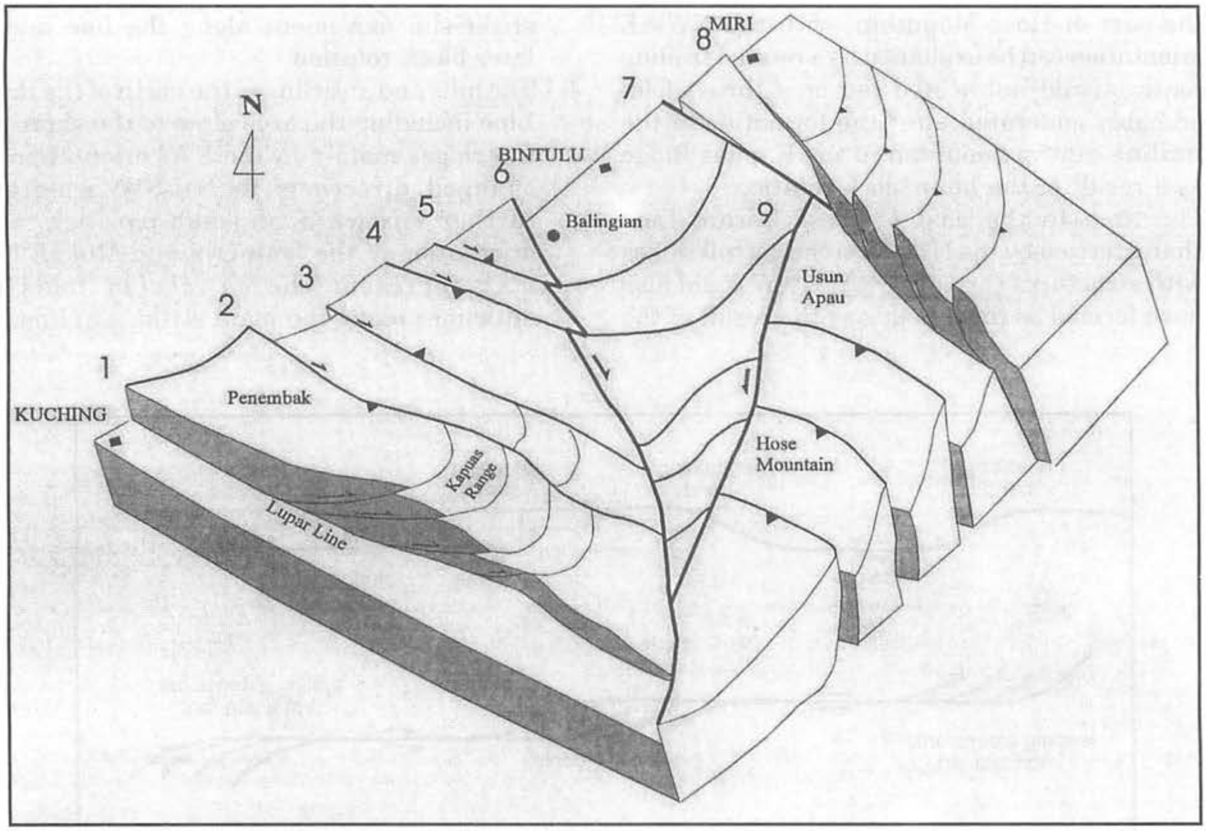


**Figure 12.** Three dimension diagram showing the relative movement and changes in the thrust direction and the orientation of the ridges forming the morphology of the Belaga Formation as the combined result of the strike-slip movement and block rotation.

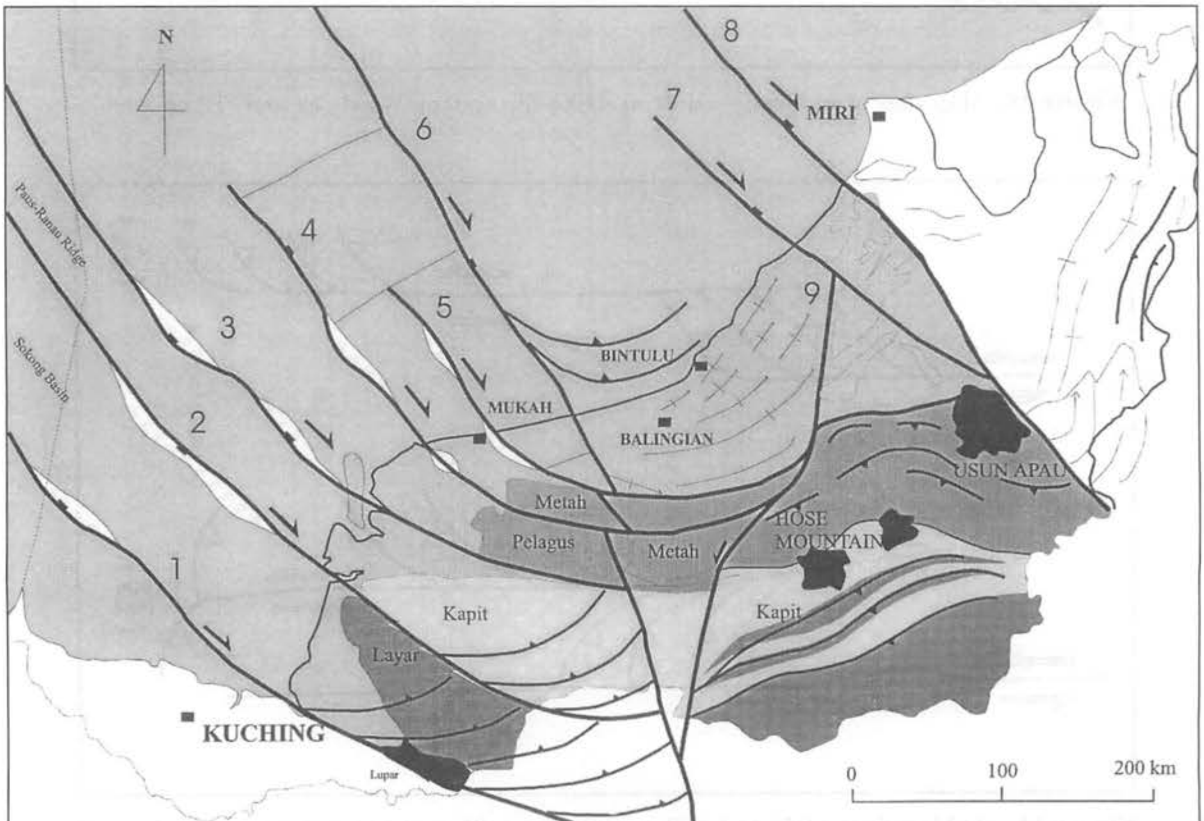


**Figure 13.** Proposed tectonic map of north-west Borneo.

## PROPOSED TECTONIC MODEL FOR NORTH-WEST BORNEO

The discussions of this paper pointed out that nine major strike-slip lineaments in the onshore Sarawak have been recognised. Besides the structural and geological phenomena related to the strike-slip tectonism, the block rotation should also be considered as the main control to the tectonic evolution of Sarawak, as its influence can be seen in the formation of the Rajang Delta depression and structural traps in the nearshore area which mainly have a counter-clockwise direction. Therefore it is proposed that the alternative tectonic model for Sarawak (Fig. 13) should be the strike-slip movement with the combination of block rotations (probably in partitions)

The new model proposed that strike-slip deformation in Sarawak commenced with the Lupar Line during the Late Cretaceous and progressed to the east through time, ending with the youngest West Baram Line during Pliocene times. The strike-slip lines, however, have been subjected to several episodes of reactivation and counter-clockwise rotation during their history. The strike-slip tectonism is not only responsible for the uplift and deformation of the basement rocks but also the formation of the Sarawak Basin and structural traps. The Belaga Formation that formed the hilly backbone area of the Sarawak hinterland and also formed the basement for the Tertiary basin partly in the onshore but mainly in the offshore area, previously called the Rajang Accretionary Prism, is a strike-slip belt in the new interpretation, is proposed that it be called the Rajang Strike-Slip Orogenic belt.

## SUMMARY AND CONCLUSIONS

1. The whole onshore area of north-west Borneo have been subjected to the strike-slip tectonism during Tertiary times. Strike-slip tectonics were responsible for the basin formation and controlled the sedimentation and formation of structural traps and were also responsible for the deformation and the generation of the strike-slip orogenic belt of the Belaga Formation and its equivalent in northern Borneo.
2. The driving force for the strike-slip tectonism in the region may have been initiated by the lateral movement between Sundaland and the South China Continental blocks, probably due to extrusion as the result of collision between the Indian and Asian Plates during the Mid Tertiary. The strike-slip movement was later derived by the opening of the South China Sea. The end result of tectonism in the region, however, was the combination of the strike-slip movements and block rotation.
3. The findings of this study have great implications in understanding the tectonic evolution of the region whereby the Tertiary tectonic model can explain most of the unexplained geological phenomena, such as the lack of igneous activity and volcanic belt and trench sediments, which would be required in the previous subduction or thrusting tectonic models. The findings of this study will definitely contribute towards a better understanding of the tectonics of the area and the proposed tectonic model should promote a new thinking about the tectonics of the region.
4. The geological model proposed by this study has significant implications for the geological related industries in the region. The proposed tectonic model could provide a general understanding for the petroleum prospectivity of the area and help in understanding structural style for hydrocarbon plays in the area. This will help the mining and petroleum companies in the acquisition of prospective exploration acreage and in carrying out of effective production plans.

## REFERENCES


FLOWER, M.F.J., HOANG, N., TRONG YEM, N., XUAN BAO, N., MCCABE, R.J. AND HARDER, S., 1993. Cenozoic magmatism in Indochina: Lithosphere extension and mantle potential temperature. *Bulletin of the Geological Society of Malaysia, Special Publication, 30*, 211–222.

HAILE, N.S., MCELHINNY, M.W. AND MCDOUGALL, I., 1977. Palaeomagnetic data and radiometric ages from Cretaceous of West Kalimantan (Borneo), and their regional significance in interpreting regional structures. *Journal of Geological Society of London, 13*, 133–144.

HARLAND, W.B., 1971. Tectonic transpression in Celedonian Spitsbergen: *Geological Magazine, 108*, 27–42.

HENG, Y.E., 1992. Geological map of Sarawak, second edition. Director General of Geological Survey of Malaysia.

HAMILTON, W., 1979. Tectonics of the Indonesia region. U.S. *Geological Survey Professional Paper 1078.*

HOLLOWAY, N.H., 1982. North Palawan Block, Philippines its relationship to the Asian mainland and role in the evolution of South China Sea. *American Association of Petroleum Geologists Bulletin, 66*, 1355–1383.

HUTCHISON, C.S., 1975. Ophiolite in Southeast Asia. *Geological Society of America Bulletin, 86*, 7897–806.

HUTCHISON, C.S., 1988. Stratigraphic-tectonic model for eastern Borneo. *Bulletin of the Geological Society of Malaysia, 22*, 135–151.

HUTTON, H.W. AND IGRAM, G.M., 1992. The Great Tonalite sill of southeastern Alaska and British Columbia: emplacement into an active contractional high-angle reverse shear zone (extended abstract). Transactions of the Rayal Society of Edinburgh; *Earth Sciences, 83*, 383–386.

ISMAIL, C.M.Z., 1993. Regional Geology and Hydrocarbon Potential of Block SK19, East Malaysia Exploration Department, PETRONAS Carigali (unpublished).

ISMAIL, C.M.Z. AND M.E. TUCKER, 1997. An Alternative Stratigraphic Scheme for the Sarawak Basin. Paper presented at: Tectonic, Stratigraphic and Petroleum system of Borneo, University Brunei Darussalam, 22–25 June 1997 (In press).

ISMAIL, C.M.Z., 1997. Subsidence History of the Sarawak Basin. *Proceeding ASCOPE 97 Conference, Volume 1* in Jakarta, in November 1997, 107–127.

JAMES, D.M.D., 1984. The geology and hydrocarbon resources of Negara Brunei Darulsalam. Brunei Museum and Brunei Shell Petroleum Company.

JASIN, B. AND HAILE, N.S., 1984. Some radiolaria from the chert of Lubuk Antu mélange, Sarawak. *Newsletter of the Geological Society of Malaysia, 19,* 205–209.

MAHADHIR, R., 1994. Photo-album report on the geological fieldwork in Sri Aman-Lubuk Antu area. PETRONAS Carigali report (Unpublished).

NEEDHAM, D.T., 1987. Asymmetric extensional structures and their implications for the generation of mélanges. *Geological Magazine, 124,* 311–318.

RAPAEE M.A., 1979. Geology and Hydrocarbon potential of Southwest Sarawak Province. PETRONAS report (unpublished).

STONE, D.S., 1995. Structure and kinematic genesis of the Quealy Wrench Duplex: Tranpressional reactivation of the Precambrian Cheyenne Belt in the Laramie Basin, Wyoming. *American Association of Petroleum Geologists Bulletin, 79,* 1349–1376.

SWARBRICK, R.E., 1993. Sinistral strike-slip and transpressional tectonics in an ancient_oceanic setting: The Mamonia Complex, southwest Cyprus. *Journal of the geological Society, London, 150,* 381–392.

SYLVESTER, A.G., 1988. Strike-Slip faults: *Geological Society of America Bulletin,* 100, 1666–1703.

TAN, D.N.K., 1979. Lupar Valley, West Sarawak, Malaysia, Explanation of Sheets 1-111-14, 15, and 16, *Malaysian Geological Survey Report 13.*

TAN, D.N.K., 1982. Lubuk Antu Mélange, Lupar valley, West Sarawak, A lower tertiary subduction complex. *Bulletin of the Geological Society of Malaysia, No. 5,* 31–46.

TATE, R.B., 1991. Cross-border correlation of geological formations in Sarawak and Kalimantan. *Bulletin of the Geological Society of Malaysia, 28,* 63–95.

TAYLOR, B. AND HAYES, D.E., 1983. Origin and History of the South China Sea Basin. *In:* Hayes, D.E. (Eds.), The tectonic and Geologic Evolution of Southeast Asian Seas and Islands: Part 2. *Geophysical Monograph, 27,* 23–56.

TJIA, H.D., 1994. Tectonic framework and development of the Sarawak Basin: An outline. Report of PETRONAS Research & Scientific Services Sdn. Bhd. (Unpublished).

UNTUNG, M., 1990. Geoscientific study along Java-Kalimantan-Sarawak-South China Sea transet (Abstr): in Fifth Circum Pacific energy and mineral resources conference; abstracts, *American Association of Petroleum Geologists Bulletin, 74,* 1007.

WOLFENDEN, E.B., 1960. The geology and mineral resources of the lower Rajang Valley and adjoining area, Sarawak. Memoir II, Geological Survey Department, British Territories in Borneo.

WOODCOCK, N.H. AND FISHER, M., 1985. Strike-slip duplexes. *Journal of Structural Geology, 8,* 725–735.

*Manuscript received 2 November 1998*