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The Balingian Shear Zone, West Balingian and West Baram Lines, Sarawak, and their importance in the early Cenozoic evolution of NW Borneo

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Abstract: A major zone of intense deformation trending WNW has been discovered in the neighbourhood of Sg. Balingian between Sibu and Bintulu. The zone probably continues offshore where a gravity lineament follows the same direction. The West Balingian and West Baram Lines mark the boundaries of the offshore hydrocarbon provinces and together with the newly discovered shear zone, appear to form a fundamental tectonic framework for this part of NW Borneo. The distribution of heat flow, igneous rocks, Oligocene deltas and Oligocene-Miocene carbonates across N Sarawak and N Kalimantan appear to be related to the framework which extends across central Borneo. The nature of the lineaments is discussed in terms of the regional tectonic evolution of northern Sarawak as well as providing clues to indicate what lies beneath this part of Borneo.

INTRODUCTION

The Balingian Shear Zone

Intense shearing of the rocks at the Sibu-Bintulu road bridge site on the Sg. Balingian was first recognised in 1976 and the shearing then attributed to a NE-trending tectonic feature related to the Mulu Shear Zone (McManus and Tate, 1976). New roadside exposures in the middle-upper Eocene Belaga Formation in the neighbourhood of Sg. Balingian between Sibu and Bintulu now reveal a major zone of deformation which seems to trend approximately WNW (Fig. 1). The zone appears to continue offshore where it is aligned with a positive gravity anomaly trending WNW indicating a major discontinuity at depth (Fig. 2). It is proposed to call this shear zone the Balingian Shear Zone and the main Sibu-Bintulu road crossing the Sg. Balingian designated as the type locality.

The rocks affected by the shear zone belong to middle-upper Eocene Belaga Formation of the Rajang Group. They comprise mainly deepwater turbidites with intercalations of purple and green shaly beds, possibly of volcanic origin, the latter exposed 3 km WSW of the bridge across the Sg. Balingian. The rocks show low grade regional metamorphism; sandstones are transformed to quartzites and shales become phyllitic. The bedded quartzites show both current and graded bedding and shearing has disrupted the competent beds into rhomboidal blocks (Fig. 5). Graphite layers and coatings are frequently associated with the quartzites and shales are also sometimes graphitic (Fig. 3). Quartz veining in the form of stringers, ptygmatic veins and tension gashes is common, especially in the more shaly rocks (Figs. 4 and 8). A dm-wide low angle thrust zone with related cleavage is visible 3 km WSW of the Balingian bridge and elsewhere the rocks are tightly folded and cleaved.

A measured section on N side of the road 200 m S of the bridge is as follows:-

100.00 m	sheared, cleaved dark grey siltstone
1.50	channel sand in silt
20.00	graphitic shales
1.00	channel sand
0.30	sand
0.10	silt
1.00	plane-bedded sand
0.30	graphitic silt
1.00	thin, multi-channel sands
2.00	disrupted sand beds with minor shear zones
3.00	graphitic silt with quartz stringers
3.00	boudinaged channel sand
7.00	cleaved silt
3.00	thin, dm-scale channel sands
2.00	very thin sandstones with quartz stringers
20.00	highly cleaved siltstone

The effects of the major shear zone appear to die out in a northerly direction, about 2 km N of the Sg. Pelagau and towards the southwest, E of Sg. Bulah. The shear zone is therefore about 8 km wide in the Balingian area.

The few structural measurements obtained from the Balingian exposures indicate a general N-S compressional direction (Fig. 10) but much more data are needed from a wider area before either the structural interpretation or lateral extent and direction of the shear zone, including whether there is any horizontal component, can be established satisfactorily. The structures are exceedingly complex. There are at least two and probably more periods of deformation indicated by the presence of at least two cleavages and an earlier cleavage is itself folded (Fig. 7). One generation of cleavage appears to be parallel to the axial plane of folds (Fig. 6). The timing of any deformation cannot be verified except that it is post-upper Eocene. It should be noted that the term "shear zone" in this paper is used in the sense of a zone of deformation — shear whether pure shear or simple shear is not inferred as no proof is yet available.

The trend of the Balingian shear zone is predicted to be WNW but as only one intersection has been observed it is perhaps premature to be certain of its lateral continuity and trend until more evidence is available. The sections exposed at Sg. Balingian suggest a WNW trend coincident with a gravity lineament offshore which is interpreted as the Mukah half graben, hading to the SSW (Dr. P. Swinburn, pers. comm. 9/94). The Balingian shear zone does not coincide with the West Balingian Line of Swinburn (1993) as the latter is aligned NNW and would appear to be a normal fault (see Figs. 2 and 9). Significantly, the outliers of Nyalau Formation at Bukit Batu Bora, S and E of the Usan Apau plateau also appear to be half graben hading to the N and NW.

The West Balingian Line

The West Balingian Line, forms the western boundary of the Balingian sedimentary basins offshore (Fig. 9) and seismic data indicate there is a major fault trending WNW with about 4 km downthrow to the east (Swinburn, 1994, *oral presentation*). The fault forms the eastern edge of the Penian high (Doust, 1981). The West Balingian

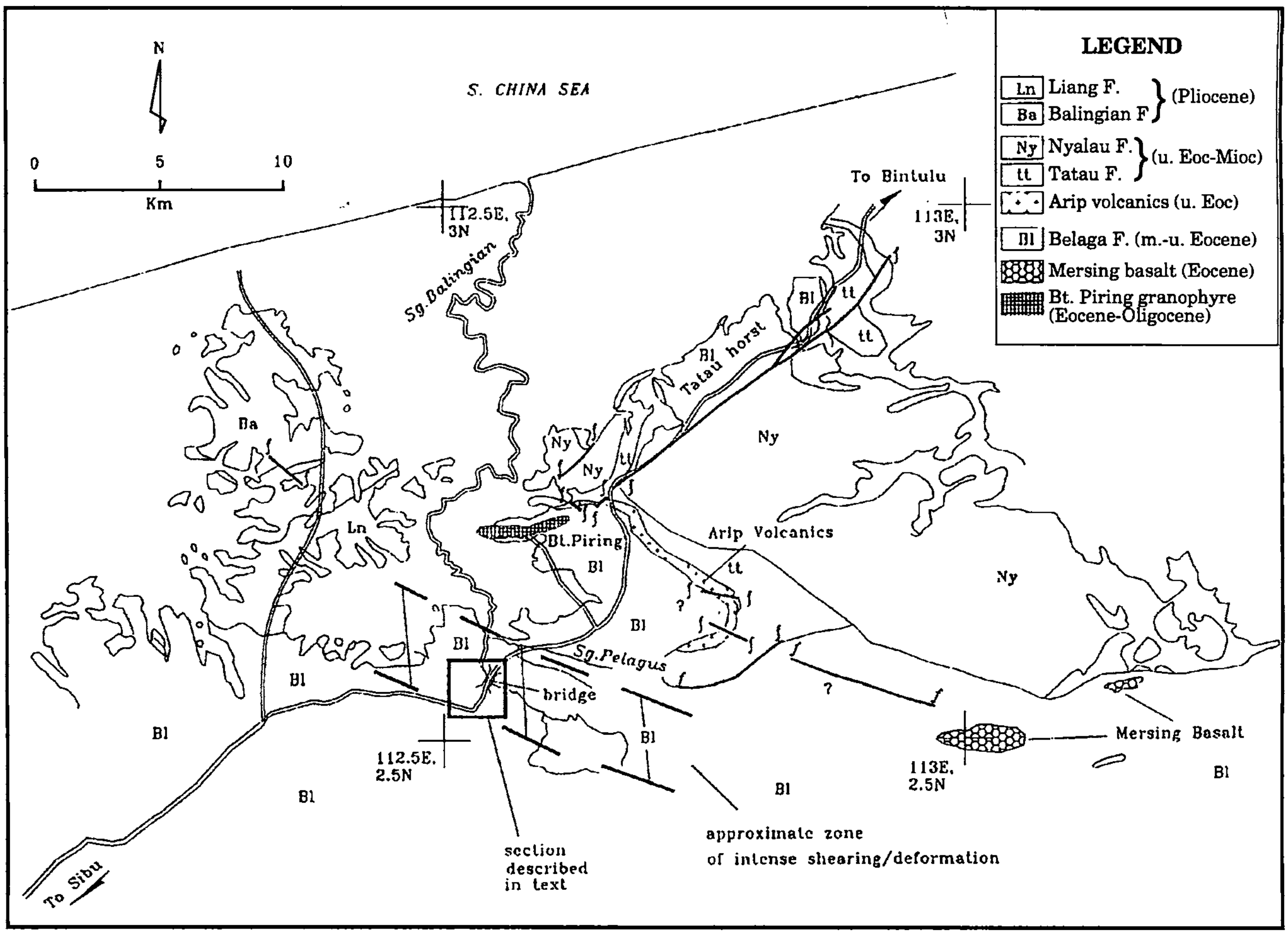

Figure 1. Location map showing the position of the Balingian Shear zone and the regional geology (Based on Liechti *et al.*, 1960; Wolfenden, 1960; Haile and Ho, pers. comm.).

Line can be identified on the published gravity map (Fig. 2) as a somewhat insignificant anomaly trending NNW, although the original gravity data show a pronounced anomaly. The onshore manifestation of the West Balingian Line has yet to be found and it perhaps occurs within the 5 km-wide deformation zone described here as the Balingian shear zone. The West Balingian Line differs in azimuth from that of the Balingian shear zone and they are not the same tectonic lineament.

The West Baram Line

The West Baram Line is an important tectonic boundary trending N45°W which separates the extensive carbonates of Luconia Province from the large deltaic sedimentary basin of the Baram Delta Province (Fig. 9). It has never been defined formally. James (1984) refers to it as a major transform fault parallel to a similar transform fault through the Balabac Strait although no evidence is mentioned which identifies transform features. The West Baram Line is clearly a major tectonic and deep-seated feature as it separates areas which have different geothermal parameters. There is a marked change in heat flow across the West Baram Line (Rutherford and Qureshi, 1981) and the higher geothermal gradients in Luconia Province are responsible for the predominantly gas-prone hydrocarbons found there whereas the Baram Delta Province has lower gradients and predominantly oil-prone. Hutchison (1994) surmises that the geothermally cooler gradients are as a result of cold oceanic crust beneath the Baram delta province rather than the insulating effect of a +12 km thick sedimentary pile overlying hotter crust.

Thus, the principal tectonic lineaments in northern Sarawak form definitive boundaries to the Cenozoic sedimentary basins of northern Sarawak but they show no consistent azimuth (Fig. 9).

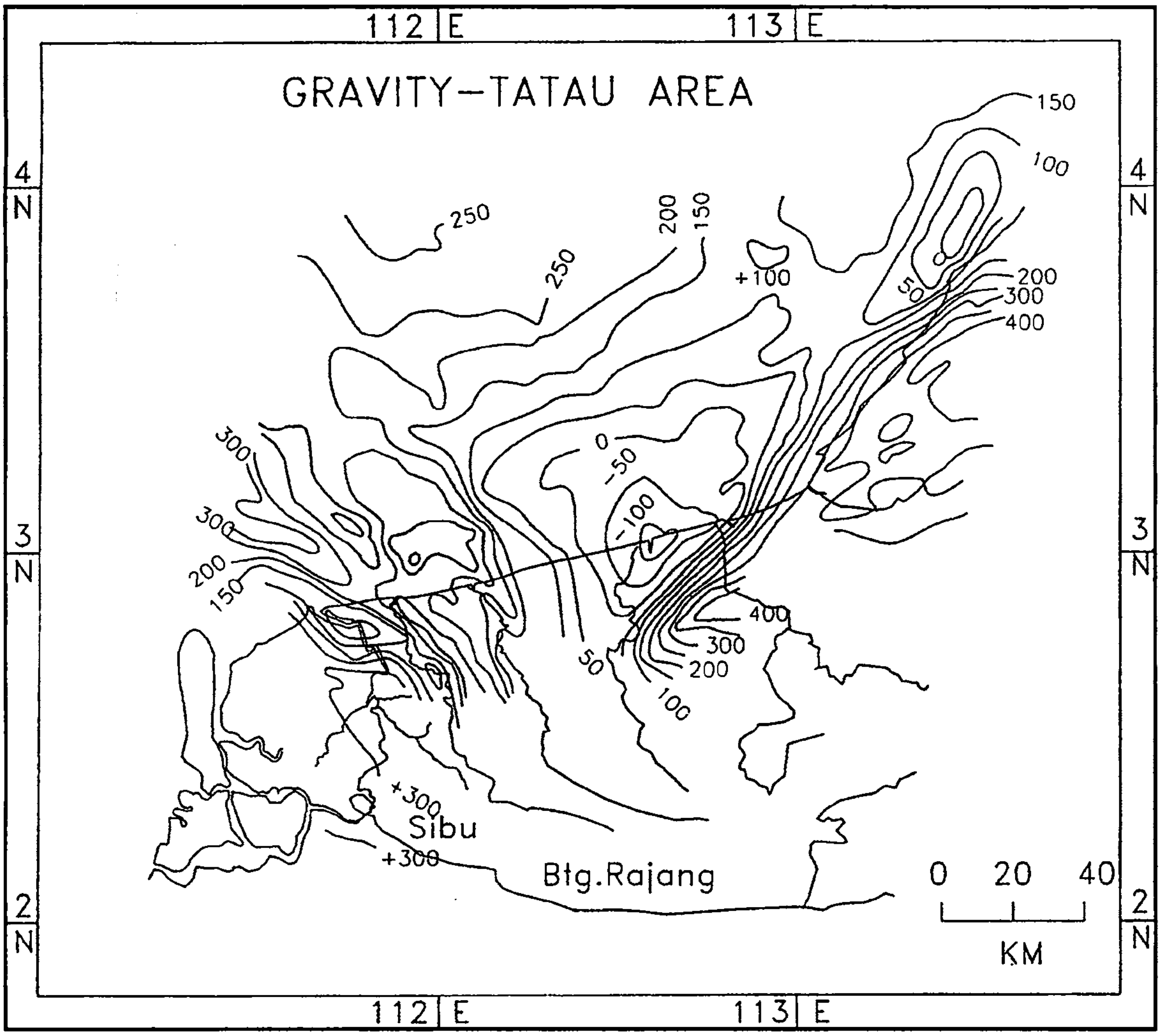

Figure 2. Gravity — Tatau area (from Hutchison, C.S. (Ed.), CCOP/IOC, 1991).

Figure 3. Belaga Formation, 150 m SW of bridge, Sg. Balingian. Dm-thick quartzites showing graded bedding interbedded with black phyllitic shales with graphite.

Figure 4. Ptygmatic quartz veins invading phyllites.

Figure 5. Competent quartzites dislocated, boudinaged and rotated by shearing.

Figure 6. Sedimentary banding outlining a fold with incipient axial plane cleavage (parallel to the pen).

Figure 7. Folded cleavage. See Figure 10.

Figure 8. Sub-parallel quartz-filled joints perpendicular to foliation. Upper left: tight fold outlined by banding. See Figure 10.

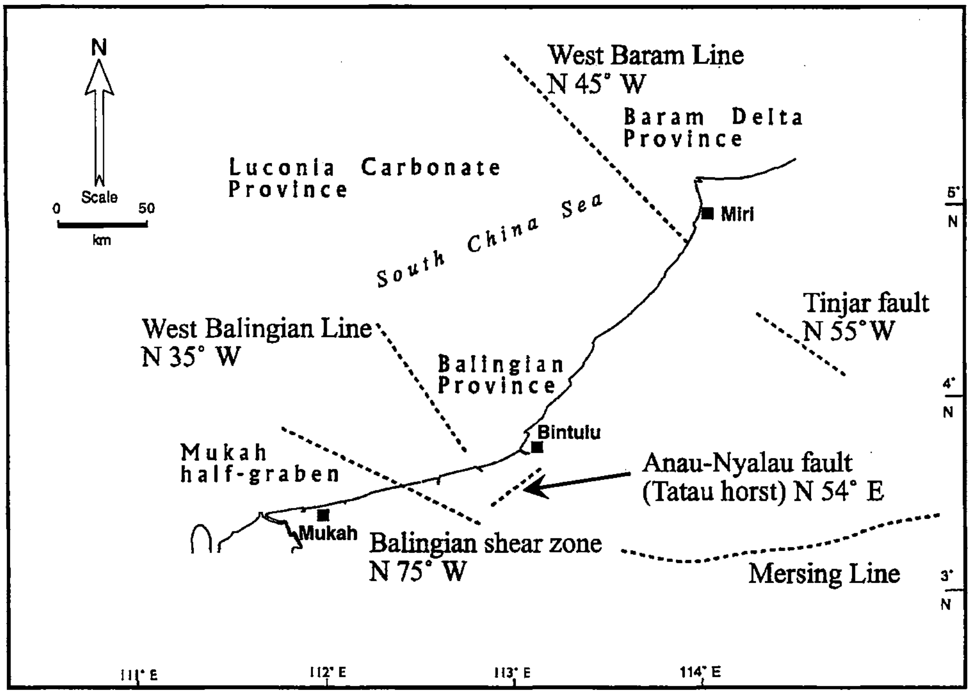

Figure 9. The principal tectonic lineaments and offshore sedimentary provinces in northern Sarawak.

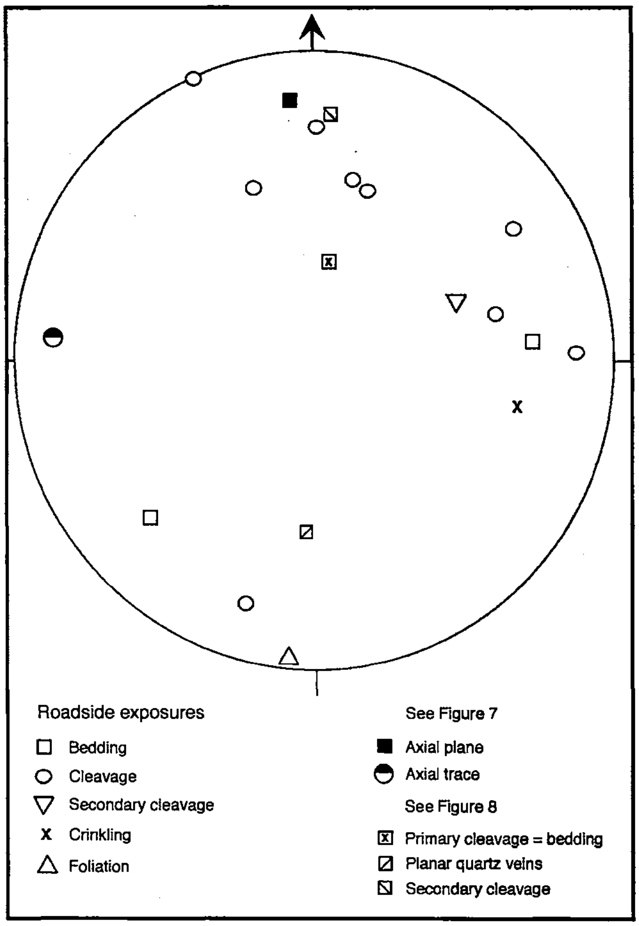

Figure 10. Stereo plots (Schmidt net, lower hemisphere) of structural measurements taken at the road exposures described in the text.

POST-UPPER EOCENE SEDIMENTATION IN NORTHERN SARAWAK

The stratigraphy of the Cenozoic sequences of northern Sarawak was originally defined by Liechti (1960) but the monotonous lithostratigraphy and absence of marker horizons proved unworkable in detail. Geiger (1963) introduced the concept of sedimentary cycles and Muller (1964) provided a biostratigraphic zonation based on pollen. Ho (1978) combined both microforaminifera and pollen to produce a comprehensive and effective biostratigraphic control, defining eight regressive sedimentary cycle units separated by thin transgressive intervals in the Oligocene to Holocene succession throughout the Sarawak shelf areas. Doust (1981) describes in detail the stratigraphic history of offshore central Sarawak and the nature of the eight sedimentary cycles in terms of coastal plain (COL), coastal fluvio-marine (COF), lower coastal plain (LCP), holomarine inner neritic (HIN), holomarine middle neritic (HMN) Fluviomarine, inner neritic (FIN), fluviomarine, middle neritic (FMN) and holomarine, outer neritic (HON).

Prior to Cycle 1, middle Eocene reefoid limestones began to accumulate in northern Sarawak across topographic highs in the Temala and Mulu areas which now form the Melinau Limestone Formation at Melinau and Batu Gading as well as the smaller masses at Bukit Tujoh-Bukit Siman in the middle Baram. Subsequently, more or less continuous limestone deposition took place at Batu Gading (middle Eocene-Lower Miocene) and Melinau (middle Eocene-Middle Miocene). The absence of Paleocene limestones in northern Sarawak and the scarcity of Paleocene limestones generally in Borneo — Paleocene limestones are known only in scattered localities in the northern part of the Meratus Mountains (Supriatna *et al.*, 1980), is probably because much of Sundaland was an extensive land surface at that time (Hutchison, 1992).

In Cycles I and II, (upper Eocene-Lower Miocene), coastal plain sequences were deposited on the flanks of the Penian High in what is now the offshore Balingian basin as well as the Nyalau Formation onshore. The "Penian high" is an expression often used in oral presentations but it has not been formally defined in the literature. The Penian high occupied a position offshore of the present day coastline between Mukah and Balingian and is envisaged to be the source of deltaic sediments in the offshore Balingian basin as well as the onshore Nyalau Formation which contains some unusually coarse-grained sandstones. In a series of palinspastic maps, Doust (1981) and Agnostinelli *et al.* (1990), show conclusively that the Oligocene coastline trended approximately perpendicular to the present coast and that the Penian High formed the source of prograding deltas trending NE.

In the Lower Miocene, Cycle II (Fig. 11, "A"), shelf carbonates began to accumulate offshore on the SW side of the West Baram Line extending southwards to Subis. In the present offshore area, Oligocene and Lower Miocene deposition to the NE of the West Baram Line was probably devoid of clastics except perhaps thin turbidites which may occur beneath the Baram delta. In Cycle III (Fig. 11, "B") deltaic deposits spread further northwards, ending deposition of shelf carbonates at Subis; by the time of Cycle V (Fig. 11, "C"), the reef limestones of Luconia Province had developed to their fullest extent and deltaic deposition had commenced in the Baram delta which in its early development was controlled by the West Baram Line. Thus, offshore of northern Sarawak, the West Baram Line acted as a steep shelf-edge from the Oligocene and probably since the Eocene breakup of Sundaland.

Onshore, the West Baram Line probably continues through the middle Baram across Borneo into Kalimantan. The predominantly silty Setap Shale Formation accumulated in the Baram valley basin to the NE whereas the Oligocene deltas of the Nyalau Formation prograde only as far as the SW side of the West Baram Line which seems to have formed a shelf edge at that time. Paleocurrent directions measured in the Nyalau Formation south of Bintulu show a NE-SW alignment (Mason, 1987) and the source would appear to be in the SW with deltas prograding northeastwards (Fig. 12). Furthermore, it is suggested that some, if not all, the areas shown as "Belait Formation" on the Geological Map of Sarawak (Tan, 1982), the Dulit Range, Bt. Sekalap, Bt. Selikan and the large areas of arenaceous sediments NW of the Tinjar knee, belong to the same sequence of Oligocene deltas as those in the Nyalau Formation NE of Bintulu. In Kalimantan, the extensive upper Oligocene-Lower Miocene Bayangkara Limestone is up to 300 m total thickness (Lefevre *et al.,* 1982) and was deposited to the SE of the extension of the West Baram Line in a position identical to the shelf limestone at Luconia (Fig. 12).

Thus, there is corroborative evidence to indicate the West Baram Line continues across Borneo in a SE direction.

TECTONIC IMPLICATIONS OF THE VARIOUS "LINES"

Offshore NW Sarawak, the West Balingian Line and West Baram Line form boundaries between sedimentary provinces and they constrain the Balingian Province sedimentary basins in the NE and SW respectively (Swinburn, 1993). The Lines are clearly of importance in separating the oil-prone Baram Delta/Balingian Province, the gas-prone Central Luconia Provinces and the barren areas of offshore SW Sarawak. The Balingian shear zone forms one side of the small sediment-filled Mukah half-graben which developed in the early Cenozoic but the zone may have had also a history of repeated movement. In the upper Eocene, it formed a zone of compression and may have been the focus of igneous activity, indicating a deep-seated tectonic fracture in a ductile part of the crust. In the Cenozoic, at shallower levels, it was reactivated in the brittle zone and deformed by extensional rifting forming a half-graben.

In the present offshore area, Oligocene deposition to the NE of the West Baram Line was probably devoid of clastics except perhaps thin turbidites which may occur beneath the Baram delta. Onshore, the predominantly silty Setap Shale Formation accumulated in the Baram valley basin to the NE whereas the Oligocene deltas of the Nyalau Formation are terminated on the SW side of the West Baram Line. In Kalimantan, the extensive upper Oligocene-Lower Miocene Bayangkara Limestone is gently dipping or sub-horizontal suggesting that there has not been much movement since the time it was deposited on presumably a relatively stable platform. Likewise, the Central Luconia carbonates reflect prolonged calcareous deposition on a stable platform.

Thus the West Baram Line had a controlling influence on the distribution of shelf carbonates

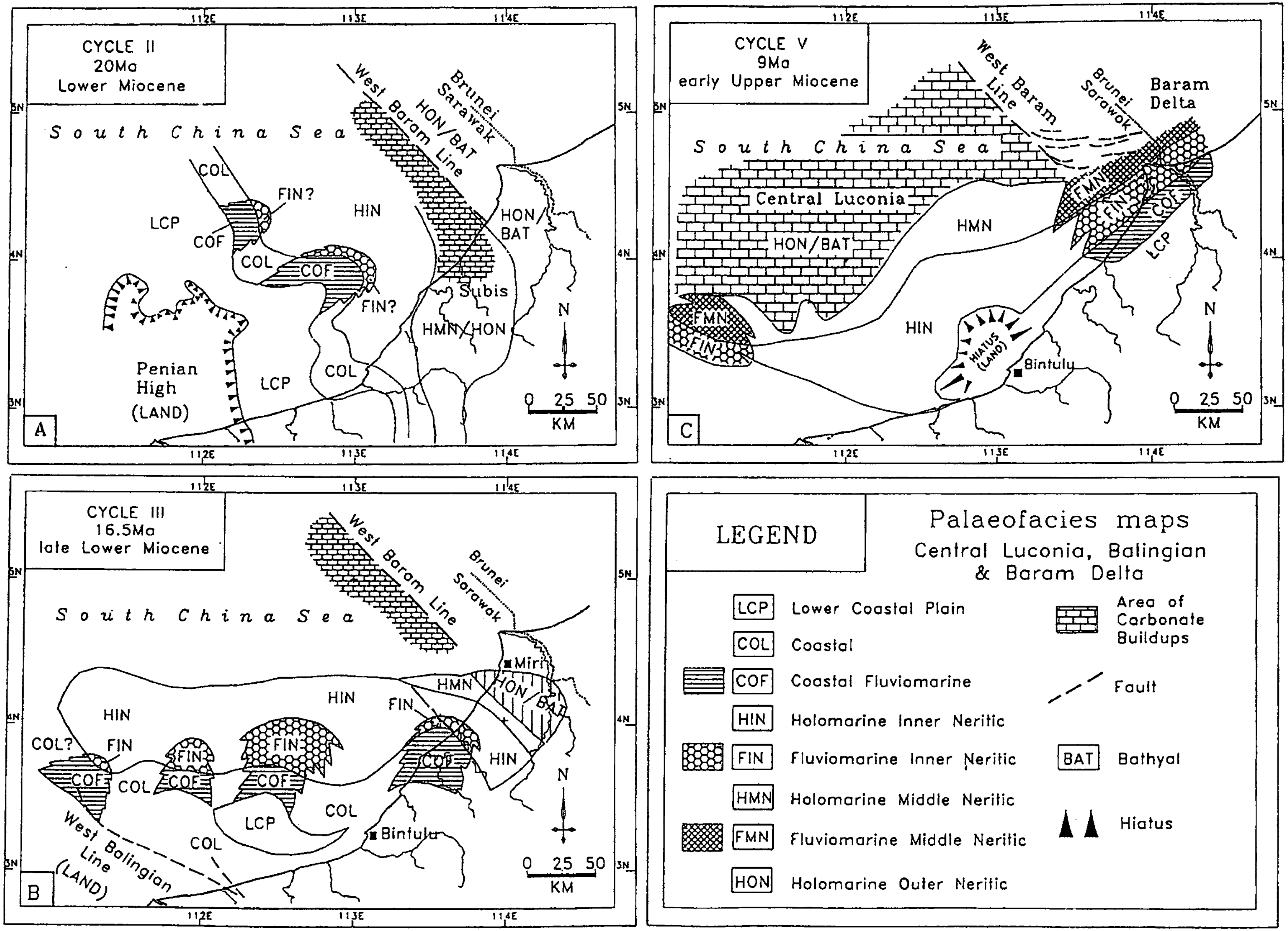

Figure 11. Paleofacies maps, Central Luconia, Balingian and Baram Delta Provinces (adapted from Doust, 1981, Agnostinelli *et al.*, 1990 and Johnson *et al.*, 1989).

and Oligocene deltas extending for a distance of some 800 km from Luconia to Mangalihat.

Both the West Baram Line and Balingian shear zone seem to be of fundamental tectonic importance in the evolution of the early Cenozoic history of NW Sarawak and the presence of igneous rocks along their length indicates that both structures extend to the deeper parts of the lithospheric crust. The Arip rhyolitic lavas, Piring granodiorite and Bukit Mersing pillow basalts (Fig. 1), (Wolfenden, 1960, Kirk, 1968) are perhaps related to the Balingian shear zone. The Bukit Mersing basalts lie roughly along the strike from Sg. Balingian and may have erupted along weakness caused by the shear zone. The considerable decomposition in the Piring granodiorite may be as a result of movement on the Balingian shear zone nearby during the later stages of intrusion or soon thereafter.

Igneous activity has occurred also along the trend of the West Baram Line across Borneo at least since the late Oligocene (Fig. 12). Middle Miocene basalts occur intruded along the Tinjar fault, a sub-parallel fracture (R.M. Banda, pers. comm., 5/91) and the twin stocks of Bukit Kalulong and Seludong located nearby are composed of Kinabalu-type granodiorite and thought to be also Middle Miocene in age. At Long Lai in Kalimantan, tin-bearing adamellites occur in small intrusions at the intersection of N and NW fractures not far from the position of the SE extension of the West Baram Line. The adamellites fit an isochron age of 26 Ma (Bambang Setiawan and Le Bel, 1988). Tin has also been reported from the Lower Cretaceous Menyukung granite in West Kalimantan (Williams and Heryanto, 1986). The presence of tin is strongly advocative of continental lithosphere at depth beneath this part of Borneo.

There is additional evidence of continental material beneath west and central Borneo. The lithophile elements antimony and arsenic occur in sporadic mineralised zones extending in a belt from NW Kalimantan and west Sarawak to northern Sarawak. The main economic deposits have been worked in the past in West Sarawak but antimony and arsenic are known from a number of localities distributed across the Belaga Formation and as far north as the middle Baram, at Long Miri and near Bukit Siman (Fig. 12). The latter occurrences are reported by Haile (1962) to be in Setap Shale Formation and are probably Miocene in age, having

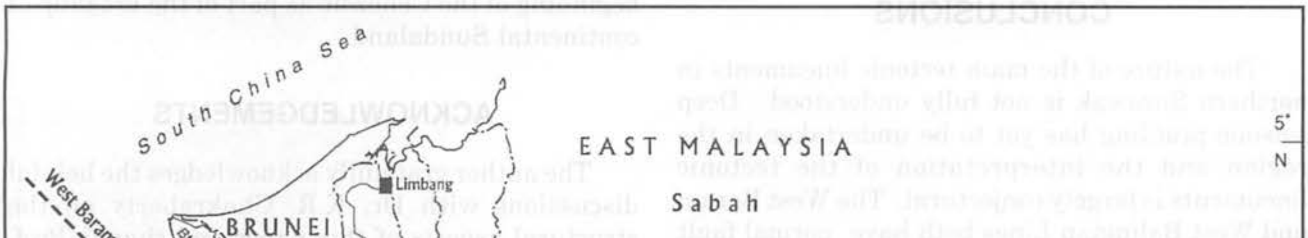

Figure 12. The West Baram Line and its relationship to some of the elements of the geology of parts of Sarawak, E. Malaysia, Brunei and Kalimantan, Indonesia (Geology based on Tan, 1982, James, 1984 and Lefevre *et al.*, 1982).

been mobilised by the intrusive events at Bukit Kalulong. The antimony and arsenic mineralization in the middle Baram is the most northerly occurrence and coincides with the southeastwards extension of the West Baram Line.

To summarize, the West Baram Line displays the following important geological features:

- it forms a boundary between hot and cold parts of the crust in the offshore areas.
- igneous activity in the form of granodioritic plugs and Sn granites are located close to the SE extension of the Line.
- basalt dykes are intruded along the sub-parallel Tinjar fault.
- the SE extension of the West Baram Line is coincident with the northern limit of Sb/As mineralization.
- it forms the margin of extensive carbonate province offshore Sarawak as well as the NE limit of a large limestone in Kalimantan.

Thus, the West Baram Line has been an active tectonic lineament which extends to deep crustal levels. The Line has also had a significant geomorphological influence on deposition since the early Cenozoic.

CONCLUSIONS

The nature of the main tectonic lineaments in northern Sarawak is not fully understood. Deep seismic profiling has yet to be undertaken in the region and the interpretation of the tectonic lineaments is largely conjectural. The West Baram and West Balingian Lines both have normal fault component characteristics but otherwise their origins are different. The West Balingian Line seems to be a normal fault with a very large throw, appears not to continue onshore and is restricted to the offshore oil basins; it is probably relatively short-lived, having formed in the early Oligocene with movement ceasing during the Middle Miocene. Conversely, the West Baram Line seems to be a more profound tectonic feature separating two markedly different parts of the lithosphere and extending across Borneo where it is associated with high-level intrusions and associated mineralization. It may be a reactivated transform fault related to seafloor spreading before the advent of the present Indonesian island arc in the Eocene (Hayes and Taylor, 1978) when the SE Sunda landmass began to rift apart.

The Balingian shear zone exhibits complicated deformation with compressive components and may be linked to nearby igneous activity, indicating its deeper features. It is tempting to link the Balingian zone with the Mersing Line but until the zone can be traced eastwards, it is premature to ascertain whether there is a relationship. If such a relationship does exist, the Balingian shear zone probably extends much further to the east. Offshore, the Balingian shear zone was reactivated in the Cenozoic during a period of extension when it provided a weakness plane which acted as a normal fault during the formation of the Mukah half-graben. In a recent paper by Jiang *et al.* (1994) on the results of geophysical investigations in the South China Sea, seismic profiling in the northern part of the Zengmu (Balingian) basin has revealed a prominent fault trending WNW near the Sarawak coast and extending northwards, changing direction to NNW, for a distance of some 600 km across the South China Sea. The fault is one of a series of major structures showing similar trends between the Lupar fault and the West Baram Line. The faults are possibly related to the anticlockwise rotation of Borneo and they may be also reactivated transforms as already indicated above.

Rifting of the Paleocene land surface and the breakup of Sundaland contributed largely to the initiation of most of the Cenozoic basins throughout SE Asia (Hutchison, 1992). The West Baram Line and the Balingian shear zone appear to be old, deep-seated tectonic lineaments reactivated at the beginning of the Cenozoic as part of the breakup of continental Sundaland.

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