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The Mulu Shear Zone – a major structural feature of NW Borneo

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Abstract: A major regional trend in the geomorphology, geology and hydrocarbon fields of NW Borneo is aligned NE-SW and parallel to the Mulu shear zone, a tectonic feature which has imposed a cleavage only on the lower part of the massive Melinau Limestone in N. Sarawak. The cleavage dies out at higher stratigraphic levels towards the NW. The Mulu shear zone can be traced northwards to Brunei where it forms a narrow belt of intensely sheared rocks in the Temburong Formation as well as causing overconsolidation in younger, softer sediments. Evidence of other shear zones which are possibly the displaced continuation of the Mulu shear zone or major shear zones parallel to it, occur in central and SW Sarawak between Miri and Bintulu, in the Tatau and Kuching areas. In west and central Sabah, NE-trending faults are prevalent, and at least one fault between circular sedimentary basins has associated dioritic plugs, indicating a deep structural weakness.

In addition to cleavage, other manifestations of the shear zone are a hardening of Tertiary sediments which spall on exposure, ptygmatic folds associated with quartz veins and the imposition of schistosity with the development of sericite. The various manifestations probably represent differing reactions to shear according to depth.

Offshore, particularly in Sabah, seismic sections across the main NE regional trend show splayed fault patterns which converge at depth to what is presumed to be a major tectonic fracture zone in basement.

Age relationships and genetic connotations of the Mulu Shear Zone and its associated structures are discussed.

INTRODUCTION

A feature of the regional trends of the geomorphology, geology and hydrocarbon occurrences of NW Borneo is a dominant alignment in a NE-SW direction which seems to be controlled structurally by the reactivation of weaknesses in deep pre-Eocene basement. An onshore manifestation of one of the NE-trending fractures has been identified in the Gunong Mulu area in north Sarawak and has been called the Mulu shear zone. The Mulu shear zone or "Mulu Shear" was first recognized and reported in 1976 (McManus & Tate, 1976) to explain the cleavage deformation of the lower part of the Melinau Limestone in north Sarawak. Subsequent field studies elsewhere in Sarawak and fault/geomorphological features on geological maps of Borneo (Roe, 1954; Liechti *et al.*, 1960) and Sabah (Wilford, 1966) suggested the existence of major tectonic lineaments trending approximately N3O°E affecting much of NW Borneo. Only preliminary details, *inter alia*, were published previously (McManus & Tate, 1976) and this paper presents additional

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evidence for what would appear to be a major tectonic feature which has influenced the post-Eocene geology and structure of NW Borneo.

The manifestation of the Mulu Shear often appears somewhat ephemeral and its surface expression easily overlooked; hardening and localised overconsolidation of argillaceous Tertiary sediments are thought to be caused by movement on shear zones at depth. Intense shearing in already folded, cleaved sediments as at Temburong, Brunei could be easily missed. The Mulu Shear or its parallel equivalents are not readily visible by remote sensing. Lee (1980) interpreted 1972 Landsat imagery covering central and western Sabah and although identifying a "Crocker Lineament" trending between NE and NNE, he was unable to recognize any major NE-trending fault, shear zone or other discontinuity resembling the Mulu Shear in western Sabah. There would, however, appear to be a NNE-trending linear feature formed by the convergence of strike ridge, about 10 km inland, parallel to the Klias peninsula and joining with part of the Kiulu lineament between Papar and Kota Kinabalu (Lee, 1980, Fig. 48).

The response of NNE-trending shear zones to gravity surveys has been noted by Bol & Van Hoorn (1980) in the offshore Sabah ridges; there is a conspicuous linear positive gravity anomaly in the Tatau region in central Sarawak (CCOP/IOC, in prep.) and in West Kalimantan, a strong gravity gradient trending NE near Siluas is attributed to an underlying regional fault zone (Rusmana and Pieters, 1989).

DEFORMATION IN THE MELINAU LIMESTONE

The main outcrop of the Melinau Limestone Formation (Wilford, 1961), the Melinau Limestone, forms a massive, NNE-trending stratigraphic unit up to 2,000 m total thickness which is paleontologically and stratigraphically unique, yielding a faunal succession extending from Upper Eocene to Lower Miocene in a single facies (Adams, 1965). The Melinau Limestone occurs on the NW margin of the Mulu anticlinorium and is underlain by the Mulu Formation which Wilford (1961) describes as ?Upper Cretaceous - Paleocene sub-metamorphic, well-cleaved, micaceous slaty shales and thin quartzitic sandstones. Cleavage has obliterated most sedimentary features and the whole area, including Gunong Mulu (2,377 m), is regarded as an "anticlinorium". The Melinau Limestone is overlain with apparent conformity by relatively unaltered and undeformed, Lower Miocene Setap Shale Formation. The age of the Melinau Limestone ranges from mid-Eocene (Tb) to Lower Miocene (Te_5). The basal contact with the Mulu Formation, observed in the Madalam river, is probably faulted. A strike fault, the Melinau fault, transects the limestone and is interpreted by Wilford (1961) as a normal fault related to a monoclinal structure. Ooi (1978) however, deduces that it is a reverse fault with much steeper dips to the NW and a greater throw. Wilford (1961) comments that the lower part of the Melinau Limestone is heavily recrystallised and brecciated, especially in the Melinau and Madalam rivers and is slightly dolomitised. Bedding is poorly developed and the recrystallisation and brecciation have almost completely removed organic features, producing a rock that is almost marble. Cleavage, which appears as closely spaced jointing in massive limestone, has been observed by the author near the base of the limestone in the Madalam river and the cleavage in the lower part of the limestone *dies out* in a NW direction and the upper part of the limestone exposed in the Madalam is unaffected. However, Ooi (1978) records intense shearing in Te strata exposed along Sg. Terekar, a tributary of the Madalam river; in general, shearing is more intense in the north and less intense in the Melinau gorge and to the south. Shearing is apparent in thin section where it distorts the shapes of larger foraminifera. The apparently localised shearing in the younger strata may be related to the Melinau fault nearby. Strata in the Melinau gorge dip between 33° and 50° to the NW or NNW and the rocks are not heavily jointed with only one major joint system trending E-W and dipping 60-70° to the south.

The disappearance of cleavage in a NW direction has important structural implications as it could not have been caused by *regional* deformation. Although the limestone is folded, the style and intensity of the folding is thought to have been insufficient to have produced an axial plane cleavage.

The underlying Mulu Formation is not well known and there is no consensus on the type and degree of deformation; Wilford (1961) mentions "well-cleaved" but Haile (1962) seems to view differently. If cleavage is restricted to certain zones rather than a widespread phenomenon, as described by Shepherd (in Haile, 1962) who comments that in the Tutoh gorge which crosses the Mulu anticlinorium slates predominate only on the flanks of the anticlinorium, the presence of cleavage probably represents a shear zone rather than deformation associated with regional dynamic metamorphism.

It is concluded that there is a major shear zone somewhere in the vicinity of the contact between the Mulu Formation and the base of the Melinau Limestone and that the shear zone trends N30°E, approximately parallel to the Melinau limestone massif. The shear zone has been termed the "Mulu Shear" and the type locality is the base of the Melinau Limestone in the Madalam river. There is no clear evidence for movement direction of the Mulu shear, although right lateral was inferred from the available geological maps. In the type locality, shearing ceased before the development of the present drainage and further detailed field observations are required to establish unequivocally the direction and amount of displacement.

SHEAR ZONES IN EAST BRUNEI

At Kpg. Sumbiling Lama on the Sg. Temburong in Temburong District, East Brunei, a narrow belt of intensely deformed rocks belonging to the Temburong Formation outcrop over a distance of several tens of metres. The rocks are highly cleaved, cut by irregular, discontinuous slippage planes and quartz veining. Nearby roadcuts between Kpg. Sumbiling Lama and Kpg. Batang Duri show excessive spalling and splintering which are features of stress relief in overconsolidated rocks.

Further south, the author has mapped exposures in the Temburong river where there is a clear relationship between cleavage and bedding. During folding, a cleavage has developed in the argillaceous sediments parallel to the axial planes of the folds which trend N15°E. Poles to cleavage, and axial planes are coincident and indicate E-W compressional along an axis aligned N105°E. The folding deformation is clearly unconnected with the shear zone which is almost perpendicular to the compression.

The shear zone at Kpg. Sumbiling Lama would appear to be the northerly linear continuation of the Mulu Shear zone. Its position is slightly offset to the west which would be consistent with the small left lateral movement on the "Jerudong line" (James, 1984, p. 93). If the shear continues in the same direction northeastwards with lateral displacement, it would pass beneath the Pandaruan syncline and across Brunei Bay to the Klias peninsula where the geomorphology shows the same trend.

NE THRUSTS & SHEARS IN SABAH

Structural mapping by oil companies prospecting offshore western Sabah has shown the existence of two principal tectonic trends, N-S and NE-SW, which appear to be influenced by deep fractures within the basement and of the two trends, that following broadly NE-SW is parallel to the strike of imbricate structures in the Crocker Accretionary Prism (James, 1984). Associated with the NE-SW trend are thrusts and sharp thrust-bounded anticlines which give rise to the island of Labuan and NE-trending shoals offshore, including Pulau Mangalum.

At the subsurface in offshore Sabah, the structural style is controlled by two intersecting fault zones, a more intense N-S to NE-SW striking set and a subordinate E-W set. The NE-SW set is roughly parallel to the present coastline and both the NE-SW and N-S sets are parallel to paleocoastlines and have ultimately affected the sedimentation and structural configuration of the west Sabah depositional basins (Bol & Van Hoorn, 1980). On seismic cross sections normal to the NE trend, particularly in offshore Sabah, a splayed fault pattern converges in depth to what is assumed to be a shear zone in the basement (Bol & Van Hoorn, 1980; Levell & Kasumajaya, 1985; Levell, 1987; Johnson *et al.*, 1989a). The continuous trend of the NNE-aligned Sabah ridges is associated with positive gravity anomalies which are thought to be major strike-slip faults in the basement (Bol & Van Hoorn, 1980). Levell and Kasumajaya (1985) surmise also that many N-S and NE-SW trending faults have a strike slip component, often left-lateral, and some have vertical throws in excess of 300 m and generally with a downthrow to the west. Northerly, left-lateral shear zones offshore W of Kota Kinabalu can be linked to shears onshore, notably the Panggi fault (Fig. 1) exposed in the Padas gorge.

Splayed fault patterns are seen also in seismic cross sections in offshore Brunei but they are exceedingly complex and although there is some convergence at depth, the faults do not merge into a single fracture which could be assumed to be a

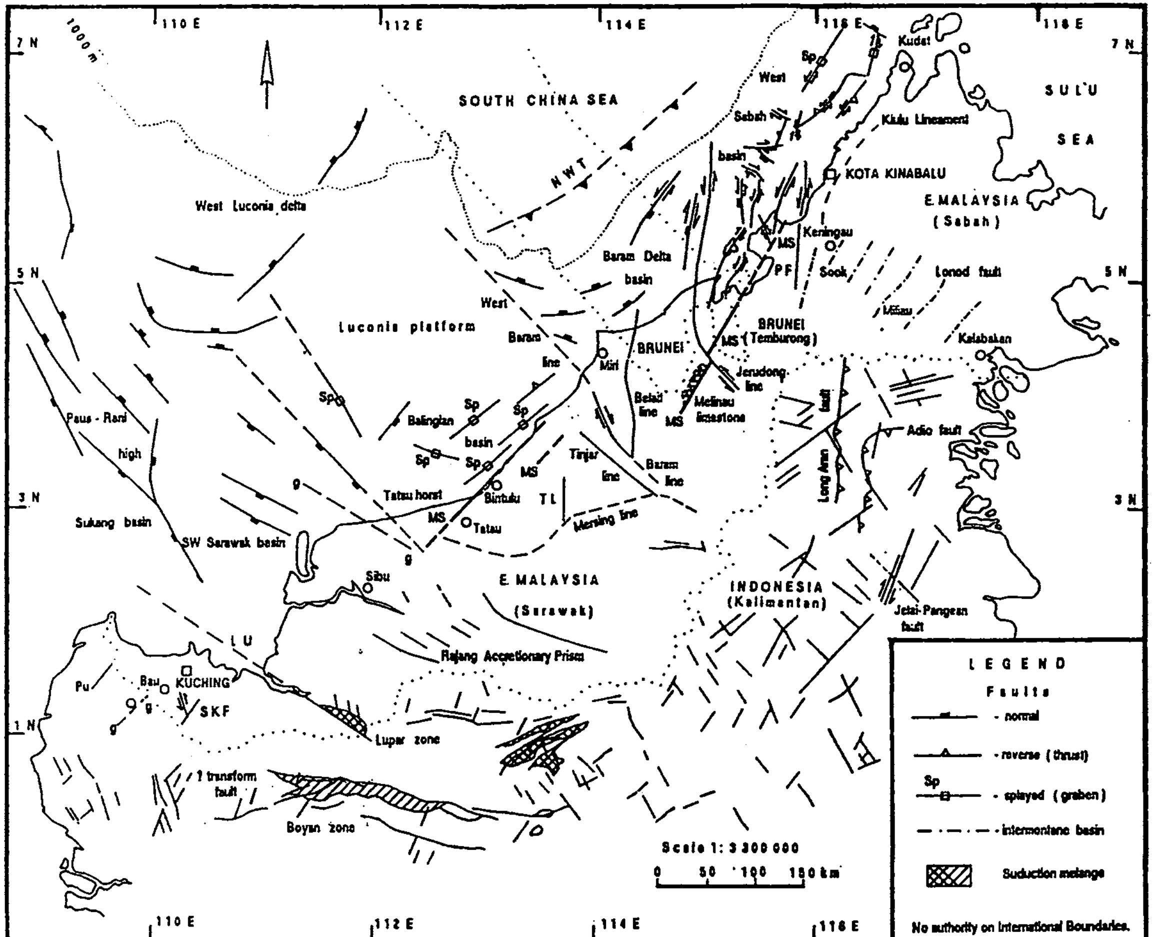

Figure 1: Fault and shear structures in central and NW Borneo. Key: MS: Mulu Shear Zone; SKF: Sarawak-kiri fault; Pu: Pueh fault; g–g: probable fault/shear structures detected by gravity surveys; TL: Tubau lineament; PF: Pangi fault; NWT: Northwest Borneo trough.

shear zone. The more complex nature of the fault patterns is perhaps due to the excessive thickness of sediment which is estimated to be up to 15 km in the deepest part of the Baram delta basin (James, 1984).

Onshore, in western Sabah, the NNE-trending Kiulu lineament has been identified on Landsat imagery by Lee (1980). Roadcuts intersecting the lineament show that it is an intensely disturbed zone with shearing in the sandstones and shales and folds indicate a east-dipping thrust zone. The subparallel Crocker lineament occurs between 16 and 20 km further east and also is probably a major thrust.

Further south, the Quaternary, parallel-sided, elongate inter-montane plains at Keningau and Sook are controlled by NNE or NE-trending faults. In central and eastern Sabah, a number of Miocene circular sedimentary basins are aligned in two principal directions. A SE trend from Miliau to Kalabakan which probably forms part of a branching rift system connected with the opening of the Macassar Straits (Hutchison, 1988). The other direction is aligned NE and extends from the Miliau basin to Tangkulap, Kuamut and Lamag and the submarine Tertiary basin offshore Sandakan. The Tertiary sedimentary basins are separated by NE-trending faults and the Lonod fault, between the Miliau and Malibau basins, is associated with two diorite plugs (Collenette, 1965) suggesting that fault is a deep structural feature. The NE tectonic grain appears to have dissected the NW trending rift into a series of circular basins, suggesting that repeated movement on the faults between the basins has been a major structural control during sedimentation.

NORTHEAST SHEAR ZONES IN CENTRAL AND SOUTHWEST SARAWAK

The Mulu shear zone, its displaced equivalents or parallel shears have been identified at several places in central and SW Sarawak. At exposures 60 km from Bintulu on the road to Miri, massive grey clayey silts belonging to the Nyalau Formation show evidence of overconsolidation and the rocks spall and splinter into oval, dm-size pieces with curved fracture surfaces. It is probable that over-consolidation of the otherwise normally compacted shales in the Nyalau Formation is a response to movement on a deep shear zone.

In the Tatau area, SW of Bintulu, highly sheared phyllitic sediments have been mapped in the Eocene Belaga Formation and in the Oligocene Tatau Formation. The phyllites mapped in the Bawang Member of the Belaga (Stage IV) Formation, occur on the western side of the NE-trending Kelawait fault (Wolfenden, 1960) in what James (1984) refers to as the "Tatau horst and graben province" situated on the NW margin of the Rajang Accretionary Prism. The upthrust, parallel-sided, elongate block brings older (?Eocene) rocks in juxtaposition with Oligocene Tatau Formation sediments. Tjia *et al.* (1985) examined roadside outcrops in both Formations near Tatau and describe slickensides and incipient crystallization of gangue minerals on surfaces of competent rock fragments. In addition, argillaceous sediments are metamorphosed to phyllites which are attributed to post-depositional shearing. The superimposed folding verging NW and orientated NE-SW reported by Tjia and others may be related to movements of a NE-trending deep shear zone. Structural analysis of fold patterns indicates a dominant N-S compressional regime has affected both the Bawang member and Tatau Formation in this region. The Kelawit fault and the Batu Kapal fault further north form an *en echelon* pair with downthrows in opposite directions which Tjia *et al.* (1985) conclude to be an important strike-slip fault zone in central Sarawak.

A marked linear gravity anomaly occurs over the Tatau horst (CCOP/IOC, in prep.) and it is clearly related to a N30°E geological feature at depth (Fig. 2). The occurrence nearby of the andesitic Arip Volcanics and Bukit Piring granitic intrusion (Wolfenden, 1960) suggests that they were extruded from a deep fracture aligned in the same direction as the anomaly. Furthermore, the gravity values increase substantially on the landward side of the fracture by some 500 μ m sec^{-2} above the regional background offshore and indicate more dense rock lie at depth SE of the fracture. Basaltic lavas are recorded at Bukit Mersing, some 30 km to the east (Wolfenden, 1960). Another linear gravity anomaly trending WNW occurs offshore and may represent a continuation of the Bukit Mersing line (Hutchison, 1975).

During the construction of the Sibu-Bintulu road, intensely deformed argillaceous sediments with ptygmatically folded quartz veins were exposed at the Balingian river crossing, about 70 km NE of Sibu and 50 km SW of Tatau. Recent fieldwork by Ho (1991) shows that the rocks here are indistinguishable from the Belaga Formation (Bawang Member). However, at the Balingian crossing, vertical shear planes strike NE, almost perpendicular to the regional NNW strike of the cleavage and bedding planes in the Belaga Formation (Fig. 3) and the shear zone here marks a deep fracture which probably represents the SW continuation of the deep structure indicated by the gravity anomaly at Tatau.

Offshore, in the Balingian basin, a series of parallel graben structures with splayed fault patterns has been recognised which are mostly parallel or sub-parallel to the Tatau structures onshore.

The continuation of the NE shear trend across the Lupar line (Hutchison, 1975) is problematical and an additional complication is caused by the supposed anticlockwise rotation of Borneo (Haile, *et al.*, 1977; Schmidke *et al.*, in press) castes some doubt on whether there is a meaningful relationship between faults south of the Lupar line to the younger NE-trending structures further north. There are undoubted shear zones, some transcurrent, in the West Sarawak - West Kalimantan area and they are now described.

Tjia (1970) reported transcurrent faulting in the Sarawak-kiri river area where the main NNW wrench fault has been traced for 8 km and shows left-lateral displacement. Other faults trending N30°E also suggest left-lateral displacement

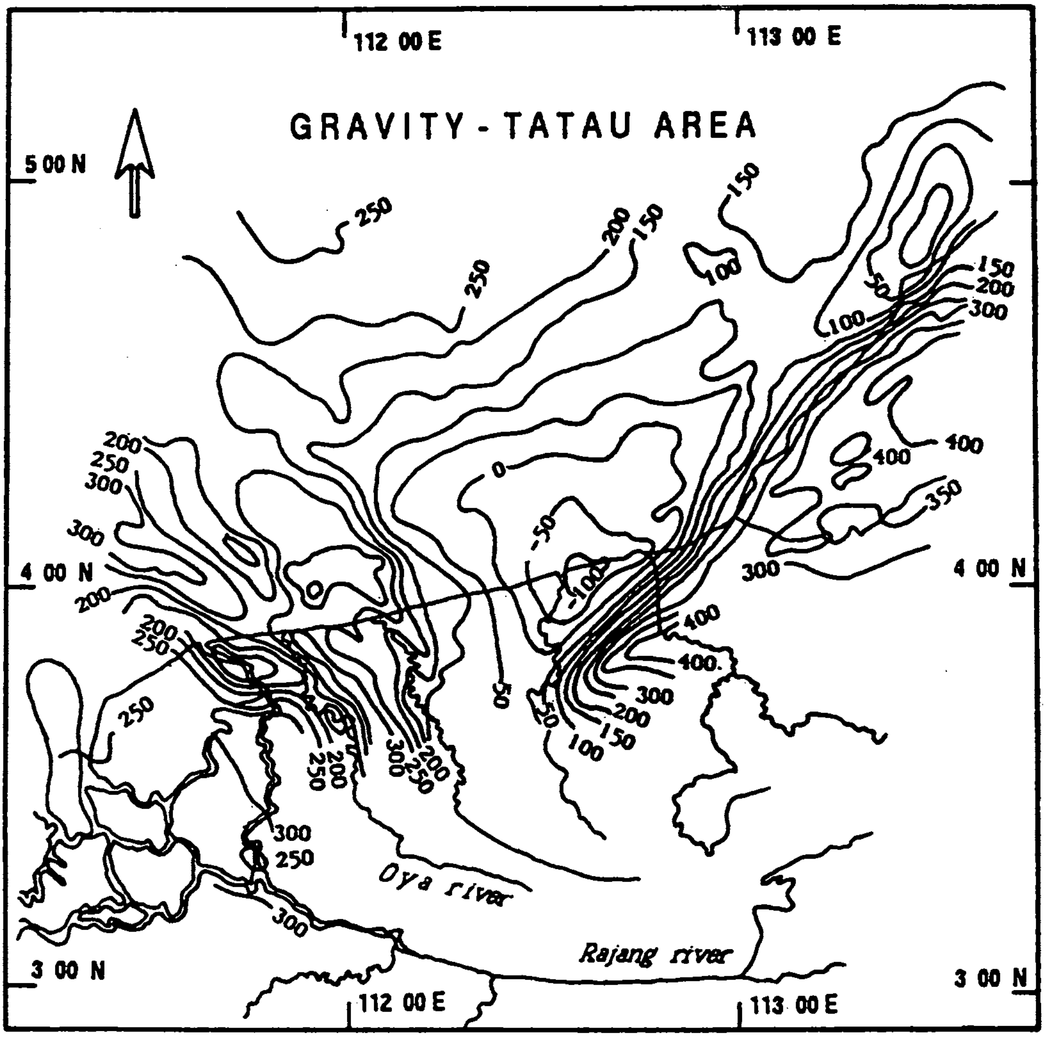

Fig. 2: Bouger Gravity Map, Tatau area. (After SEATAR – IOC, Transect VII, CCOP, Bangkok. In preparation.) Contours at 50mgal intervals.

Fig.3: Shearing and ptygmatic folding aligned NE, Sibu-Tatau road bridge, Balingian river, Sarawak. Sericite and/or muscovite is developed in argillaceous rocks and sub-vertical cleavage planes are aligned NE at right angles to the regional trend of the Rajang Group.

but they are perpendicular to the regional structural strike and are considered by Tjia to be older than the main wrench fault. A Lower Paleogene age is attributed to the transcurrent faulting in this part of Sarawak.

In the same region of West Sarawak, recent field studies of the pre-Late Triassic Jagoi granodiorite (Wilford, 1955) show that the northern margin is intensely sheared (Ting, C.S., 1991). The shear zone strikes approximately E-W but it appears only to be within the granodiorite and is apparently unrelated to a NE trend. However, in the same area, a shear zone is exposed within the Bau Limestone - Padawan Formations on a new road S of Pejiru; closely spaced jointing and an exposed fault plane occur in the limestone and the adjacent Pedawan shales are highly sheared and fractured. On satellite imagery of the border region, there is a lineament trending N15°E clearly visible in the Kayan basins in Kalimantan and trends across into Sarawak and sub-parallel to the Tertiary dacitic intrusives. Northeast structural control of the Miocene dacitic intrusives is evident on the NW and SE margins of the Kayan basin to the west of Kuching.

The gold, mercury and antimony mineralisation at Bau, SW of Kuching is related to the heat source from a NNE line of mid-Miocene dacite porphyry and microgranodiorite porphyry intrusions (Chen, Hon, and Kho, 1986) which continue across to Indonesian Kalimantan as representatives of the Sintang Intrusive Suite

(Rusmana & Pieters, 1989). The Miocene intrusions to the SW of Bau appear to be structurally controlled by NNE-aligned weaknesses at depth.

A geological feature which has remained unexplained in publications to date is the apparent discontinuity of the Rajang Accretionary Prism into offshore Sarawak. Oil companies operating in Sarawak infer a rapid wedging out of the Rajang Group sediments towards the WNW, to be replaced along the strike, by the Tertiary to Recent Sukang sub-basin, Paus-Rani high and SW Sarawak basin (Hageman, 1987; Johnson *et al.*, 1989b). It is suggested that there may be major NE shear zones beneath the present Rajang delta responsible for the abrupt termination of the thick Rajang Group turbidites and possibly the same shear zones continue across the Lupar line to Kuching, Bau and Siluas. The antimony, arsenic and gold mineralisation on the western margin of the Lower Rajang (Wolfenden, 1960) may be the result of remobilisation caused by heat from an intrusion formed on a NE trending shear zone at depth, similar to mineralisation at Bau, although the mineralized zones are located along NW faults.

DEPOSITION OF NE-TRENDING SHEAR ZONES IN SARAWAK

If the indications of a deep shear zone between Bintulu and Tatau represent the southerly continuation of the Mulu shear there is a right lateral offset of the order of 100 km. Right lateral movement agrees with the sense of relative offset on the West Baram line-Tinjar fault (James, 1984, Fig. 12) and the amount is similar, of the order of 80-100 km. If the shear zones in the Tatau area represent the same fracture system, the right lateral offset is about 120 km. In Sabah, the NE shear belt extends from central Sabah west to the offshore region, a distance of at least 450 km and it is probable that NE shearing affects a similar width of country further south in Kalimantan.

FRACTURE PATTERNS IN CENTRAL AND EAST KALIMANTAN

The fracture patterns in central and east Kalimantan are determined largely from remote sensing data and knowledge of dating and fault movements is constrained by insufficient field evidence. They appear superficially to show similar relationships to the N- and NE-trending fractures in NW Borneo but only the Jelai-Pangean fault in east-central Borneo has evidence of being a deep structure as it is associated with Miocene volcanic extrusives, small acid intrusions and gold mineralisation (Lefevre *et al.*, 1982). The fault has been traced over a distance of 160 km and exhibits minor right lateral displacement.

The Long Aran fault, trending N-S for a distance of at least 150 km, is described as an easterly dipping thrust fault resulting from movement from east to west (Lefevre *et al.*, 1982). Brecciation is reported but not intense shearing. It is thought to have been synsedimentary and separates two contemporaneous sedimentary Formations. Lee (1980) notes that although the Witti fault is not apparent on Landsat imagery, the Crocker-Sapulut boundary along the Witti Range is visible and lies some 16 km further east than the position established by Collenette (1965). The Crocker-Sapulut lineament may be the northerly continuation of the Long Aran fault.

The Adio Fault suture lies 25-30 km east of the Long Aran fault and forms a narrow belt of highly disturbed rocks composed of gabbros, mylonitised serpentinite, spilite, diabase and chert (Lefevre *et al.*, 1982). It can be traced for more than 80 km and is aligned mainly N-S but veers to an E-W alignment in the north. Although the fault is described as a "suture", the nomenclature is inappropriate as the fault does not separate two widely differing geological regions. It would appear to show greater similarity with the Tinjar and Mersing lines in Sarawak, which are essentially dislocation zones along which sheared and broken fragments of deep-seated rocks occur. Of the three major faults described, only the Jelai-Pangean fault has features which display similarities with the deep shear structures in NW Borneo but movement on the fault is right lateral instead of the predominant left lateral in NW Borneo. The remaining faults are aligned WNW or NE-ENE, are younger and appear to have virtually no transcurrent element.

In West Kalimantan, near the international border, Rusmana and Pieters (1989) report that the intrusive Mesozoic Pueh granite has a locally sheared contact on the NNE flank of the pluton and a NNE-trending fault is evident on Landsat imagery towards the southern margin. The age of the fault is probably older than Upper Cretaceous. Further south, at Siluas, a linear strong gravity gradient trending NE may represent an underlying regional fault zone and the trend is parallel to faults in the Sarawak-kiri region.

AGE OF THE MULU AND SIMILAR SHEAR ZONES

Repeated reactivation of deep tectonic fractures prevents a specific age to be assigned to the Mulu shear or its associated fractures. The oldest movements are probably post-Eocene in the type locality and the youngest sediments affected by NE shears are probably Pliocene or even Quaternary in offshore areas. Shear movement seems to vary in time and space. For example, in offshore Sabah between Labuan and Mangalum, the main tectonic phase occurred in Upper Miocene and led to the formation of steep, upthrusted, narrow anticlinal trends separated by broad synclines thought by Bol & Van Hoorn (1980) to have been induced by basement wrench faulting. Further north, towards the Kudat Peninsula, tectonism occurred later in the Lower Pliocene.

In West Sarawak, Tjia (1972) deduced that the structural grain of the Bau, Kuap and Sarawak-kiri regions was probably achieved by the end of the Mesozoic. The somewhat elongate ?Eocene Kayan basin appears to be structurally controlled probably by two NE-trending shear zones on the NW and SE flanks and subsequent repeated movement on the shears at depth has enabled the weakness planes to act as a focus for dacitic intrusions in mid-Miocene.

GENETIC IMPLICATIONS OF THE MULU SHEAR ZONE

A curious feature of the Mulu shear and its relatives is the absence of any clearly demonstrable lateral displacement, even though shearing has been of such intensity as to cause cleavage in massive limestone and the development of sericite and muscovite in phyllites. Yet repeated movement on deep fractures has occurred at least since Eocene, and possibly earlier. A left lateral movement is inferred from the offset of the Mersing line deduced from the gravity anomalies, west of Tatau and there is evidence of both left- and right-lateral movement in Sabah (Figs. 1 & 2).

In a preliminary synthesis of a tectonic scenario for Eastern Borneo (Hutchison, 1988), the eastern margin of the Miri Zone (Haile, 1974) is interpreted as an Atlantic-type continental margin with down-faulted continental crust giving way eastward to Late Cretaceous-Eocene oceanic lithosphere. Further N, continental crust of probable Jurassic age underlies the Reed Bank (Hinz and Schluter, 1985) It seems probable that high heat flows indicate continental crust beneath Luconia province which was a sufficiently stable platform throughout the middle Tertiary to allow the buildup of considerable thicknesses of carbonates. If the continental crust underlying the Reed Bank and the Miri Zone represents part of the rifted continent which broke away from China, and if there has been NO rotation of Borneo (Haile, *et al.*, 1977) or of southern China, the NE-trending tectonic fractures in NW Borneo are parallel to fractures of similar orientation in Guangdong Province which are responsible for widespread horst and graben features of SE China. The latter are Jurassic in age but are probably also controlled by older, deep structures.

An alternative explanation which allows for the anticlockwise rotation of Borneo (Schmidtke, *et al.*, in press), lies in the possible oblique subduction of oceanic crust resulting in wrench faulting, as occurs at the present day in Sumatra or in California. The stress patterns on the continental side of an oblique subduction zone tend to produce lateral slip within the underlying continental basement. Most palinspastic reconstructions of the South China Sea (Holloway, 1981; Taylor & Hayes, 1983; Gatinsky and Hutchison, 1984) describe Late Cretaceous rifting eventually causing S or SE spreading of the southern part of the South China Sea during the Paleogene, pushing continental fragments towards Borneo; at the same time, the western part of Borneo began rotating anticlockwise. The resultant forces of the two movements may have caused repeated NNE or NE shear movement in the continental crust beneath the NW part of Borneo which translated upwards to form NNE or NE shear zones in the overlying rocks. Levell (1987) considers that transcurrent movement on left-lateral shears appears to have outlasted the end of subduction (mid-Miocene) at the NW Borneo-Palawan trench and persisted into the Pliocene.

There is a possibility that a remnant transform fault system lies at depth beneath Borneo, or at least beneath NW Borneo. The idea was first proposed by McManus and Tate (1976) who linked the transforms with NE trending transforms in the Indian ocean. Recently, Williams *et al.* (1988), in reconciling the geological evolution of central and west Kalimantan, have identified a major NNE-striking geological boundary separating an "accretionary domain" in the east and a "NE Kalimantan domain" in the west (see Williams *et al.*, 1988, Fig. 7). They interpret the boundary as a dextral transform fault active in the north and against which subduction ended in the Late Cretaceous. The position of the transform lies at a change in direction of the present coastline and would explain the abrupt termination of the Rajang Accretionary Prism as well as the apparent discontinuity of the Lupar zone to the NW. If the Boyan and Lupar zones were originally part of the Early Cretaceous subduction of the western Pacific, as envisaged by Taylor and Hayes (1983), the associated transforms would have been orientated roughly latitudinally. Subsequent anticlockwise rotation of Borneo by about 60° would align them to their present NNE orientation. However, the dextral motion on the transform in Kalimantan is ambiguous with the dominantly sinistral motion reported from further north.

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