Geol. Soc. Malaysia, Bulletin 27, November 1990; pp 261 – 292

The Maliau Basin, Sabah: Geology and tectonic setting

H.D. TJIA[1]*, IBRAHIM KOMOO[1], P.S. LIM[2] & TUNGAH SURAT[2]

[1] Department of Geology, Universiti Kebangsaan Malaysia
43600 Bangi, Selangor
[2] Geological Survey of Malaysia, 88320 Kota Kinabalu, Sabah

Abstract: A field survey of the eastern half of the Maliau Basin established the presence of several good quality coal seams in the dominant mudstone sequence of the Early to Middle Miocene Tanjung Formation. Although volumetrically minor, the several metres thick sublitharenite beds dominate the landscape forming high waterfalls, concentric cuesta and other ridges with dipslopes inclined into the basin. Sandstone channel fills are common. Sedimentary current indicators including current ripple marks, tabular and trough cross beds, and lineation of carbonised plant fragments indicate that the majority of currents was towards northeast. The presence of coal, dominant mudstone, marine body and trace fossils suggest that the Tanjung Formation developed in low-energy environment, probably in wide tidal flats. Except for one locality exposing open folds, the beds dip uniformly and gently inward forming an eccentric basinal structure associated with normal faulting. These phenomena could have only been caused by gravitational subsidence without tectonic compression.

The northern boundary strike ridge intercepts internal strike ridges at oblique angles. This pattern and the off-centre position of the youngest beds suggest that the Maliau Basin during the deposition of the Tanjung Formation became progressively narrower while its depocentre migrated towards the south rim.

The structural basins containing the Tanjung Formation and time-equivalent Kapilit Formation are arranged in northeast and southeast rows; the Maliau basin occupying the junction of these two directions. Geologically the Maliau Basin is the landward extension of the Tarakan Trough and is at least partially floored by melange rocks of the Kinabalu Suture Zone. Subsidence of this basin and other early-middle Miocene basins of east Sabah began when the East Sabah Terrane stopped drifting south and isostatic readjustment sank the denser ophiolitic basement of the suture zone.

INTRODUCTION

The planimetric shape of the Maliau Basin *sensu stricto* is circular, extending 25 km and 22 km along E-W and N-S axes, respectively. The larger Maliau basin area is elongated and extends 55 km in NE-direction. This structural basin is composed of lower to middle Miocene Tanjung Formation that has been estimated by Collenette (1965) to reach a thickness of 40,000 feet (12 km). Collenette assigned a Te_5-f age (Early Miocene; mistakenly considered as "Upper Miocene" in his report) based on benthonic and pelagic foraminifera. On the Third Edition geological map of Sabah compiled by Lim (1985), the Tanjung Formation is indicated as being of early to middle Miocene age (Figure1). In the Maliau Basin proper, ridge-forming layers of sandstone form strike ridges with

Presented at GSM Petroleum Geology Seminar 1989
* *Present address: School of Physics, Universiti Sains Malaysia, 11800 Penang*

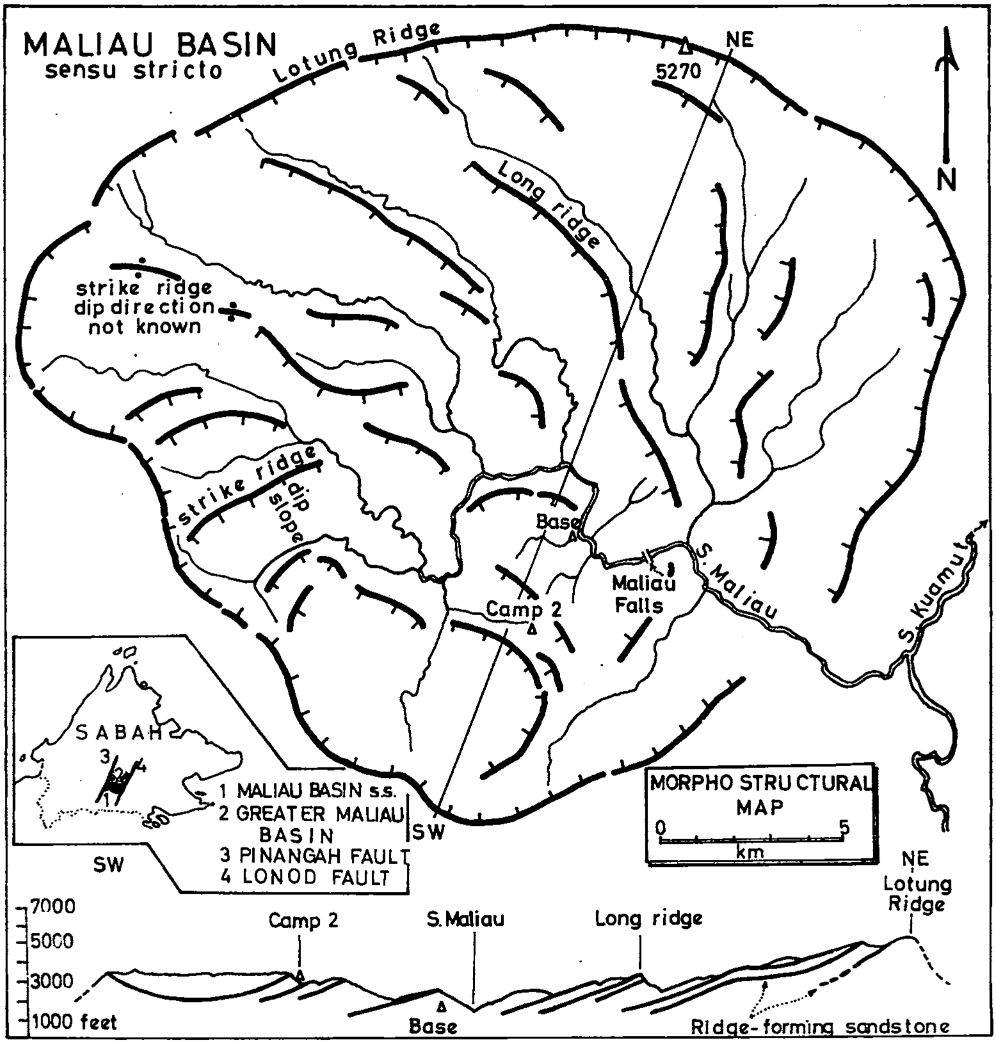

Figure 1: Morphostructural map of the Maliau Basin *sensu stricto*. Heavy lines are strike ridges, their dipslopes are indicated by short dashes perpendicular to the lines. Gunung Lotung (alternative spelling Lutung) on the outer ridge is 5270 feet high. Although mudstone is the dominant lithology, interacalations of several metres-thick sandstone control the morphology. Note the off-centre position of the upper unit of the Tanjung Formation to the south of Camp 2. The major faults Pinangah and Lonod bracket the basin. A NE-SW cross section is shown.

gentle dip slopes inclined at less than 15 degrees. As expected, in the central part of the basin dips are much gentler and some are horizontal.

The present report is based mainly on fieldwork in April-May 1988 in the central portion of the basin (HDT and IBK, 10 field days) and in a larger northeast sector (by PSL and TS in an extended reconnaissance survey). We were members of an expedition organized by Yayasan Sabah and World Wide Fund (Malaysia) to study various aspects of the natural environment of the basin. Geological observations along part of the Maliau river are included in Memoir 12 by Collenette (1965), but we know of no other publications on the field geology of the Maliau Basin *sensu stricto*.

LITHOLOGY

The sedimentary rocks that occur in the central portion of the basin, that is, in the vicinity of our Base Camp and Camp 2 (Figure 1) comprise the upper portion of the Tanjung Formation. The dominant rocks are ***mudstone*** intercalated with thin and thicker layers of ***siltstone*** to ***medium-grained sandstone***. Locally occur conglomerate, clayey lignite and thin laminae of reddish brown claystone/slate within sandstone. The same lithology outcrops in the northeast portion of the basin in addition to relatively thick coal seams (Plate 1).

The mudstone is grey to dark grey (due to high carbon content) and occurs in massive sequences (Plate 2) or may contain intercalations of siltstone beds, hard sandstone disks, and/or small to large channel fillings of sandstone. The channel fills range in size up to 1.5 m high and may be more than 2.5 m across (Plate 3). Occasionally rectangular mudcracks appear on bedding surfaces of the mudstone. In certain sequences, flat clay-ironstone concretions (limonitic nodules), a few centimetres long, occur parallel to the stratification. Mudstone overlying and underlying coal seams are often coaly. Laminations within the mudstone are caused by intercalated siltstone or carbonaceous material. In a 2-metre thick mudstone layer are cross laminae (Plate 4). The mudstone is commonly lithified, is brittle and displays conchoidal fractures.

Thin siltstone layers (sometimes carbonaceous and containing resin) form frequent intervals within mudstone occurrences. Fine to medium grained sandstone may occur as moderately thick beds 0.5 to a metre thick and as channel fills among the mudstone sequences. Quartz grains are common but quartzitic sandstone was only seen as float among the river boulders. Other constituents are grains of mudstone, siltstone, small carbonized plant fragments, and rarely granules of lustrous coal. Several sandstone banks may occur together to form intervals of competent rock each not more than 5 m thick. These intervals create rapids and waterfalls that in the vicinity of the Base Camp and Camp 2 reach great heights in the order of 10 to almost 30 metres (Plate 5). Outside the central basinal area sandstone banks form scarps, dip slopes

Plate 1 : A 1.65 m thick blocky, clean coal roofed by a 2 m sequence of thin interbeds of mudstone and sandstone, and floored by a 1 m thick carbonaceous mudstone. Locality is in the lower reaches of the easternmost tributary to the Maliau River.

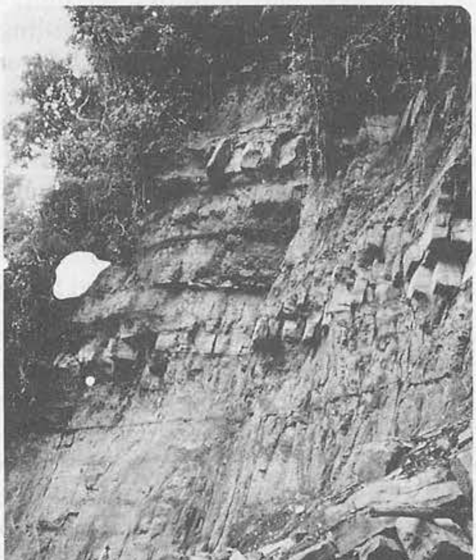

Plate 2 : Massive laminated mudstone overlain by a sequence of thick sandstone and mudstone interbeds. Locality is at the middle reaches of the river east of Long Ridge.

Plate 3 : Well-developed channel filling of sandstone in dominantly mudstone lithology. Locality near Base Camp.

Plate 4 : Cross laminated massive mudstone between massive tabular laminated mudstone (on top) and fine grained sandstone (below). Cross laminae dip gently towards SW. Locality is in the river at the south end of Long Ridge.

Plate 5 : Thin mudstone layers intercalated with thin to thick sandstone beds form the Maliau Falls. The total fall height is 28 m.

(cuestas on the perimeter) and ridges. The sandstone bottoms may be flat to irregular, the latter being the result of scour-and-fill processes. A host of markings may adorn the sandstone upper surfaces. Among the markings are current, interference and less commonly festoon ripple marks, organic tracks, crescentic flutes and at one locality also rain pits. In a sandstone float, slide marks suggest penecontemporaneous slumping. Internal markings of the sandstone layers comprise tabular and trough cross beds, lamination in the finer grained varieties, burrows normal, oblique and/or parallel to bedding. *Ophiomorpha* may occur as single or branching shafts. The sandstone that form the channel fills is usually medium grained and may contain internal bedding as well as cross beds. Thin (not more than 5 cm) wafers of reddish brown claystone or slate sometimes occur as interbeds in the sandstone. The claystone/slate is transected by regular fracture patterns that have promoted differential weathering. In a later paragraph we will show that the fracture pattern is genetically related to the inclination of the associated beds. However, no fractures could be seen in the sandstone enlosing the claystone/slate interbeds. Mineralogically, the different varieties of sandstone are similar. Quartz is the main component at 45 to 60 percent and occurs as individual, subangular to subrounded fractured grains with undulose extinction or as clusters of grains possessing interlocking edges. Rock fragments constitute up to 20 per cent of the sandstone and consist mainly of subangular to subrounded chert with minor basic volcanic and metamorphic rock fragments. Feldspars, micas, zircon and opaques also occur in minor amounts. The groundmass is usually clay and finegrained quartz sand although carbonaceous matter makes up a significant portion of the groundmass of carbonaceous sandstone. According to McBride's (1963) classification, the sandstones are sublitharenites.

Flat, hard claystone pebbles and rare pebbles of other lithologies a few centimetres across may occur among the sandstone beds. They form matrix-supported conglomerate in which the matrix consists of uniform grain size. The uniform texture of the groundmass and the thinness of the pebble distribution led us to interpret the conglomerate as representing lag-gravel. Thicker (decimetre-size) clast-supported conglomerate composed of sandstone and claystone clasts often contain mollusc shells, mainly bivalves. This conglomerate and the lag conglomerate are commonly of reddish brown colour.

In the area around the Base Camp clayey lignite layers as thick as 0.5 m occasionally crop out. Lustrous coal was only seen as float.

Figures 2, 3,4 and 5 are stratigraphic sections that are representative of the Tanjung Formation in the central and eastern parts of the basin.

PALAEOSLOPES

Palaeoslopes are indicated by penecontemporaneous glide planes and possibly also by normal faults of consistent strike. Figure 6 is an outcrop of mudstone with thin siltstone interbeds exhibiting glide planes subparallel to bedding and are therefore interpreted as penecontemporaneous normal faults. The attitude of glide planes and drag features (including a rollover structure) suggest gliding or slumping towards southeast. Larger scale normal faults (Figures 7 and 8) indiceate tension in the NE-SW direction. This direction is parallel to the dominant current sense (Figure 9). In Figures 7 and 8, the 140/10 and 325/30 faults appear to represent listric faults. The rollover associated with the 325/30 fault and its listric nature suggest that the rocks were plastic during deformation, perhaps because the structures were formed penecontemporaneously. The clear indication of tension in NE-SW direction and prevalent currents in the same direction suggest that the palaeoslope trended NW-SE.

PALAEOCURRENTS

Many sandstone surfaces possess current ripple marks. Current structures contained by sandstone beds comprise planar and trough cross beds, preferred orientation of long pebble-axes in lag conglomerate horizons and that of elongated, carbonised plant fragments. At one locality along the Maliau river about 2 km upstream from Base Camp, crescentic flutes occur on a sandstone surface

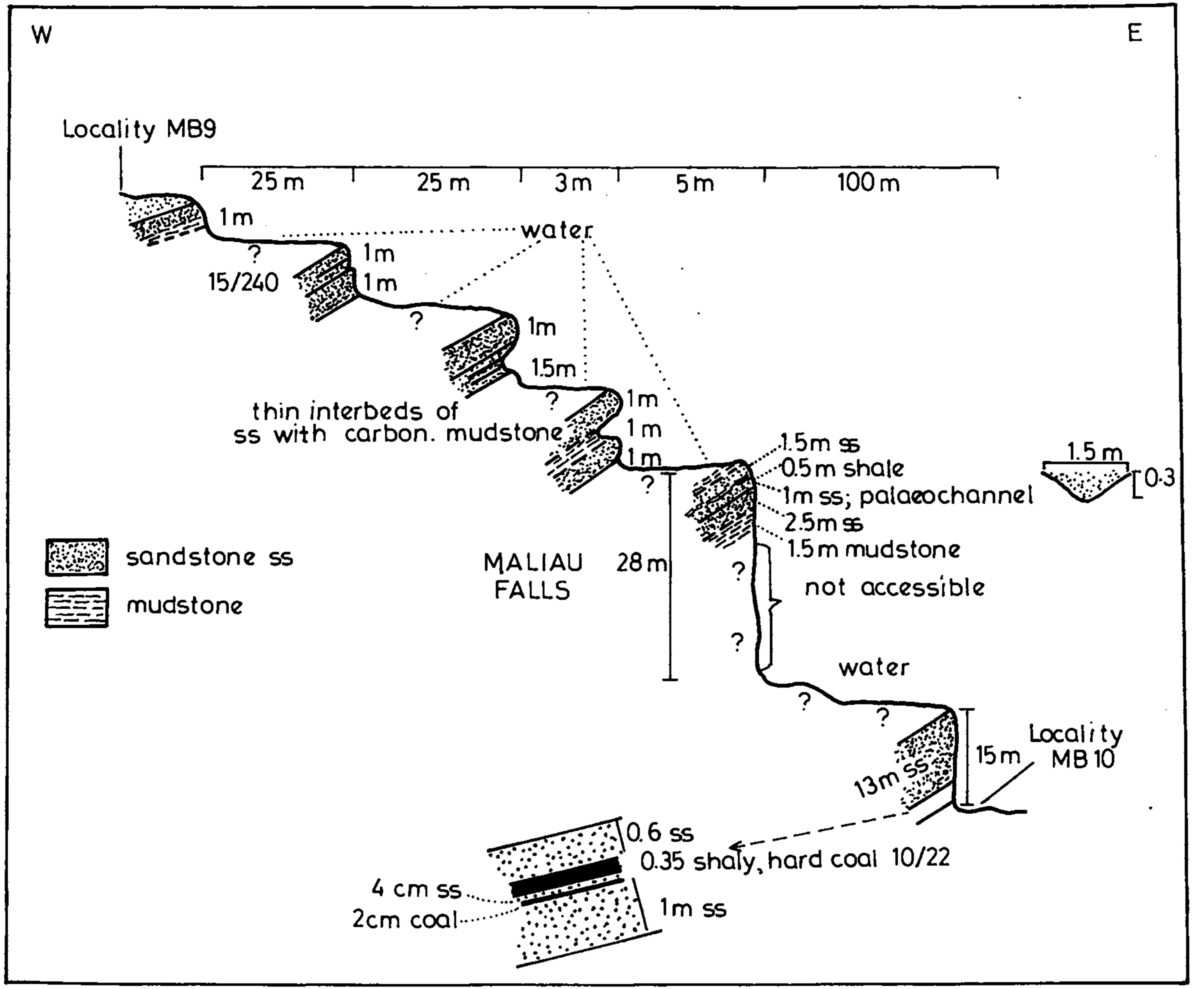

Figure 2: Diagrammatic stratigraphic section at the Maliau Falls. Bedding attitudes are indicated by dip value/dip direction.

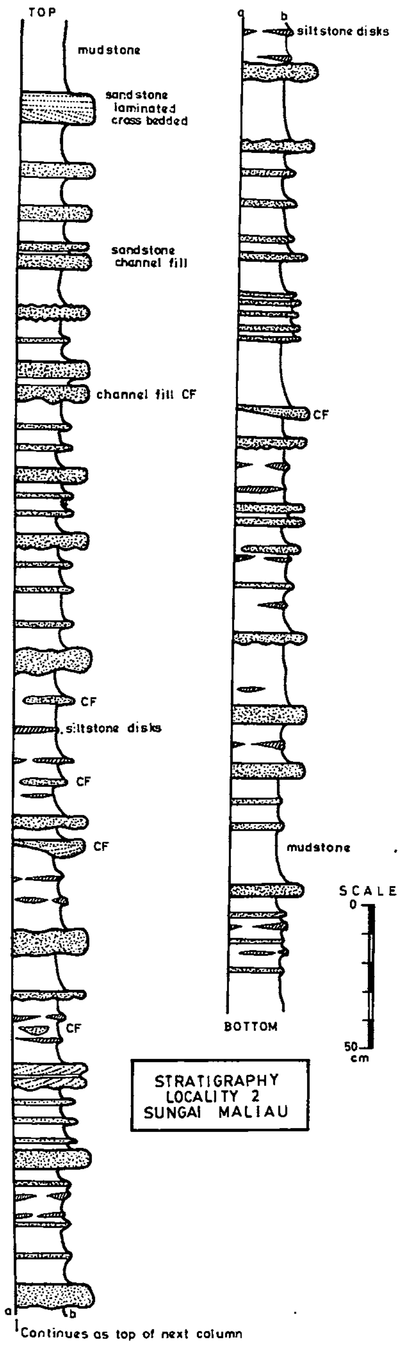

Figure 3 : Detailed stratigraphic column of mudstone and sandstone intercalations of the Tanjung Formation. Locality is along the Maliau River, a few hundred metres upstream from Base Camp.

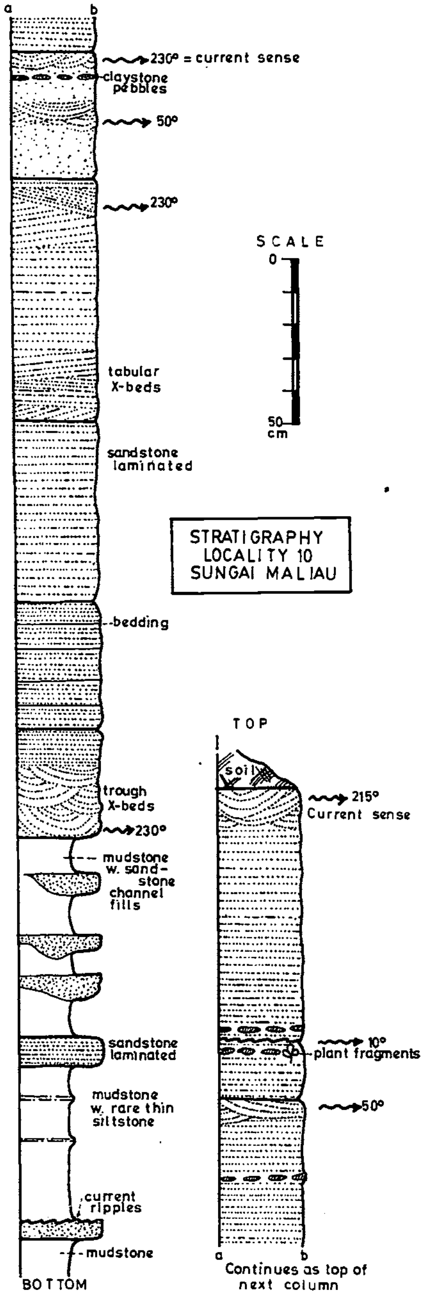

Figure 4 : Stratigraphic column of mudstone and sandstone intercalations of the Tanjung Formation. Locality is along the Maliau River, a few hundred metres upstream from Base Camp.

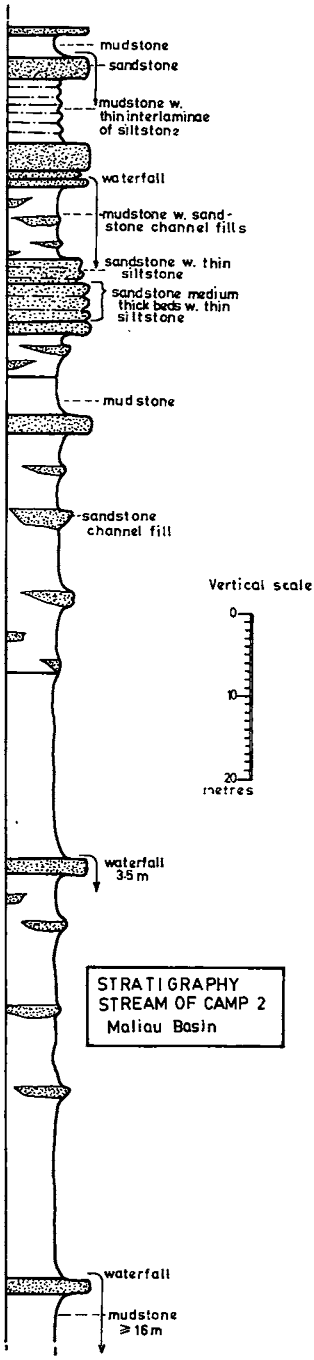

Figure 5 : Stratigraphic column of one of the dominantly mudstone sequences of the Tanjung Formation, intercalated with thinner sandstone intervals. These intervals form rapids and waterfalls. Note the smaller scale of this column compared with those of Figures 3 and 4. The section is along tributary flowing from Camp 2 into the Maliau River.

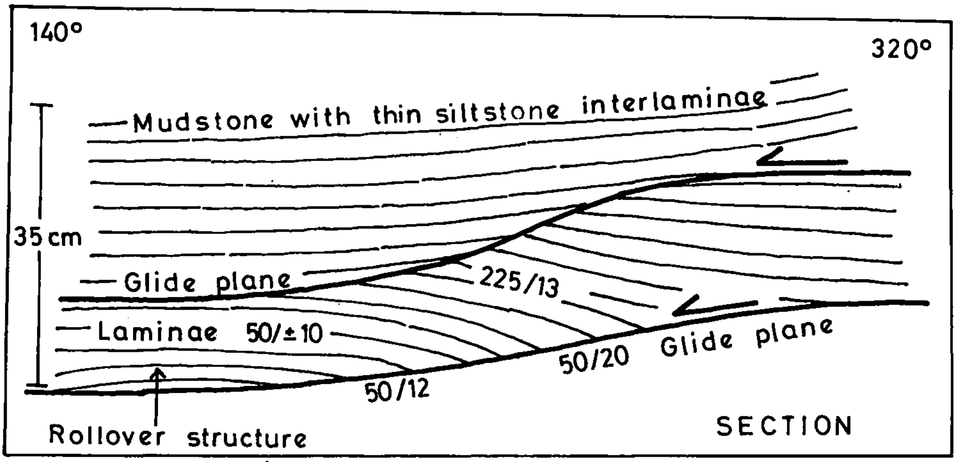

Figure 6 : Penecontemporaneous slumping is indicated by glide planes subparallel to stratification. Note the small rollover. Locality is on the right bank of the Maliau River, a few hundred metres upstream from Base Camp.

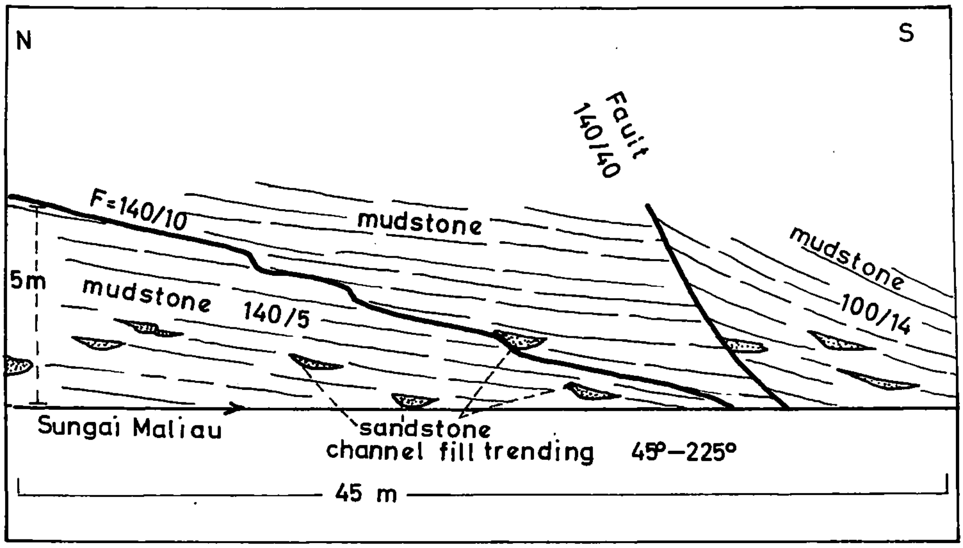

Figure 7 : Normal faults in the Tanjung Formation (one is listric) along the Maliau River near Base Camp.

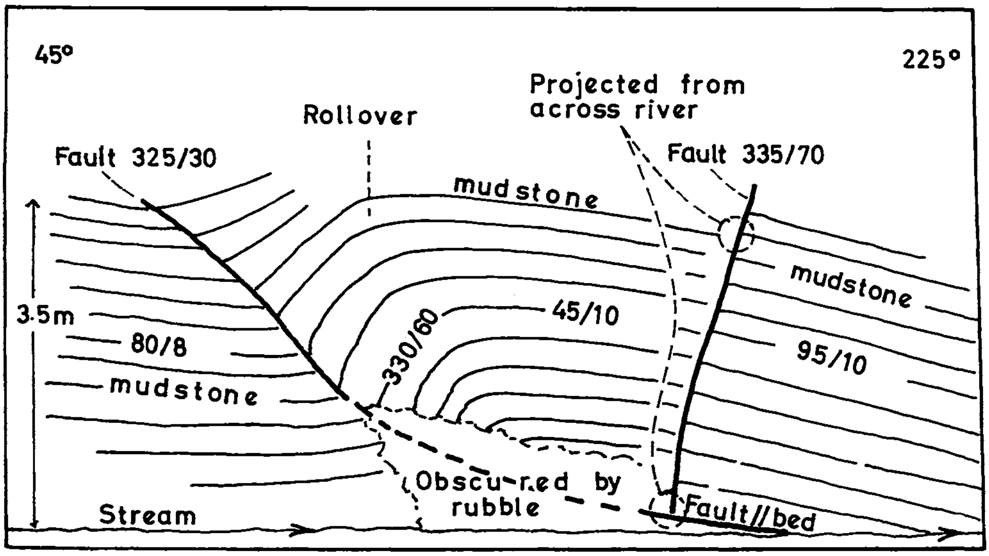

Figure 8 : Normal faults in the Tanjung Formation near Camp 2 along a tributary to the Maliau River. Note the steeper dips and the rollover structure.

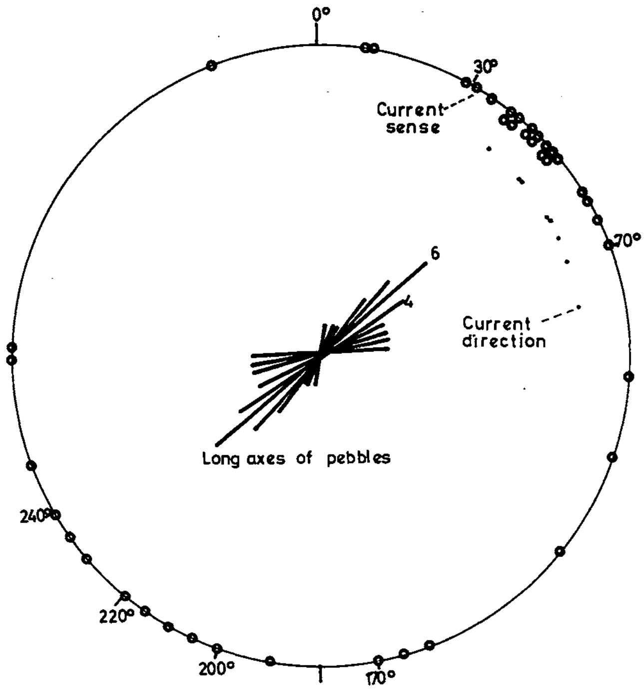

Figure 9 : Circular plot of current sense determined from current ripples, tabular and trough cross beds. Current direction indicated by long pebble axes in the lag conglomerates and by aligned plant fragments. Note that current directions are only plotted in the east half of the figure.

that also exhibits rain pits (Plate 6). Some of the ripple marks have been partially abraded and only current direction could be determined. Figure 9 is a plot showing the distribution of palaeocurrents determined from ripple marks (often as current sense) and long axes of pebbles. The prevalent palaeocurrent sense was towards 30° - 70°. Less common are currents towards the opposite sector. Most long pebble axes are also aligned in this direction. The prevalent current sense towards northeast is interpreted to indicate that deeper water existed in that direction.

Plate 6 : Crescentic flute on a sandstone surface on the Maliau River, 2 km upstream from Base Camp. Current sense is indicated by the pencil.

PALAEOENVIRONMENT

Ophiomorpha is not diagnostic for a particular marine environment but is abundant in littoral setting (Frey *et al.*, 1978). The presence of sandstone channel fills in dominantly mudstone lithology suggest a very shallow near- or onshore, commonly low-energy environment. Carbonized plant fragments and resin are consistent with such an environment. Current ripples and trough cross beds suggest that occasionally higher energy regimes prevailed. Rain pits and mudcracks indicate subaerial exposure.

These environmental indicators can occur together in an extensive (low-energy) tidal flat or in the middle to distal parts of a large delta. The prevalent current sense suggest that deeper water occurred towards the northeast. Currents towards SW probably represented those generated during rising tides or during storms. The extraordinary thickness of the Tanjung Formation further suggests that sedimentation took place upon a subsiding substratum.

The Geological Survey field party also noted sole markings on sandstone layers comprising flute casts, groove casts and load casts (Plate 7).

Plate 7 : Load casts at the bottom of a sandstone block. Locality as Plate 2.

PALAEONTOLOGY

Four mudstone samples were found to contain pollen and spores that indicate an Early Miocene age for the Tanjung Formation outcropping in the eastern part of the basin. Sarawak Shell Berhad geologists examined these samples and their results are shown in Table 1. Microplankton was also found in samples J13086 and J13102. Foraminifera are in the samples J13102 (*Quinqeloculina* sp.) and J13106 (*Rotalia* sp.). Trace fossils occur at the top surface of several sandstone blocks, among which *Chondrites* (Plate 8) and *Granularia* (Plate 9) have been identified by T.P. Crimes (written communication). Indeterminate big worm burrows 3 cm in diameter, 25 cm long are found within thick mudstone beds (Plate 10). These burrows taper towards the top of the mudstone layers. Single and branching stalks of *Ophiomorpha* are rather common in the upper part of the formation that outcrops near the basin centre.

The mudstone and sandstone often contain fossilised tree stems and plant roots which are rimmed by coaly zones.

Table 1: Pollens and Spores from the Tanjong Formation.

POLLENS AND SPORES \ SAMPLE NUMBER	J13086	J13088	J13102	J13106
Alangium sp.	×			
Barringtonia sp.	×	×		×
Brownlowia sp.	×	×	×	×
Casuarina sp.	×	×		
Cephalomappa sp.	×			
Dacrydium sp.				×
Durio sp.		×	×	×
Florschuetzia trilobata	×	×	×	×
Gonystylus sp.		×		×
Lycopodium phlegmaria		×		×
Hycopodium cernuum				×
Picea type	×			
Pinus type		×		
Rhizophora sp.	×		×	
Stenochlaena areolaris				×
All determinations by Palynologists of Sarawak Shell Bhd. All four samples gave a Early Miocene age.				

Plate 8 : Radiating *Chondrites* on the surface of a sandstone block. Locality as Plate 2

Plate 9 : *Granularia* on the surface of a sandstone block. Locality as Plate 2.

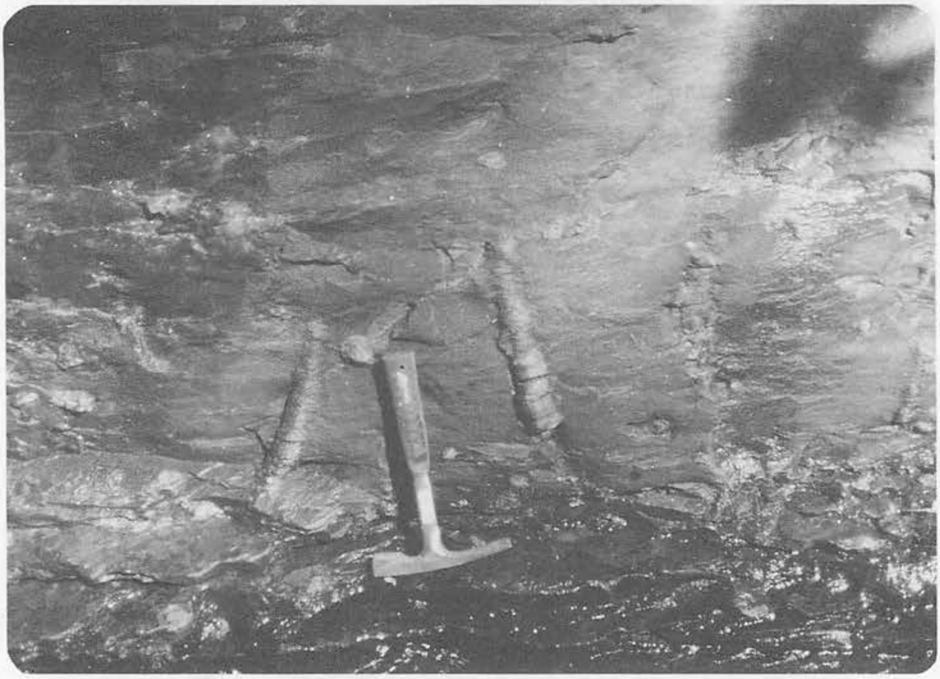

Plate 10 : Indeterminate large worm burrows in mudstone. Locality in the upper reaches of the easternmost tributary to the Maliau River.

GEOLOGICAL STRUCTURES

The outcrops of the Tanjung Formation that we surveyed displayed gentle dips of less than 15 degrees (Plate11). Some steeper attitudes are clearly related to faults (Figures 7 and 8). The equal-area plot of Figure 10 shows the gentle attitudes of the strata. Those near camp 2 have average orientations of 100/10 and 170/8. In the vicinity of the Base Camp and the Maliau Falls gentle dips are also the rule (Figure 11). Common strikes are SE with dips of about 10 degrees towards SW. Normal faults (see also Figures 7 and 8) strike SE or NW and indicate tension in NE-SW direction.

At one locality (Figure 12) outcrop the only group of observed open folds that plunge gently southward. In view of the general centripetally dipping beds in the Maliau Basin, this fold may represent penecontemporaneous slumping rather than representing tectonic deformation.

Long fractures, up to several tens of metres long, may occur as bundles in wide zones a hundred or more metres wide (near Camp 2) displaying regular spacing of approximately a metre and of 1.3 - 1.4 m distance. The preferred attitudes of the long fractures are 50/80 and 70/90. In other words, fault strikes

Plate 11 : Thick and thin sandstone beds dipping 15 degrees SW (camera faces NW). Note prominent vertical joints trending E-W and NW-SE. Locality about 1 km downstream from that of Plate 10.

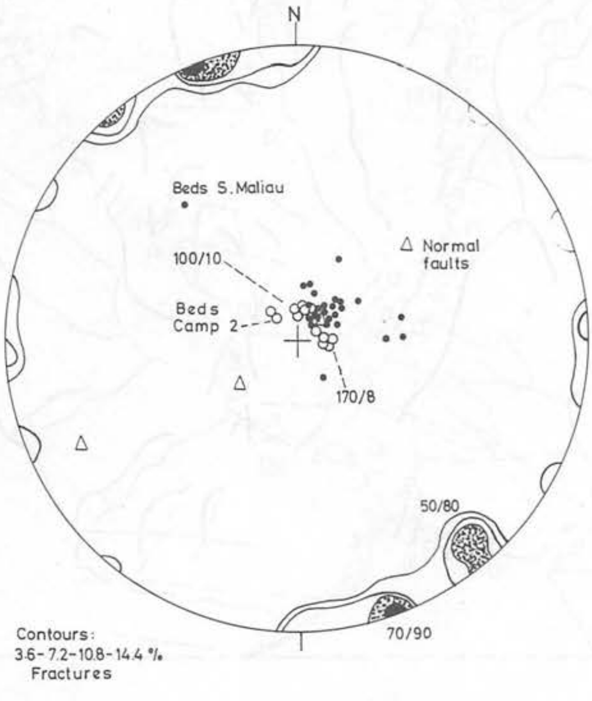

Figure 10 : Equal area projection, lower hemisphere of beds near Camp 2 (open circles) near Base Camp (solid dots), normal faults (triangles) and long fractures indicated by density contours. The majority of such fractures has preferred orientations 50/80 (strike directions/dip value) and 70/90.

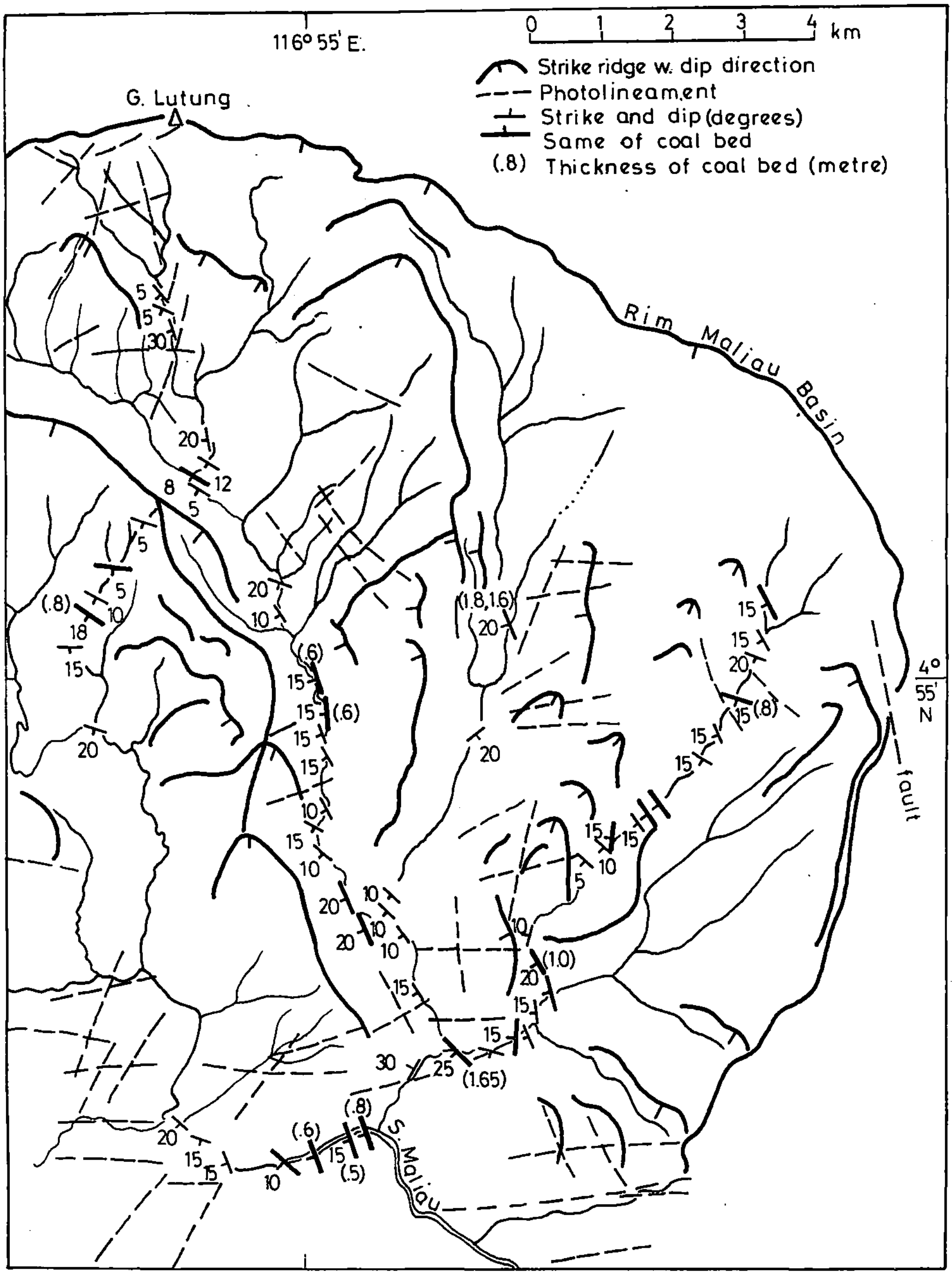

Figure 11 : Geological sketchmap of the eastern half of the Maliau Basin *sensu stricto*.

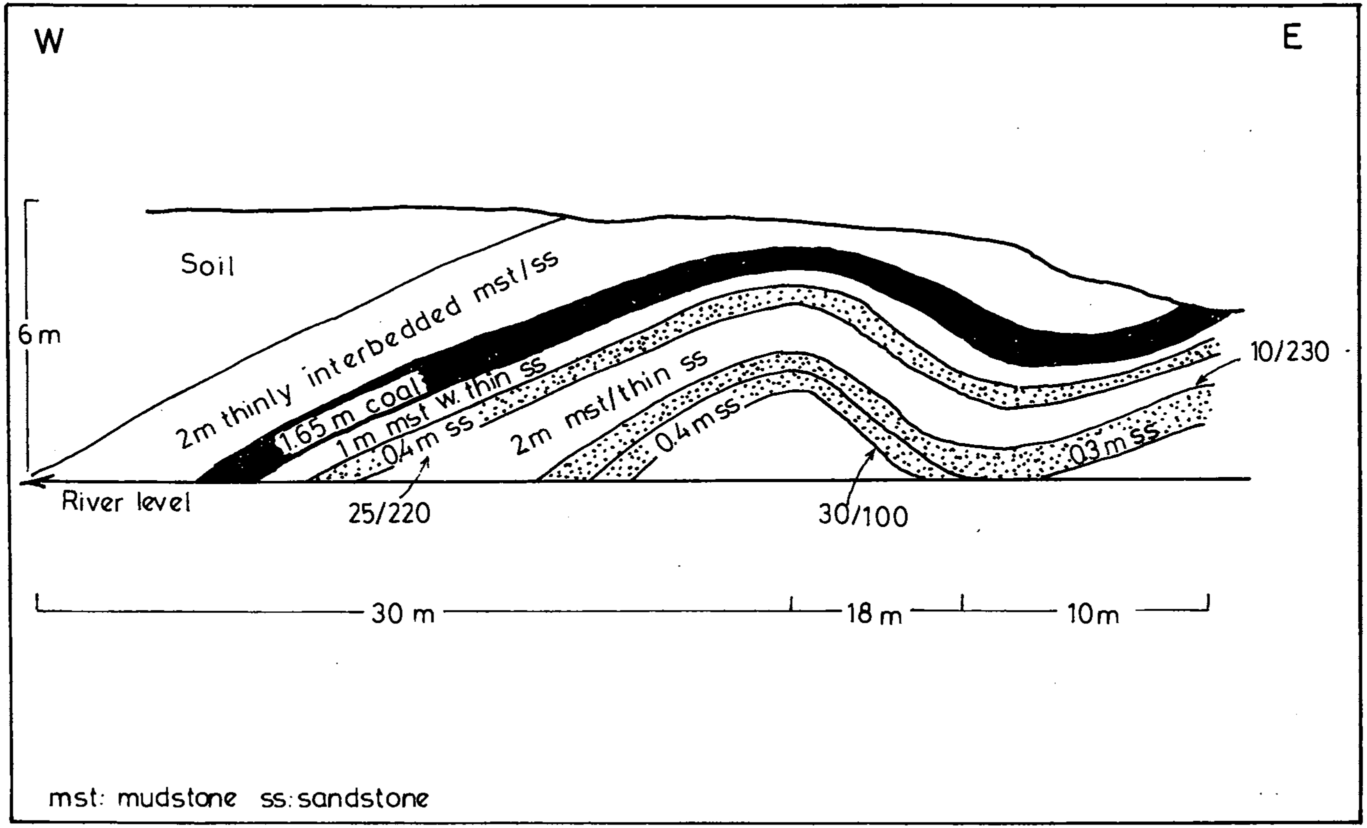

Figure 12: The only open folds recorded in the field. Bedding attitudes are indicated as dip value/dip direction. Locality is about 4 km ENE from Base Camp along a tributary to the Maliau River.

are subparallel to the general dip direction. Fracture patterns occur in the thin claystone/slate interbeds within sandstone sequences. Frequently the patterns consist of vertical to subvertical fractures parallel and normal to the local dip direction. Consequently, these small fractures appear to have formed as result of tilting of the beds. In addition, vertical to subvertical shear fractures may also be present and are disposed symmetrically about and making acute angles with the local strike direction.

The photo lineaments shown on Figure 11 that covers the eastern half of the Maliau Basin, represent major fractures. Lineament strike frequencies and the dominant strikes of inclined beds are shown on Figure 13. In this eastern half of the basin, the dominant bedding strike is 150° and a subsidiary strike is 125°. Many photo lineaments strike east and 65 °. Smaller numbers of lineament strikes are generally parallel to bedding strike and grouped in the sector 20-40°.

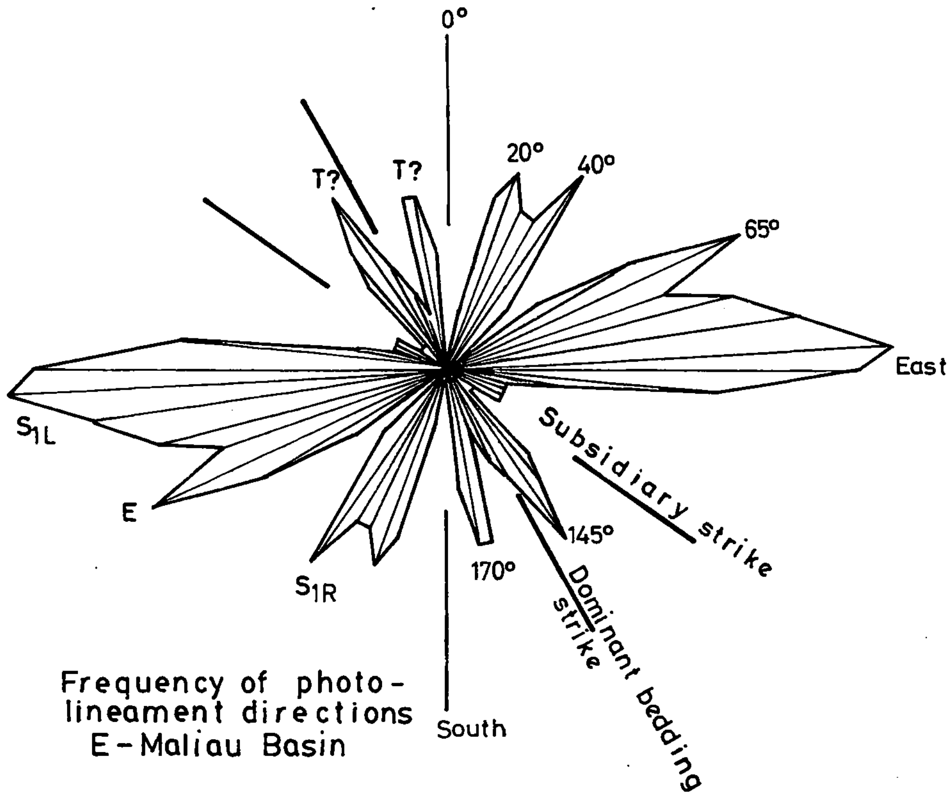

Figure 13 : Strike frequency of photo-lineaments in the east half of the Maliau Basin. See also Figure 11 and discussion in the text. Abbreviations of lineament directions: E = extension; T = tension; S_{1R} = right lateral first-order shear; S_{1L} = left lateral first-order shear.

Those parallel to bedding strikes originated as tensional fractures. The genetic classification of the other lineament strike frequencies are, therefore, extensional (65°), left lateral (S_{1L} = 90°), and right lateral (S_{1R} = 20-40°). The regional compression that is related to this lineament pattern should strike ENE to NE. The influence of the tectonic grain, which is NW-SE in the Maliau Basin area, is still noticeable near the basin centre where bedding strikes along the Maliau River are in that direction (Figure 11, bottom, to left of centre).

Thepattern of strike ridges (Figure 1) indicates that while those marking the outer rim of the Maliau Basin form an uncomplicated closed figure, the strike ridges within the basin are generally not concentric with respect to this rim. The so called 'Long Ridge' and several other ridges within the basin approach the boundary Lotung Ridge at oblique angles, suggesting the existence of an angular unconformity within the lower and middle portions of the Tanjung Formation. The morphologically determined attitude of the beds forming 'Long Ridge' is consistent with field measurements. The ridge pattern further indicates that the structural centre of the basin lies lopsidedly in the southern part of the Maliau Basin and underlies what has been named the 'Kerangas Forest'.

We believe that the oblique intersections between internal ridges with the rim ridge do not represent an angular unconformity, but were caused by shifting of the depocentres and progressively narrowing of the sedimentary basin (Figure 14). After the Maliau Basin subsided during Stage 1, successive subsidence occurred in a smaller NW-SE elongated portion of the original basin (Stage 2) and finally terminated as in Stage 3 on the figure. The various centres of subsidence in figure 13 have been interpreted as the central areas of basins as suggested by the configuration of their rims in Stage 1 through Stage 3.

TECTONICS

The Maliau Basin is one of the sedimentary depressions in eastern Sabah that contain Lower to Middle Miocene clastics of the Tanjung and the Kapilit formations (Figure 15). The lithological descriptions given above for the Maliau Basin is also generally valid for the other occurrences of the Tanjung Formation. The Kapilit Formation consists of sandstone and mudstone with minor layers of coal, conglomerate and limestone. Its more sandier character, the presence of limestone and its fold style differ from the Tanjung Formation. The Kapilit beds were deformed into a series of gentle synclines and steep anticlines striking northwest (Collenette, 1965). Such fold style is commonly ascribed to nontectonic causes that involve large scale slumping or diapirism by differential loading onto subsurface mobile layers.

Figure 15 shows that the lower-middle Miocene sedimentary basins of east Sabah are arranged in rows trending northeast and southeast, where the greater Maliau Basin occupies the joint of this dog-leg arrangement. Hamilton (1979) has followed earlier investigators in assigning the Maliau and adjacent basins to the Tarakan Trough *sensu lato.*

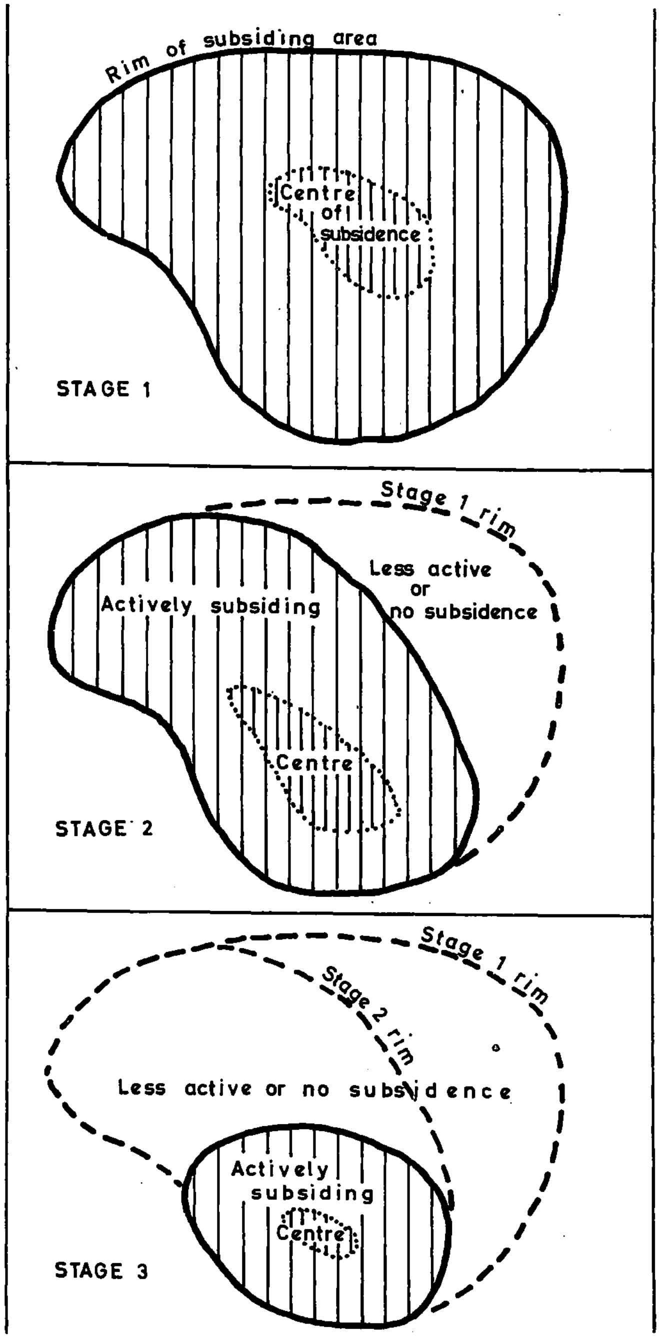

Figure 14 : During the deposition of the Tanjung Formation in the Maliau Basin, areas of subsidence became progressively smaller and the depocentres shifted southward resulting in the non-concentric configuration of the strike ridges. See also Figure 1.

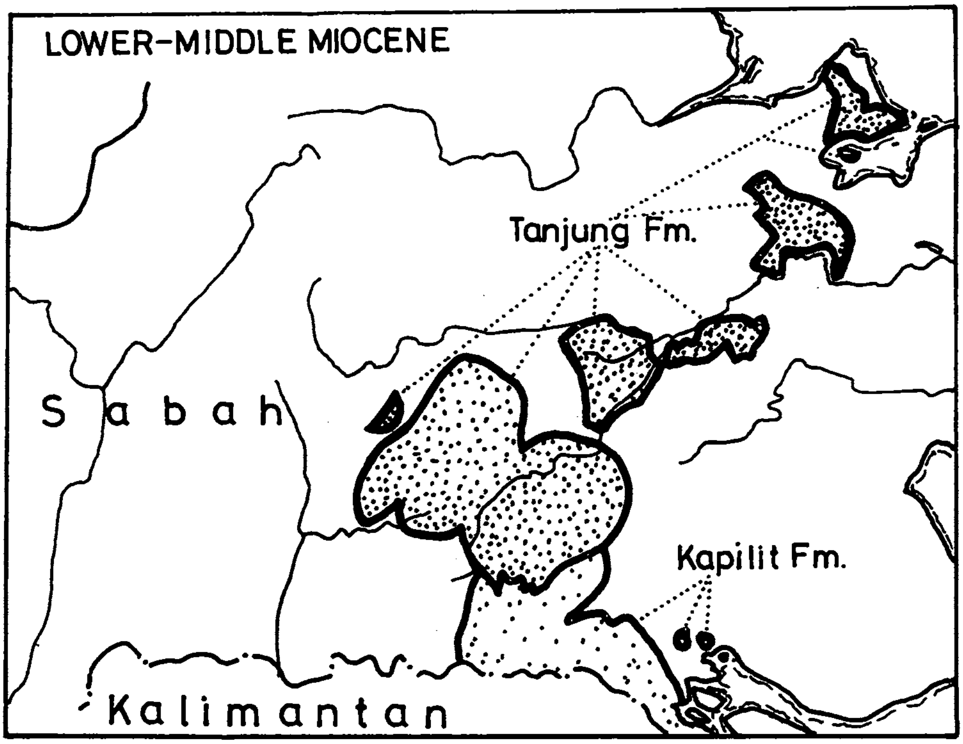

Figure 15 : The basins filled by Lower-Middle Miocene Tanjung and Kapilit formations are aligned in NE and SSE directions.

The tectonics of the region surrounding the Maliau Basin will now be described in brief. Figure 16A shows that the Tarakan Depression is hemmed in by the East Sabah Terrane, the main island of Borneo, and the Palaeo-Makassar — Sulawesi depression.

Structural ternds in east Sabah are different from those in the adjacent parts of Borneo. Tjia (1988) has postulated that eastern Sabah is a agglomeration of a continental margin crustal fragment and obducted oceanic crust, together called the East Sabah Terrane. This terrane is separated from the rest of Borneo by a broad zone of chaotic rock assemblage (including ophiolite) of Late Cretaceous to Oligocene age, desingnated as the Kinabalu Suture Zone. The fragment of continental margin crust probably originated from eastern Asia, more specifically from the vicinity of present Hongkong. This fragment rifted from it in the Early Tertiary and drifted south to its present position by opening of the South China Sea Basin. The youngest magnetic anomaly in that basin is the 5e anomaly that is equivalent to 17 Ma or Early Miocene.

The Sulawesi Depression is characterised by northeast trending magnetic lines of anomalies 18 - 20 (Late Eocene) according to Weissel (1980) or anomalies

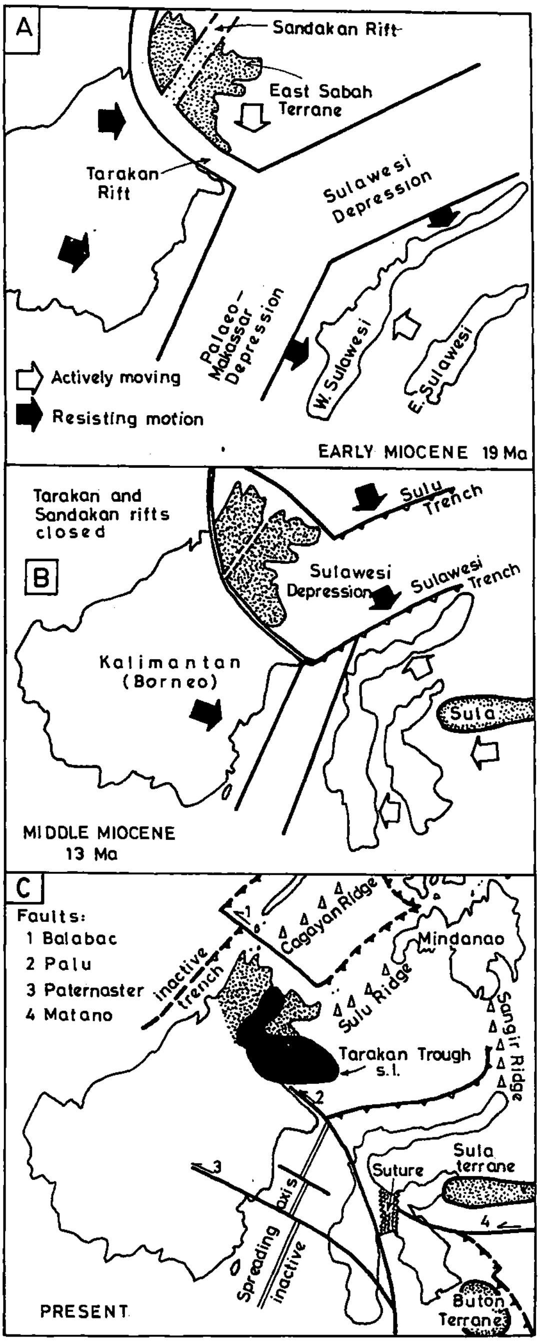

Figure 16A, B, C : Show the tectonic development of the region around the Maliau Basin. Discussion in the text.

33 - 30 (Cretaceous) in the opinion of Lee and McCabe (1986). The magnetic anomalies young northwestward and because of this fact the basement rocks of the Sulawesi Basin have been generally accepted to represent trapped Indian Ocean floor.

Katili (1978) interpreted the present NNE-striking Makassar Depression as result of seafloor spreading in Quaternary time. From palaeomagnetic studies, Sasajima et al. (1980) have suggested that west Sulawesi (consisting of the south and north arms) became sutured to east Sulawesi (east and southeast arms) during Early to Middle Miocene time (19-13 Ma).

In Figures 16A through 16C we show our interpretation of the tectonic development of the region around the Maliau basin.

In the Early Miocene (19 Ma) the East Sabah Terrane had approached Borneo from which it was separated by the proto-Kinabalu Suture Zone. Into this narrowing and presumably shallow sea depression poured in clastic sediments from the adjacent land masses. At the same time a NE-trending corridor across the East Sabah Terrane (named Sandakan Rift in Figure 16A) subsided to become another series of depocentres for the Tanjung Formation. This corridor may have developed along existing zones of weakness in the basement rocks. Geometrically the Sandakan and Tarakan rifts appear to form a triple junction where the greater Maliau Basin is located. However, we do not know of evidence -such as high heat flow at that point or a regional domal structure centred about the Maliau Basin- to support the possibility that the Tarakan and Sandakan rifts are aulacogens. Moreover, the early-middle Miocene age of the Tanjung and Kapilit formations and their weak deformation are well accomodated by the timing of docking of the East Sabah Terrane with Borneo.

As Katili (1978) already indicated, a wide sea basin some 800 km across existed between Borneo and the Sulawesi arcs, possibly even before Miocene time. For convenience sake we refer to this sea basin as the Palaeo-Makassar depression. The westward progression of the Pacific Plate combined with the northward push of the Australian Plate narrowed the Palaeo-Makassar - Sulawesi depressions.By the Middle Miocene (Figure 16B) the Sabah-based Tarakan and Sandakan rifts had closed and deposition of the Tanjung and Kapilit formation had terminated. At the same time the Sulu and Sulawesi subduction trenches were formed, mainly by resistance of the South China Sea block against plate movements from the south and from the east. Sasajima *et al.* (1980) concluded that west and east Sulawesi became welded at this time (19-13 Ma). Katili thought the welding occurred in the Pliocene.

In the Quaternary a NNE-trending spreading axis rifted off a fragment from southeast Borneo and in the process developed Strait Makassar (Katili, 1978). That crustal fragment of Borneo became incorporated in west Sulawesi and upper Tertiary vertebrate mammal fossils of Asiatic affinities have only been found in the present south arm of Sulawesi (Musser, 1987), whereas in the rest of the island Tertiary fossil and living fauna show mixed Asiatic-Australian characteristics or are endemic. The opening of Strait Makassar also created the Palu and Paternoster transcurrent faults (Figure 16C). Volcanic activity on the Cagayan and Sulu ridges are related to the subduction process. In southeast Sabah, lava flows of slightly less than 30,000 years old (Kirk, 1968; Bellwood, 1988) suggest that plate tectonic processes in that region had been active until that time.

We conclude that the early-middle Miocene Maliau Basin is located at the junction of the Tarakan and Sandakan rifts and that at least part of its basement consists of melange of the Kinabalu Suture Zone. Subsidence of the Maliau Basin and other time-equivalent basins of Sabah probably began when the southward drift of the East Sabah Terrane came to a halt 17 Ma ago, or Early Miocene, when the South China Sea Basin stopped spreading. Subsidence was a consequence of isostatic adjustment of the denser ophiolite material in the suture zone. The weak to moderate deformation of the Tanjung and Kapilit formations associated with normal faulting and gentle synclines-steep anticlines in the latter formation indicate that gravity had been the cause rather than lateral tectonic compression.

APPLIED AND ECONOMIC GEOLOGY

Hydro-power- The structural Maliau Basin and its centripetally inclined beds of the Tanjung Formation form an ideal reservoir. The damsite could be located on the Maliau River a few kilometres upstream from its confluence with Sungai Kuamut.

Hydrocarbons- The extreme thickness of the Tanjung Formation in the Maliau Basin *sensu stricto* and the presence of carbonaceous mudstone appear favourable for the occurrence of hydrocarbons. Collenette (1965) and the new regional geological map of Sabah show that the basin is bounded by northeast striking faults; the Pinangah and Lonod faults in the west and the east, respectively. These fault zones should be considered potential traps for probable hydrocarbons that had migrated updip from the basin.

Coal- In the upper part of the Tanjung Formation that outcrops near our camps, only clayey lignite layers not exceeding 0.5 m in thickness were seen. However, lustrous coal float among the river gravel suggests that better quality coal does occur elsewhere in the Maliau Basin. The middle part of the formation that was surveyed possesses several thick coal layers. A total of 31 coal seams ranging in thickness from 0.02 to 1.8 m were observed at 24 localities (Figure 11). Figure 17 shows a schematic representation of the major coal seams. The seams are floored and roofed by either carbonaceous mudstone or sandstone (Plate 1), and sometimes the material is coaly mudstone. The coal is usually bright, clean, blocky although muddy and weathered in some outcrops. The sparsity of

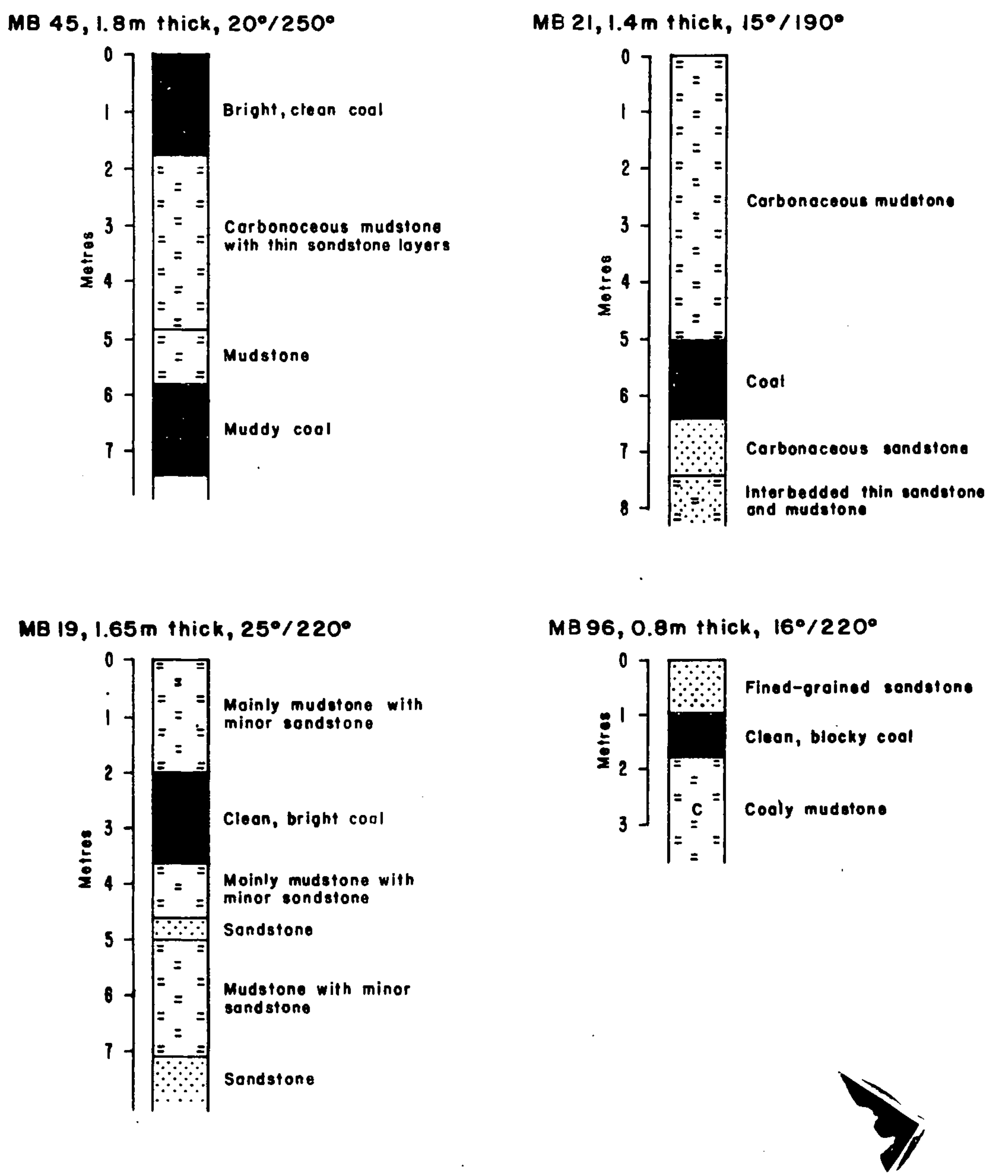

Figure 17 : Schematic representation of selected coal outcrops.

Table 2: Analytical data of coal from Northeast Maliau Basin

SAMPLE NUMBER	PROXIMATE (mass – %)		GROSS CALORIFIC VALUE dry (mj/kg)	ULTIMATE (mass – %)								
	Total Moisture / Moisture	Ash Dry / Volatile Matter Dry (d. a. f.)		dry				d.a.f.				F S I
				C	H	N	Total S	C	H	N	Total S	
J13081	6.3 / 2.5	70.1 / 15.9 (–)	8.16	–	–	–	2.20	–	–	–		
J13082	6.4 / 2.9	67.8 / 17.0 (–)	9.16	–	–	–	1.23	–	–	–		
J13098	3.4 / 1.7	2.3 / 43.6 (44.7)	34.6	81.0	6.09	1.54	2.29	83.0	6.24	1.58		7.5
J13101	4.6 / 2.0	2.2 / 32.2 (33.0)	23.65	55.9	4.32	1.22	4.80	77.9	6.01	1.71		4.0

Note: d. a. f. = dry, ash-free; FSI = Free swelling Index.
Analysis by Coal Laboratory, Geological Survey Malaysia Kuching.

traverse lines, lack of marker horizons and inaccurate topographic map do not permit accurate correlation of the coal seams. However, there appears to be at least five coal seams greater than one mètre thickness.

Quality tests were conducted on two coal samples according to standard methods outlined in the International Organization for Standardization (ISO). Table 2 lists the results that indicate the samples have generally low moisture content. Of the two samples analysed, only sample J13098 exhibits qualities of a good coal. Its ash content is low and its corresponding gross calorific value is high. Carbon and hydrogen values are also consistent with quality. The high free swelling index of 7.5 suggests that blending might further enhance the quality of the coal. However, the swelling characteristics shown by sample J13101 appears anomalous in view of its fairly high ash content. This sample will have to be investigated further by petrographic means.

The samples analysed show good chemical properties and high heating values and are of better quality compared to those from the Silimpopon-Serudong area. Taking into consideration the thickness, quality, gentle dips of the coal seams and the relatively undisturbed nature of the strata, the eastern part of the Maliau Basin has a very good potential for coal, more so because of the existence of thick coal seams on the north side of the Lotung escarpment.

ACKNOWLEDGEMENTS

Participation in this field study was on the invitation of Yayasan Sabah (PSL and TS) and of Professor Mohd. Nordin Hassan, chairman of World Wide Fund Malaysia (to HDT and IBK). Sarawak Shell Berhad studied the microfossils. Dr. T.P. Crimes of the University of Liverpool is gratefully acknowledged for comments and identification of the trace fossils. The coal samples were analysed by our colleagues at the Coal Laboratory, Geological Survey of Malaysia, Sarawak.

REFERENCES

BELLWOOD, P.S. 1988. *Archaeological research in South-Eastern Sabah.* Sabah Museum and State Archives, Sabah.

COLLENETTE, P. 1965. *The geology and mineral resources of the Pensiangan and upper Kinabatangan area, Sabah, Malaysia.* Geological Survey, Borneo Region, Memoir **12**: 150 p.

FRANCIS, W. 1954. *Coal -Its formation and composition.* Edward Arnold, London.

FREY, R.W., J.D. HOWARD & W.A. PRYOR 1978. *Ophiomorpha*: its morphologic, taxonomic and environmental significance. Palaeogeography, Palaeoclimatology, Palaeoecology **23**: 199-229.

HAMILTON, W. 1979. *Tectonics of the Indonesian region.* U.S. Geological Survey Professional Papers **1078**: 345 p.

KATILI, J.A. 1978. Past and present geotectonic positions of Sulawesi, Indonesia. *Tectonophysics* **45** 289-322.

KIRK, H.J.C. 1968. *The igneous rocks of Sarawak and Sabah.* Geological Survey, Borneo Region. Bulletin **5**.

LEE, C.-S. & R. MCCABE 1986. The Banda-Celebes-Sulu basins: a trapped piece of Cretaceous-Eocene oceanic crust. *Nature* **322**: 51-54.

LIM, PENG SIONG (compiler) 1985. *Geological map of Sabah, third edition*. Geological Survey Malaysia, scale 1 : 500,000.

McBride, E.F. 1963. A classification of common sandstone. *Journal Sedimentary Petrology* **33**: 664-669.

MUSSER, G.G. 1987. The mammals of Sulawesi. *In T.C. Whitmore (editor). Biogeographical evolution of the Malay Archipelago,* Clarendon Press, Oxford: 73-93.

SASAJIMA, S., S. NISHIMURA, K. HIROOKA, Y. OTOFUJI, TH. VAN LEEUWEN & F. HEHUWAT (1980). Paleomagnetic studies combined with fission-track datings on western Sulawesi, East Indonesia. *Tectonophysics* **64**: 163-172.

TJIA, H.D. 1988. Accretion tectonics in Sabah: Kinabalu Suture Zone and East Sabah accreted terrane. *Bulletin Geological Society Malaysia* **22**: 237-251.

WEISSEL, J.K. 1980. Evidence for Eocene oceanic crust in the Celebes Basin. *In D.E. Hayes (editor). The tectonic and geologic evolution of Southeast Asian seas and islands,* American Geophysical Union, Geophysical Monograph **23**: 37-47.

Manuscript received 13th September 1990.