GEOSEA '98 Proceedings, Geol. Soc. Malaysia Bull. 43, December 1999; pp. 51-59

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

Regional geological correlation of Paleogene sedimentary rocks between Sabah and Sarawak, Malaysia

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Abstract: Field observations, aided by SAR and satellite images interpretation, have enabled the recognition of at least three groups of Paleogene sedimentary rock units that can be correlated regionally between Sabah and Sarawak. The three informal groups of rock units have been mapped based on similarities in their ages, lithological characteristics and degree of structural deformation. The first unit has been interpreted to range in age from Lower Paleocene to early Eocene. A large part of this unit has been metamorphosed to slate, sub-phyllite and metasandstone. The remaining part of the unit consists mostly of sandstone and shale with minor occurrence of conglomerate and lenses of limestone. Structurally, this unit has suffered intense deformation, characterised by the presence of folded cleavage, quartz veins and refolded folds. The second unit has been interpreted to range in age from late Lower Eocene to early Upper Eocene. This unit is mainly made up of a thick sequence of sandstone interbedded with shale. Structurally this unit is also characterised by intense deformation, where most of its bed dip steeply due to tight folding and thrust faulting. The thrust faults generally show transport direction to the north and northwest. The development of cleavage is restricted to the core of folds. The minor occurrence of cleavage, lack of refolded fold and lack of quartz veins differentiate this unit from the older unit above. The third unit is interpreted to range in age from early Upper Eocene to late Upper Oligocene. The unit is composed mainly of sandstone and shale, with local occurrence of conglomerate, limestone and marl. A large part of the unit also shows intense deformation, characterised by tight upright folds and thrust faults, similar to Unit 2. The thrust faults also generally show a transport direction to the north or northwest. Regional geological interpretations suggest that the Paleogene sediments were deposited in a large elongated basin along NW Borneo. The deposition and deformation of sediments occurred in successive stages—younger sediments were deposited on top or in front of older accreted sediments, in response to northwest-southeast closure of the elongate basin.

INTRODUCTION

The understanding of the early geological history and tectonics of Sabah and Sarawak is still not very clear although many studies have been carried out since the early 50s. This is partly due to its complex geology and lack of sufficient sedimentological and structural data. Many earlier studies have also been confined to a particular geographical area with varied scope of studies. Recent detailed studies tend to focus their attention more to the productive Neogene sedimentary rocks. Thus, the regional geological correlation of older sedimentary rocks between the two states, including Brunei (Leichti *et al.*, 1960; Haile, 1969; Hamilton, 1979; Lee, 1979) has not progressed very much. The existing regional geological correlation has been strongly based on similarities of depositional environments (e.g. Rajang group flysch sediments), rather than on the geological history and tectonics of a particular rock unit. This type of correlation which attempted to separate shallow water deposits with deep turbidite deposits, has led to Haile's geosynclinal hypothesis of northwest Borneo. The geosyncline hypothesis was subsequently reinterpreted by Hamilton as the northwest Borneo subduction complex.

During the past few years, there have been numerous good sedimentary rock exposures in both the states of Sabah and Sarawak due to the

construction of major road networks. Remotely-sensed data, of high quality like those of SAR images has also been available for both states to complement satellite images and conventional aerial photographs. These good rock exposures and newly acquired SAR images provided an opportunity to re-look into the early geological evolution of Sabah and Sarawak, together. To do this, regional correlation of similar rock units between the two states has to be carried out.

Field observations, aerial photographs and satellite images interpretations, especially in Sabah have been an ongoing activity for the past few years. Recent fieldwork in Sarawak was carried out during supervision of student's mapping projects (Freddy, 1995; Lau, 1995; Jaul, 1996; Lim, 1996). Earlier SAR images interpretations was carried out in collaboration with PETRONAS exploration department staffs (Tongkul, 1995).

REGIONAL SETTING

Sabah and Sarawak, occupying the northwestern part of Borneo lies at the intersection of three major plates, the Eurasian, Indo-Australian and Philippines located to the north, south and east, respectively (Fig. 1). The movement of the three major plates relative to one another in a complex and poorly understood pattern has resulted in accretion of terrain and creation of marginal basins since early Tertiary times. Sabah and Sarawak represent part of an accreted terrain, lying adjacent to an extended continental margin to the north. The continental margin presently occupied by the Luconia and Dangerous Grounds Platform is believed to have rifted from the southeastern margin of the Eurasian Plate or locally called the Sundaland Craton (Hutchison, 1989; Taylor and Hayes, 1983).

The accreted terrain in Sabah and Sarawak, commonly referred to as the NW Borneo fold-thrust belt or NW Borneo subduction complex (Hamilton, 1979) extends over a distance of more than 1,000 km along strike and reaches a width of over 300 km. Its northwest margin ends somewhere along the NW Borneo trough, whereas its southern margin lies near the international border of West Sarawak and West Kalimantan. The southern margin being marked by the presence of ophiolitic mélange (Tan, 1979; Williams *et al.*, 1986). The northeastern margin ends somewhere in the Sulu Sea. The development of the marginal South China Sea and Sulu Sea basins has exerted a more complex deformation towards the accreted terrain in Sabah (Rangin, *et al.*, 1990; Tongkul, 1991, 1994).

REGIONAL CORRELATION

The existing geological map of Sabah and Sarawak (Yin, 1985, 1992; Hon, 1992) is mostly based on the old regional compilation map of Leichti (1960) and Wilford (1967), as most of the stratigraphic relationships between rock units have not been fully resolved yet, due to lack of precise age indicators. The Tertiary sedimentary rocks are basically differentiated based on their age (e.g. Paleogene and Neogene), depositional environments (marine, continental or mixed) and degree of regional metamorphism (weak or strong). Based on these criteria it has been possible to correlate sedimentary rocks in Sabah and Sarawak in a broad manner. Lacking concrete field evidences, however, the Paleogene sedimentary rocks, up to now, have been assumed to be conformable with each other, their depositional environments and degree of metamorphism remain unquestioned.

During this present study, attempt has been made to group the numerous existing rock formations based on their broad similarities, using age, lithological characteristics (depositional histories) and degree of structural deformation (structural styles, regional continuity and metamorphism) as a criteria.

Based on different sedimentation histories and structural styles, the Paleogene sedimentary rocks of Sabah and Sarawak have been grouped into three informal tectono-stratigraphic units (Figs. 2 and 3). Except for some changes in geological boundaries and subdivisions of units, the three units proposed generally follows the distribution of Paleogene rock units mapped by the Geological Survey (Hon, 1992). The three informal units show excellent structural lineaments. Groups of lineaments can be easily traced for hundreds of kilometres across Sabah and Sarawak, especially where overlying deposits are absent (see Fig. 2).

Tectono-stratigraphic Unit 1

This unit is the oldest, ranging in age from Lower Paleocene to early Eocene, based on findings of previous workers (Collenette, 1958, 1965; Wolfenden, 1960). The Layar, Kapit and Metah Members of Belaga Formation, Lupar and Mulu Formations in Sarawak, and the Trusmadi and probably part of Sapulut Formations in Sabah are included here. A large part of this unit has been metamorphosed to slate, sub-phyllite and metasandstone. The remaining part of the unit consists mostly of sandstone and shale with minor occurrence of conglomerate. Lenses of limestone have been reported to be associated with this unit (Collenette, 1958, 1965; Leichti *et al.*, 1960; Haile,

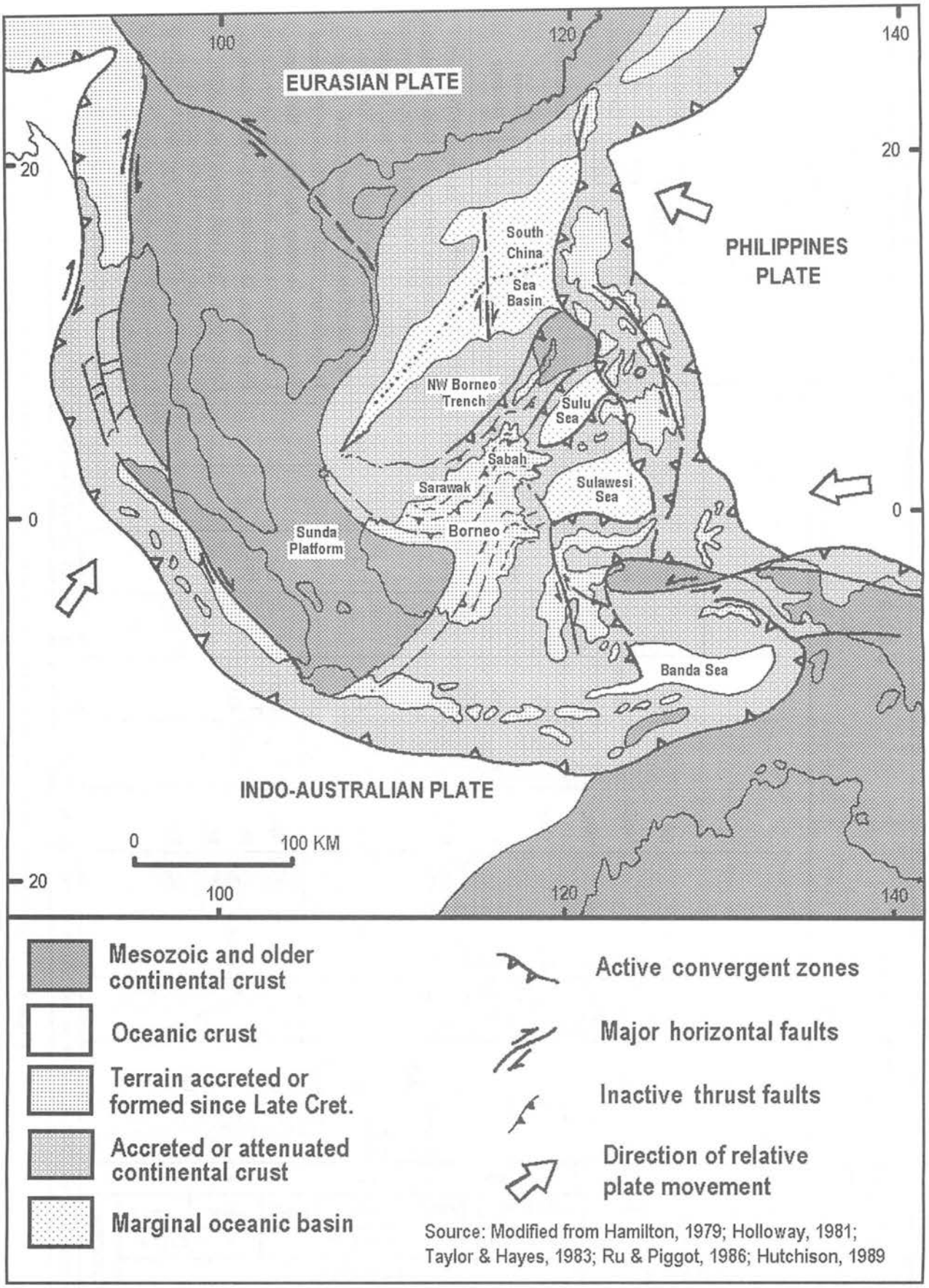

Figure 1. Geological and tectonic setting of Sabah and Sarawak. Sabah and Sarawak form part of an accreted terrain since late Cretaceous time.

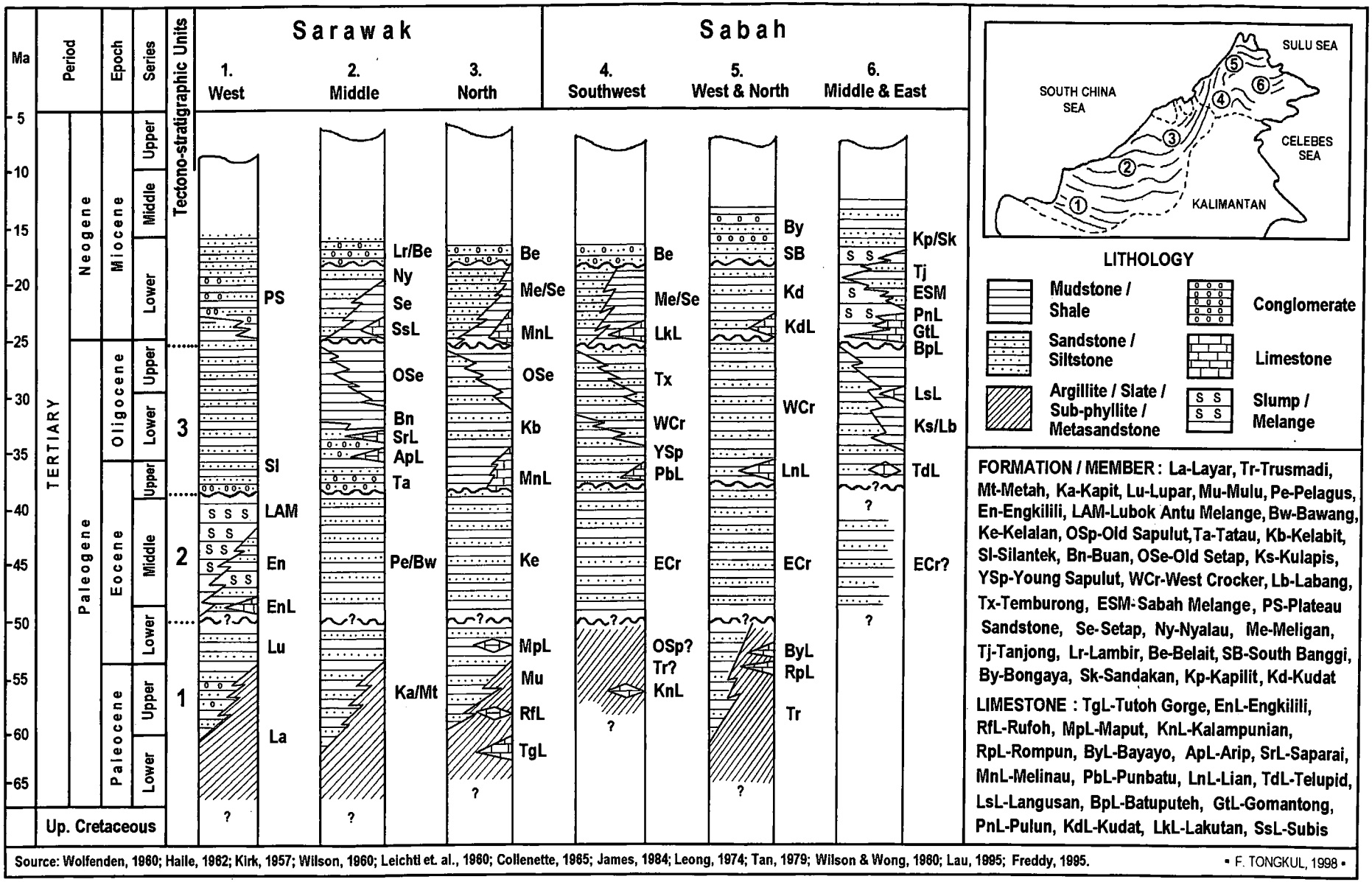

Figure 2. Regional correlation of tectono-stratigraphic units across Sabah and Sarawak.

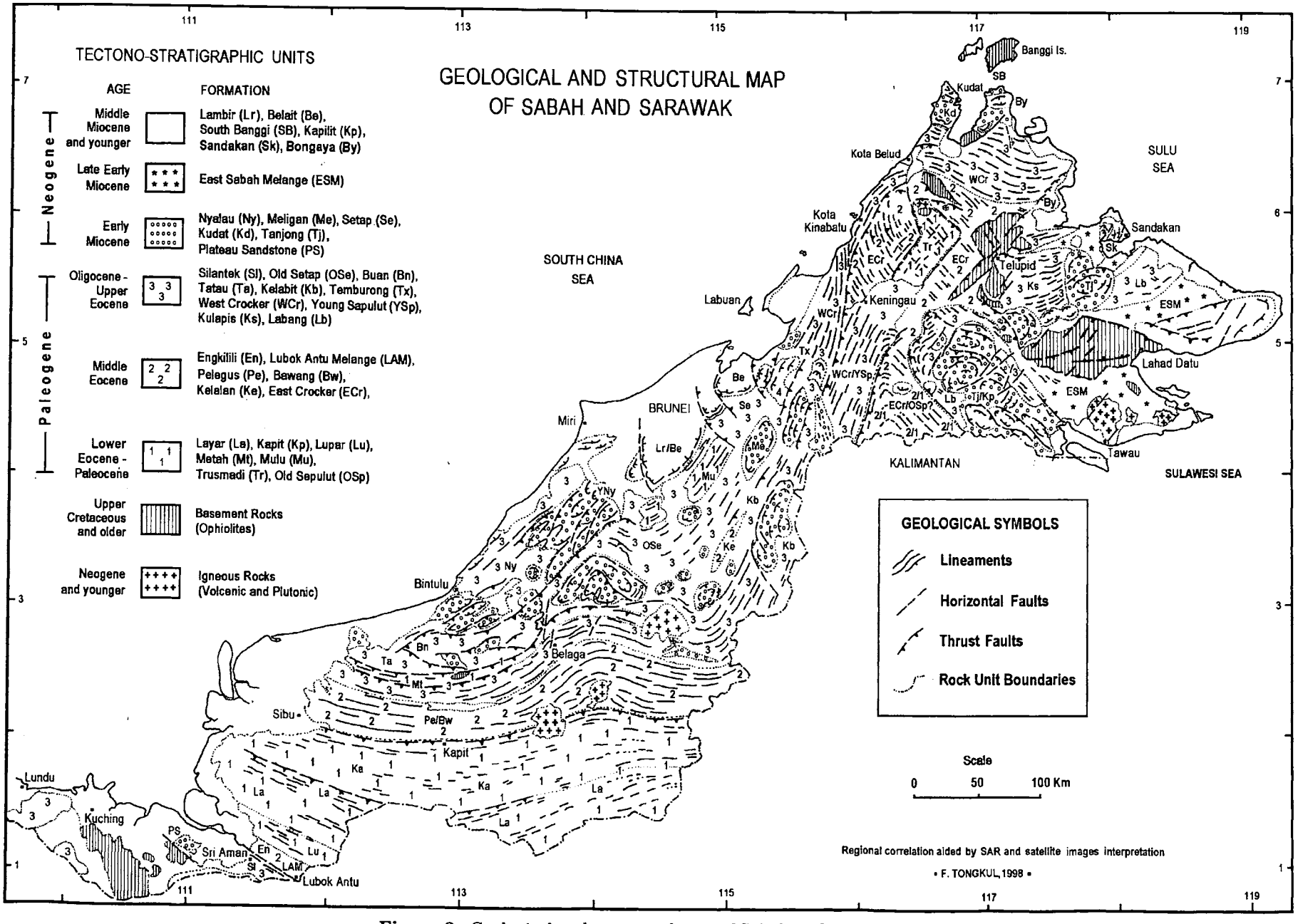

Figure 3. Geological and structural map of Sabah and Sarawak.

1962).

A large part of the unit (e.g. Belaga, Mulu and Trusmadi) was deposited in a deep-water submarine fan environment, characterised by turbidite and mass flow deposits. The predominance of argillaceous sequence suggests an open basin plain depositional setting. In Sarawak, some of this unit (e.g. Lupar) commonly shows slump beds, channeled pebbly sandstone and vertical burrows suggesting deposition on slope settings (Freddy, 1995).

Structurally, this unit has suffered intense deformation. The presence of folded cleavage and numerous quartz veins are characteristics of this metamorphosed unit (Cheing, 1994; Lim, 1996). Refolded folds are evident in both the metamorphosed and unmetamorphosed part of the unit. The Layar and Kapit Members of the Belaga Formation in Sarawak shows an earlier fold axis trending approximately NW-SE, followed by a NE-SW trend (Jaul, 1996; Lim, 1996). In Sabah, the metamorphosed Trusmadi Formation shows two fold axis trending NW-SE and NE-SW (Tjia, 1974; Cheing, 1994).

The relationship of this unit with the older rocks in Sabah and Sarawak is uncertain. The contrasting lithologies between the Mesozoic ophiolitic rocks and Unit 1 suggests and unconformable relationship.

Tectono-stratigraphic Unit 2

This unit is interpreted to range in age from late Lower Eocene to early Upper Eocene, also based strongly on earlier findings of previous workers mentioned above. The Engkilili Formation (Lubok Antu Mélange), Pelagus and Bawang Member of Belaga Formation, and Kelalan Formation in Sarawak and East Crocker Formation in Sabah are included here. This unit is mainly made up of a thick sequence of sandstone interbedded with shale of various thickness.

In Sabah, the East Crocker Formation shows a typical deep water submarine fan deposits, reaching more than 1 km in thickness (Cheing, 1994; Khor, 1994). Paleocurrent directions suggest the source of sediments to the south. Similar depositional settings have been observed in most of the units, near Selangau in Sarawak (e.g. Lau, 1995). However, near Sibu town, the Pelagus Member is represented by a thick sequence of dark grey carbonaceous shale interbedded with thin laminated sandstone. Vertical burrows are commonly seen in some of the shale interbeds, probably suggesting shallow water deposition. Near Sri Aman, the Engkilili Formation is characterised by an intercalation of undeformed and deformed sequence. The deformed sequence is associated with primary slump structures, whereas the undeformed sequence comprise mainly of thick shale interbedded with thin to medium sandstone (Freddy, 1995). Blocks of limestone, dated to be older than Middle Eocene, are associated with the deformed sequence. Tan (1979) referred to this deformed sequence as the Lubok Antu Mélange.

Structurally this unit is also characterised by intense deformation, where most of its bedding is steeply dipping due to tight folding and thrust faulting. Folds with wavelengths between 200–300 metres are common. Repetition of sedimentary sequence due to thrust faults is also characteristic of this unit. The thrust faults generally show transport direction to the north and northwest (Tongkul, 1990; Lau, 1995). Low-grade metamorphism with the development of cleavage is restricted to the core of folds. In Sabah this unit, represented by the East Crocker Formation, trends approximately NW-SE, faulted against Unit 1.

The minor occurrence of cleavage, lack of refolded fold and lack of quartz veins differentiate this unit from the older unit above. These differences suggest an unconformable relationship between Unit 2 and Unit 1. In Sarawak, the Rajang River, at least between Sibu and Kapit is the site of a major faulted boundary.

Tectono-stratigraphic Unit 3

This unit range in age from early Upper Eocene to late Upper Oligocene (Collenette, 1958, 1965; Wilson and Wong, 1960; Wolfenden, 1960; Tan, 1979). The Silantek, Tatau, Buan, Kelabit and older part of Setap Formations in Sarawak and West Crocker, Temburong, Kulapis, Labang and younger part of Sapulut Formations in Sabah are included here. The unit is composed mainly of sandstone and shale, with local occurrence of conglomerate, limestone and marl. The unit is characterised by a variety of depositional settings, ranging from deep-water submarine fan to continental environment.

Except for the Silantek Formation in Sarawak, structurally the rest of the unit also shows intense deformation, characterised by tight upright folds and thrust faults, similar to Unit 2. The thrust faults also generally show a transport direction to the north or northwest. The Silantek Formation dips moderately to the south, forming a large syncline with its axis trending NW-SE.

This unit is interpreted to sit on Unit 2 with marked unconformity. The basal part being represented in Sarawak by the occurrence of the Melinau Limestone and conglomeratic Tatau Formations. Similarly the Punbatu and Lian limestones occurring in the West Crocker and younger Sapulut Formations represent the basal part of the unit in Sabah. This unit is overlain

unconformably by moderately deformed Neogene sediments, marked by the presence of Subis and Melinau limestones in Sarawak, and Lakutan, Kudat and Gomantong limestones in Sabah.

IMPLICATIONS ON REGIONAL GEOLOGY

What the Correlation Show

The three informal tectono-stratigraphic units defined in this study show that the huge expanse of Paleogene sediments in Sabah and Sarawak could be broadly classified. The three units generally occupy its own distinctive fold-thrust belt. In Sarawak, the older unit, Unit 1 dominates the southern belt and progressively gives way to Unit 2 and 3 to the north (Fig. 4). The lateral northward extension of Unit 2 is punctuated by the lack of information on the Kalimantan side. Unit 2 and Unit 3 appear to sit on top of Unit 1. While Unit 2 and Unit 3 exhibits a sharp bend in its belt near Belaga, Unit 1 appears to be not affected very much.

In Sabah the situation is a bit complex. Unit 3 appears to sit on both Unit 1 and Unit 2. Whereas Unit 1 overrides Unit 2. While Unit 1 is mostly found in Sarawak, Unit 3 occurs widely in both states (see Fig. 4). Fold belt on Unit 3 also bend sharply near Kota Belud in Sabah, affecting the original orientation of Unit 2 and Unit 1.

Although each unit has its own depositional histories and environmental settings, paleocurrent directions indicate a common major source of sediments from the south or southwest.

What the Correlation Mean

The presence of the three informal units indicates that the Paleogene sedimentary rocks have undergone several stages of regional deformation. The earliest was probably during the late Lower Eocene (50–52 Ma), followed by early Upper Eocene (37–39 Ma), and then by late Upper Oligocene (25–27 Ma). Structural evidence from Central Sarawak, indicate that the earliest deformation was associated with NE-SW compression, whereas the latter two was associated with NW-SE compression.

The general distribution of the three tectono-stratigraphic rock units in Sarawak indicates progressive southeastward accretion of younger sediments against older accreted sediments. Younger sediments were also deposited on top of the accreted sediments in accretionary basins (Fig. 5). Similar process may have also occurred in Sabah, but with some variation due to its different tectonic setting. The Middle Miocene (14–18 Ma)

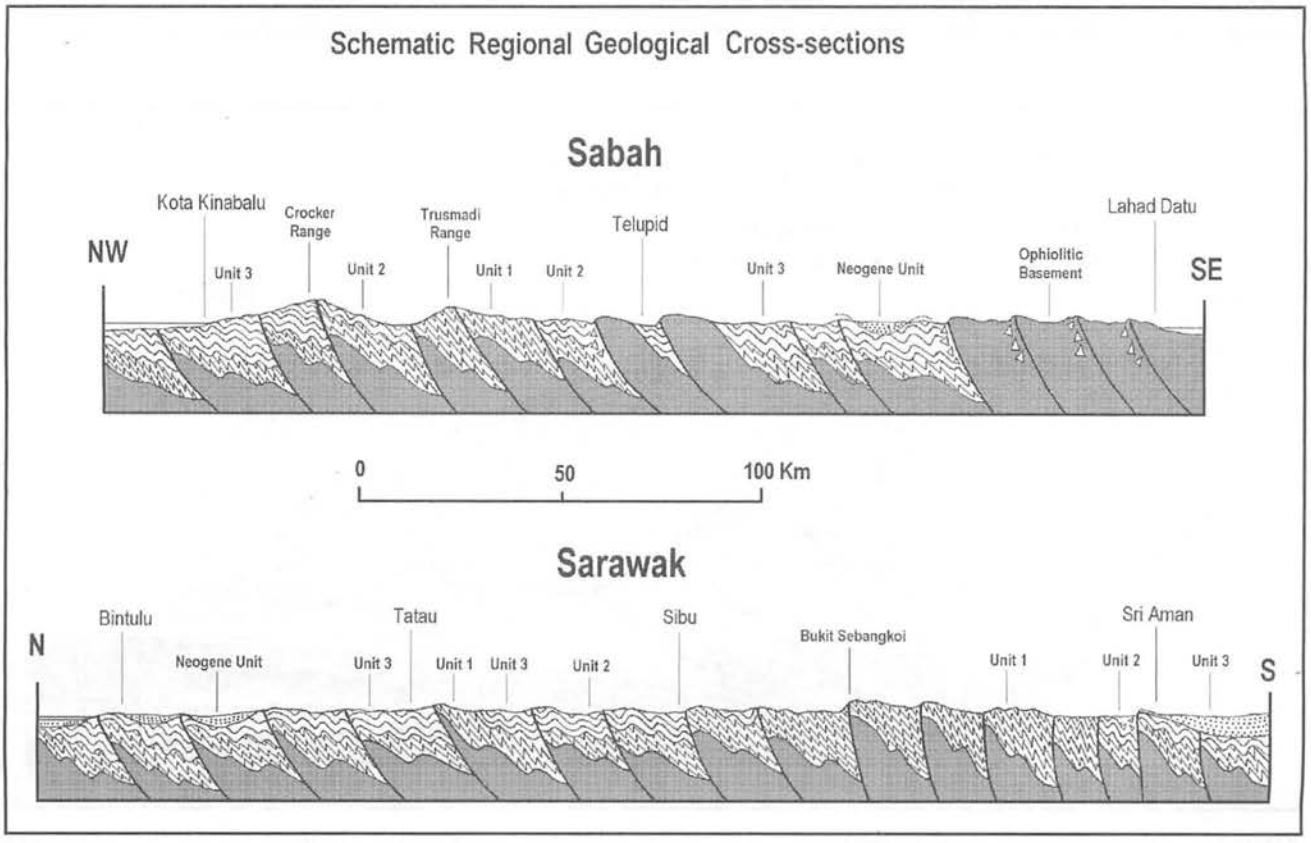

Figure 4. Schematic regional geological cross-sections of Sabah and Sarawak.

marking a major compression and uplift in Borneo, may have been responsible for the sharp bends and tightening of structures on Unit 2 and Unit 3.

The common source of sediments from the south or southwest suggests that a huge elongate basin must have existed along NW Borneo to accommodate the deposition of enormous amount of sediments, which was accreted later.

SUGGESTIONS FOR FUTURE WORK

Due to the huge size of Sabah and Sarawak, fieldwork coverage is still inadequate. The present work still relied heavily on previous works and on remote sensing data in doing the correlation. Much information regarding the ages of Paleogene sediments is still lacking. It would be advisable to carry out more paleontological work on these sediments to elucidate its proper stratigraphic positions.

It would be interesting to see whether similar tectono-stratigraphic units can be mapped out from the Paleogene sediments in Kalimantan, Indonesia. If there were such a correlation, then perhaps it would be easier to reconstruct the depositional and tectonic history of Paleogene basins in Borneo.

ACKNOWLEDGEMENTS

I would like to thank Universiti Kebangsaan Malaysia for supporting this research. I wish to thank Lau, Freddy, Lim and Jaul for their companionship during the Sarawak fieldwork; for the Geological Survey of Malaysia in Kota Kinabalu and Kuching for their continued support and access to secondary information; and for PETRONAS for granting me access to their SAR imagery data.

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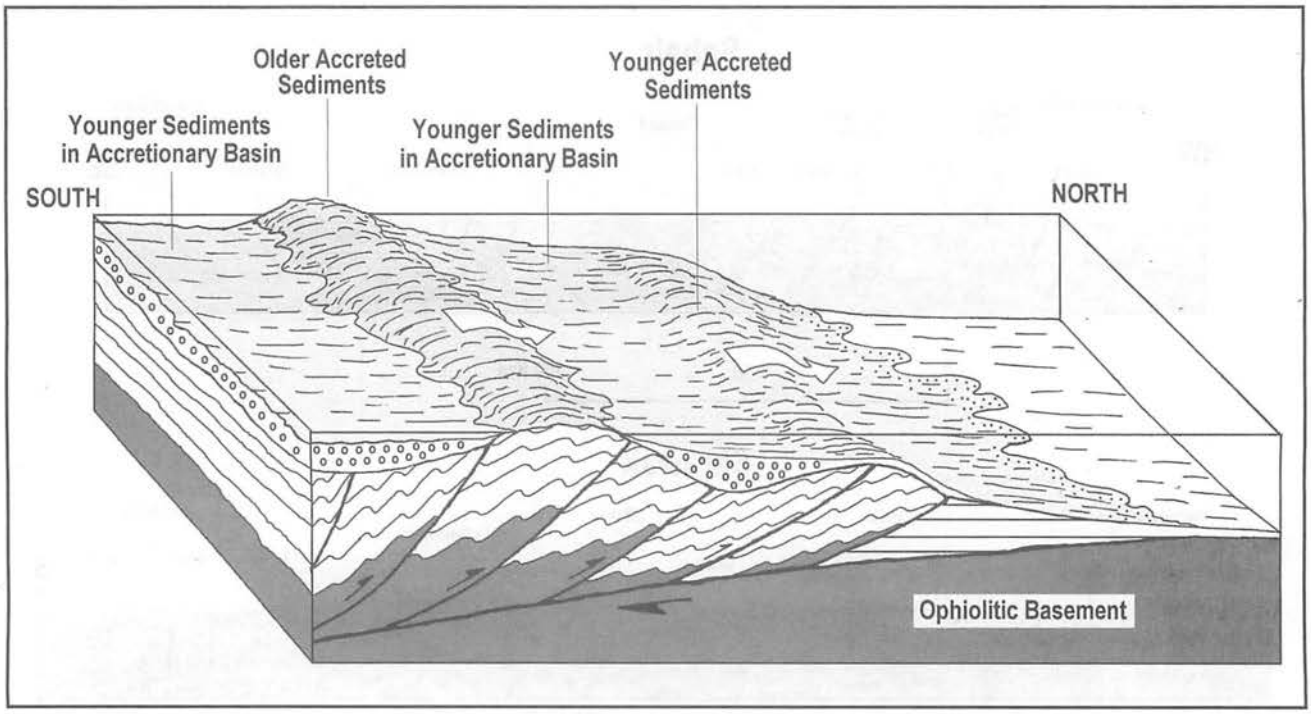

Figure 5. Schematic model to show the progressive southward accretion of younger sediments against older accreted sediments.

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Manuscript received 18 August 1998