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Tertiary stratigraphy and basin evolution of southern Sabah: implications for the tectono-stratigraphic evolution of Sabah, Malaysia

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Abstract: Integrated surface mapping, dating and radar image interpretation of strata in southern Sabah (northern Borneo) has made it possible to revise the lithostratigraphy, chronostratigraphy, structure and tectonic evolution of the area. The recognition in the field of an Early Miocene regional unconformity, which may be equivalent to the Deep Regional Unconformity recognised offshore, has allowed the development of a stratigraphic framework of groups and formations which correspond to stages in the sedimentary basin development of the area. Below the Early Miocene unconformity the succession can be resolved into deposits of an accretionary complex of Eocene age overlying an ophiolitic basement, and late Palaeogene deep water succession which formed in a forearc basin. The late Palaeogene deposits underwent syn-depositional deformation, including the development of extensive mélanges, all of which can be demonstrated to lie below the unconformity in this area. Some localised limestone deposition occurred during the period of uplift and erosion in the Early Miocene, following which there was an influx of clastic sediments deposited in delta and pro-deltaic environments in the Middle Miocene. These deltaic to shallow marine deposits are now recognised as forming two coarsening-upward successions, mapped as the Tanjong and Kapilit Formations. Their map distribution have been revised. The total thickness of these two formations in the southern Sabah Basin amounts to 6,000 m, only half of the previous estimates.

The Tanjong and Kapilit Formations are deformed into broad NW-SE-trending synclines separated by narrow anticlines. The anticlines are sub-parallel to major faults and associated with high angle reverse faults, and positive flower structures. Secondary fold-faults formed oblique to the major faults. The structural style suggests that the NW-SE trending faults acted as major left-lateral transpressional zones. The faults may in part be reactivated basement structures. The Early Miocene unconformity is interpreted to be the result of deformation and uplift following underthrusting of continental crust of the South China Sea which terminated Paleogene subduction beneath North Borneo. Renewed subsidence is related here to rifting in the Sulu Sea which led to the development of a major Miocene depocentre above the older forearc accretionary complex. The major transpressional deformation probably occurred during the Late Pliocene, and is possibly related to propagation of deformation from Sulawesi towards NW Sabah. This strike-slip deformation which uplifted the area is termed here the Meliau Orogeny. Renewed extension during the Quaternary has caused some sequence repetition. The 'circular basins' of the Meliau, Malibau and Tidung areas, are interpreted as remnants of a single large basin, deformed in the NW-SE trending transpressional fault zones.

INTRODUCTION

The geology of Sabah, the province of Malaysia in the northern part of Borneo (Figs. 1 and 2), has been the subject of a number of studies, some regional in nature (e.g. Hutchison, 1988; Hutchison *et al.*, 2000; Rangin *et al.*, 1990) others focussed on particular areas or aspects of the geology (Clennel, 1991; Tongkul, 1995; Hutchison, 1996; Noad, 1998). Geological maps have been published (Wilford, 1967; Lim, 1985) and these provide a framework of the distribution of the main rock types. However, there are a number of aspects of the terrain and the geology which have made it difficult to build up a coherent structural and stratigraphic model for the area.

The natural vegetation in northern Borneo is tropical rainforest over most of the area and this dense vegetation cover both obscures the bedrock and limits access. Streams and the upper reaches of rivers provide some natural exposure where there is incision into bedrock, but otherwise natural

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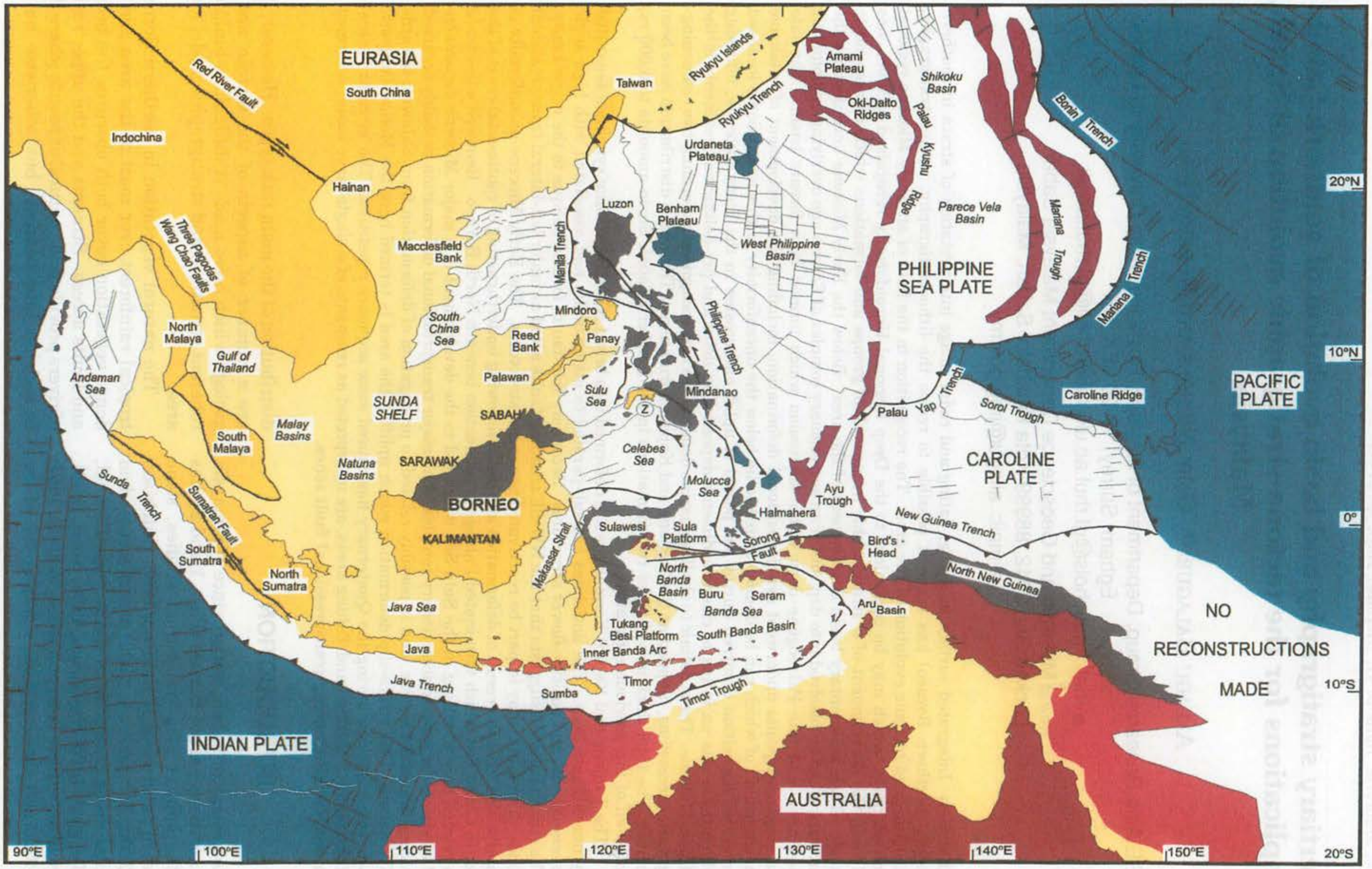

Figure 1. Borneo in its regional context (from Hall, 1996).

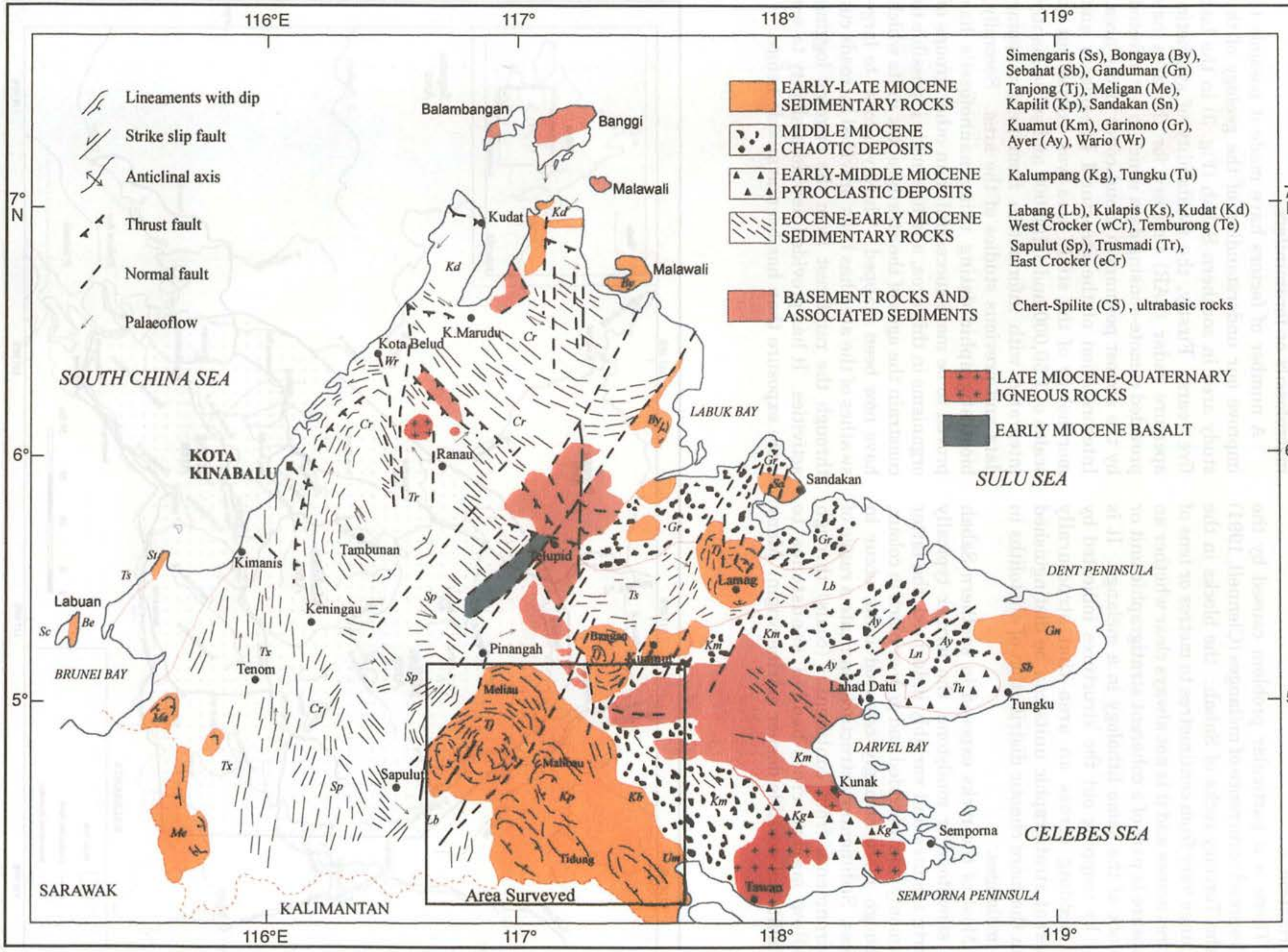

Figure 2. Outline of the main geological units in Sabah.

exposures are sparse, localised and often small, providing little structural or stratigraphic information.

There is a particular problem caused by the widespread occurrence of mélanges (Clennell, 1991) in the Tertiary rocks of Sabah: the blocks in the mélange vary from centimetres to metres or tens of metres across and it is not always clear whether an exposure is part of a coherent stratigraphic unit or a block of the same lithology in a mélange. It is only by mapping out the structures indicated by the bedding across an area that structurally coherent stratigraphic units can be distinguished from the more chaotic distribution of olistoliths in the mélanges.

Most of the rocks exposed in southern Sabah are sandstone or mudstone, the former typically quartz arenites and variably indurated, the latter commonly thinly bedded and grey or black in colour, although more strongly coloured units occur in places. Sedimentary structures indicate a range of environments from continental (coals) through shallow marine cross-bedded sandstones to turbidites of possible deeper marine origin. Many of the rock units are very poorly fossiliferous providing little biostragraphic information from macrofossils or foraminifers.

A number of factors have made it possible to improve our understanding of the geology of the study area in southern Sabah (Fig. 3) in the last five years. Firstly, the availability of synthetic-aperture radar (SAR) imagery for the area has provided remote-sensing data which is not affected by the almost permanent cloud cover of the area. Interpretation of the structural lineaments and morphology of the study area was carried out at scales of 1:50,000 and 1:100,000 and subsequently integrated with information from field mapping data and previous studies of the area. Secondly, biostratigraphic dating using nannofossils has proved to be more successful than other groups of organisms in this area, and has made it possible to constrain the ages of the stratigraphic units which have now been mapped. Thirdly, access to large swathes of the area has been provided by roads cut through the rainforest from the ongoing logging activities. It has provided new accessibility to see more exposure than has been available before.

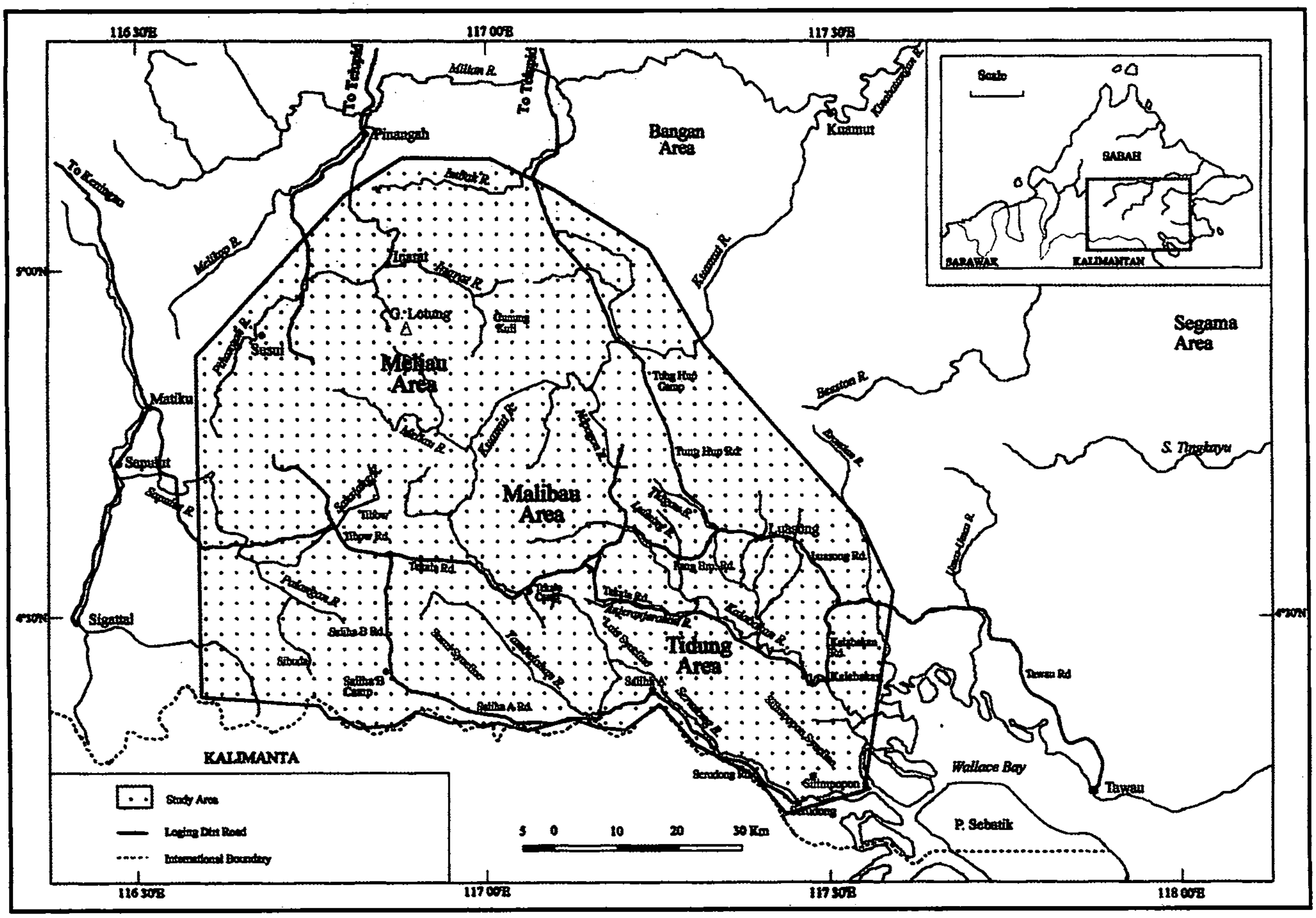

Figure 3. Map of the main rivers, logging roads and settlements in the study area of southern Sabah.

TECTONIC SETTING

The island of Borneo formed by the Mesozoic accretion of microcontinental fragments, ophiolite terranes and island arc crust onto a Palaeozoic continental core (Hamilton, 1979; Hutchison, 1989; Metcalfe, 1996) (Figs. 1 and 2). At the beginning of the Cenozoic Borneo formed a promontory of Sundaland (Hall, 1996, 2002), partly separated from Asia by the proto-South China Sea. The oceanic part of the proto-South China Sea was subducted during the Palaeogene and a large accretionary complex formed along the northwestern margin of Borneo. In the early Miocene uplift of the accretionary complex occurred as a result of underthrusting of thinned continental crust in northern (Hamilton, 1979; Taylor and Hayes, 1983; Tan and Lamy, 1991; Hazebroek and Tan, 1993). Uplift may have also resulted from shortening due to the counter-clockwise rotation of Borneo between 20 and 10 Ma (Fuller *et al.*, 1991; Hall, 1996, 2002) as a consequence of Australia-SE Asia collision. Large volumes of sediment were shed into basins which lie offshore to the west, north and east of Borneo, and into a Neogene basin which is currently exposed in large areas of eastern and southern Sabah (Hall and Nichols, 2002). To the southeast, the Miocene to Recent island arc terranes of the Sulu archipelago extend into Borneo (Kirk, 1968): the older volcanic arc material appear to be formed by SE-dipping subduction (Hall, 1996, Hall and Wilson, 2000) but the younger volcanics are likely to be the result of NW-dipping subduction of the Celebes Sea (Hall and Wilson, 2000).

In Sabah, five distinct tectono-stratigraphic provinces can be recognised (Fig. 2) (Tongkul, 1995):

(a) an ophiolite complex, which is considered to form the basement to the sedimentary succession of Sabah (Hutchison, 1989);
(b) the Rajang-Crocker accretionary prism, an arcuate belt consisting of deformed deep-marine, Eocene-Oligocene sediments (Rangin *et al.*, 1990, Tongkul, 1990; Hall, 1996);
(c) broken formations and mélanges which show characteristics of tectonic, sedimentary and diapiric origin and are thought to have formed in a series of related events in the Early to Middle Miocene (Clennell, 1991);
(d) Neogene sedimentary rocks, which are mostly shallow marine to fluvio-deltaic facies deformed into sub-circular- to elliptical-shaped, fault bounded areas which are known as the 'circular basins' of Sabah;
(e) the Semporna-Sulu Arc, a region andesitic to dacitic volcanic activity of Miocene to Quaternary age in the Dent and Semporna peninsulas.

This study focuses on the southern part Sabah (Fig. 3) where a Neogene sedimentary succession forms part of the fill of the Central Sabah Basin. In this area parts of the basement and the Rajang-Crocker complex are exposed along with broken formations and are unconformably overlain by the less deformed Neogene strata. The area has now been remapped using field and satellite imagery and material from each of the formations dated biostratigraphically. These new data have made it possible to refine the stratigraphy of the area and consider it in terms of the evolving tectonic setting of Sabah in regional context.

PREVIOUS STRATIGRAPHIC SCHEMES

Collenette (1965) who formalised the original lithostratigraphic framework of the study area (Figs. 4 and 5) recognised eleven formations. The five oldest formations were placed in the Rajang Group, and the six youngest in the Kinabatangan Group (Table 1). He proposed that sediments of the Oligo-Miocene Kinabatangan Group were deposited in epigeosynclinal basins resting on the eugeosynclinal basement of the Rajang Group of Cretaceous to Oligocene age.

Recent syntheses of the stratigraphy of Sabah summarised in Clennell (1996) and Hutchison *et al.* (2000) a late Eocene unconformity has been recognised which excludes the West Crocker and Kulapis Formations from the Rajang Group. A Middle Miocene unconformity separates the Tanjong Formation (and related Sandakan Formation to the north) from the older, deeper marine deposits and mélanges. These schemes are based on studies of the more accessible parts of Sabah to the north and west of the study area.

STRATIGRAPHY OF SOUTHERN SABAH

The new stratigraphy and geological map of the southern Sabah area (Balaguru, 2001) are shown in Figure 4 and Figure 6 respectively. Several revision made on the geological map can be compared with the old geological map (Lim, 1985) in Figure 5.

Basement Rocks

The oldest rocks are exposed in the northeastern part of the study area. They are part of an ophiolite complex which extends further east to the Segama and Darvel Bay areas and also outcrops in central Sabah in the Telupid and Bidu-Bidu Hills. The complex has been described by Reinhard and Wenk (1955), Fitch (1955), Dhonau and Hutchison (1966), and Koopmans (1967) and comprises hornblende schists, gneisses, and ultramafic rocks (peridotites

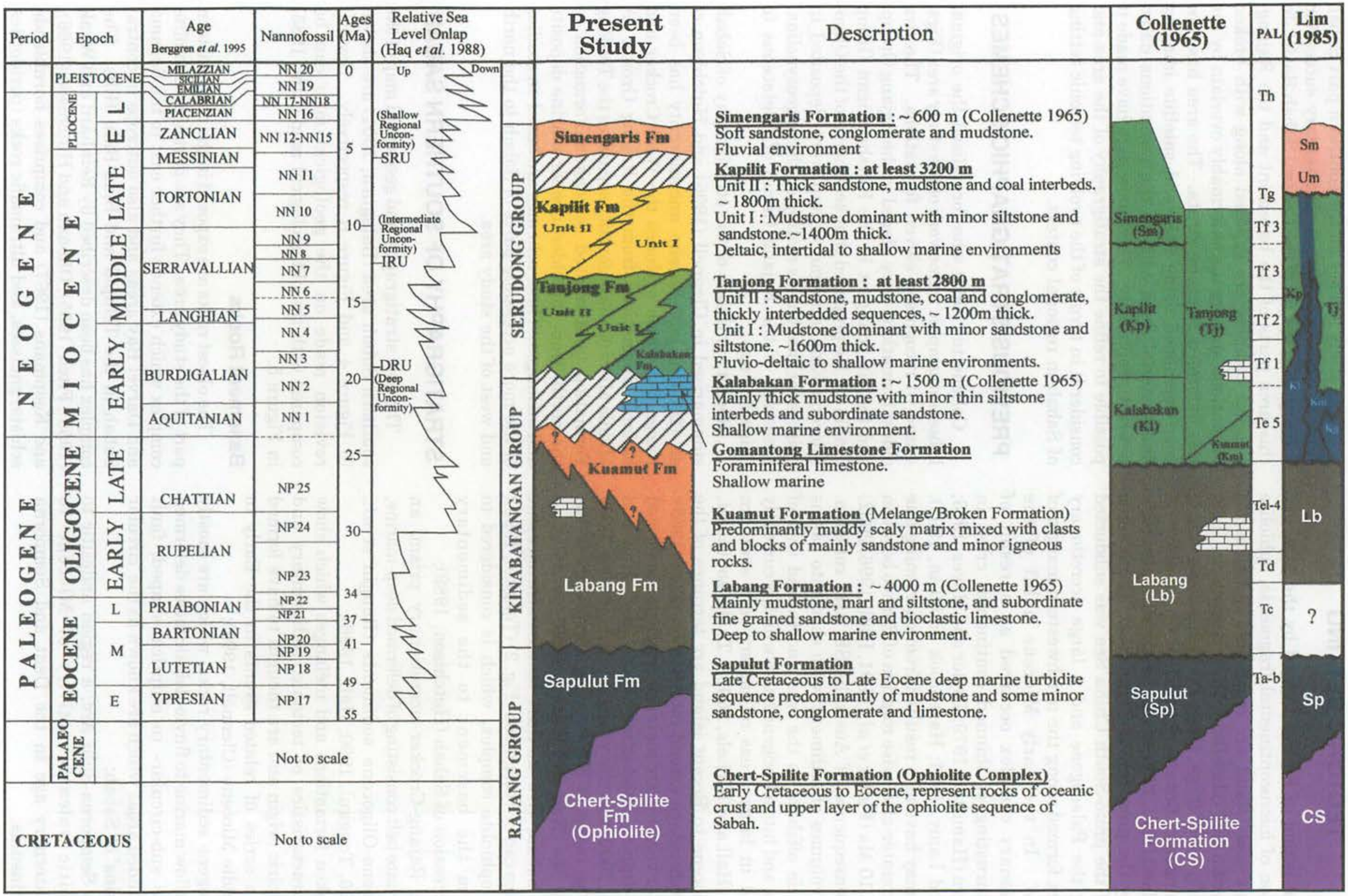

Figure 4. The stratigraphy of the southern Sabah study area based on new data from field relationships and biostratigrahic information. The scheme for this area of Collenette (1965) is shown for comparison.

and serpentinites) with the top part of the ophiolite complex represented by the Chert-Spilite Formation made up of pillow basalt, banded chert and turbiditic sandstone. These rocks are thought to form the basement rocks of Sabah (Kirk, 1968; Basir *et al.*, 1985; Leong, 1974; Rangin *et al.*, 1990; Hutchison, 2000; Hall and Wilson, 2000). K-Ar age dates of these rocks range from 210 Ma (Leong, 1970) to 137 Ma (Rangin *et al.*, 1990) and the Chert-Spilite Formation has yielded radiolaria of Early Cretaceous age (Kirk, 1968; Leong, 1977; Jasin and Tahir, 1988).

Sapulut Formation (Late Cretaceous to Late Eocene)

The Sapulut Formation is a thick succession (possibly 9,000 m) of slightly metamorphosed deep-marine sandstones and shales with minor conglomerates, which lie unconformably on the basement (Collenette, 1965). The strata have been strongly folded but lack a dominant structural trend with both NE-SW and NW-SE trends noted (Colenette, 1965; Tongkol, 1995). Along with the Trusmadi and East Crocker Formations, the

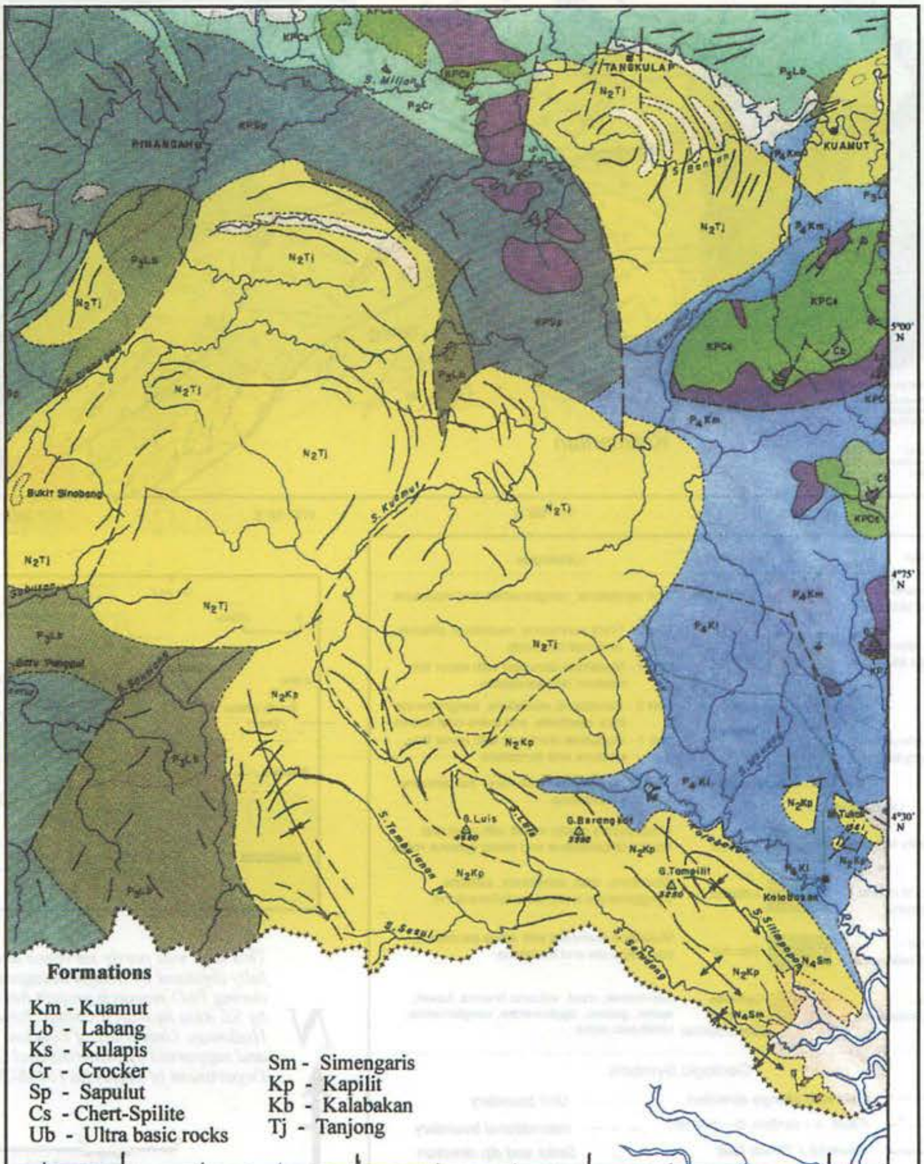

Figure 5. The published geological map of southern Sabah (Lim, 1985).

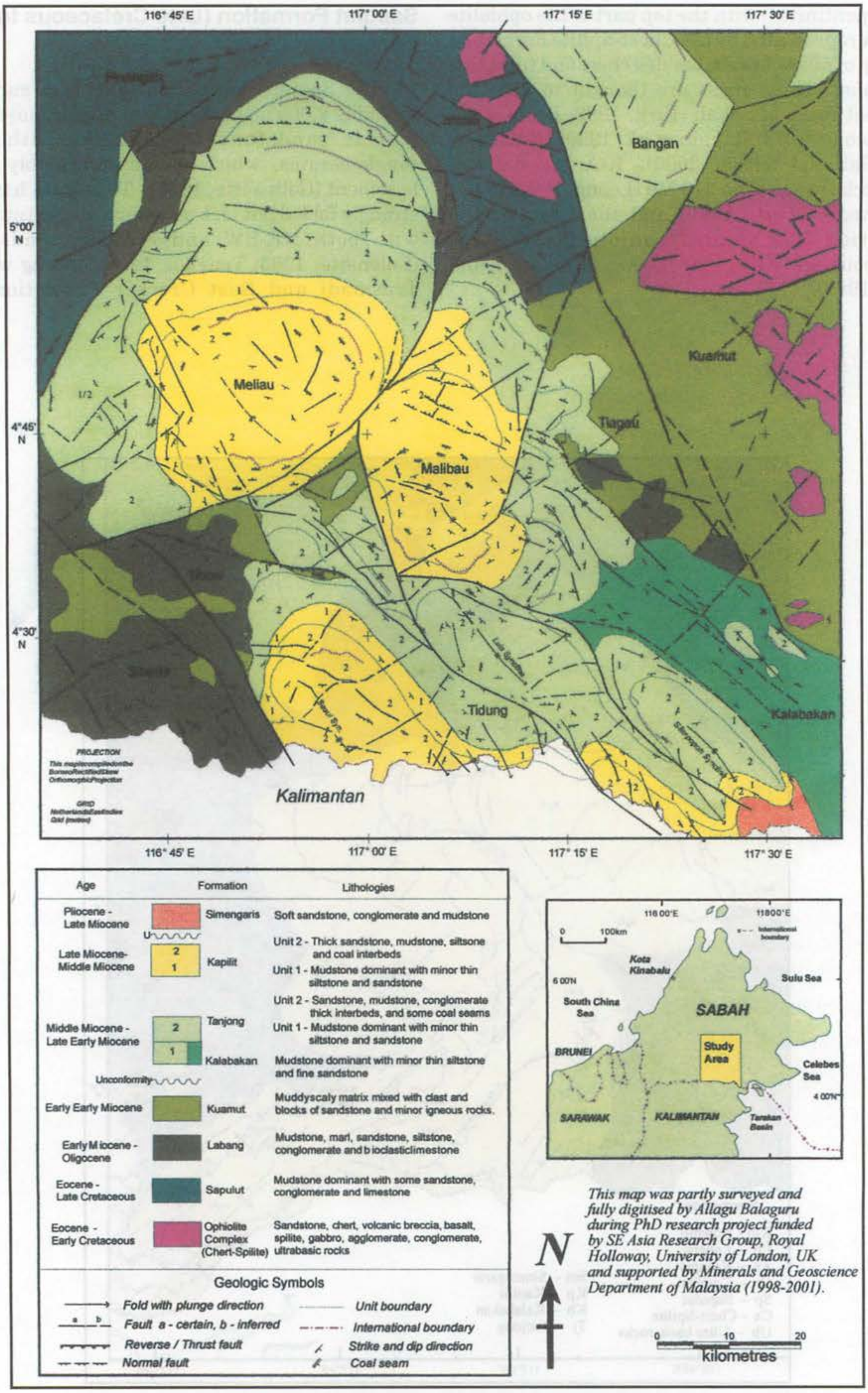

Figure 6. The proposed new geological map of southern Sabah (Balaguru, 2001, 2003).

Table 1. A comparison of the stratigraphic nomenclature of Collenette (1965) and that used in this study for the southern Sabah study area.

	Collenette (1965)		This study (Balaguru 2001)		
Group Name	**Formations**	**Thickness**	**Thickness**	**Formations**	**Group Name**
KINABATANGAN GROUP	Simengaris	>600 m		Simengaris	SERUDONG GROUP
	Kapilit	>4,500 m	~3,200 m	Kapilit	
	Kalabakan	>1,500 m		Kalabakan	
	Tanjong	12,000 m	~2,800 m	Tanjong	
	(Gomantong)			Gomantong	
	Kuamut	1,500 m		Kuamut	KINABATANGAN GROUP
	Labang	3,000 m		Labang	
RAJANG GROUP	Kulapis	3,000 m		*Kulapis* *	
	Crocker	6,000 m		*W Crocker* *	
	Trusmadi	4,500 m		*E Crocker* * *Trusmadi* *	RAJANG GROUP
	Sapulut	9,000 m		Sapulut	
	Chert-Spilite			Chert-Spilite	

* formations not present in southern Sabah study area.

Sapulut forms part of the Rajang Group (Collenette, 1965; Tongkul, 1995; Hutchison, 1996), which outcrops across large areas of western and northern part of Sabah. Lithostratigraphic relationships between the three formations of the Rajang Group are obscure and contacts shown on the maps of Collenette (1965) and Lim (1985) are generally faulted. Age determinations range from Late Cretaceous to Late Eocene, based on the calcareous benthic and pelagic foraminifera (Collenette, 1965), to Middle Eocene (Rangin *et al.*, 1990). The type section is exposed in the Sapulut River (Collenette, 1965), to the west of the study area (Fig. 3).

Labang Formation (Oligocene)

The term Labang Formation was introduced by Collenette (1965) for predominantly grey coloured sandstones, mudstones and shales of Oligocene age which outcrop in the Labang River valley of south-central Sabah. The formation comprises a thick sequence of calcareous sandstone, shale and mudstone beds with some foraminiferal limestone units. The sandstone and mudstone beds are characteristically normally graded in 'Bouma' sequences with flute and groove casts also indicative of turbidite deposition; they are interbedded with hemipelagic shales (Clennel, 1996) and contain abundant deep-water trace fossils. The limestone units, which include some corals, may indicate shallower water deposition, but are likely to have been redeposited in deeper water (Haile *et al.*, 1965). Hutchison (1992) suggested that the occurrence of radiolarian chert clasts in the Labang Formation indicate that the provenance was from the ophiolite complex. The Labang Formation mainly occurs in the southern and eastern parts of Sabah.

Collenette (1965) reported that the Labang Formation rests unconformably on the Sapulut Formation in the Sapulut River type area. In the study area, another unconformity separates the contorted Labang Formation from gently dipping beds of the Tanjong Formation along the Pang Brothers Road (Fig. 3). The Labang Formation is strongly deformed throughout the area, with outcrops of overturned beds common, and in places the chaotic lithologies of Labang Formation are included in the mélange unit of the Kuamut Formation (see below). Extensive deformation makes estimation of the stratigraphic thickness difficult, but Collenette (1965) cites a thickness of 3,000 m and seismic lines in the Sibuda area indicate 2,000–3,000 m thickness (*pers. comm.* C. Elders, 2001) of Labang Formation strata.

The reference section for the Labang Formation in southern Sabah lies in a tributary of the Sibuda River (Fig. 3). From this and other exposures in the area six calcareous mudstone and marl samples have been dated as Early to Late Oligocene (NP23-NP25) based on nannofossil determinations (Appendix Table 1)

Kuamut Formation (Early Miocene)

The term Kuamut Formation was introduced by Collenette (1965) and Leong (1974) for rocks in central Sabah which are 'broken formations' of sandstone, mudstone and conglomerate, with scattered occurrences of limestone, chert, tuff, spilite, basalt, and peridotite, all of which are found to be blocks derived from older formations. In southern Sabah the Kuamut Formation is now found in the Sibuda and Tibow areas as well as the type section in the Kuamut valley (Fig. 3). Outcrops in the study area are strongly tectonised and chaotically deformed with strong scaly fabrics developed in the matrix; they contain brecciated blocks of sandstone with slickensides common on the block surfaces.

In the western part of the study area, blocks of sandstone in the mélanges are almost exclusively Labang Formation material. Poor outcrop does not allow the relationship between the Labang and Kuamut Formations to be determined in the field, but it is possible to consistently map coherent units of these lithologies as Labang Formation and the broken and mélange units as Kuamut Formation. Towards the eastern part of the area, the Kuamut Formation includes clasts of pillow basalts and serpentinites and further east the Kuamut Formation is thought to be unconformable on the Ophiolite Complex (Chert-Spilite Formation, Collenette, 1965).

An exposure of the Kuamut Formation exposed at East Malibau, along the old Pang Brothers logging road (Upper Luimang River) provides key evidence of the unconformable relationship with the overlying Tanjong Formation. The younger unit is well bedded, gently dipping mudstone which is unconformable on top of a highly indurated, quartz-veined and chaotically deformed mélange unit of the Kuamut Formation. An unconformable contact with the Tanjong Formation is also mapped in the Napogon River and in the southwestern part of the study area, whilst in the east-southeastern part of the area, the Kalabakan Formation unconformably overlies the Kuamaut Formation.

Collenette (1965) and Leong (1974) concluded that the age of the Kuamut Formation is largely Early Miocene but includes reworked foraminifera of Oligocene and Middle Miocene (Te5-f). In this study five calcareous shale samples from the Kuamut Formation contained nannofossil assemblages of Oligocene (NP24-NP25) age (Appendix Table 2).

Gomantong Limestone Formation (Early Miocene)

Limestones found as blocks and lenses of various sizes in southern Sabah were assigned to the Labang and Tanjong Formations by Collenette (1965) based on ages from foraminifera assemblages. During this study and Balaguru (1996), several limestone blocks and lenses were found in the Malibau (Anjeranjeramut River) and Sibuda (Tibow Road) areas. Samples from exposures were found to contain Burdigalian foraminifera (Appendix Table 3) including *Lepidocyclina brouweri* and primitive *Lepidocyclina ferreroi* which suggest an Early Burdigalian, N5 age (Early Miocene, NN2). The age determinations allow these limestone outcrops in southern Sabah to be considered part of the Gomantong Limestone Formation which occurs mainly in northeastern Sabah (Noad, 1998).

Field exposures of the limestones are poor and limited but their occurrences indicate that they most probably lie between the Labang/Kuamut Formations and the Tanjong Formation. This is consistent with outcrops in eastern Sabah where clasts of Labang Formation are found in the Gomantong Limestone (Noad, 1998) and show that the deposition of the Gomantong Limestone post-dated the strongly deformed Labang/Kuamut Formations.

Tanjong Formation (Early to Middle Miocene)

The Tanjong Formation was described by Collenette (1965) as a thick succession of sandstone, mudstone and siltstone with lenses of conglomerate in the Pensiangan and Upper Kinabatangan Rivers in central Sabah. The distribution was noted as occurring in a number of elliptical 'basins' in the Meliau, Malibau, Bangan and Bukit Garam areas, although this study has shown that these 'basins' are in fact geomorphological features, and not basins of sedimentation. Further outcrops have now been mapped in the Tidung area.

The formation can be divided into a lower mudstone and siltstone dominated sequence (Unit I) which is overlain by a sandstone and mudstone dominated sequence (Unit II) to form a coarsening-upward megasequence. Coarse grained sandstone, conglomerate, carbonaceous mudstone and coal seams up to 5 m thick are common in Unit II. On the basis of cross-sections constructed from structural mapping, the total preserved thickness of the Tanjong Formation is estimated to be 2,800 m, made up of 1,200 m for Unit I and 1,600 m for Unit II.

The Tanjong Formation is overlain by the Kapilit Formation. The top of the Kapilit Formation is a regional erosional surface with locally deeply incised surfaces. Previous studies in southern and eastern Sabah suggested that the age of the Tanjong Formation is Early to Middle Miocene (Collenette, 1965; Leong, 1974; Clennell, 1992) and palynological studies carried out by Sarawak Shell (Balaguru, 1996, 1997) indicated an Early Miocene age. Recent dating using nannofossils (Appendix Table 4) has refined the age to Late Early Miocene to Middle Miocene (NN3-NN5) (Balaguru, 2001).

The reference sections for the Tanjong Formation in southern Sabah lie along three roads, the Pang Brothers Road (subparallel to the Upper Kalabakan River), Silimpopon Road and Saliha A Roads (Fig 3). Along the first of these there is an almost continuous succession through Unit I into Unit II and the Silimpopon Road represents the middle section of the formation. The section along the Saliha A Road represents the best exposure of the upper part of the Tanjong Formation and subsequent transition into the lower part of the Kapilit Formation.

Kalabakan Formation (Early Miocene to Middle Miocene)

The Kalabakan Formation is a thick unit of grey mudstone and siltstone exposed in the Kalabakan Valley (the type section) up to the upper part of the Tiagau area (Fig. 3). It has very similar characteristics to the mudstone in Unit I of the Tanjong Formation. Previous studies had placed the Kalabakan Formation within the mélanges of Sabah (Collenette, 1965; Lim, 1985), but new mapping has shown that it is the lateral equivalent of Unit I of the Tanjong Formation. Field evidence from inliers of chaotically deformed and indurated Kuamut/Labang Formation within the Kalabakan Formation, which is distinctly less indurated and deformed indicate an unconformity at the base of the Kalabakan Formation.

Only one sample of this formation, from the Kalabakan Road, provided a nannofossil assemblage (Appendix Table 5) which could be dated and this indicated a Late Early Miocene (NN4) age (Balaguru, 2001).

Kapilit Formation (Middle to Late Miocene)

Collenette (1965) used the term Kapilit Formation for the thick sandstone and mudstone succession in the Silimpopon, Luis and Susui Valleys (Tidung area, Fig. 3, Lim, 1985). However, in this study the distribution of the Formation has been revised, and it is now considered to occur in the central Susui, Malibau and Meliau areas (Fig. 3). The reference section is in the Susui area where the Kapilit Formation is well exposed along the Tambulanan River and the Serudong Road.

The Kapilit Formation is a coarsening-upwards megasequence similar to the underlying Tanjong Formation. The two formations are quite similar in outcrop, but their superposition can be recognised from the SAR interpretation. The Kapilit Formation can be subdivided into two units, a lower mudstone and siltstone dominated sequence (Unit I) which is overlain by Unit II of interbedded sandstone, conglomerate, carbonaceous mudstone and coal seams. The thickness of the Kapilit Formation had previously been estimated to be greater than 4,500 m, but newly-constructed cross-sections now indicate 1,400 m for Unit I and 1,800 for Unit II.

The Kapilit Formation overlies the Tanjong Formation with a bedding parallel, deeply incised erosional contact in the Tidung area. The contact is seen on radar and in the field as the sequence passes from the scarp-forming outcrop of Unit II of the Tanjong Formation to the less resistant mudstones of Unit I of the Kapilit Formation. In the southeast the Kapilit Formation is overlain by the Pliocene Simengaris Formation with a slight unconformity.

In previous studies the age of the Kapilit Formation is unresolved (Collenette, 1965), but palynological data from Balaguru (1996, 1997) indicate a Middle to Late Miocene age using the palynological and planktonic foraminiferal zones used in the biostratigraphy of Brunei Darussalam (Sandal, 1996). Only one sample, from the Malibau area, provided an index foraminifera *Stenochlaena areolaris*, which suggests a Latest Middle Miocene to Early Late Miocene age. Nannofossil assemblages (Appendix Table 6) indicate that the age of the Kapilit Formation is most probably Middle to Late Miocene (Balaguru, 2001).

Simengaris Formation (Late Miocene to Pliocene)

The Simengaris Formation is poorly exposed in a small part of the southern Sabah area to the southeast of the Silimpopon Syncline (Fig. 3), where it occurs as interbedded thick mudstone and sandstone with locally developed basal conglomerate, all highly weathered and poorly consolidated. The type area of the Simengaris Formation is in the Simengaris Valley a few kilometres south of the border in Kalimantan (Collenette, 1965). The Simengaris Formation is thought to be unconformable on the Kapilit Formation and is believed to be Latest Miocene to Pliocene in age and at least 600 m thick (Collenette, 1965).

REVISIONS TO THE STRATIGRAPHY OF THE AREA

Figure 4 and Table 1 illustrate the revised stratigraphy of the Southern Sabah area. The boundary between the Labang/Kuamut formations and the overlying Tanjong (and locally the Gomantong Limestone) formations is significant because it is a regional unconformity which separates a succession of deformed and indurated deep water sediments and mélanges below the unconformity from more gently folded, less cemented, shallow marine and deltaic deposits above. A revision of boundaries between the groups of formations is therefore has been made to ensure that the group definitions conform to general stratigraphic practice and also to reflect the stages in the basin development. The Tanjong, Kalabakan, Kapilit and Simengaris Formations are now separated from the Kinabatangan Group and are reclassified into new group, the Serudong Group, named after the major river which cuts through these formations.

The Labang and Kuamut Formations remain in the Kinabatangan Group and in southern Sabah are Oligocene to Early Miocene in age. In the Serudong Group, the Kalabakan Formation is now considered to be a lateral equivalent of the Tanjong Formation and is not part of the mélange unit as shown in the existing geological map of Lim (1985). The Tanjong and Kalabakan formations are dated as late Early Miocene to Middle Miocene. The Middle Miocene to Late Miocene Kapilit Formation is now placed above the Tanjong Formation, separated by an erosional surface. Previously the Tanjong and Kapilit Formation were thought to be lateral equivalents of the same age (Collenette, 1965; Lim, 1985). The Simengaris Formation is unconformable above the older Miocene sediments and was deposited during the latest Miocene to Early Pliocene.

Collenette (1965) estimated the thickness of the Tanjong Formation as 12,000 m, but in the newly defined Serudong Group, this figure can now be considerably reduced to between 6,000 m and 7,000 m for the whole of the group of post-middle Miocene shallow marine and deltaic sediments (Balaguru, 2001). Despite these revisions to the estimates of the thicknesses of Neogene strata preserved in Sabah, there is evidence that much greater thicknesses formerly covered the area (Balaguru, 2001).

STRUCTURE

The structural synthesis of the Southern Sabah Basin suggests that the complex structural style was the result of progressive deformation including extension and strike-slip activity. Basement lineaments are interpreted to be predominantly oriented NW-SE and NE-SW, and they possibly influenced basin development during reactivation in the Neogene (Fig. 6) (Balaguru, 2001).

The deep-water Labang Formation was subjected to multiple deformation and polyphase folding probably in a forearc region. The outcrops typically show abundant syn-depositional and syn-diagenetic extensional faults which suggest a very active tectonic setting from at least the Early Oligocene until the Early Miocene.

The Kuamut Formation includes similar deep-water sedimentary rocks which are chaotically deformed mud-rich blocky mélanges (Type III), and mudstone-dominated brittle fault rocks (Type IV) of Cowan (1985). They indicate diverse tectonic settings and were probably formed by a combination of tectonic and sedimentary processes in a forearc region. They are subduction-related and include tectonic mélanges, olistostromes and mud-rich diapirs, probably representing different structural positions in the accretionary wedge. The Labang/Kuamut Formations were strongly deformed and then uplifted to levels where they were subjected to erosion. They are unconformably overlain by the Lower-Middle Miocene Tanjong Formation. This indicates rapid tectonic change between the Late Oligocene and Late Early Miocene.

The Miocene sediments of the Tanjong and Kapilit Formations show prominent NW-SE-trending broad synclines separated by narrow anticlinal structures. The tight anticlines are sub-parallel to the major faults and associated with high angle reverse faults, and are associated with positive flower structures. Some small folds formed oblique to the major faults. Syn- and post-depositional extensional faults trend broadly NW-SE and NE-SW. These are interpreted as the results of various stages of deformation including extension, strike-slip activity and renewed extension during the Early Miocene to Pliocene. The overall structural style and fold architecture suggest that major NW-SE trending faults acted as left-lateral transpressional zones during the Late Pliocene. Deformation may have continued until the present day.

TECTONO-STRATIGRAPHIC EVOLUTION

The stratigraphy of southern Sabah related to the evolving tectonic setting of Sabah is shown in Figure 7.

Pre-Cenozoic

The presence of granitic and metamorphic rocks of possible continental origin (Reinhard and Wenk,

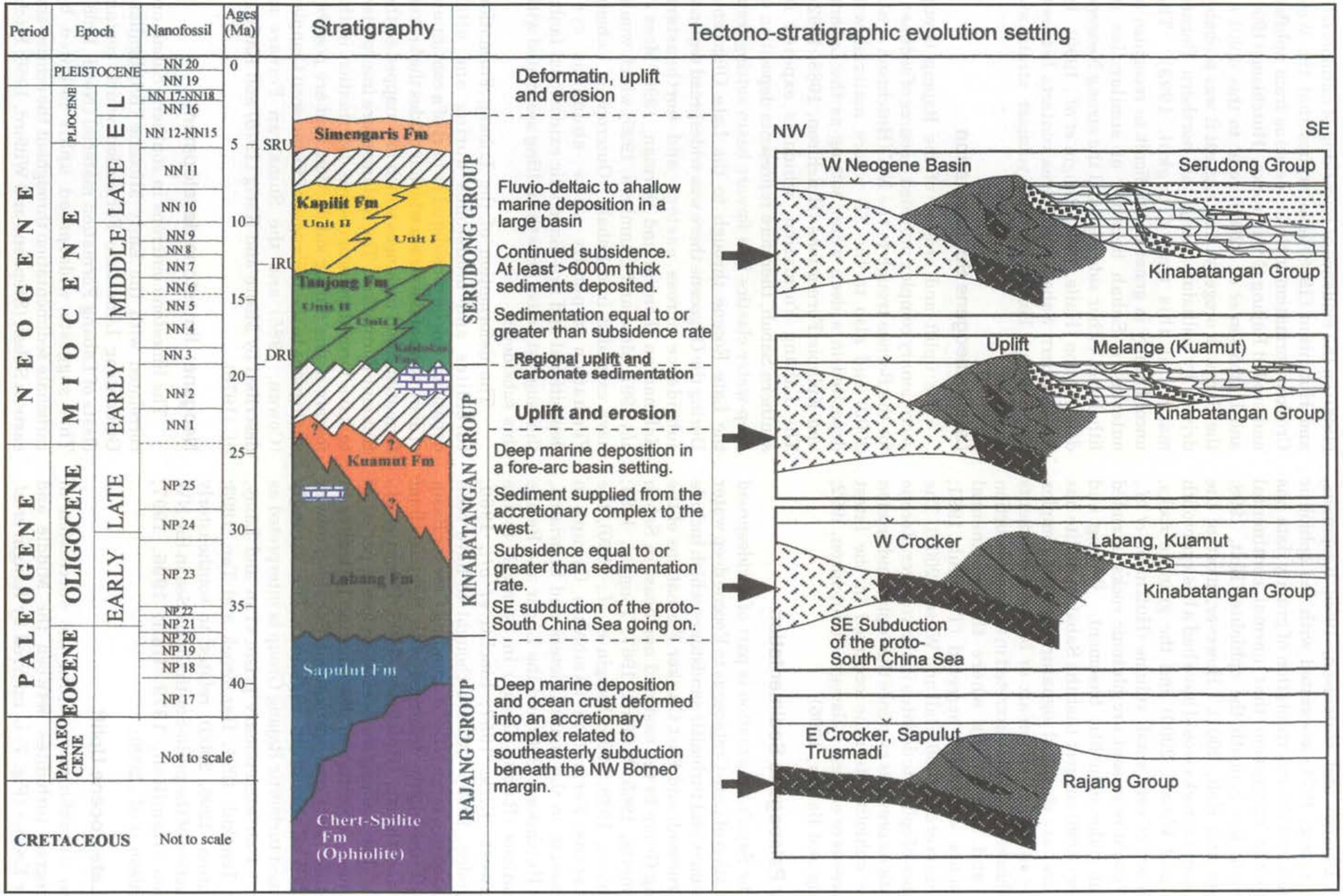

Figure 7. The stratigraphy of southern Sabah related to the evolving tectonic setting.

1951; Dhonau and Hutchison, 1966; Koopmans, 1967; Leong, 1974) associated with the ophiolitic complex and the interpretation of gravity data has led to the suggestion that normal continental basement lies beneath the ophiolite (Holt, 1998; Milsom and Holt, 2001). However, most of the metamorphic rocks would have had a basic protolith (Hall and Wilson, 2000) and the granitic rocks, which are of very small volume (Hutchison *et al.*, 2000) could represent arc plutonic rocks intruded into an older ophiolitic basement. Omang and Barber (1996) suggest that the Sabah ophiolite has an island arc chemical signature and the complex can be envisaged as forearc or backarc fragments (Hutchison *et al.*, 2000) accreted in supra-subduction zone and arc setting where the continental fragments were also accreted (Tongkul, 1991; Hutchison *et al.*, 2000; Hall and Wilson, 2000). The presence of ophiolitc detritus in the younger, Eocene formations provides evidence that uplift and erosion of the ophiolitic terrane occurred in the latest Cretaceous or earliest Palaeogene (Hutchison, 1992; Omang and Barber, 1996).

Early Palaeogene Sedimentation

The Sapulut Formation is part of a widespread association of Late Cretaceous to Eocene deep water mudstones and turbiditic sandstones which include the Trusmadi and East Crocker Formations of the Rajang Group to the east and northeast in Sabah (Collenette, 1965; Wilford, 1967; Tongkul, 1994; Hutchison, 1988, 1996; Rangin *et al.*, 1990), the Mentarang Formation (Ambaluh Group) in Kalimantan to the south (Pieters and Supriatna, 1990; Hutchison, 1996) and the Lupar and Belaga Formations (Rajang Group) in Sarawak to the southwest (Kirk, 1957; Liechti *et al.*, 1960; Wolfenden, 1960). All are thought to have been deposited in a large NE-SW trending Crocker Basin and all are highly deformed with tight isoclinal folds and thrusts (Hutchison, 1996; Honza *et al.*, 2000). The Palaeogene was therefore a period of continued deposition of deep marine turbidites in the study area and throughout Sabah, Sarawak and NW Kalimantan regions. The strongly deformed turbiditic Rajang Group is interpreted as a part of an accretionary prism (Tan and Lamy, 1990; Tongkul, 1991; Hazebroek and Tan, 1993; Hutchison, 1996, 2000), related to southeasterly subduction of the proto-South China Sea in the NW Borneo (Hamilton, 1979; Hall, 1996, 1997; Hutchison *et al.*, 2000).

Mid-Late Eocene Uplift

An unconformity within the succession of Palaeogene turbidites between the Middle and Upper Eocene (Fig. 7) is inferred by Rangin *et al.* (1990) on the evidence of reworking of nannofossils and Hutchison (1996) also argues that the West Crocker Formation includes detritus from uplifted and eroded Rajang Group rocks. Hutchison (1996) and Hutchison *et al.* (2000) refer to this uplift as the 'Sarawak orogeny', and suggest it was probably driven by collision along the northern Borneo margin at this time (Tongkul, 1993). The unconformity is generally difficult to recognize in outcrop in Sabah because of similarities in lithologies either side of it and the strong Neogene deformation (Haile, 1994; Rangin *et al.*, 1990). In the southern Sabah study area contacts between the Sapulut Formation and younger strata are obscure.

Late Palaeogene Sedimentation

The uplift and erosion of the Rajang Group accretionary complex provided a source of sediment for the Borneo trough to the NW (Hutchison *et al.*, 2000) and also to the SE where material was deposited in a deep water setting as the Labang and Kulapis Formations (Hutchison, 1988, 1992). The Labang Formation, which is exposed in southern Sabah, therefore represents deposition of deep-water clastics in a forearc basin setting from the Late Eocene through to the Late Oligocene. During the Oligocene there was widespread regional subsidence across eastern and northeastern Kalimantan (Lentini and Darman, 1996; Moss *et al.*, 1997; Moss and Chambers, 1999) which would have extended into Sabah. Outcrops of Labang Formation typically show abundant syn-depositional and syn-diagenetic extensional faults that suggest active growth faulting associated with this subsidence.

The deformation of the Labang Formation turbidites and mudstones during and after deposition can be considered as part of a continuum of disruption of the strata which includes the broken formations and mélanges which are mapped as the Kuamut Formation. The mélanges are interpreted to have formed by progressive deformation in the forearc region during subduction, and are possibly analoguous to the mélanges of Franciscan Complex (Cowan, 1985) and the Sumatran Forearc as described by Moore and Karig (1976) and Karig *et al.* (1978).

Neogene: limestone development

The limestone outcrops in southern Sabah are correlated with the Early Miocene (Burdigalian) Gomantong Limestone Formation which contain clasts of Labang Formation material (Noad, 1998). This suggests widespread uplift followed by carbonate sedimentation throughout the central and eastern Sabah (Stephens and Wilford, 1956; Fitch, 1958; Wilson, 1960; Wilson and Wong, 1964; Tongkul, 1991). Hinz and Schluter (1985) and Fulthorpe and Schlanger (1989) also recognised this change in depositional environment in offshore NW Sabah. Further south in Kalimantan, carbonate sedimentation also occurred during this time in the Tarakan Basin (Lentini and Darman, 1996) and the Kutai Basin (Moss *et al.*, 1997). In eastern Sabah the Gomantong Limestone outcrops in a ENE-WSW-trending belt stretching at least 200 km, which suggests that this may have been a zone of uplift along which localised carbonate sedimentation occurred, isolated from any clastic sediment influx from the west.

Mid-Cenozoic deformation

The inclusion of Labang Formation clasts in the Gomantong Limestone demonstrates that uplift and deformation in southern and eastern Sabah had started by the Burdigalian (Early Miocene), between approximately 22 and 19 Ma. This is earlier than the Early to Middle Miocene boundary age (17 Ma) given by other authors for the Deep Regional Unconformity (DRU), a widespread surface recognisable on seismic profiles offshore NW Sabah (Bol and Van Hoorn, 1980; Levell, 1987; Hinz *et al.*, 1989; Hinz *et al.*, 1991). However, as noted by Clennell (1996) the time period represented by the DRU is variable, and the early Miocene was a period of widespread mélange development (Clennell, 1991, 1992, 1996). It is therefore likely that deformation continued for several million years, with the Gomantong limestone forming on structural highs during relatively quiescent times in the Early Miocene.

In the study area this unconformity can be identified in the field separating deformed and lithified mélange of the Kuamut Formation from the less tectonised strata of the Tanjong Formation (Balaguru, 2001). It is interpreted to mark a major tectonic event, with associated uplift and erosion providing detritus to supply the deltaic to shallow marine Middle to Upper Miocene succession. The cause of this uplift and consequent change in depositional environment in the study area has been related to changes occurring along the northern margin of Borneo where continental blocks were being thrust beneath the accretionary complex (Hutchison, 1989, 1992; Tongkul, 1993; Clennell, 1996).

Neogene clastic sedimentation

The end of the period of early Miocene deformation is marked by the onset of Tanjong Formation clastic deposition, the oldest dates for which are late Burdigalian (NN3/NN4, 18-16 Ma). The absence of widespread syn-sedimentary deformation in the Tanjong Formation suggests that it was deposited during a period of relative tectonic quiescence which lasted through the deposition of the Kapilit Formation which includes strata which are late Middle Miocene (approximately 12–10 Ma) or younger. There must have been continued subsidence, however, because the Serudong Group sediments were all deposited in coastal to shelf environments but have a cumulative thickness of at least 6,000 m. The Middle Miocene subsidence in the Central Sabah Basin is possibly related to coeval development of the Sulu Sea Basin in a back-arc setting (Nichols *et al.*, 1990) or regional thermal subsidence (Ismail *et al.*, 1995).

Facies trends in the Tanjong, Kalabakan and Kapilit Formations indicate that detritus eroded from uplifted strata of the Rajang and Kinabatangan Groups in the west was deposited in a deltaic to shallow marine system which prograded towards the northeast. All the Neogene 'circular basins' of eastern Sabah were part of a single NE-SW trending shallow basin. The southeastern margin of the basin was defined by the uplifted Segama ophiolite which also acted as a source for some coarse detritus.

Fluvio-deltaic deposition of Unit II of the Tanjong Formation was terminated by a relative sea level rise, and Unit I of the Kapilit Formation was deposited in a shallow marine environment. This transgression could be related to a global eustatic sea level rise in the late Middle Miocene (Haq *et al.*, 1987) but regional subsidence related to extension in the Sulu Sea or regional thermal subsidence reported in Sarawak (Ismail *et al.*, 1995) are also likely causes. Progradation of a large delta resumed during the time of the Kapilit Formation, following a very similar pattern to the underlying Tanjong Formation.

The unconformity between the Kapilit and Simengaris formations may be related to a widespread base level drop during end-Miocene which is known from offshore data as the Shallow Regional Unconformity (Bol and Van Hoorn, 1980; Levell, 1987). The Simengaris Formation consists of shallow marine to fluvio-deltaic sediments deposited during a subsequent transgression. The present outcrop pattern of the Serudong Group strata is the product of transpressional tectonics and inversion during the Latest Pliocene (Balaguru, 2001, 2003).

Late Pliocene Major Tectonic Activity and Structural Uplift

The latest phase of major tectonic event deformed the study area into NW-SE trending narrow faulted anticlinal zones with intense deformation separated by broad synclinal areas with gently folded strata. These structures are interpreted to be related to strike-slip faulting and transpressional fault movement in this region (see Fig. 6). The detailed structural style of the southern Sabah area and the mechanism which control the development and origin of the 'circular basins' of Sabah is well illustrated in Balaguru (2003).

Transpressional movement from the Late Pliocene onwards resulted in major structural inversion and uplifted most of the southern and eastern parts of Sabah where the Miocene strata now are exposed onland with a highest point at 1,500 m (Gunung Lotung) above the sea level. This event is here termed the Meliau Orogeny. The majority of the Miocene coal samples from the Malibau area are high volatile bituminous (A/B) type (Balaguru, 1996, 1997). The vitrinite reflectance (Vr%) of the coal samples suggest approximately 4–5 km of structural uplift occurred since the Miocene and several kilometres of sediments were uplifted and eroded. At least 6 km thick of the Miocene sediments are now exposed onland in southern Sabah.

This structural uplift resulted in new clastic source areas for the younger Plio-Pleistocene deltaic development in the present offshore areas. Large amounts of sediment have been shed into the NE Kalimantan Basin where at least 7,500 m of Plio-Pleistocene sediments have been deposited (Wight *et al.*, 1993). This indicates rapid uplift, erosion and deposition from the Latest Pliocene onwards.

Quaternary extension in the study area is indicated by the presence of post-inversion extensional faults trending broadly NE-SW and WNW-ESE. These faults are interpreted to be significant as they caused a repetition of sequence. This indicates a period of relaxation during the Quaternary after the major transpressional tectonic event and uplift (Balaguru, 2001, 2003).

CONCLUSIONS

This study has provided new insights into the stratigraphy, the distribution of the formations and the structural style of the study area based on surface mapping and SAR image interpretation. It has produced a new stratigraphy and geological map of southern Sabah area, and proposed a new tectono-stratigraphic evolutionary model for southern Sabah and the surrounding areas of Sabah in a regional context.

An unconformity has been recognised separating Palaeogene deepwater facies and mélanges (Labang and Kuamut formations) deposited in a fore-arc setting from Neogene deposits of the Serudong Group. Clasts of Palaeogene lithologies in the Burdigalian Gomantong Limestone and the age of the Tanjong Formation sediments above the unconformity indicate that uplift occurred over a period between 22 and 16 Ma. The unconformity exposed in southern Sabah may therefore be correlated with the Deep Regional Unconformity dated at 17 Ma offshore. A redefinition of the Kinabatangan Group is required to exclude the formations above this unconformity.

The Neogene basin development can be related to regional extension and subsidence due to back-arc extension in the Sulu Sea to the northeast: approximately 6,000 m of deltaic and shallow marine sediments accumulated during this stage (about half of the previous estimates for the thickness of this succession). The relationship between the Tanjong, Kalabakan and Kapilit formations has been resolved and a new group defined, the Serudong Group, to encompass these formations which all lie above the unconformity at the top of the Kinabatangan Group.

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Appendix Table 1: Labang Formation

Location	No	Age	Fossils
AB295 Tekala-Tibow Main Road	S99/137	Late Oligocene NP24	*Cyclicargolithus floridanus (ab), Sphenolithus ciperoensis (c), Sphenolithus distentus (c), Discoaster deflandrei (9), Coccolithus pelagicus (8), Helicosphaera intermedia (4), Sphenolithus pseudoradians (3), Dictyococcites bisecta (c), Sphenolithus miroformis (6), (3), Sphenolithus sp.cf.S.dissimilis (4), Cyclicargolithus abisectus (11).*
AB298 Tekala-Tibow R	S99/139	Indeterminate	*Coccolithus pelagicus(5), Cyclicargolithus floridanus (4), Pontosphaera sp. (2), "Coccolithus"sp. (c).*
AB322 Tibow Road	S99/153	Late Oligocene NP24	*Coccolithus pelagicus (5), Discoaster deflandrei (5), Cyclicargolithus floridanus (10), Sphenolithus distentus (6), Sphenolithus ciperoensis (5), Micrantholithus flos (1), Dictyococcites bisecta (8).*
AB325 Tibow Road, Sapulut Forest Camp	S99/157	Late Eocene NP16-NP19	*Cyclicargolithus floridanus (c), Dictyococcites bisecta (c), Reticulofenestra umbilica (6), Sphenolithus moriformis (10), Coccolithus pelagicus (c), Helicosphaera compacta (2), Sphenolithus pseudoradians (3), Ericsonia formosa (6), Chiasmolithus solotus (1), Duscoaster saipanensis (3), Cribrocentrum reticulatium (7), Helicosphaera intermedia (6), Pontosphaera sp. (2).*
AB374 Umas Umas	S99/184	Late Eocene - Mid Miocene ?	*Discoaster deflandrei (c), Cyclicargolithus floridanus (c), Helicosphaera intermedia (4), Sphenolithus moriformis (c), Coronocyclus nitescens (2), "Coccolithus" sp. (c), Marthasterites tribrachiatus (1).*
AB384 Behind Sapulut Forest Camp	S99/198	Early Oligocene NP23	*Sphenolithus pseudoradians (6), Sphenolithus moriformis (6), Cyclicargolithus floridanus (c), Coccolithus pelagicus (5), Dictyococcites bisecta (c), Sphenolithus predistentus (6), Coccolithus miopelagicus (3), Sphenolithus distentus (7), Cyclicargolithus abisectus (7), Helicosphaera Intermedia (4), Chiasmolithus altus (1).*
AB210 Tambunan-Tekala Road	S99/261	Late Oligocene NP23-NP24	*Discoaster sp. (3), Cyclicargolithus floridanus (7), Coccolithus pelagicus (8), Sphenolithus sp. (4), Dictyococcites bisecta (5), Sphenolithus distentus* (3 poorly preserved specimen).
AB527 Luasong Feeder Road	S99/301	Late Oligocene NP23	*Dictyococcites bisecta (8), Coccolithus pelagicus (common), Discoaster deflandrei (common), Coccolithus miopeelagicus (6), Sphenolithus distentus (12), Sphenolithus predistentus (c), Zygrhablithus bijugatus (8), Cyclicargolithgus floridanus (c), Discoaster saipanensis, Discoaster barbadiensis, Discoaster multiradiatus, Discoaster ladoensis, Discoaster tani, Reticulofenestra umbilica, Ericsonia farmosa, Cribrocentrum reticulatum.*

Appendix Table 2: Kuamut Formation

Location	No	Age	Fossils
AB242 Saliha B Road	S98/107	Late Oligocene NP24-NP25	*Sphenolithus predistentus, Sphenolithus distentus, Sphenolithus ciperoensis, Helicosphaera recta, Discoaster deflandrei, Cyclicargolithus floridanus, Coccolithus pelagicus, Dictyococcites bisecta, Coccolithus eopelagicus, Sphenolithus Helicosphaera recta moriformis, Cyclicargolithus abisectus.*
AB361 Tekala Road	S99/173	Late Oligocene NP24	*Cyclicargolithus floridanus (ab), Sphenolithus distentus (c), Sphenolithus ciperoensis (c), Dictyococcites bisecta (c), Discoaster deflandrei (c), Sphenolithus miroformis (8) Coccolithus pelagicus (c), Coccolithus miopelagicus (4), Pontosphaera plane (3), Sphenolithus pseudoradians (4), Helicosphaera intermedia (7), Helicosphaera recta (3).*
AB372 Brantian River, SE Tiagau Area	S99/182	Late Oligocene NP24	*Cyclicargolithus floridanus(c), Sphenolithus distentus (c), Coccolithus pelagicus (6), Sphenolithus moriformis (4), Sphenolithus Ciperoensis (8), Dictyococcites bisecta (c), Discoaster deflandrei (5), Cyclicargolithus abisectus.*
AB398 Tung Hup Camp, Tiagau Area	S99/214	Late Eocene- (?) NP16-NP17	*Sphenolithus pseudoradians (5), Coccolithus pelagicus (9), Discoaster tani (9), Cyclicargolithus floridanus (c), Sphenolithus moriformis (5), Dictyococcites bisecta (10), Sphenolithus Reticulofenestra Umbilica (c), Sphenolithus radians(6), Discoaster saipanensis (3), Discoaster binodosus (2), Ericsonia farmosa (3), Braarudosphaera bigelowii (1), Thoracosphaera SP. (1).*
AB474 Kuamut River, SW Malibau	S99/257	Late Oligocene NP24	*Cyclicargolithus floridanus (common), Sphenolithus ciperoensis (7), Sphenolithus moriformis (5), Coccolithus pelagicus (common), Sphenolithus distentus (6), "Coccolithus" sp., (common), Dictyococcites bisecta (12), Discoaster deflandrei (6), Helicosphaeera sp. (3), Sphenolithus sp. cf S. pseeudoradians (2), Discoaster sp. cf. D. deflandrei (2).*

Appendix Table 3: Gomontong Limestone Formation

Location	No	Age	Fossils
AB335, Tekala-Tibow Road	S99/161	Burdigalian N5 (NN2)	*Lepidocyclina brouweri, Lepidocyclina oneatensis, Lepidocyclina (N.) sumatrensis, Lepidocyclina parva, Lepidocyclina nipponica, Lepidocyclina ferreroi.*
AM187, Tributary of Kuamut River (Lime River)	R116	Early Tf1, Burdigalian	*Operculina, Operculinella, Amphistegina, Heterostegina, Lepidocyclina (Nephrolepidina) oneatensis, Lepidocyclina (Lepidocyclina) isolepidinoides, Lepidocyclina (Nephrolepidina) rutteni, Lepidocyclina (Nephrolepidina) sumatrensis, Austrotrillina howchini, Cycloclypeus, Globigerinoides, Miogypsinoides, Lepidocyclina praedelicata, Lepidocyclina oneatensis, Lepidocyclina sunatrensis, Austrotrillina howchini, Heterostegina, Lepidocyclina praedelicata, Austrotrillina howchini.*
AM267, Ulu Kuamut River (Tekala Quarry)	R125	Early Tf1, Late Burdigalian	*Austrotrillina howchini, Lepidocuclina sp., Lepidocyclina (Nephrolepidina) sumatrensis, Lepidocyclina (Nephrolepidina) brouweri, Cycloclypeus, Dasyclads, Miogypsinoides dehaarti, Amphistegina, Operculina, Lepidocyclina rutteni, Amphistegina, Amphisorus, Flosculinella bontangensis, Miogypsina, Lepidocyclina (N) brouweri, Dasyclads, Rodophytes.*
Kalabakan (Bakan River)	R4705/145	Tf1, Burdigalian	*Miogypsinoides, Flosculinella bontangensis, Miogypsina.*
Kalabakan River	R4705/135A	Tf1, Burdigalian	*Lepidocyclina stratifera, Gypsina, Rodophytes, Austrotrillina cf. Howchini, Amphistegina, Carpenteria, Dasyclads.*
Kalabakan River	R4705/90	Tf1, Burdigalian	*Planorbulinella larvata, Miogypsina, Cycloclypeus, Miliolids, Amphistegina, Rodophytes, Dasyclads.*
Kalabakan River	R4705/54B	Tf1, Burdigalian	*Ostracods, Operculinella, Miogypsina, Rodophytes.*
Kalabakan River	R4705/38	Tf1, Burdigalian	*Rodophytes, Gypsina, Miogypsina, Lepidocyclina.*
Kalabakan River	R4705/27	Tf1, Late Burdigalian	Packed with *Lepidocyclina sumatrensis* and *Lepidocyclina rutteni, Globigerinoides, Globigerinoides triloba, Miogypsina inflata, Miogypsina, Operculina, Dentoglobigerina altispira, Globigerina, Globoquadrina dehiscens, Carpenteria, Quinqueloculina, Carpenteria.*
Kalabakan River	R4705/25	Early Tf1, Late Burdigalian	*Lepidocyclina, L. (N.) verrucosa Heterostegina (Vlerkina) sp., Miogypsina, Lepidocyclina brouweri, Operculinella, Miogypsina inflata, Miogypsina digitata, Miogypsina tani, Miogypsina sabahensis, Rodophytes.*
Kalabakan River	R4705/12A	Late Te, Early Burdigalian	*Lepidocyclina sumatrensis, Spiroclypeus, Amphistegina, Miogypsina inflata, Gypsina, Miogypsina digitata, Flosculinella reicheli, L. (N.)sumatrensis, L. praedelicata, Rodophytes.*

Appendix Table 4: Tanjong Formation

Location	No	Age	Fossils
AB103 Silik Avernue Road	S98/49	Early to Middle Miocene NN3-NN5	*Discoaster deflandrei, Helicospheara kamptneri, Sphenolithus heteromorphus, Cyclicargolithus floridanus, Sphenolithus moriformis, Calcidiscus macintyrei.*
AB135 Silimpopon Road	S98/64	Mid to (early) Late Miocene NN8-NN10	*Cyclicargolithus floridanus, Discoaster variabilis, Discoaster bollii, Discoaster pentaradiatus, Discoasteer sp., Helicospheara kamptneri, Helicospheara (?)intermedia, Coccolithus pelagicus.*
AB379 Sg Anjeranjeramut River - border	S99/192	Early To Middle Miocene NN4-NN5	*Sphenolithus heteromorphus (7), Cyclicargolithus floridanus (11), Helicospaera kamptneri (5), Coccolithus pelagicus (7), Discoaster variabilis (3).*
AB190 Saliha A Road	S99/83	Early to Middle Miocene NN4-NN5	*Sphenolithus heteromorphus (6), Helicospaera kamptneri (3), Discoaster deflandrei (5), Discoaster variabilis (2) Coccolithus pelagicus (10), Cyclicargolithus floridanus (7), Chiasmolithus sp. (1)-reworked.*
AB485 Malibau Tekala Road	S99/269	Early Miocene NN3 to NN4	*Cyclicargolithus floridanus (4), Sphenolithus sp cf S.belemos (3), Coccolithus pelagicus (8), Discoaster deflandrei (3).*

Appendix Table 5: Kalabakan Formation

Location	No	Age	Fossils
AB 60 Kalabakan Selatan Road	S98/32	Early Miocene NN4	*Spheenolithus.heteromorphus,Cyclicargolithus floridanus, Helicosphaera Kamptneri, Helicospheara intermedia, Discoaster deflandrei, Sphenoolithus moriformis, Discoaster variabilis, Calcidiscus macintyrei, Cocolithus pelagicus, Coronocyclus nitescens.*

Appendix Table 6: Kapilit Formation (* — samples from Balaguru 1996)

Location	No	Age	Fossil Assemblages
AM68 Malibo R, N. Malibau	R47*	Late Middle Miocene	Flora *Stenochlaena areolaris.*
AM47 Pang Brothers Road	R30*	Mid Pliocene- L Mid Miocene	*Globoquadrina altispira, Globigerinoides subquadratus Stenochlaena palustris.*
AM110 Napagon River	R75A* R75B*	Middle Miocene	*Globigerinoides sp Stenochlaena palustris.*
AM193 Kuamut River	R117A*	Middle Miocene to Recent	*Globorotalia sp.*
AM335 Pang Bros- Tekala Road	R146*	Middle Miocene to Recent	*Globorotalia sp. Globigerinoides subquadratus Globigerinoides sicanus.*
AM336 Pang Bros- Tekala Road	R147C*	Middle Miocene	*Globigerinoides sp., Globigerinoides immaturus, Globigerinoides steanus, Globoquadrina sp.*
AB204 Tambulanan R	S98/89	Middle Miocene NN4-NN5?	*Sphenolithus heteromorphus, Sphenolithus moriformis, Discolithus multipora, Discoaster variabilis, Helicosphera kamptneri, Helicosphera intermedia, Discoaster diflandrei, Coccolithus pelagicus, Discoaster (?)exilis.*
AB231 Saliha Camp A3 Road	S98/99	E- Mid Miocene NN4-NN5	*Sphenolithus heteromorphus, Cyclicargolithus floridanus, Discoaster variabilis, Discoaster sp., Coccolithus pelagicus.*
AB216 Saliha A Main Road	S99/203	E- Mid Miocene NN3-NN5	*Triquetrorhadbulus carinatus (3), Sphenolithus heteromorphus (7), Cyclicargolithus floridanus (6), Coccolithus pelagicus (5), Reticulofenestra sp. (2).*
AB382 Tekala Road, Pang Brothers Road	S99/193	Early to Middle Miocene NN4-NN5	*Helicosphaera intermedia (3), Sphenolithus heteromorphus (c), Coronocyclus nitescens (3), Discoaster deflandrei (3), Sphenolithus moriformis (4), Discoaster perplexus (1), Cyclicargolithus floridanus (7), Coccolithus pelagicus (4), Coccolithus miopelagicus (2), Discoaster variabilis (2), Helicosphaera kamptneri (3), Cyclicargolithus abisectus (5) reworked.*
AB478 Tambunan Road	S99/264	Middle Miocene NN5	*Discoaster sp. (3), Sphenolithus moriformis (3), Sphenolithus heteromorphus (6), Discoaster variabilis (4), Helicosphaera kamptneri (2).*