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Structural geology of the Neogene Maliau Basin, Sabah

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Abstract: The Maliau Basin (Maliau outlier) is made up of about 7,500 metres thick sandstone and mudstone layers deposited in a deltaic-coastal environment, assigned the Kapilit Formation. The layers at the base of the basin consist mainly of mudstones reaching up to 2,000 metres thick. Near the rim of the basin, thick sandstone layers and coal seams occur. Towards the centre of the basin a series of sandstone-dominated and mudstone-dominated sequences of various thicknesses occur. The deposition took slight unconformity place during the Middle Miocene (10–15 million years ago). The basin sits with slight unconformity on older sedimentary rocks (Tanjong Formation), also comprising of thick layers of sandstone and mudstone. The orientation of bedding generally follows the semi-circular shape of the basin. The dip of bedding varies from 5–10 degrees at the centre to 45–50 degrees at the rim. Sub-vertical to vertical fractures shows four main fracture orientations, NW-SE, NE-SW, NNW-SSE and WNW-ESE. Faulting is quite rare inside the basin. However, outside the basin, minor normal faults occur trending E-W and NE-SW. A sheared zone occurs at the southeastern part of the basin, possibly due to a major fault, the Lonod Fault. Based on regional and local structures the Maliau Basin is interpreted to have developed initially in an extensional regime, whereby an enormous amount of sediments were deposited in a subsiding basin and later subjected to compression (inversion).

INTRODUCTION

The Maliau Basin is one of a series of saucer-shaped sedimentary basins found in Central and Southeast Sabah (Fig. 1). The peculiar shape of the basin has never been solved satisfactorily. Earlier regional geological studies indicate that the development of these saucer-shaped basins are controlled by deep-seated geological structures (e.g. Lee and Coong, 1989; Tongkul, 1993). Local geological studies within the Maliau Basin by Tjia *et al.*, (1990) and nearby Malibau Basin by Allagu (1997) also support the above interpretation. However, the exact mechanism as to how the geological structures controlled the shape of these saucer-shaped basins is not clear due to lack of geological and structural information.

In other to obtain a better understanding on how the Maliau Basin developed a more detailed study on its structural geology was carried out. Aerial photographs together with satellite and radar imageries were used to determine the regional structure of the Maliau Basin and surrounding areas and fieldwork inside and outside the basin was carried out between October 2000 to March 2002.

GEOLOGICAL SETTING

Tectono-Stratigraphic Units

The southeastern and central part of Sabah comprised mainly of sedimentary and igneous rocks with minor occurrence of metamorphic rocks ranging in age from probable Triassic to Pliocene (Fig. 2). The Mesozoic basement rock represents the oldest rock group, comprising igneous, metamorphic and sedimentary rocks. The igneous rock consists of serpentinite, gabbro, basalt and granodiorite whereas the metamorphic rock consists of gneiss, amphibolite and schist (Yin, 1985). The sedimentary rock consisting of cherts and red shales are closely associated with the basalts. The rock units included here are the Crystalline Basement and Chert-Spilite Formation (Leong, 1974). The basement rock is interpreted as remnant of an old oceanic lithosphere obducted over East Sabah (Hutchison, 1988). The basement rock has undergone intense deformation and its present regional structural trend is NW-SE. Lying unconformably on top of the basement rock are intensely deformed Paleogene sedimentary rocks comprising mainly of sandstone, mudstone and

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minor occurrence of limestone. The rock units included in this group are the Sapulut Formation, Labang Formation and Kulapis Formation. The rock group has a regional structural trend oriented NW-SE and SW-NE. Steeply dipping beds and overturned beds are common. Neogene chaotic deposits or melange deposit lie unconformably on the basement and Paleogene sediments. The deposit is characterised by the occurrence of chaotic mixtures of blocks of a single lithology or different exotic lithologies in a grey or red mud matrix. The rock unit is represented by the Kuamut Formations. This rock unit is interpreted to represent deposits due to regional sliding and slumping (Clennell, 1992). Moderately deformed Neogene sedimentary rock comprise of sandstone, mudstone with minor occurrence of conglomerate, limestone and coal – subdivided into an older and younger rock group. The older Neogene, which is comparatively more deformed includes the Kalabakan and Tanjong Formations, whereas the younger Neogene which shows little deformation includes the Kapilit and Simengaris Formations. These rock group occurs as sedimentary depressions, characterised by their circular- and ellipsoid-shaped basins. The youngest rock group comprises of Quaternary sedimentary rocks and volcanic rocks. The sedimentary rocks comprised of gravel, sand, silt, mud and coral fragments. The volcanic rocks consist mainly of andesitic and basaltic lava flows.

Regional Structures

The structural lineaments which represents bedding strikes on the sedimentary rock units show various trends in central and Southeast Sabah (see Fig. 2). The Paleogene sediments show NW-SE and NE-SW structural lineaments. In contrast, the Neogene sediments show concentric (circular

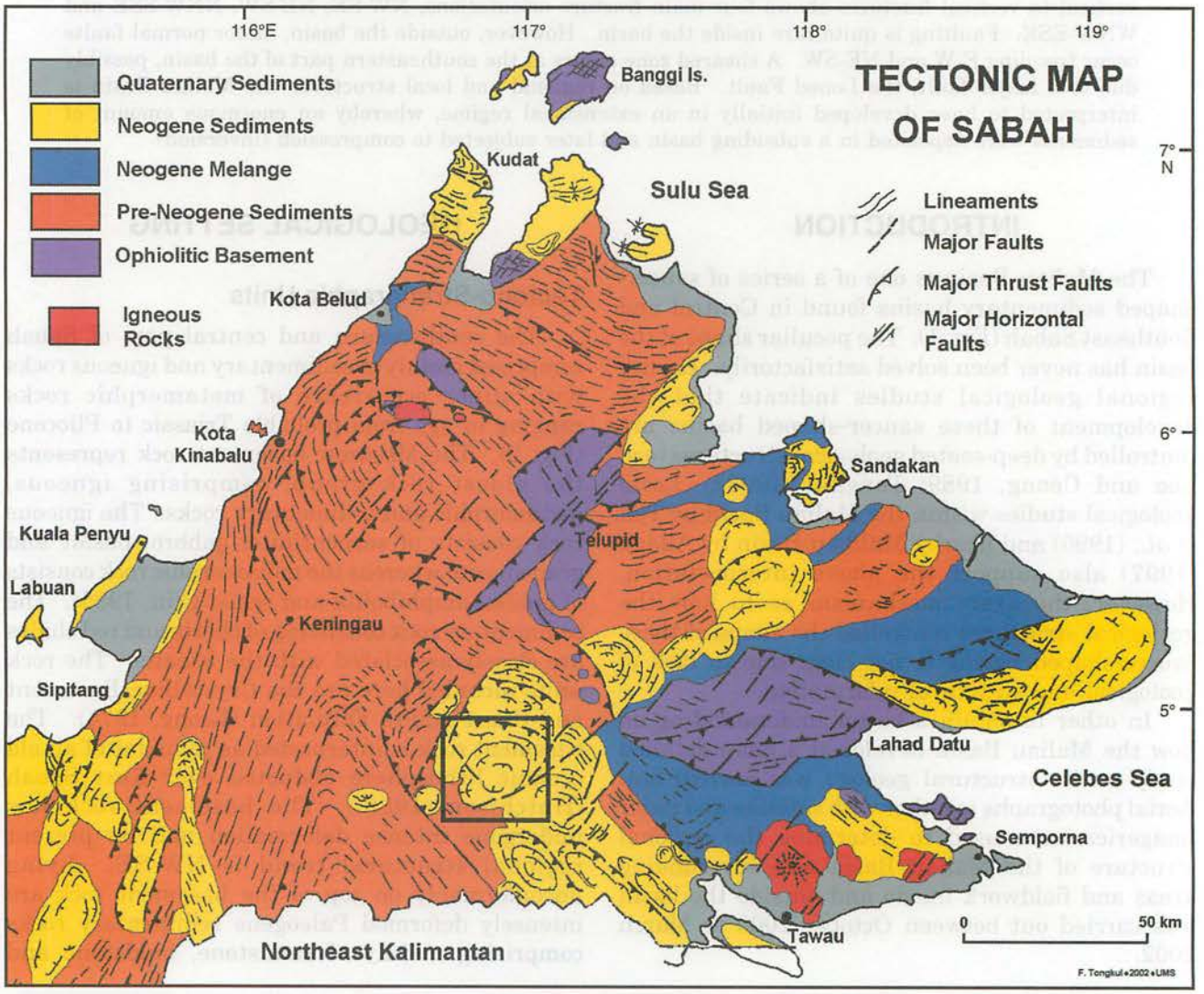

Figure 1. Location of the Maliau Basin. The basin has been gazetted as a Protection (Class 1) Forest Reserve in 1997 and is now known as the Maliau Basin Conservation Area.

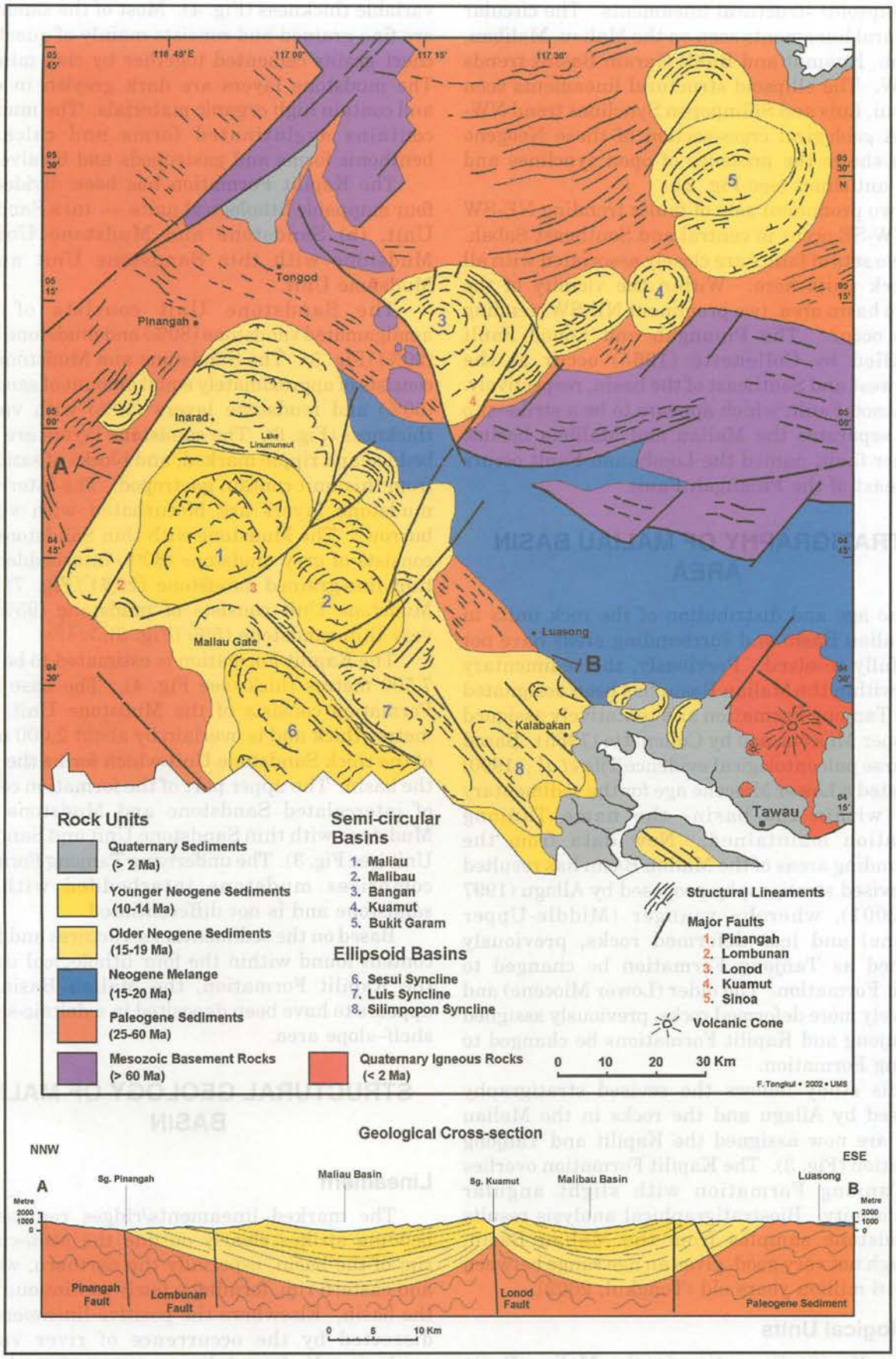

Figure 2. Regional geological map of Southeast Sabah. The geological cross-section across the Maliau Basin shows open synclines and tight anticlines.

and ellipsoid) structural lineaments. The circular structural lineaments seen on the Maliau, Malibau, Bangan, Kuamut and Bukit Garam Basins trends NE-SW. The ellipsoid structural lineaments seen on Sesui, Luis and Silimpopon Synclines trend NW-SE. A geological cross-section of these Neogene basins shows the presence of open synclines and tights anticlines (see Fig. 2).

Two prominent sets of faults trending NE-SW and NW-SE occur in central and Southeast Sabah. The two sets of faults are closely associated with all the rock units here. Within the vicinity of the Maliau basin area, two prominent NE-SW trending faults occur. The Pinangah and Lonod Fault identified by Collenette (1965) occur at the Northwest and Southeast of the basin, respectively. The Lonod Fault, which appears to be a strike-slip fault, separates the Maliau and Malibau basins. Another fault, named the Lombunan Fault occurs Southeast of the Pinangah Fault.

STRATIGRAPHY OF MALIAU BASIN AREA

The age and distribution of the rock units in the Maliau Basin and surrounding areas have not been fully resolved. Previously, the sedimentary rocks within the Maliau Basin has been designated as the Tanjong Formation and tentatively assigned an Upper Miocene age by Collenette (1965). Based on sparse paleontological evidence Tjia *et al.*, (1990) suggested a Lower Miocene age for the sedimentary rocks within the basin—the name Tanjong Formation maintained. New data from the surrounding areas of the Maliau Basin has resulted in a revised stratigraphy proposed by Allagu (1997 and 2001), whereby younger (Middle-Upper Miocene) and less deformed rocks, previously assigned as Tanjong Formation be changed to Kapilit Formation. The older (Lower Miocene) and relatively more deformed rocks, previously assigned as Tanjong and Kapilit Formations be changed to Tanjong Formation.

This study follows the revised stratigraphy proposed by Allagu and the rocks in the Maliau Basin are now assigned the Kapilit and Tanjong Formation (Fig. 3). The Kapilit Formation overlies the Tanjong Formation with slight angular unconformity. Biostratigraphical analysis results of mudstone samples from the Maliau Basin, although not very good, gives an age range between 10 to 16 million years old (Tongkul, 2002).

Lithological Units

The Kapilit Formation in the Maliau Basin consists of sandstone and mudstone layers of variable thickness (Fig. 4). Most of the sandstones are fine-grained and consists mainly of quartz and chert grains cemented together by clay minerals. The mudstone layers are dark greyish in colour and contain high organic materials. The mudstone contains agglutinated forms and calcareous benthonic forms and gastropods and bivalves.

The Kapilit Formation has been divided into four mappable lithological units — (a) a Sandstone Unit, (b) Sandstone and Mudstone Unit, (c) Mudstone with thin Sandstone Unit and (d) Mudstone Unit.

The Sandstone Unit consists of thick amalgamated sandstone (80%) and mudstone layers (20%) (Fig. 5). The Sandstone and Mudstone Unit consists of approximately equal amount of sandstone (50%) and mudstone layers (50%) with variable thickness (Fig. 6). The sandstone layers are cross-bedded and ripple marked, and blocks of sandstone from this unit contain gastropod. The intervening mudstone layers are bioturbated with vertical burrows. The Mudstone with thin Sandstone Unit consists of grey mudstone (80%) interbedded with thin fine-grained sandstone (20%) (Fig. 7). The Mudstone Unit consists of mudstone (95%) and very thin sandstone (5%) (Fig. 8).

The Kapilit Formation is estimated to be about 7,500 metres thick (see Fig. 4). The base of the Formation consists of the Mudstone Unit, 2,000 metres thick and is overlain by about 2,000 metres of the thick Sandstone Unit which forms the rim of the basin. The upper part of the formation consists of intercalated Sandstone and Mudstone Unit, Mudstone with thin Sandstone Unit and Sandstone Unit (see Fig. 3). The underlying Tanjong Formation comprises mudstone interbedded with thin sandstone and is not differentiated.

Based on the sedimentary structures and faunal content found within the four lithological units of the Kapilit Formation, the Maliau Basin area appears to have been deposited in a deltaic-shallow shelf–slope area.

STRUCTURAL GEOLOGY OF MALIAU BASIN

Lineament

The marked lineaments/ridges representing bedding strikes clearly outline the semi-circular rim of the basin, especially the northern, western and eastern rim, forming a fairly continuous rim of the basin. Elsewhere the positive lineaments are dissected by the occurrence of river valleys, producing V-shaped lineaments referred to as flatirons (Fig. 9).

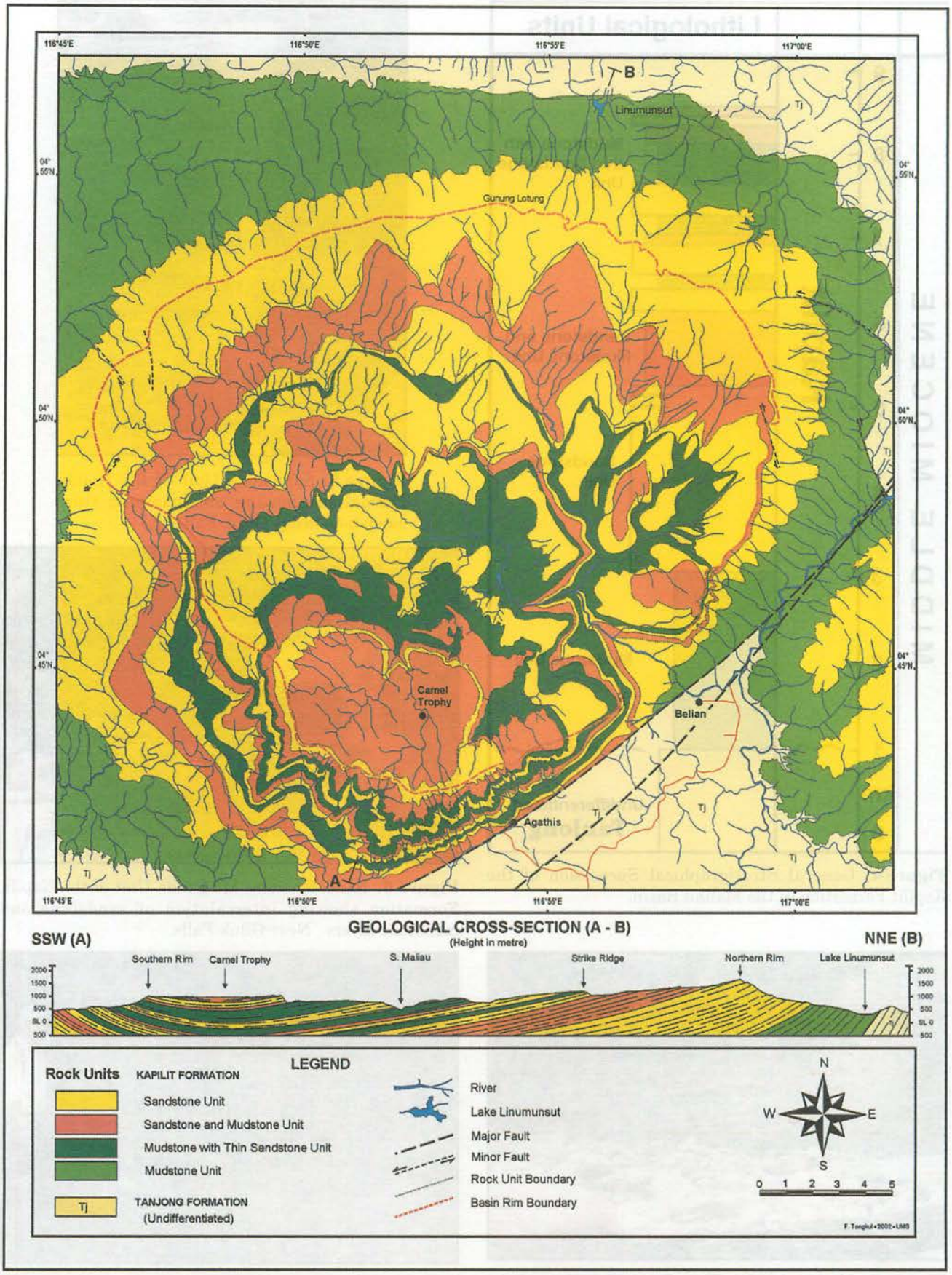

Figure 3. Geological map of Maliau Basin showing the distribution of rock units. The geological cross-section shows an increase in dip angle towards the side of the basin.

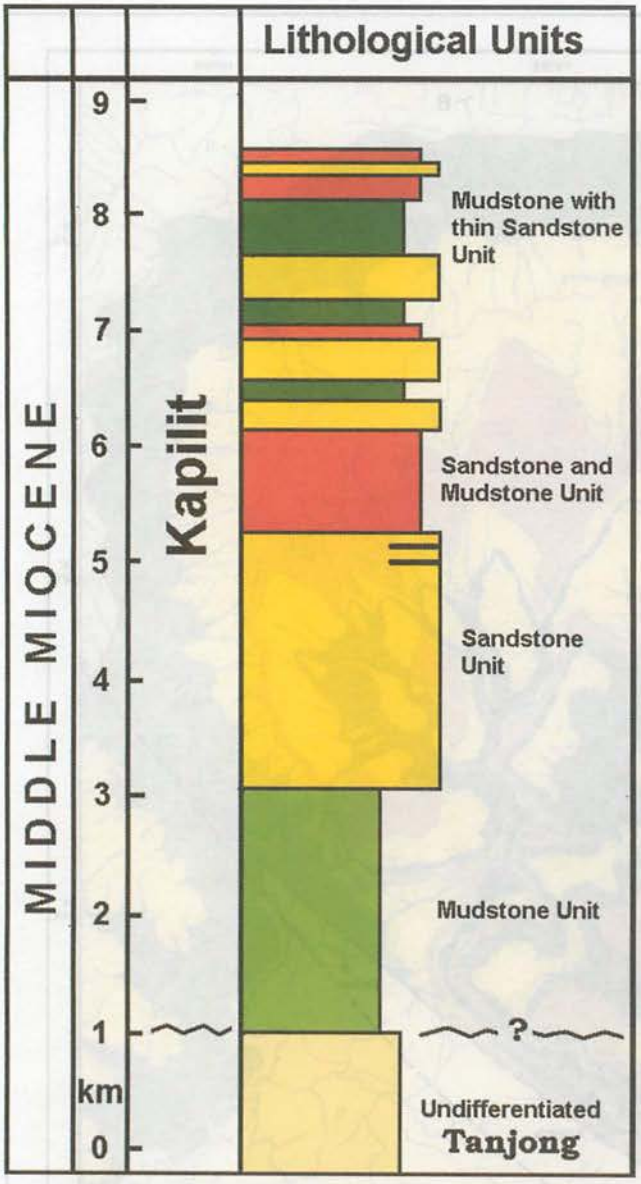

Figure 4. General Stratigraphical Succession of the Kapilit Formation in the Maliau Basin.

Figure 5. Sandstone Unit of the Kapilit Formation showing amalgamated thick sandstone beds. Giluk Falls.

Figure 6. Sandstone and Mudstone Unit of the Kapilit Formation showing intercalation of sandstone and mudstone layers. Near Giluk Falls.

Figure 7. Mudstone with Thin Sandstone Unit of the Kapilit Formation. The sandstone layers pinch-out laterally. Near Maliau Falls.

Figure 8. Mudstone Unit of the Kapilit Formation showing massive mudstone with concretions. Near Lake Linumunsut.

Bedding/Strata

The orientation of bedding in the Kapilit Formation generally follows the semi-circular shape of the basin. The dip changes progressively within the basin with bedding dips between 40–50 degrees (Fig. 10) at the base of the basin and between 20–25 degrees at the rim. Towards the centre of the basin, the bedding dips gently between 5–10 degrees (Fig. 11). The geological centre of the Maliau basin has been located near the Camel Trophy Field Station where the strata are horizontal (Fig. 12).

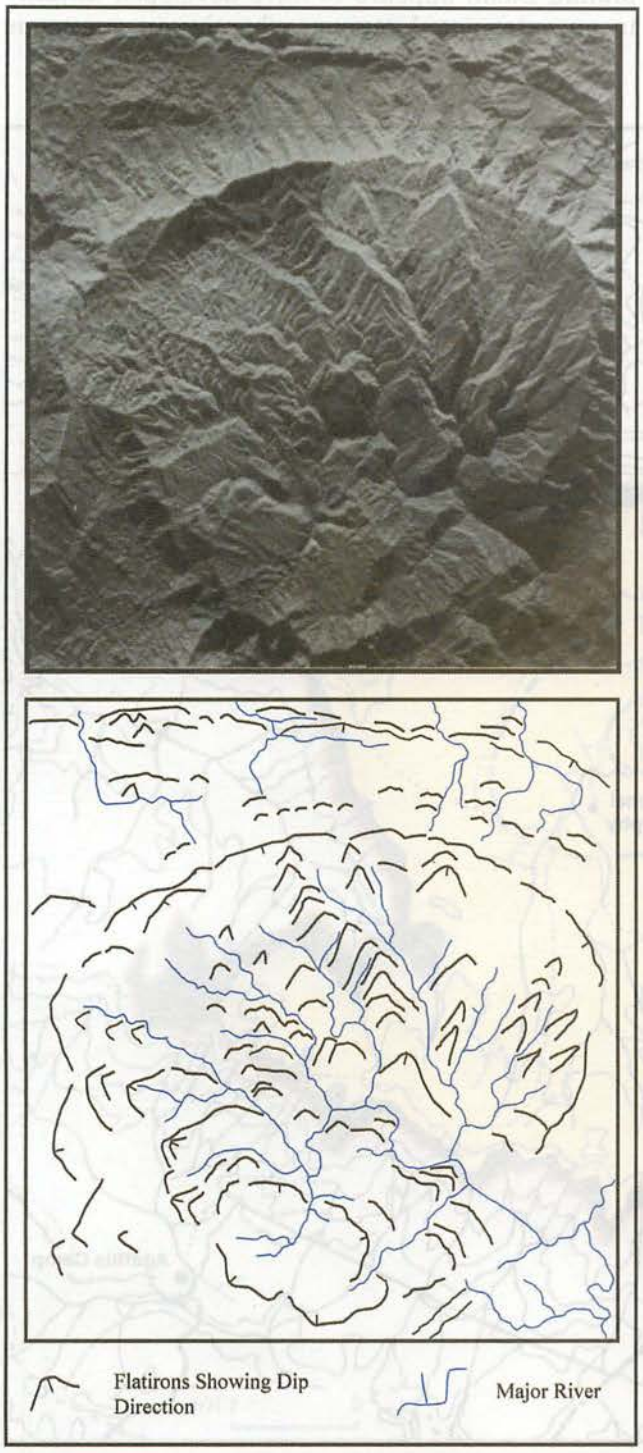

Figure 9. Positive lineaments representing bedding strikes derived from a radar image of the Maliau Basin.

Fractures/Joints

Sub-vertical to vertical fractures of various scales (some reaching tens of meters long) are commonly within the basin (Fig. 13). The fractures, which usually occur perpendicular and parallel to the strike of bedding, show various orientations with dominant orientations, NW-SE, NE-SW, NNW-SSE and WNW-ESE (Fig. 14).

Faults

Faulting is quite rare inside the basin and no fault has been seen in the Kapilit Formation. A previous study by Tjia *et al.* (1990) recorded a few minor normal faults trending NW-SE. Outside the basin, minor normal faults have been recorded in the Tanjong Formation near Lake Linumunsut, trending E-W and southwest of the basin, trending NE-SW. The presence of a deformed zone (Fig. 15)

Figure 10. Steeply dipping sandstone and mudstone layers outside the basin. Near Lake Linumunsut.

Figure 11. Gently dipping sandstone and mudstone layers inside the basin. Near Maliau Falls.

characterised by sheared and brecciated sandstone blocks, south of the Maliau Basin along the road to Belian Camp possibly indicates field evidence for the Lonod Fault.

Style of Deformation

The lack of local faulting and folding on the Kapilit sediments suggests that the Maliau Basin has not been subjected to intense tectonic deformation. The semi-circular strike pattern, the radial fracture pattern and the progressive increase in dip angle of bedding from the centre to the rim of the Maliau Basin are interpreted as being due to subsidence caused by the mass of newly deposited sediments.

TECTONIC EVOLUTION OF THE MALIAU BASIN

Based on the regional and local structures the Maliau Basin appears to have developed initially in an extensional regime, whereby an enormous

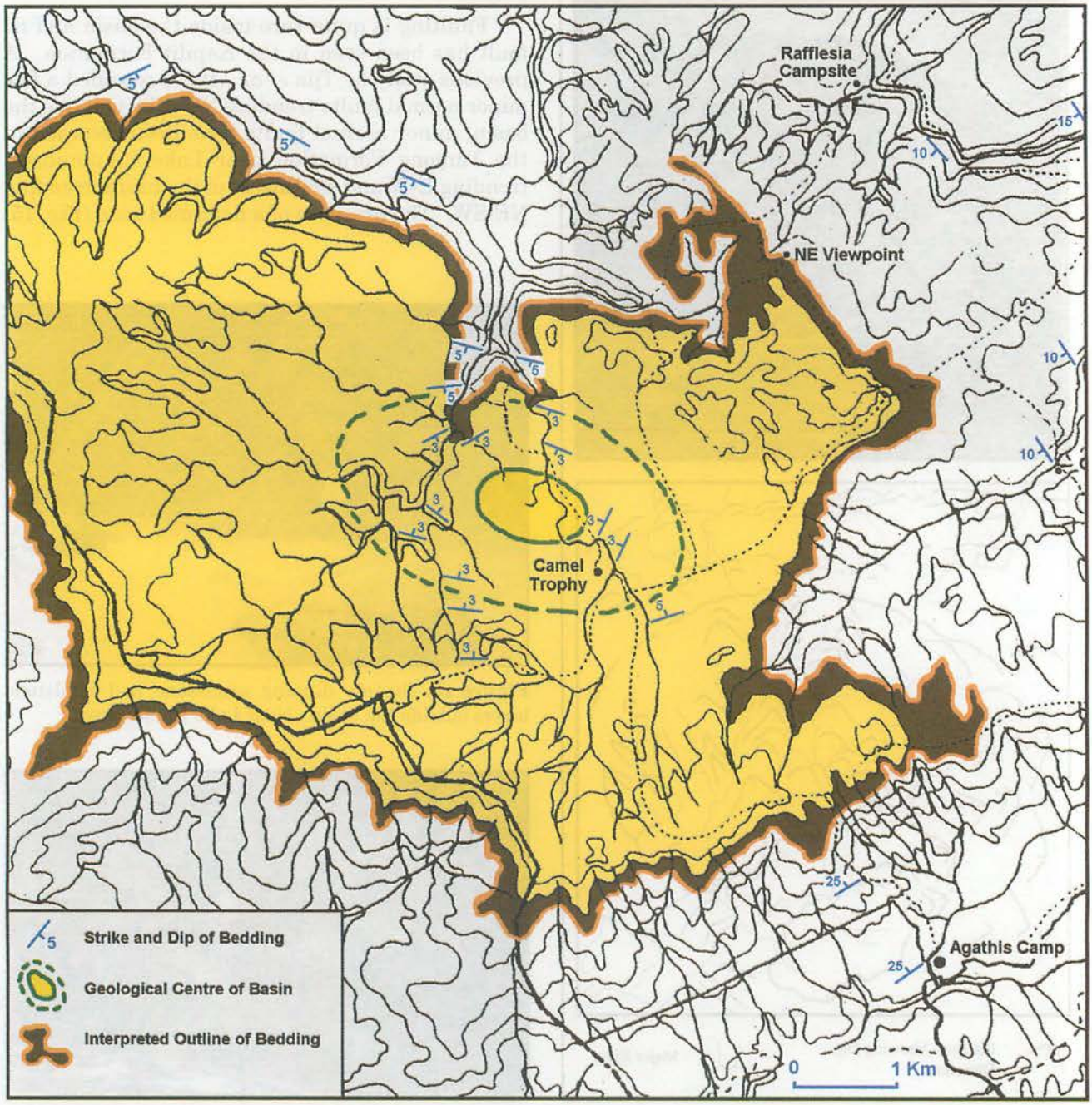

Figure 12. Geological centre of the Maliau Basin located near Camel Trophy Camp based on convergence of dip direction.

Figure 13. Two sets of vertical fractures orientated perpendicular to each other on sandstone beds. Near Giluk Falls.

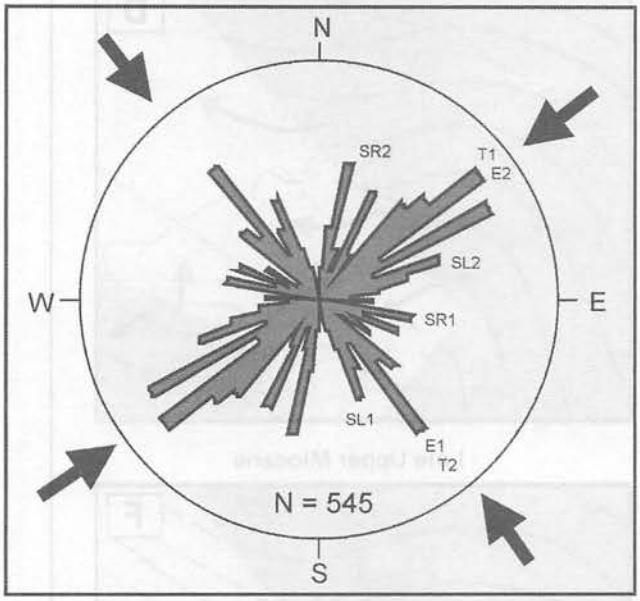

Figure 14. Orientation of fractures inside the Maliau Basin. E — Extension, T — Tension, SL — Shear Left, SR — Shear Right. The arrows show possible directions of compression.

Figure 15. Disrupted and sheared beds of sandstone and mudstone possibly due to faulting. Near Belian Camp.

amount of sediments were deposited in a subsiding basin which was later subjected to compression (inversion). The subsiding basin was probably part of a much larger basin in East Sabah, which started to develop during the early Miocene as a result of NW-SE extension, related to the opening of the Sulu Sea Basin (Rangin, 1989; Nichols *et al.*, 1990). A major NW-SE strike-slip fault south of Sabah possibly formed the southern boundary of the extension. It is postulated that the NW-SE extension was accompanied by a NE-SW extension in south-central Sabah (Fig. 16a). It is envisaged that the NW-SE and NE-SW extension created a large elongate basin trending NE-SW and NW-SE, respectively. The newly formed L-shaped basin became the depositional site for the older Neogene sediments (Tanjong and Kalabakan Formations) derived from the surrounding pre-Neogene rocks. As the region continued to extend and subside more and more sediments accumulated (Fig. 16b). In unstable slope areas large submarine slumps and slides occurred producing the Kuamut Melange deposits (Clennell, 1992).

By mid-Middle Miocene, the eastern part of Sabah was subjected to N-S compression as tectonic plate interaction affected this region. The N-S compression may have propagated from the north as Palawan collided with Cagayan Ridge (Rangin, 1989). The compression resulted in the uplift and gentle folding of the older Neogene sediments, where the regional fold axis followed the pre-Neogene fold belt (Fig. 16c). The compression may also have reactivated old faults trending NE-SW. It is envisaged that the development of the circular shape of the Maliau Basin and other Neogene basins may have been controlled by these pre-existing regional structures. The regional folds and faults acted as structural boundaries for the development of sub-basins within the larger basin (Tongkul, 1993).

Following the segmentation and uplift of the L-shaped basin, coarser younger Neogene sediments (Kapilit Formation) were deposited on the older Neogene sediments (Fig. 16d). The accumulated weight of sediment created a circular shape to the sub-basins (Fig. 16e) which was probably enhanced by a NW-SE compression (Fig. 16f), related to propagation of deformation from Sulawesi during the late Upper Miocene (Rangin, 1990; Clennell, 1996). The compression may have contributed to the creation of tight anticlines between individual sub-basins similar to those reported from the Kutai Basin of Kalimantan (Chambers and Daley, 1995). Following its uplift during the Pliocene, intense erosion eroded the tight anticlines, leaving apparent circular basins or synclinal remnants (outliers).

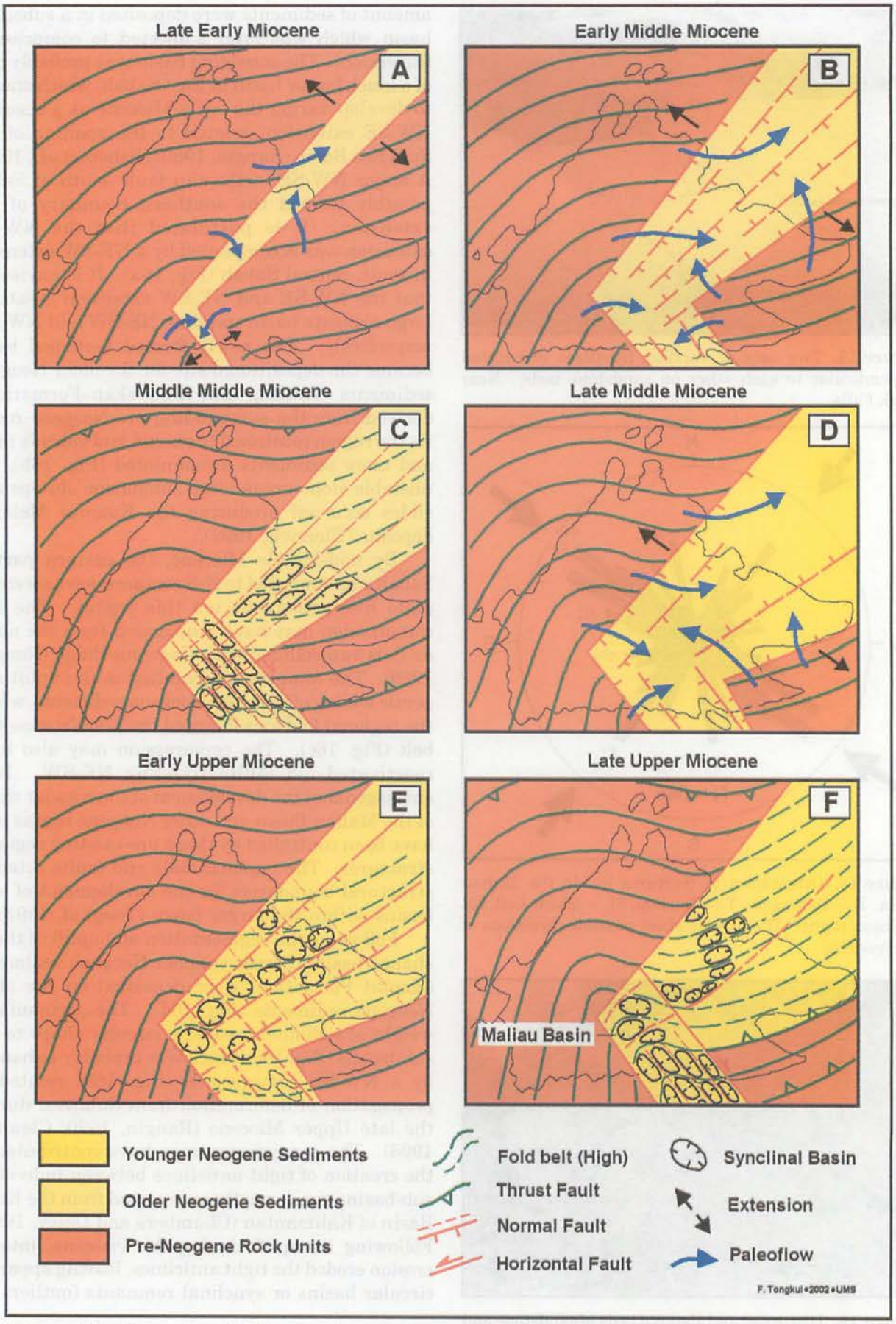

Figure 16. Schematic model showing the tectonic evolution of the Maliau Basin. See text for explanation.

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