Tectonic Evolution and Sedimentation of Sabah, North Borneo, Malaysia*

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Abstract

The diverse structural trend and depositional framework of Sabah (North Borneo) were developed by several regional tectonic events which occurred since the early Tertiary. At least three major episodes were linked to NW-SE compression coinciding with the ongoing subduction of the proto-South China Sea during the Late Eocene, Early Miocene and Middle Miocene. The Late Eocene tectonic deformation is characterized by folding and thrusting of basement rock and older paleogene sediments. The Paleogene regional tectonic setting of Sabah seems to be very complex, with southeasterly subduction in the NW Borneo, and extension in the SE in the Celebes Sea and Makassar Strait.

The Early Miocene deformation is interpreted to mark a major tectonic event, causing formation of the mélanges, major uplift and erosion which produced the Base Miocene Unconformity. This was followed by a change in depositional environment from deep-water to a shallow deltaic.

The Late Early Miocene marked the NW-SE rifting of the Sulu Sea, interpreted to have rejuvenated the Central Sabah Basin with regional extension and subsidence, and initiated rift basins as part of the formation of the Sulu Sea in a back arc setting. Middle Miocene collision of the Cagayan Arc and Palawan micro-continental block caused another Middle Miocene Unconformity, and has been noted to mark the Deep Regional Unconformity in Sabah.

The Late Miocene tectonic event marks another major folding and uplift which can be correlated as the Shallow Regional Unconformity of this region. This latest tectonic event was probably caused by strike-slip faulting and transpressional fault movement which continued during the Pliocene to present day.

Introduction

Sabah, located in the northern part of Borneo, lies at an important junction between the Eurasian, Indo-Australian, Pacific and Philippines Sea plates. It also occupies a central position between three marginal basins: the Sulu, Celebes and South China Seas (Figures 1 and 9). The evolution of this area is still far from resolved and makes Sabah an interesting site for geological investigations. The main tectonic elements of Sabah are a major fold-thrust belt trending northeast in the west (NW Borneo Trend) and bending to the east and southeast towards the north and eastern part (Sulu Trend) of Sabah. This arcuate belt consists of a deep-marine Eocene-Oligocene accretionary complex (Figure 8).

Five distinct tectono-stratigraphic provinces can be recognised. Figure 8 shows a simplified geological map and stratigraphy of Sabah.

(a) An ophiolite complex, which is considered to form the basement of the sedimentary succession of Sabah;
(b) The Rajang-Crocker accretionary prism, an arcuate belt consisting of deformed deep-marine, Eocene-Oligocene sediments;
(c) Broken formations and melanges 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;
(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 remnants or outliers known as the 'circular basins' of Sabah;
(e) The Semporna-Sulu Arc, a region of andesitic to dacitic volcanic activity of Miocene to Quaternary age in the Dent and Semporna peninsulas.

Tectono-Stratigraphic Evolution of Sabah

Pre-Cenozoic

The presence of granitic and metamorphic rocks of possible continental origin (Reinhard and Wenk, 1951; 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 (Figure 8).

Paleocene to Eocene Sedimentation

The Rajang Group is a widespread association of Late Cretaceous to Eocene deep water mudstones and turbiditic sandstones which include the Sapulut, Trusmadi and East Crocker formations (Figure 2). All are thought to have been deposited in the large NE-SW trending Crocker Basin and all are highly deformed with tight isoclinal folds and thrusts (Hutchison, 1996). The Palaeogene was therefore a period of continued deposition of deep marine turbidites. The strongly deformed turbiditic Rajang Group is interpreted as a part of an accretionary prism related to southeasterly subduction of the proto-South China Sea in the NW Borneo.

Late Eocene Uplift

An unconformity within the succession of Palaeogene turbidites between the Middle and Upper Eocene 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 and East Crocker Formation rocks. Hutchison (1996) refer to this uplift as the 'Sarawak orogeny' and suggest it was probably driven by collision along the northern Borneo margin at this time. 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. In general the contact is obscure.

Late Eocene-Oligocene Sedimentation

The uplift and erosion of the Rajang Group accretionary complex provided a source of sediment for the Borneo trough to the NW and also to the SE where material was deposited in a deep water setting as the West Crocker, Labang and Kulapis formations (Figure 3). The fold-thrust belt of the West Crocker Formation, which is well exposed in western Sabah, represents the accretionary complex related to continued southeasterly subduction of the proto-South China Sea in the NW Borneo. The Labang and Kulapis formations exposed in eastern Sabah represent 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. Outcrops of Labang/Kulapis Formation typically show abundant syn-depositional and syn-diagenetic extensional faults that suggest active growth faulting associated with this subsidence.

Early Miocene Deformation

The early Miocene was a period of progressive tectonic deformation in the forearc region during subduction and widespread melange development in Sabah. The inclusion of Labang Formation sandstone and mudstone clasts in the Gomantong Limestone demonstrates that uplift and deformation started by the Early Miocene, between approximately 22 and 20 Ma (Balaguru et al., 2003) (Figure 4). 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.

This unconformity separates the deformed and lithified melange unit of the Kuamut, Garinono, or Ayer formations from the less tectonised strata (Balaguru, 2001, 2003). The Early Miocene (22-20 Ma) deformation is interpreted to mark a major tectonic event, causing formation of the mélanges, major uplift and erosion, which produced the Base Miocene Unconformity (BMU or Pre-DRU). This tectonic event is related to subduction and collision of the Dangerous Ground Continental Block to the NW Borneo and referred as the 'Sabah Orogeny' (Hutchison, 1996). This was followed by a change in depositional environment from deep-water to a shallow deltaic setting (Balaguru, 2001; Balaguru et al., 2003; Van Hattam, 2005). The associated major uplift and erosion provided sediment supply to the deltaic to shallow marine Middle to Upper Miocene successions of the Meligan and Tanjong Deltas.

Early Miocene Limestone Development

The limestone outcrops in southern Sabah are correlated with the Early Miocene (Burdigalian) Gomantong Limestone Formation, which contains clasts of the Labang Formation (Noad, 1998). This suggests widespread uplift followed by carbonate sedimentation throughout the central and eastern Sabah. This change in depositional environment is also recognized 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.

Late Early Miocene to Middle Miocene Clastic Sedimentation

The end of the period of early Miocene deformation is marked by the onset of Tanjong, Meligan or Kudat Formation clastic deposition, the oldest dates for which are late Burdigalian (NN3/NN4, 18-16 Ma) (Figure 5). 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 late Middle Miocene (12-10 Ma) or younger strata. Continued subsidence created 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 and 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.

Middle Miocene Deformation and Clastic Sedimentation

Arc-continent collision in the northern Borneo between the Cagayan Arc and Palawan Continental Block (Rangin, 1991) created another Middle Miocene Unconformity (MMU, 15.5 Ma) which marks the Deep Regional Unconformity (DRU) in onshore and offshore Sabah. This deformation had stopped the extension and caused inversion of the early Middle Miocene sediments and

continued with post-rift sedimentation (Figure 6). There had been continued subsidence after this tectonic event, which continued to deposit the thick prograding post-rift sediments. Progradation of a large delta (Champion and Kapilit deltas) resumed during the time following a very similar pattern to the underlying Meligan and Tanjong deltas.

Late Miocene Deformation and Uplift

The Late Miocene (SRU, 8.6 Ma) tectonic event marks another major folding and uplift which can be correlated as the Shallow Regional Unconformity (SRU) of this region (Levell, 1987). The Kinabalu emplacement (10-8 Ma) event plausibly contributed to uplift and supply of sediments. This was followed by development of the Baram Delta which prograded to NW Sabah, and Kinabatangan Delta prograded to NE Sabah (Figure 7). The Late Pliocene tectonic event caused by NW-SE trending strike-slip faulting and transpressional fault movement in this region resulted in major structural inversion and uplift. This event is here termed the Meliau Orogeny (Balaguru et al., 2003). All the Miocene outliers in central Sabah were part of a single shallow basin (Figure 8). The present outcrop pattern of the Miocene strata is the product of regional strike-slip and transpressional tectonics and inversion during the Late Miocene (8.6 Ma) onwards and probably lasted until the latest Pliocene.

The transpressional movement along the major strike-slip faults in this region would better explain the structural development in these areas and is possibly related to propagation of deformation from Sulawesi towards NW Sabah. The Late Pliocene strike-slip deformation is regionally significant and occurred at a similar time as important deformation in NE Kalimantan, Sulawesi and NW Sabah. This transpressional movement is interpreted to be the cause of the major orogenic deformation, uplift and final structural development in Sabah region and possibly continued to the present day (Figure 9).

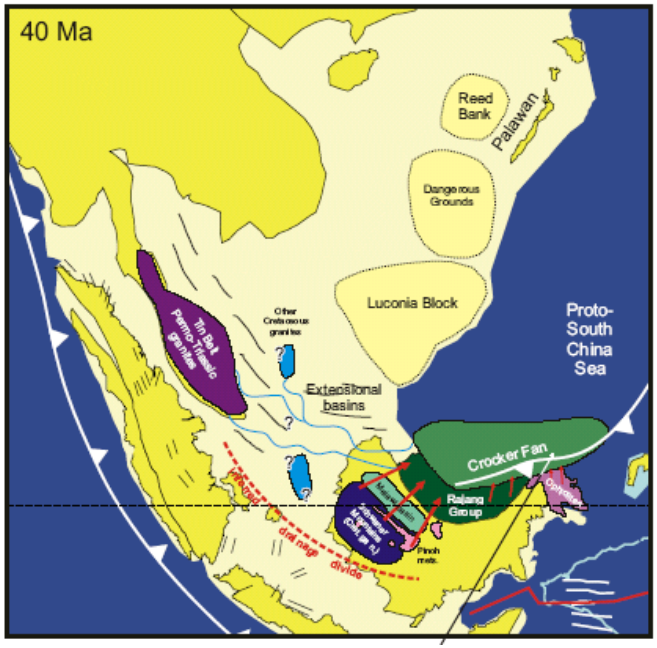

Figure 1. Location map and reconstruction of SE Asia around 40 Ma shows ongoing subduction of Proto-South China Sea and drifting of several continental blocks, followed by progressive development and deformation of the Rajang-Crocker basins.

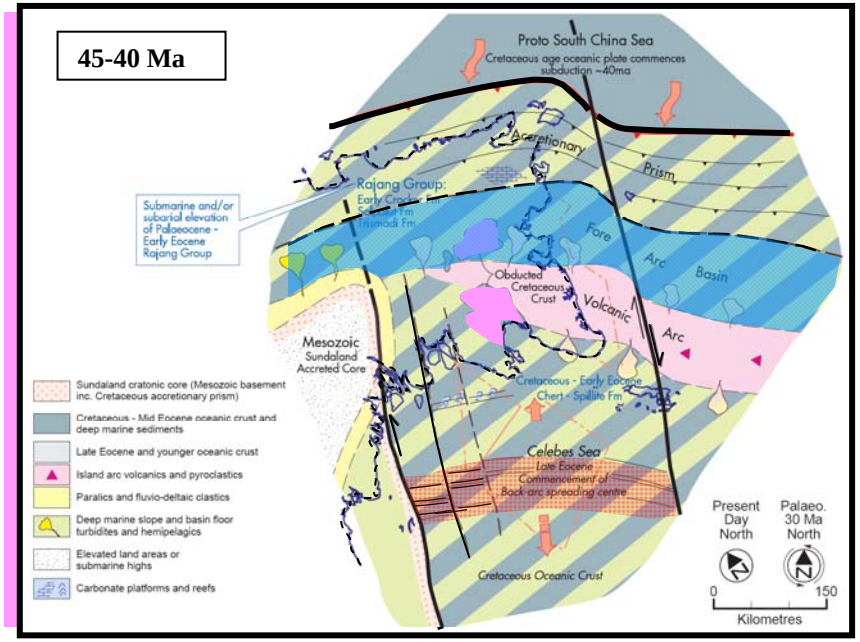

Figure 2. Reconstruction of Sabah during Middle to Late Eocene shows deposition of the deep marine turbidites of the Rajang-Crocker Group throughout Sabah and Sarawak.

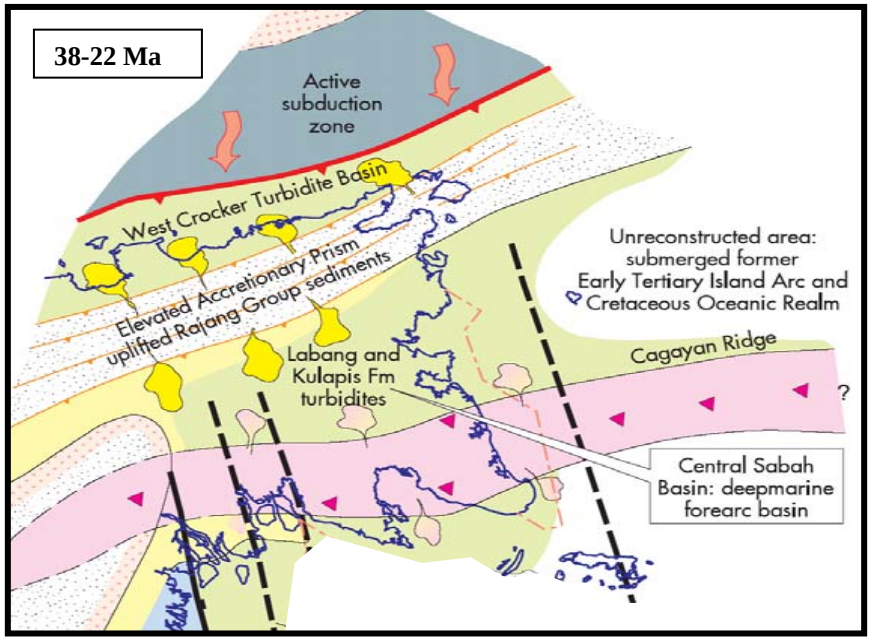

Figure 3. Reconstruction of Sabah during Oligocene to Early Miocene shows uplift and erosion of the Rajang Group accretionary complex provided source of sediments to the NW and central Sabah basins where material was deposited in a deep-water forearc basin setting.

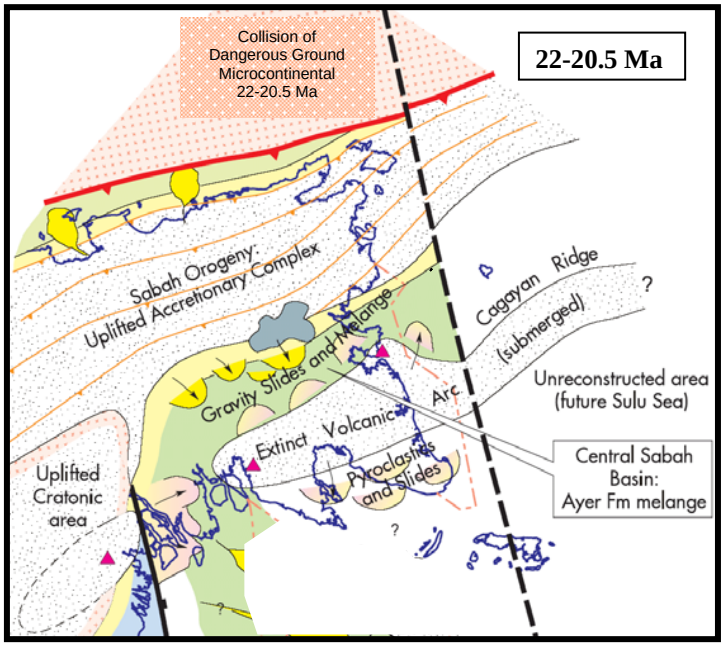

Figure 4. Reconstruction of Sabah during Early Miocene shows period major tectonic deformation in Sabah. The melanges are formed by progressive deformation in the forearc region during subduction. This deformation caused major uplift and erosion which produced the Base Miocene Unconformity (BMU).

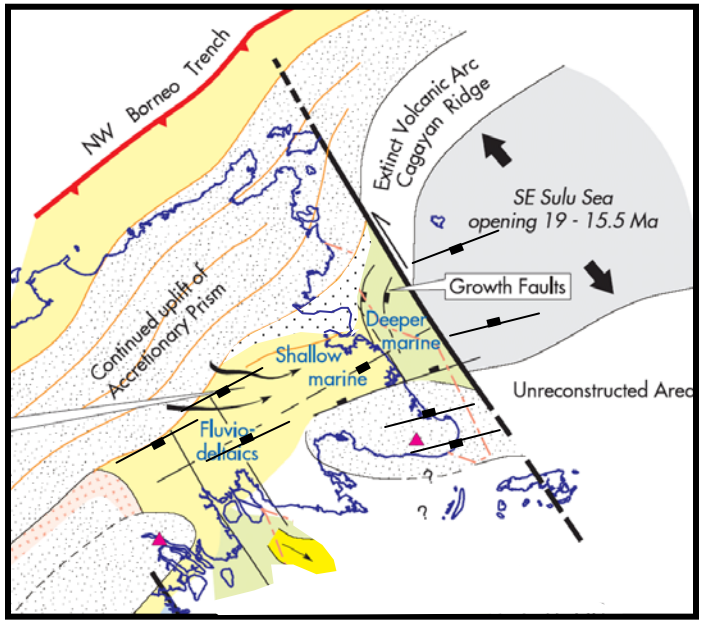

Figure 5. Reconstruction of Sabah during Early Miocene to Mid Miocene shows a change in depositional environment from deep-water to a shallow deltaic setting to the NW and SE of Sabah. Limestones formed on structural highs during relatively quiescent times in the Early Miocene. The associated major uplift and erosion provided sediment supply to the deltaic to shallow marine Middle to Upper Miocene syn-rift successions.

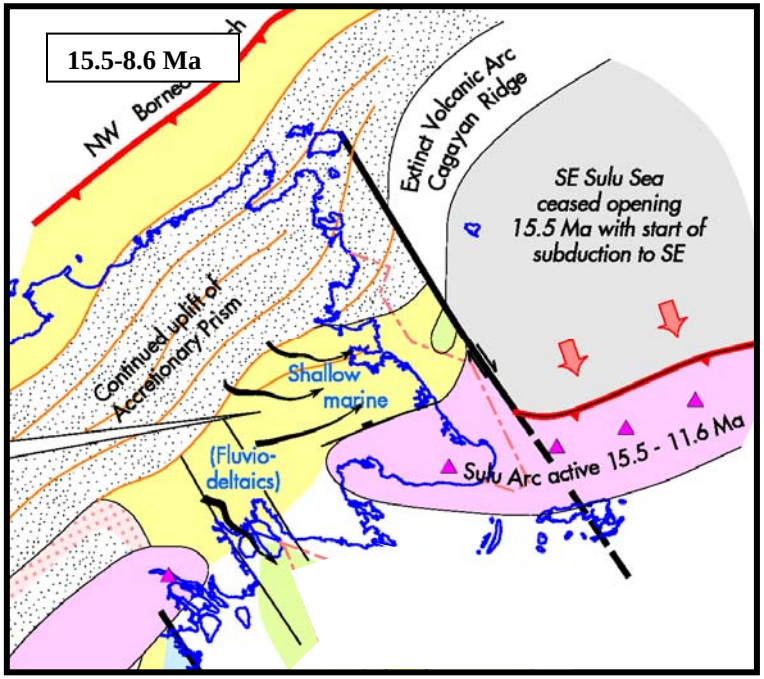

Figure 6. Reconstruction of Sabah during Middle Miocene to Late Miocene shows period of post-rift sedimentation in Sabah. Arc-continent collision in the northern Borneo caused another Middle Miocene Unconformity (MMU) which referred to mark the Deep Regional Unconformity (DRU) in onshore and offshore Sabah.

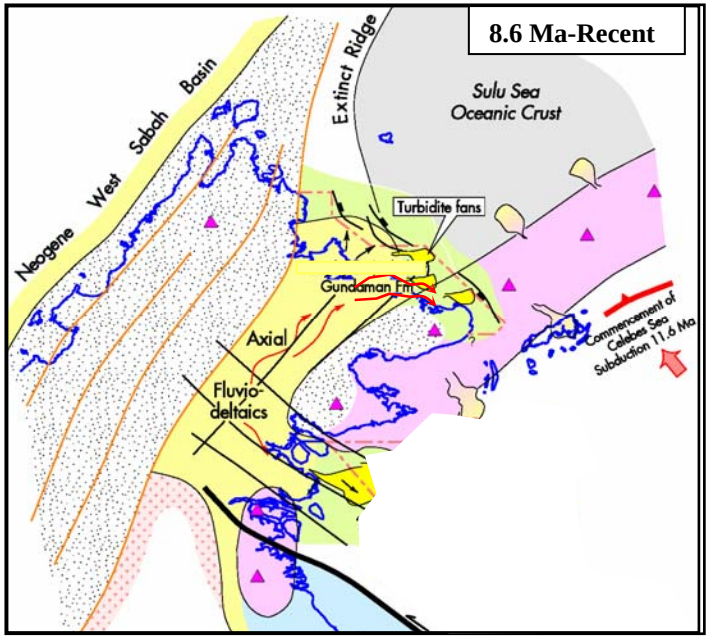

Figure 7. Reconstruction of Sabah during Late Miocene to Pliocene shows continued deposition of deltaic to shallow marine clastics following the wide spread regional unconformity during Late Miocene which is known from onshore and offshore data as the Shallow Regional Unconformity (SRU, 8.6 Ma).

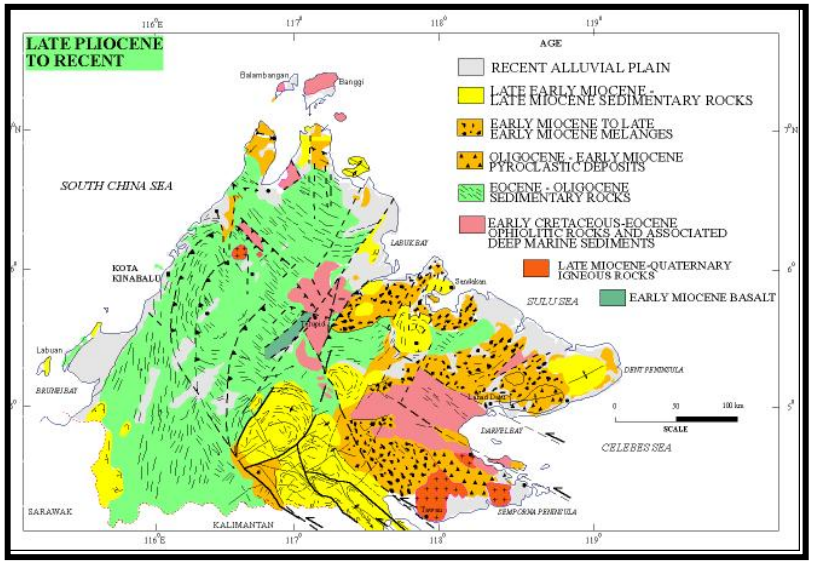

Figure 8. Geological Map of Sabah. The Miocene outliers were part of a single shallow basin. The present outcrop pattern is the product of regional strike-slip faulting transpressional tectonics and inversion during the Late Miocene and Pliocene onwards.

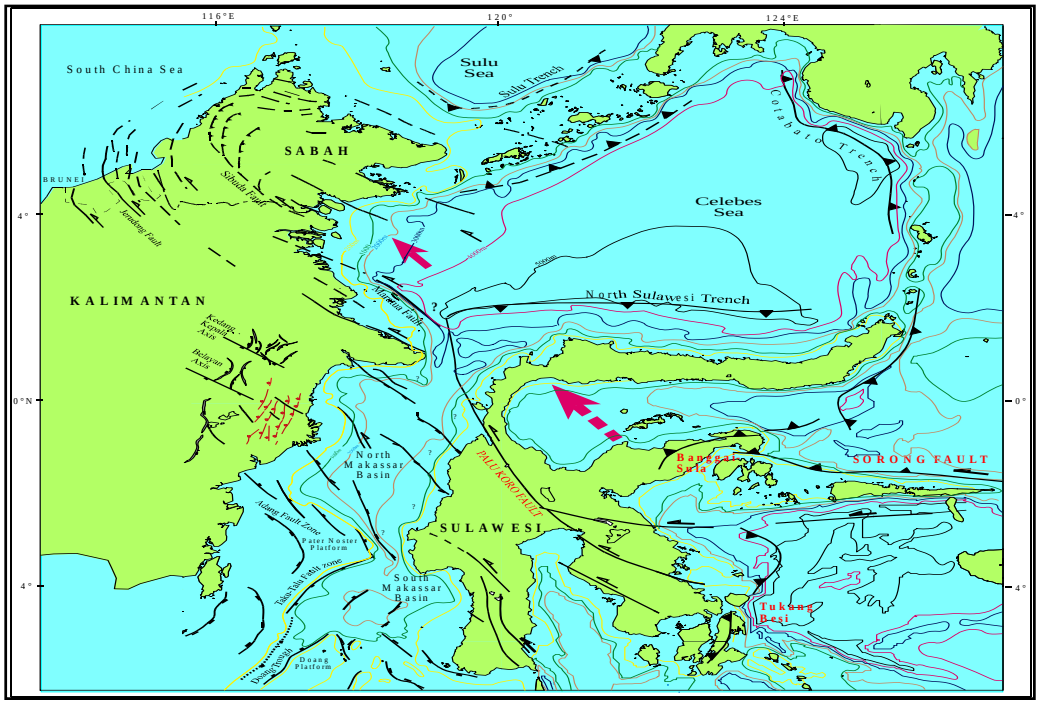

Figure 9. Structural framework and regional stress regime of the Borneo region show strike-slip faulting and transpressional tectonism from the Late Pliocene to the present day which probably caused major structural development.

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