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Northwest Sabah Overthrust System

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Abstract: The NE to NNE structural trends of West Sabah change drastically on approaching the Balabac fault and the West Baram Line. Outcrops show duplex and medium to large recumbent folds in the West-East Crocker and Trusmadi formations with general NW vergence that becomes northerly in northern Sabah. In the Baram area (Brunei and north Sarawak) the regional trend is represented by several strike-slip faults that bend to become N-S near the West Baram Line. In the offshore, a large "Lower Tertiary Thrust Sheet" was mapped next to the NW Sabah Trough. The combined indicators from outcrops and subsurface offshore suggest the existence of a major overthrust sheet measuring 700 km parallel to the shoreline and about 300 km in width. This rectangular Northwest Sabah Overthrust System is boxed in by the NW Sabah Trough, the Balabac fault in the NE, the West Baram Line in the SW, while the Kinabalu Suture closes off its SE corner. The character of its remaining boundary in the south is not known. Overthrusting occurred during the transition from Early to Middle Miocene and produced the Deep Regional Unconformity. In the vicinity of its flanking strike-slip faults, the NW surging overthrust sheets were deformed by drag, the latter producing the prominent strike changes. The Northwest Sabah Overthrust System is planimetrically identical to the Pine Mountain Thrust Sheet at the tri-state border area of Kentucky-Tennesses-Virginia in the Appalachian Range of the United States.

BACKGROUND

In West Sabah structural strikes run northeast to north-northeast and from Tuaran northward seem to bend easterly maintaining this strike over East Sabah (Figure 1). This structural framework is based on the work of the Geological Survey of Malaysia (summarised on the regional map compiled by Lim, 1985) and a number of own field observations carried out over a period of 30 years. The regional geological map further suggests an acute structural bend in Sabah's interior, approximately at the Trusmadi Range. From the regional works from Liechti (1960), Tongkul (1994) to Tate (2001) and references therein, the oroclinal bend in Northwest Sabah was noted and some explained the strike change as result of interference with major transcurrent fault zones trending WNW (Figure 2). The major structures of Figure 2 were interpreted from SAR (Synthetic Aperture Radar) images commissioned in the early 1990s by the national oil company. Sabah as well as Sarawak are completely covered. The radar images clearly indicate the WNW major fault zones and a trans-Sabah fault system extending from Cowie Harbour in the southeast clear across the state towards the northwest. Circular structures ranging in diameter from about 10 km upward were also detected.

Figure 1 shows that pre-Tertiary ultramafics, banded chert and Jurassic-Triassic (or earlier) metamorphic and igneous complexes-the Crystalline Basement-occur within a well-defined belt separating West Sabah from East Sabah. Palaeogene sheared melange in parts of the Crocker and Trusmadi formations are also present. This belt has been interpreted as a suture-the Kinabalu Suture Zone-between East Sabah and the remainder of Borneo. The exotic Sabah Terrane has continental crust; West Sabah consists of mixed crust (Tjia 1988). The suture zone, and branches extending across the East Sabah Terrane, experienced renewed tectonic activity in Early Miocene (Te5) that comprised rifting followed by compression. This activity manifested in the formation of Middle Miocene chaotic deposits: Wariu, Garinono, Ayer, Kuamut and Kalabakan formations. Towards the end of the Miocene, the central northern part of the suture was intruded by felsic magma giving rise to the Kinabalu massif (13-9 Ma) and satellite bodies. Pleistocene andesitic-basaltic volcanism was active near the SE end of the suture. There in the Semporna Peninsula volcanic morphology still dominates the landscape.

Figures 1 and 2 use onshore information. The PETRONAS book (Leong, editor 1999) has now allowed access to the wealth of offshore data collected in petroleum exploration activities since the mid 1970s. Stratigraphic correlation for "Greater Sabah" is also available (p. 480).

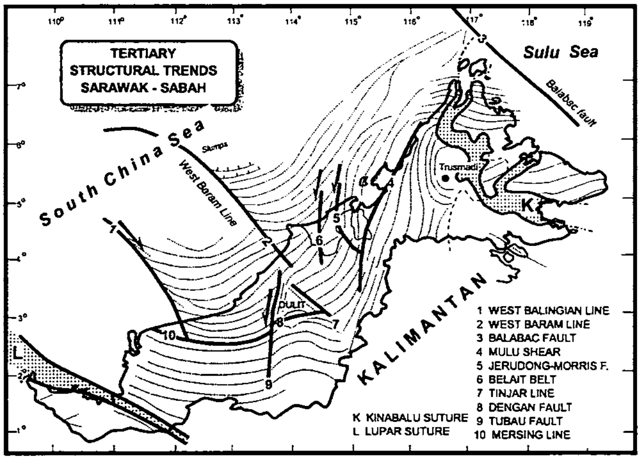

Figure 1. Tertiary structural trends in northwestern Borneo. Note the sharp changes in trends in the vicinity of large fault zones.

These combined data sets, a sizeable number of personal, seemingly unrelated, field observations collected during the years, and the recurrent encounters with thrust faulting, duplexes and consistent NW-verging overfolds and structures in the field seem to fit into a large scale overthrust system in northwest Sabah. In the following paragraphs evidence will be discussed and a geometrical analogue in the Appalachian Range of the United States will be shown.

STRUCTURAL ANALYSES

Duplex of recumbent folds and low-angle thrusts, mengaris

Mengaris quarry is a large stone quarry located a few kilometres south of the trunk road junction leading to Kudat and to Marudu, at the head of Marudu Bay in north Sabah. The quarry face strikes NE-SW and is about 35 metres high (Figure 3; see Figure 2 for location). The structures that outcrop there strike perpendicular to the quarry face and consists of low to moderately SE-inclined faults separating a large recumbent synform, medium-sized asymmetrical folds and an open warp (Figure 3). On the regional geological of Sabah, the quarry is located in the Oligocene-Lower Miocene West Crocker Formation consisting of well-bedded turbidites, massively bedded grain-flow sandstone units and occasional intervals with soft-sediment structures. The sandstones are graywacke to subgreywacke. Stratigraphic facing is indicated by local angular unconformities. The lower one third of the quarry exposes a broad warp whose northeast limb is gently inclined. The middle and upper parts of the outcrop consist of SW-NE striking folds and low-angle reverse faults indicating tectonic transport of the duplex toward northeast.

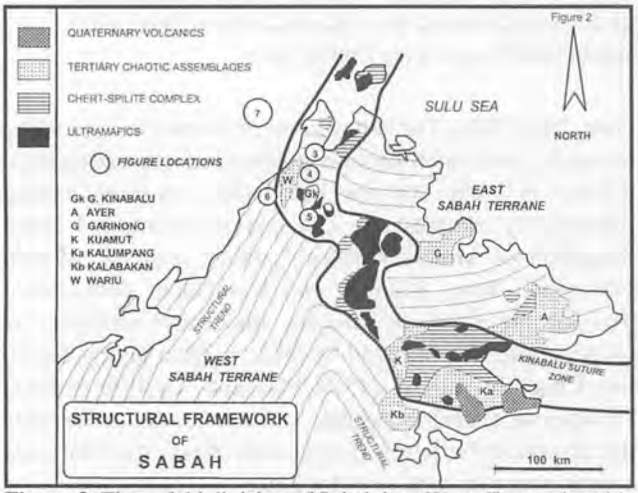

Figure 2. Three-fold division of Sabah into West, East and a wide suture zone. The NE regional strike changes into easterly strike in northern Sabah and also sharply into SE direction in the interior.

West Crocker and Wariu Formation, Tenoman River

Sungai Tenoman lies south of Kota Belud and drains Gunung Tambuyukon. Figure 4 is a lower hemisphere equal-area plot of observations along about 2.5 km stretch of the river in the vicinity of Kampung Sayap-Sayap. The outcrops comprise steeply to overturned beds of West Crocker and Wariu sandstone intercalated with dark-coloured argillite. The latter is often subphyllitic Stratigraphic tops are determined by the presence of sole markings. Asymmetrical to overturned folds of moderate dimensions appear as outcrops. Fracture planes in the sandstones have subhorizontal to horizontal striations and most are strike-slip faults (Figure 4; location on Figure 2). One striated reverse fault plane strike 80° dipping steeply south. A light-coloured aphanitic igneous sill follows bedding that strikes SE and dips SW at moderate angle. Part of the strike-slip fault striations, most fold axes and

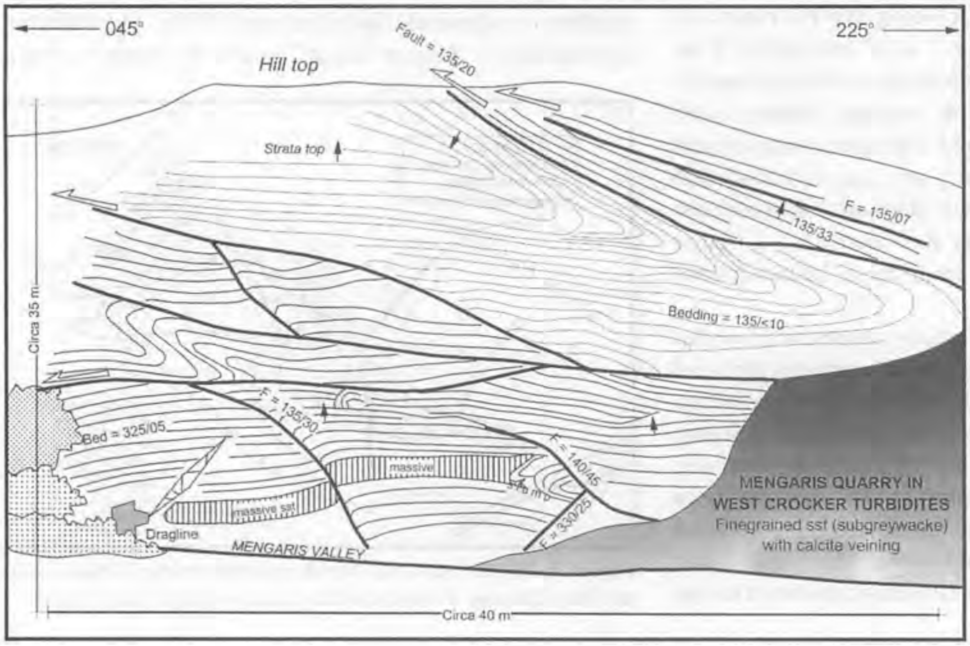

Figure 3. The Mengaris stone quarry exhibits duplexes with tectonic vergence towards northeast (left). Scale is indicated by the dragline.

the bedding attitudes indicate NNW to NW striking structures corresponding with a maximum horizontal compression in 80°-260° direction (P1 = SHmax). The reverse fault striation and an other part of strike-slip fault striations are interpreted to have responded to a later (P2) Horizontal maximum stress direction in NNW -SSE direction or almost normal to P1. P2 is the direction almost normal to the easterly strikes of East Sabah.

Structures in roadcuts near Kundasang

In early 1970s detailed structural observations were carried out on excellent roadcut and stream outcrops in the area between Ranau and Tenompok on the S and SE sides of Kinabalu Mountain. Eocene-Oligocene East Crocker and Trusmadi turbidites with wide intervals of olistostromes crop out as asymmetrical folds cut by low-angle reverse faults and normal faults. Beside intervals of olistostrome that have olistoliths of the same lithology as the East Crocker and Trusmadi formations were also exposed wide zones of slump structures. Abundant sole markings, some of extraordinary large proportions and graded beds facilitated definite identification of stratigraphic facing. The outcrops turned out to represent low-angle thrust packets verging in divergent directions towards north and towards south (Tjia 1974). Figure 5 shows two examples of the structures. The upper part of the figure shows a large overturned anticline striking E-W and verging NW to NNW. The entire structure appears to have experienced warping about an ESE-SE striking axis with possible tectonic transport northeasterly. In other words, the outcrop suggests superimposed deformations resulting first from northwesterly verging tectonic compression that produced the large overturned fold, succeeded by deformation responding to NE-SW horizontal maximum stress. In the same general area of Kundasang is the roadcut in the lower part of the figure. Thick-bedded East Crocker sandstone rests upon a decimetre thick mylonite that tops a recumbent fold composed of massive-bedded sandstone. If the structure is an anticline produced as fault drag, tectonic transport was ESE-ward normal to the fold strike. Tectonic vergence was in the opposite direction if the recumbent structure is a syncline. The latest deformation was by normal faulting striking NW-SE and downthrowing a few metres towards SW.

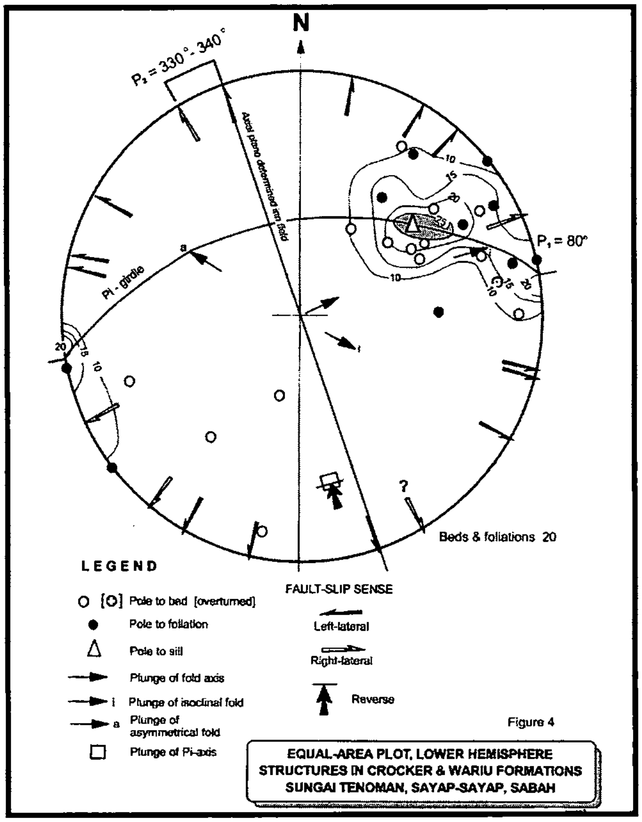

Figure 4. Structural elements in Wariu and West Crocker sediments cropping out along Tenoman River near Sayap-Sayap village (location is on Figure 2). The plot is interpreted to show earlier ENE-WSW regional compression followed by NNW-SSE compression.

Flake duplexes in West Crocker Formation at Tamparuli

A moderately large outcrop on the Tuaran-Ranau road near Tamparuli exhibits three thin overthrust sheets, each less than 10 metres thick and partitioned by subhorizontal faults (Figure 6). Northwest verging asymmetrical to recumbent folds are decapitated by these faults. Sole markings define strata top; the average fold trends of N230°E point to geological transport towards N320°E, that is, perpendicular to the fold axes.

Stress fields NW Sabah offshore

Structures in the subsurface and offshore NW Sabah have been published by Hinz *et al.* (1985, 1989), Tan and

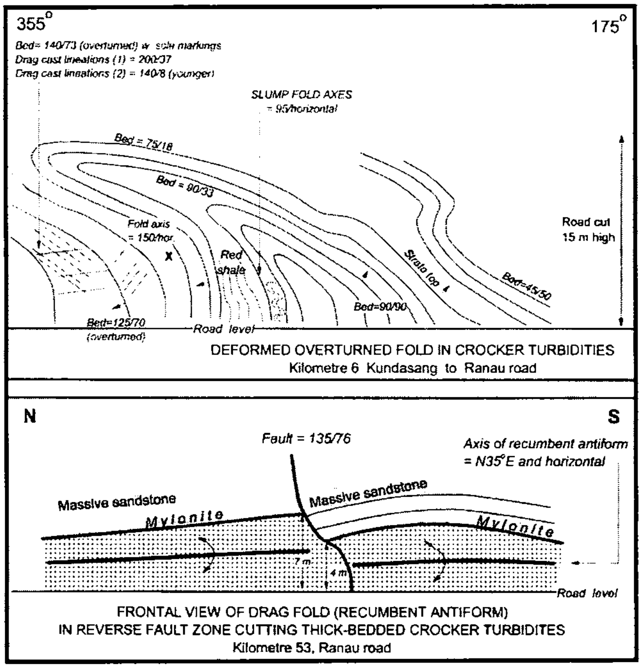

Figure 5. Two roadcuts of East Crocker and Trusmadi formations on the south flank of Mount Kinabalu within the suture zone (see Figure 2 for location). Description in the text.

Lamy (1990), Hazebroek and Tan (1993) and Leong (1999b). Figure 7 shows a simplified structural map constructed from the published information. Most of map area show the maximum principal stress (SHmax) in NW direction that changes to become northerly in the area of the Batu Mandi-1 exploration well and farther to the east in the Kudat Peninsula. The northern part of the map is dominated by a completely different stress field. It is marked by tensional structures (normal faults and the large Siagut syncline) that resulted from a stress system where the maximum principal stress is vertical (gravity) and the minimum principal stress is NW.

Seismic and well data were compiled into a structural framework map (Hazebroek and Tan, 1993, p. 200) of the NW Sabah offshore where a large NE-trending rectangular area adjacent to the Northwest Sabah Trough was indicated as a "Lower Tertiary Thrust Sheet" (indicated on Figure 8). The disposition of thrust faults bounding the sheet in the west and with the trough indicate NW vergence. The thrusting event was most probably the cause of the so called Deep Regional Unconformity (DRU) of Langhian (early Middle Miocene) age. In the offshore and subsurface stratigraphy the DRU forms the base of Stage IV and younger sedimentary units.

Baram Delta-Northeast Sarawak

In the coastal plain of the above mentioned area are only outcropping post-DRU sediments. In Sarawak, a near-time equivalent of the DRU is the Middle Miocene Unconformity (MMU) that separates Cycle III (older) from Cycle IV sediments. Farther seaward, the MMU surface becomes a conformable depositional surface. A significant geological lineament strikes NW from about Tanjung Bungai a score of kilometres SW of Miri town. This is known among Malaysian-based geologists as the West Baram Line and is generally believed to separate deeper marine conditions to its east from neritic to coastal depositional environments to its west. The regional geological book of Brunei does not attach tectonic importance to a WBL, possibly because it is a pre-Middle Miocene geological feature (see Sandal, editor 1996) Instead, the Tinjar, a lineament occurring some 50 km more to the west and running parallel to WBL is prominently shown (Figure 2.3, p. 52). The figure also shows several regional N-S left-lateral faults in the SW Sabah and Baram Delta area (Kimanis, Muara-Labuan, Jerudong, Belait and the earlier mentioned Tinjar faults). The strike change of the Tinjar fault from N-S to NW-SE occurs in the general area of WBL. Other major structures in the Baram Delta area are concave-to-north gravity faults affecting Neogene and younger sedimentary units.

The Northwest Sabah Overthrust

The change of structural trend from a regional SW-NE to easterly in northeastern Sabah is demonstrated by the selected outcrops discussed above. Towards SW this regional trend also changes sharply, but into southerly (or S-N) strikes in Brunei. These N-S trends are shown by a bundle of sinistral strike-slip faults and by synclinal structures of the Neogene Belait and time-equivalent formations.

Asymmetrical folds, overfolds, recumbent folds and thrust faults are known from the greater Kota Kinabalu area (central NW Sabah) to have resulted from NW tectonic transport. From Tuaran northwards, tectonic vergence becomes NNW to NNE-ward.. The structural trend change in the SW (Brunei and northern Sarawak) is from a regional SW to southerly and is also displayed by sinistral strike-slip faults.

It is now postulated the a 700-km long and about 300 km wide area of NW Sabah (including the offshore area) represents a large overthrust system verging NW (Figure 8). The overthrust sheets consist of pre-Langhian rocks. The overthrust system is limited by the Balabac lineament in the north, by the NW Sabah Trough in the NW and by the West Baram Line in the SW. Its landward limit is presently not known, except in the SE where the tectonic boundary is the Kinabalu Suture Zone (Figure 1). The NW-striking Balabac lineament (a linear magnetic anomaly) is probably a strike-slip fault whose latest activity shifted

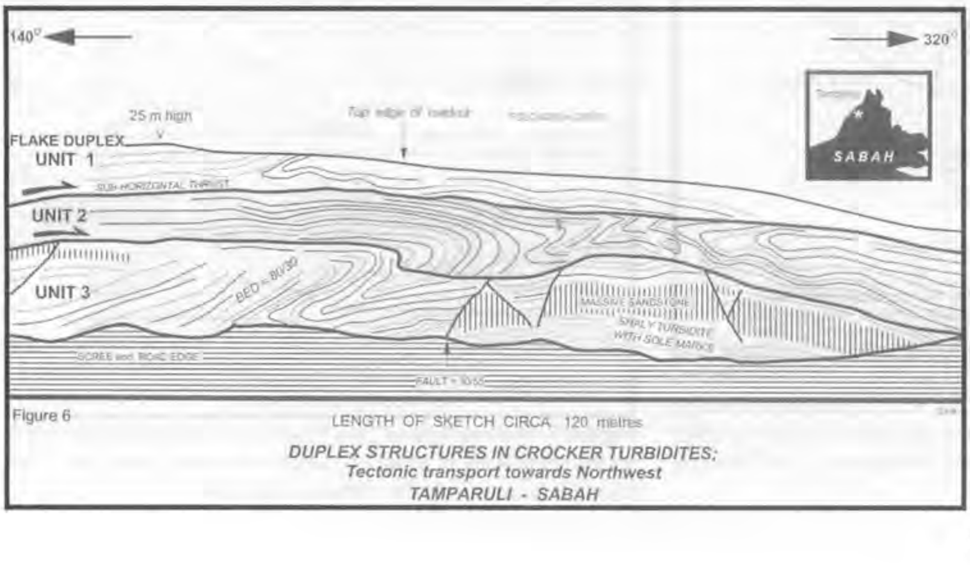

Figure 6. Flake duplexes in West Crocker Formation near Tamparuli. Tectonic vergence is northwest.

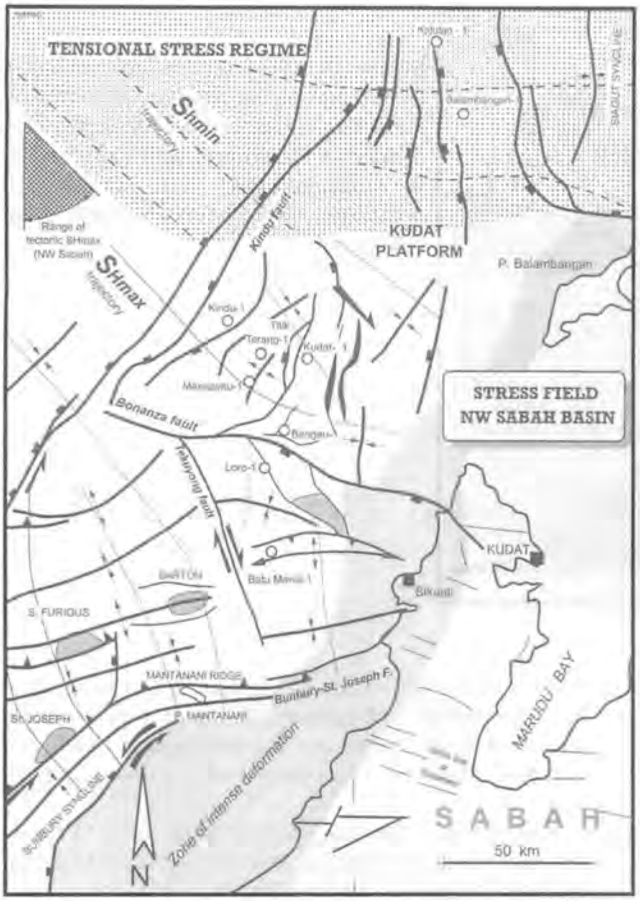

Figure 7. Simplified plan of structures and their causative principal stress directions in the NW Sabah offshore.

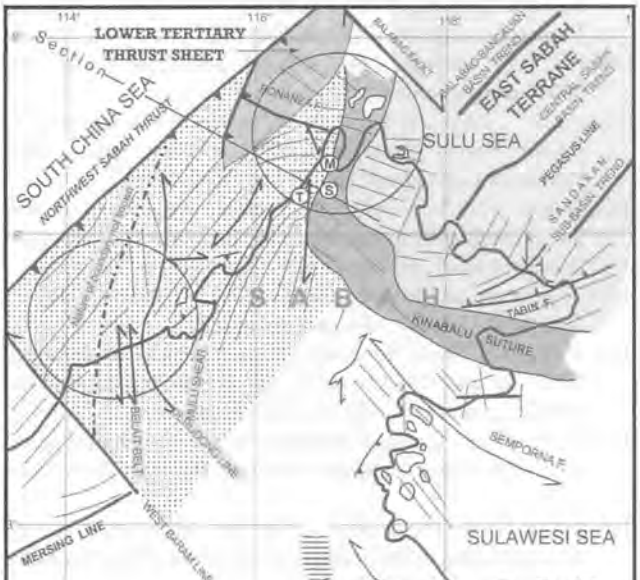

Figure 8. The Northwest Sabah Overthrust System (NWSOS) and its geological boundaries. Prominent strike changes take place near the Balabac fault and near the West Baram Line.

ophiolites in Balabac and Palawan islands some 50 km to the left with respect to similar rock associations in the Marudu Bay area. It is suggested that during the tectonic emplacement of the NW Sabah overthrust (NWSOS), the West Baram Line and the Balabac Lineament confined the slab and acted as regional strike-slip faults, respectively of left and right-lateral sense. The constricting boundary strike-slip faults also caused adjacent structures of the NWSOS to be dragged and bent approaching parallelism with the Balabac and the West Baram faults, respectively. In other words, in NW Sabah the strike change from NE into easterly trends is attributed to regional drag along the Balabac fault when the NWSOS surged during the overthrusting event. In the SW, the bundle of N-S strike-slip faults in the SW Sabah-Brunei area, is considered as drag features when NWSOS travelled along the West Baram lineament/fault faster NW-ward relative to northern Sarawak on the west side of WBL (Figure 8).

A planimetric analogue to NWSOS is the Pine Mountain Thrust Sheet in the Appalachians of the United States (Figure 9, simplified from Woodward *et al.* 1989). This overthrust sheet has rectangular plan (no scale was given in the original figure, but length and width are certainly at least in the tens of kilometres, if not larger category) elongated northeast. It is boxed in by thrust/overthrust faults with tectonic transport NW-ward while at the shorter bounding thrust faults, vergences are outward in NE and SW direction, respectively.

Figure 10 shows my interpretation of a regional section of the Northwest Sabah Overthrust System. The DRU marks the widespread Langhian unconformity in Sabah and its existence is now attributed to the overthrusting event. The Palaeogene sediments below the DRU are strongly deformed into duplexes and recumbent folds (Mengaris quarry; Tamparuli roadcut) verging NW. The nature and positions of the large reverse and some normal faults and the toe-thrusts in Figure 10 have been adapted from publications, such as Hazebroek and Tan (1993), Leong (1999b) and others. Stage IV (Middle Miocene) and younger sediments are floored by DRU and have been the targets of hydrocarbon exploration.

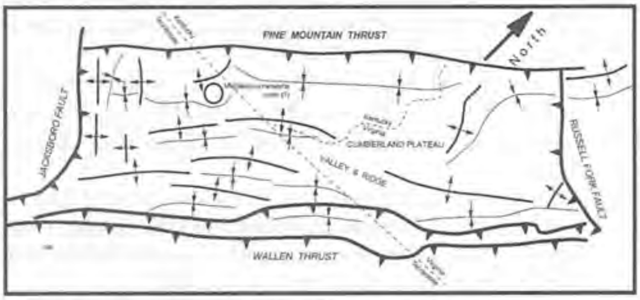

Figure 9. The rectangular Pine Mountain Thrust Sheet simplified from Woodward et al. (1989). Note the drastic changes of structural trends in the Jacksboro and Russell Fork faults. In NW Borneo these two bounding faults are "emulated" by the West Baram Line and the Balabac fault.

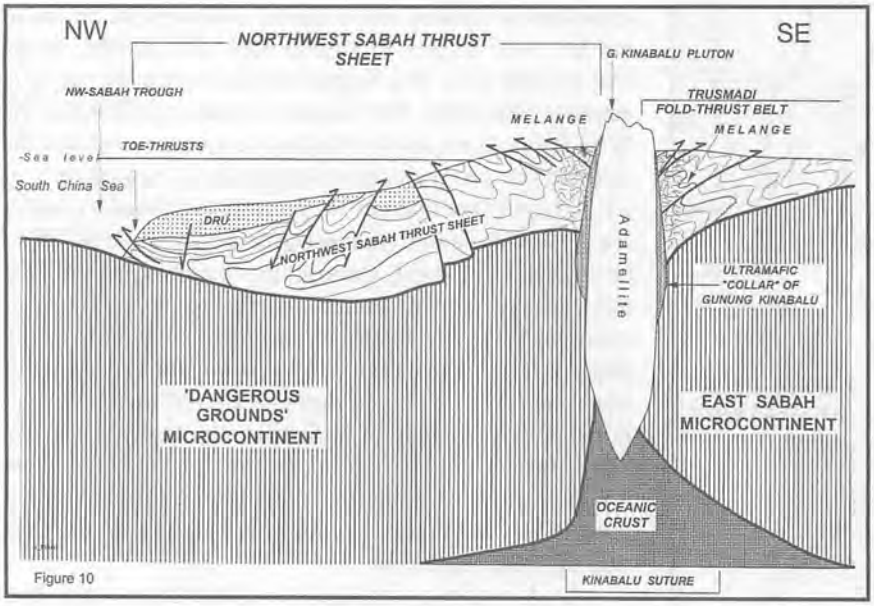

Figure 10. Cross section and geological architecture of the NWSOS or Northwest Sabah Thrust Sheet between Mount Kinabalu and the NW Sabah rough. Although a cartoon, the structural styles and their respective positions have been adapted from publications.

CONCLUSIONS

Structures in Palaeogene sediments onshore West Sabah and in the adjacent offshore comprise asymmetrical to recumbent folds commonly associated with low-angle thrusts and duplexes that regionally verge northwest. The NE structural strike changes sharply into Easterly trends nearing the Balabac fault in the north, while in the south strike change is displayed by a bundle of north-south trending strike-slip faults in a wide belt next to the West Baram Line. These structural indicators combined, indicate the existence of a 700 km x 300 km slab of crustal material that moved towards northwest as an overthrust unit that also accounted for the Deep Regional Unconformity (Langhian, or at the transition of Early to Middle Miocene). The drastic changes of structural trends from a general SW-NE to east in northern Sabah and to N-S in Brunei resulted from drag along the two flanking major faults, that is, the Balabac and West Baram tectonic lines.

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