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Kundasang (Sabah) at the intersection of regional fault zones of Quaternary age

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Abstract: The Crocker fault zone (CFZ) is more than 170 km long and several kilometres wide. It contains the Quaternary structural valleys Tenom, Keningau, and Tambunan which are aligned in a northerly to N20°E trend. Its most northern segment, Lobou-Lobou, displaced a tarred road for 15 cm left-laterally. In addition to normal faulting, as the association with valley-fill deposits suggests, tributaries of the Pegalan river that cross the CFZ boundary also display abrupt sinistral course shifts of several hundred metres. The Mensaban fault zone (MFZ) strikes WNW and is traceable over a distance of 110 km from Tuaran toward east into the interior of Sabah. Faceted ridge spurs indicate Quaternary activity of normal faulting with individual downthrows up to 50 m high. Along a Mensaban fault strand in the vicinity of Kundasang, the sudden course change of the Liwagu river suggests recent and sustained sinistral slip. In this area the MFZ is 12 km wide and intersects the CFZ. Continued activity on these two regional faults is one of the root causes of widespread mass movements in the Kundasang area.

Abstrak: Zon sesar Crocker dikesan sepanjang 170 km lebih dan selebar beberapa kilometer. Di dalamnya terkandung lembah struktur Tenom, Keningau dan Tambunan yang menjurus antara utara hingga U20°T. Ruas zon sesar paling utara, Lobou-Lobou, telah menganjak jalan berturap sebanyak 15 cm ke kiri. Bersamaan dengan sesaran menurun, seperti dicadangkan persekutuannya dengan isian sedimen Kuaterner lembah, sejumlah anak sungai kepada Sungai Pegalan ketika melintasi sesar sempadan lembah mengalami anjakan lateral sejauh beberapa ratus meter ke kiri. Zon sesar Mensaban berjurus timur-tenggara dan berpanjangan 110 km daripada Tuaran di barat ke arah pedalaman Sabah. Hujung rabung topografi yang berfaset mewakili aktiviti Kuaterner yang melibatkan sesaran menurun sehingga 50 m pada tempat tempat tertentu. Di sekitaran Kundasang, Sungai Liwagu tiba tiba teranjak lateral ke kiri sejauh hampir 2 km . Zon sesar Mensaban berkelebaran 12 km. Di sana pula, kedua dua sesar aktif serantau menyilang dan merupakan salah satu sebab utama kepada berlakunya susutan-darat yang meluas.

INTRODUCTION

The Kundasang area is located in the Sabah highlands on the southeast side of Gunung Kinabalu. Kundasang township straddles the trunk road between Tuaran and Ranau (in Figure 1 the Kundasang area is marked by a rectangle). The geology was mapped by Collenette (1958), by Jacobson (1970) and by others who reported on detailed observations on certain parts of the area. The adjusted stratigraphy is mainly based on Jacobson's work (Figure 2b). Widespread ground movements pose the main hazard. This phenomenon was described and analysed by Ibrahim Komoo and C.S. Lim of Lestari (2002, 2003). Three fundamental causes for ground instability were identified (Tjia 2006): (1) original earth material of the Oligocene submarine chaotic deposits (mapped by most previous reporters as Trusmadi Formation, Figure 2a), (2) the Kundasang area being located within the WNW-trending wide and Quaternary Mensaban fault zone, (3) the still rising Kinabalu pluton that may have disturbed the isostatic equilibrium and causes local normal faulting as adjustment. The present article resulted from re-examination of aerial photographs of 1970 and of subsequent vintages until year 2002, of radar satellite images, and a short field survey in 2006 conducted together with the Minerals and Geoscience Department team entrusted with updating the Malaysian seismotectonic map. The latest study gathered evidence that a second regional fault zone crosses the Kundasang area, cutting and displacing Quaternary deposits (Figure 3). Segments of this fault zone bound the Tenom, Keningau and Tambunan structural valleys. This regional fault zone occurs at the eastern edge of Banjaran Crocker and is named the Crocker fault zone (CFZ). About 15 kilometres more to the west, Lee (1980) identified a roughly similar trending satellite lineament and named it the "Crocker Lineament". Another clear lineament extending from Terusan on the Sulu Sea coast via Telupid to Pinangah in central Sabah runs roughly parallel to CFZ.

THE CROCKER FAULT ZONE

Field indications of young activity along the Crocker Fault Zone (CFZ) were observed at the localities described below. Most of the indications are already known and published; this article interprets the individual fault depressions and brings together similarly trending fault segments into one regional fault zone of Quaternary activity. The CFZ includes the following segments:

(a) Tenom Quaternary depression, strike N10°E, > 55 km long between Tomani and Melalap, up to 0.6 km wide;
(b) Keningau Quaternary depression, strike N20°E, ~30 km long and 1 km wide;

(c) Tambunan Quaternary depression, strike N20°E, ~ 15 km long and 0.4 km wide;
(d) Lobou-Lobou active fault, strike N20°E, along the SE side of Mt. Kinabalu.

Segments (a) through (d) has a combined length of 175 km (Figure 4). Through the elongated depressions Tambunan and Keningau runs Sungai Pegalan in southerly direction until near Tenom it joins Sungai Padas that arrives by flowing northerly from the small Tomani depression and past Kemabong (Figure 5; Geological Survey of Malaysia map of Sabah, GSD, 1985).

Tenom depression

Between Kemabong and Tenom, this 25-km segment of the elongated depression is flanked by normal faults forming a graben filled with Quaternary deposits (Figure 5; GSD, 1985). Its eastern flank subsided more compared to the other flank and this is shown by the asymmetrical distribution of the older Quaternary deposits occurring on the west side (implying uplift there). On radar satellite image, the fault on the east side of the depression continues farther north as a distinct lineament for another 30 km.

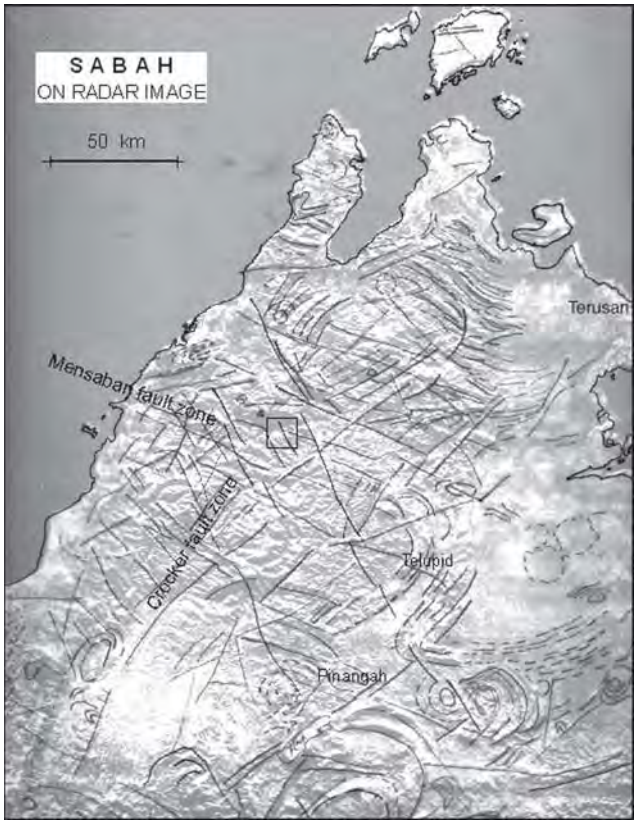

Figure 1: Lineaments and curvi-lineaments on radar image of western and central Sabah. Kundasang (square) lies at the intersection of the Mensaban and Crocker fault zones. In the east, the Mensaban fault zone terminates against a major tectonic lineament that extends from Terusan via Telupid to Pinangah. A large multi-ring structure south of Marudu Bay centres about Marak Parak and could represent an impact structure.

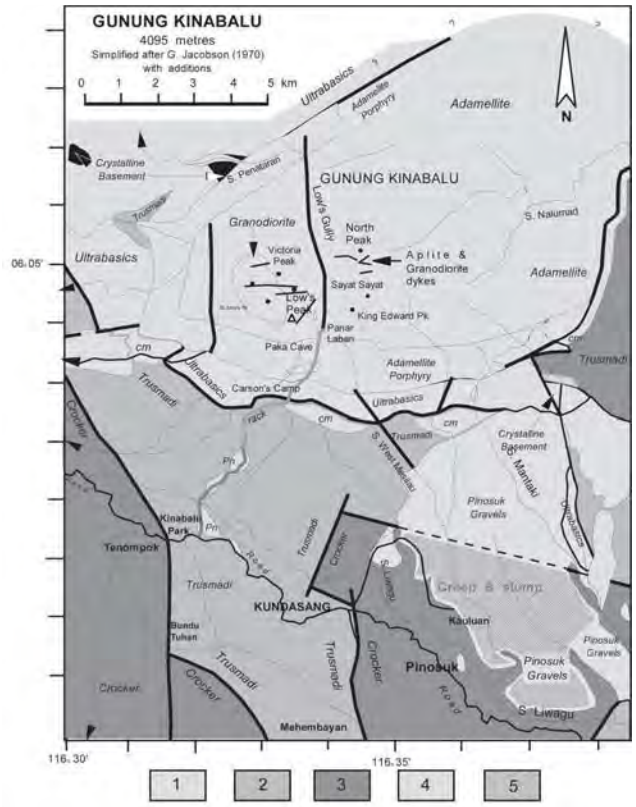

Figure 2a: Simplified geological map of the Kundasang area, mainly after Jacobson (1970) with revisions and additions. (1) Igneous rocks, undifferentiated; (2) "Trusmadi" rocks of sheared diamictite; (3) Crocker Formation; (4) Undisturbed blanket of Pinosuk Gravels; (5) creep and slumps under a thin cover of Pinosuk Gravels; cb = crystalline basement (black); cm = contact-metamorphic zone; Pn = Pinosuk Gravels; bold lines are fault contacts.

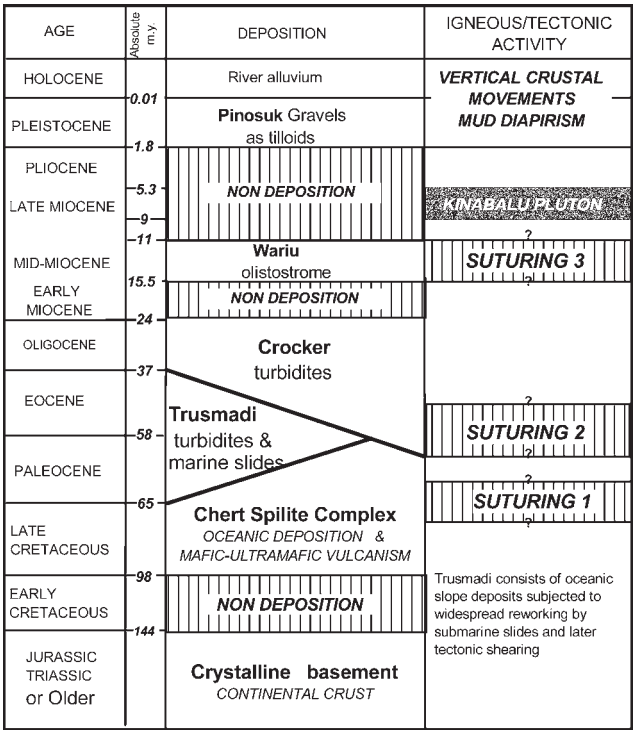

Figure 2b: Stratigraphy of the Kundasang area, adapted from various sources and field checks.

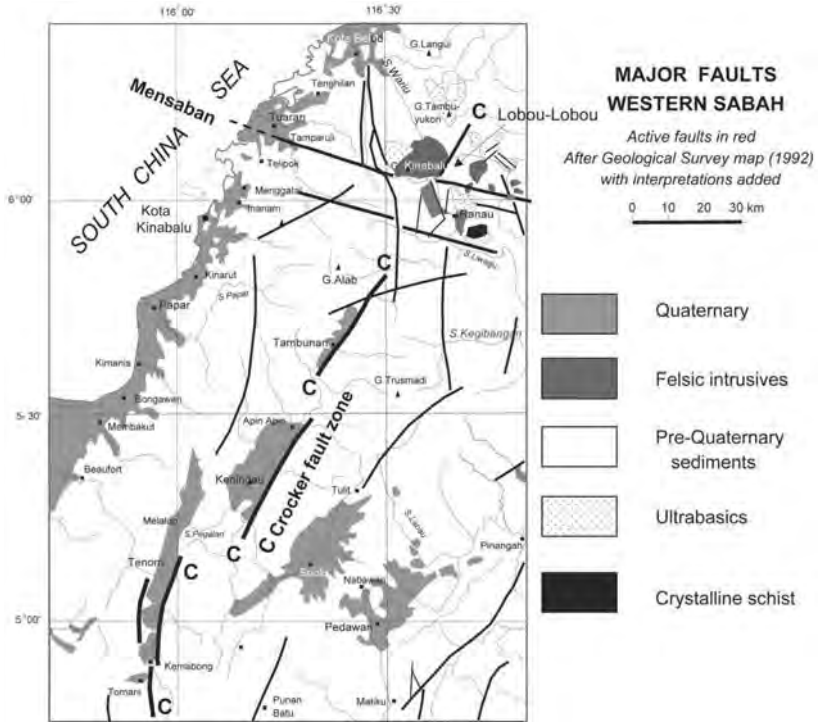

Figure 3: Major faults in western Sabah derived from images of radar satellite, regional geological map of Sabah (1985) with field checks since 1969.

Keningau

The Keningau depression is ~ 30 km long and 1 km wide. Roughly half way on the road between Tenom and Keningau, Shariff Abd Kadir S. Omang *et al*. (1987) studied a set of normal faults cutting into Quaternary gravels. The fault zone occurs in an up to 20 m high roadcut over an across-fault exposure distance of more than 50 metres. The faulted deposits are of fluvial origin and consist of thick, well-rounded gravel and boulder beds intercalated with thick beds of argillaceous sandstone (Figure 6a). The normal-faults strike NE and SW forming a series of graben with throws reaching over 7 m. Fault drag is common and is consistent with normal fault slip (Figure 6b). This particular outcrop appears to mark the north extension of the eastern boundary fault of the Tenom structural depression.

Sivam (1966) studied the entire Keningau depression and showed that it was essentially a NNE-elongated half graben whose eastern side dropped progressively as response to spasmodic rise of the Crocker Range on the west side of the depression. The successive episodes of down-faulting developed a staircase of river terraces on the west side of this structural valley. The highest terrace reached over 30 m above the main river, the Sungai Pegalan, that flows in southerly direction. The geological map of Sabah (Figure 5) again shows the asymmetrical distribution of most of the Quaternary deposits, named as Apin-Apin gravels by Sivam. The older part occurs on the west side of the half graben, a situation that is consistent with greater downthrow on its east side. In the south part of the Keningau valley, however, high Pleistocene-covered terraces are distributed evenly suggesting relative uplift of this part (Figure 5).

Tambunan Depression

This depression is a smaller version of the Keningau half graben. Three steps of Holocene fluvial terraces are on the west side while the Pegalan river course closely follows the eastern boundary of the depression. The highest terrace is 40 m above Sungai Pegalan. Quaternary fluvial gravels and sands fill the depression. The older deposits (interpreted as Pleistocene Tambunan Gravels) are again exposed with the higher terrace on the west side of the depression (Figure 5; Raj 1973; GSD, 1985). Cross faults, the Mangi-Pangi fault and the Lotong fault box in the Tambunan depression in the north and in the south, respectively.

Lobou-Lobou

About a kilometre north of Kundasang at Lobou-Lobou village, a narrow tarred road is cut and displaced left-laterally by a N20^{o}E fault. The sinistral displacement of 15 cm is shown by offset of one of the road edges and the white central line (Figure 7). The other road edge is masked by silts and mud. The fault displacement is tectonic in nature, as the lateral movement had been upslope. This stretch of road deck is probably less than 10 years old and built to replace an older failed road segment located some metres down slope of the present location. Soil creep may have been the cause of failure of that road segment. The Lobou-Lobou fault segment lies in the continuation of the Tambunan fault (Figure 3) and is therefore considered part of the Crocker fault zone.

Nature of Faulting

The Quaternary valley fills of the Tambunan, Keningau and Tenom valleys indicate the Crocker fault zone to have

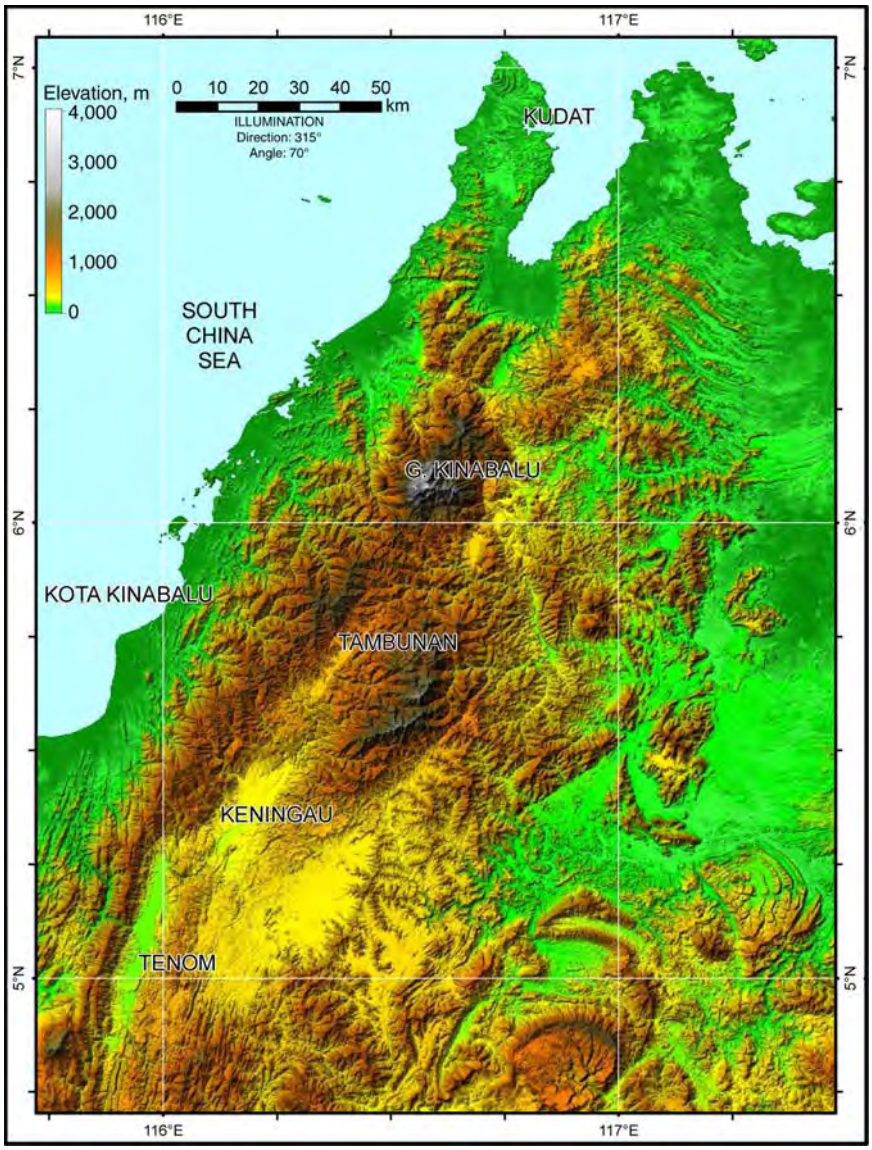

Figure 4: The Tenom-Keningau-Tambunan valleys mark the Crocker fault zone. The WNW lineament passing just south of G. Kinabalu represents the Mensaban fault zone. Extracted from Ng (2007).

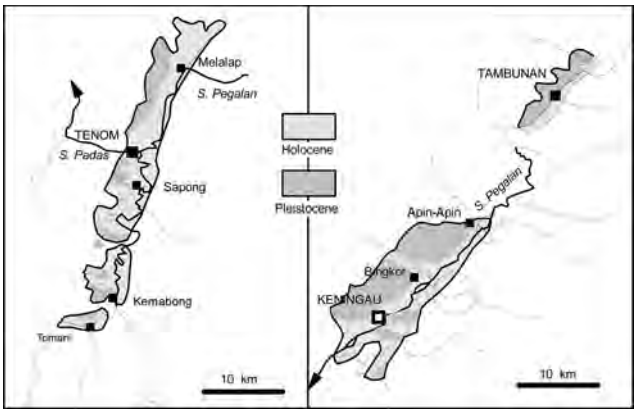

Figure 5: The Tenom, Keningau, and Tambunan structural valleys are segments of the Crocker fault zone. Note that Pleistocene fluvial deposits occur predominantly on one side of the valleys, implying faulting continuing into the Holocene.

been active during that time. The asymmetrical distribution of Pleistocene valley fills and progressive shifts of river terraces suggest fault activity into the Holocene. The fault displacements favour normal faulting as the main mode of structuring. However, rivers originating in the Trusmadi range to the east of the CFZ, show distinct sinistral course shifts of a few hundred metres distance before joining S. Pegalan. This can be seen near the north end of the Tambunan depression, at the north (Apin-Apin vicinity) and middle part of the Keningau depression near Bingkor (circled on Figure 5; GSD, 1985). Major drainage derangements in this part of Sabah has been proposed by a number of researchers and referred to by Liechti (1960, p. 321-326). In the geologically recent past, the Pegalan river could have drained into the Sulu Sea via the Kinabatangan river. The stream derangements are thought to have taken place by ?Middle Pleistocene time.

Field evidence has shown the Lobou-Lobou fault segment as a currently active fault with sinistral

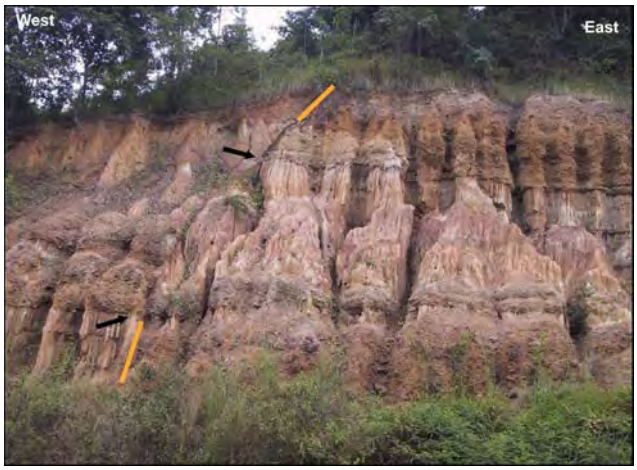

Figure 6a: Thick interbeds of Quaternary fluvial gravel and sand (Apin-Apin Gravels) cut by normal faults that run parallel to the Crocker fault zone. The young faults occur between the Keningau and Tenom depressions. Pamilan ("Keningau") fault strand strikes 220° and dips 62° (orange). Displacement circa 6 metres between black arrows. Quaternary gravels, road cut km 18 Keningau-Tenom, Sabah.

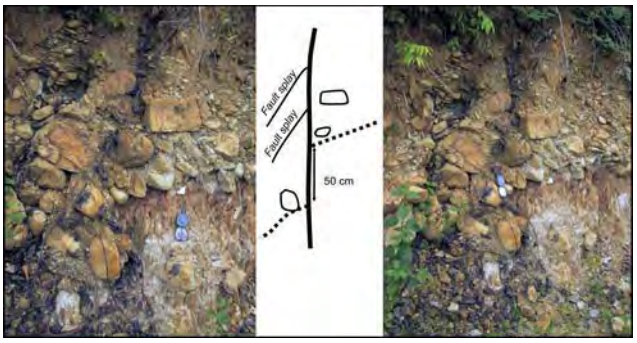

Figure 6b: Detail of the Quaternary faults at the west end of the outcrop.

Figure 7: Active strike-slip faulting on the Lobou-Lobou segment of the Crocker fault zone in the vicinity of Kundasang; photograph taken on 19 July 2006.

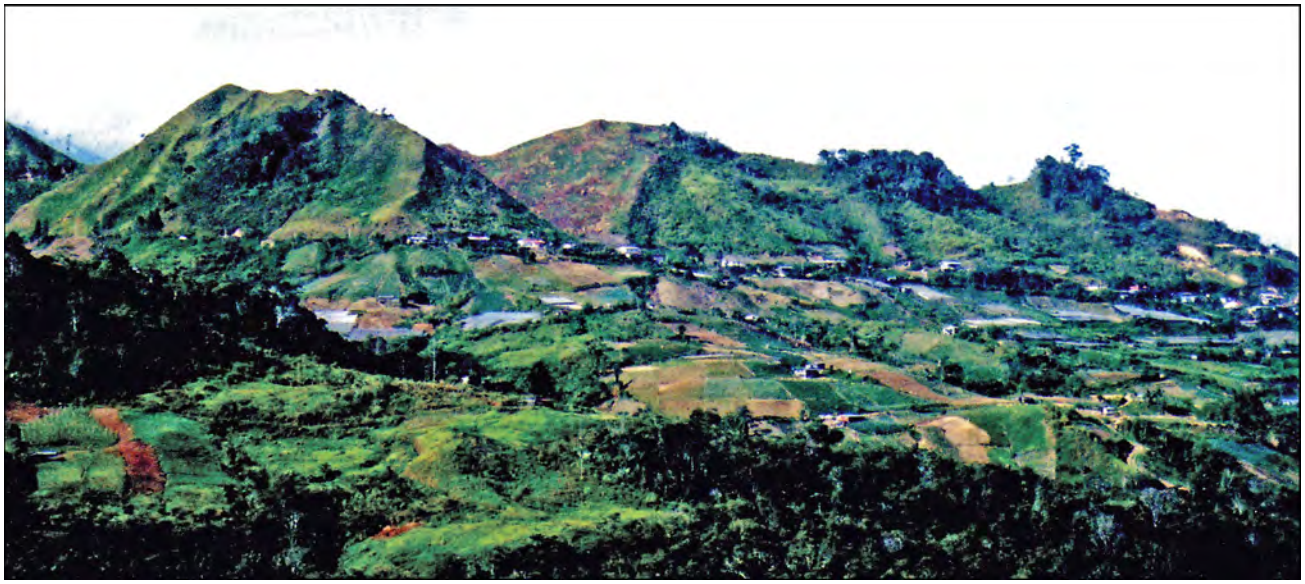

Figure 8: Faceted ridge spurs reaching up as high as 50 m above their base indicate Quaternary normal faulting along the Mensaban fault zone; east side of the Kundasang area. In the foreground are other parallel fault strands associated with hummocky topography.

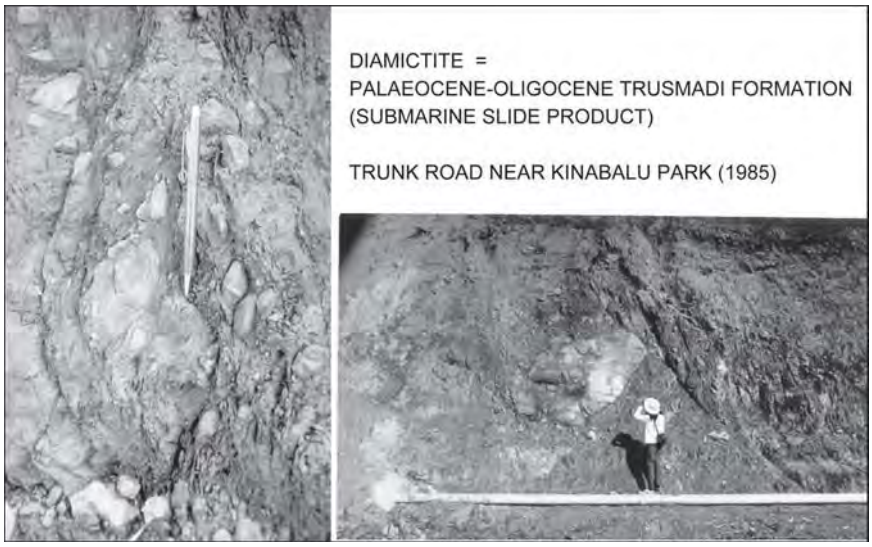

Figure 9: The "Trusmadi" rocks of the Kundasang area consist diamictite resulting from Palaeogene synsedimentary slides; subsequently the rock assemblage was tectonically sheared. The competent clasts are broken and their outlines streamlined into their current appearance. The clasts are predominantly arenite.

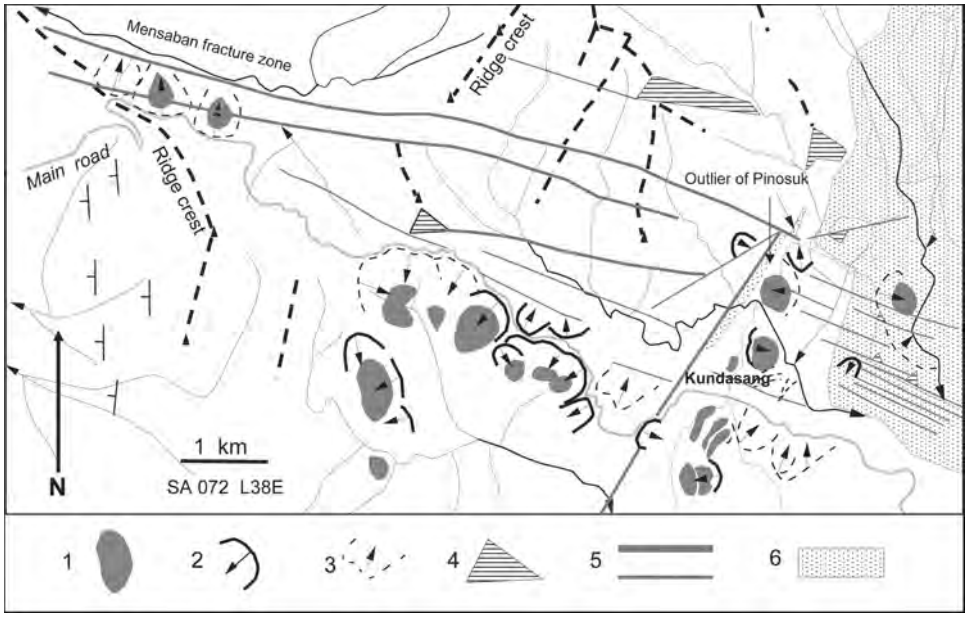

Figure 10: Interpretation from aerial photographs of 1972 vintage. The Mensaban fault zone is closely associated with mass movements in the Kundasang area. (1) landslide debris; (2) landslide scar, arrow indicates slide direction; (3) old landslide scar; (4) fault surface exposed as facetted slope; (5) fault line, major and minor; (6) Pinosuk Gravels.

displacement. In the Kundasang area, it is not uncommon to observe mass movements associated with NNE orientation which would indicate control by and reactivation of structures within the Crocker fault zone.

THE MENSABAN FAULT ZONE

Just east of Kundasang, a row of faceted ridge spurs define two WNW - ESE trending strands of the Mensaban fault zone (Figure 8). The faceted ridge spurs reach about 50 m above the base and is masked by broken sandstone blocks of the Crocker Formation. Downslope from the faceted spurs are more parallel fault lines with low scarps that are associated with hummocky surfaces indicative of soil creep. The material is a chaotic assemblage of non-sorted metre-long and smaller deformed clasts in an argillaceous groundmass mapped as Palaeogene Trusmadi Formation. This particular rock unit (the so called "Trusmadi" unit) has been as products of widespread subaqueous, syndepositional mass movements in the Kinabalu Suture Zone (Tjia 1989). Subsequently, its synsedimentary deformation was enhanced by tectonic movements during closure of the suture zone and achieved its present sheared appearance (Figure 9). The youthful morphology of faceted ridge spurs and fault lines in the Pinosuk Gravel suggest the Mensaban fault zone to have been active in the Quaternary. This is supported by about 2 km sinistral displacement of the Liwagu river course parallel to the Mensaban fault trend. At the same time the displacement may well represent the sense of faulting.

The "Trusmadi" rocks in the Kundasang area were once covered by a blanket of Late Quaternary Pinosuk Gravels that was removed by deep-reaching denudation. An outlier of the gravel unit is exposed on the south side of the main Kundasang-Ranau road, now over a hundred metres above the Liwagu river running through the "Trusmadi" area of Kundasang. These exhumed "Trusmadi" rocks form the unstable material that is one of the root causes of widespread and continuous mass movements (Tjia, 2006). Previous studies erroneously

considered the Pinosuk Gravels as the unstable material. Slumping involving the gravel only occurs at the edges of the contiguous cover of Pinosuk Gravel (such as at Desa Cattle and farther north, where the underlying "Trusmadi" has become exposed to weathering.

Aerial photographs and regional SAR (synthetic aperture radar) images indicate that in the study area the Mensaban fault zone (MFZ) is at least 12 km wide (Figure 10). The fault zone extends west to Tuaran where it disappears under coastal plain deposits. Eastward the fault zone intersects with a regional lineament that extends from Terusan (north of Labuk Bay) via Telupid to Pinangah in central Sabah. The MFZ as described above is 110 km long (Figure 1).

CONCLUSIONS

The WNW - ESE Mensaban fault zone and the NNE trending Crocker fault zone have been active in the Quaternary. The CFZ includes the structural valleys Tenom, Keningau, and Tambunan where normal displacements dominated. Probable young left-slips of several hundred metres are suggested by river course offsets on tributaries entering the Pegalan river from the east (Figure 5). A segment of CFZ, the Lobou-Lobou fault, shows sinistral slip.

The Mensaban fault zone is ~12 km wide in the Kundasang area and shows up on radar images over a distance of 110 km. Its Quaternary age is suggested by the near-pristine appearance of its faceted ridge spurs and some of its faults cutting across the Pinosuk Gravel surface. In the Kundasang area the faceted spurs indicate normal faulting downthrowing south. In addition, the abrupt change of the Liwagu river course suggests sinistral slip of about 2 kilometres.

The widespread mass movements of the Kundasang area can be partially attributed to active movements on the Crocker and Mensaban fault zones that intersect in this area.

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Radar satellite images of several scenes of western Sabah were made available by Fredolin Javino (JMG Sabah). Discussions in the field with the Mineral and Geoscience Department's Seismotectonic Map team members contributed to a better understanding of the geology of Sabah. To all these colleagues: a heart felt thanks.

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