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The Dulit triangle in Sarawak: a most striking example of detachment tectonics

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Abstract: The Dulit triangle is a conspicuous kink in the general NE and ENE structural trendlines of central and north Sarawak. The 45-km high triangle comprises an ENE-striking base of about 75 km length, and NE and NW sides. Study of radar images and field observations confirm that the disharmonic structures of the triangle comprise open synclines of Neogene Belait Formation and tight folds in upper Oligocene-lower Miocene Nyalau Formation that were bent about vertical axes into NE and SE trending structures. The triangular plan is constrained by deeply reaching, regional strike-slip faults forming a frame about the area. The Dulit triangle developed as result of frame-folding and detachment of post-Setap sedimentary strata by the mobile Setap mudstone from the underlying pre-Setap formations. The constricted Dulit triangle also moved *en bloc* towards west, being extruded laterally along the Dengan and Sekiwa faults.

INTRODUCTION

In central and northern Sarawak, Tertiary structural trendlines run in broad curves, that are easterly for the bulk of the Paleogene-Upper Cretaceous Rajang Group in a large part of Sarawak's interior and northeast to almost northerly in the rest of central and northern Sarawak (Fig. 1). A marked change in structural direction occurs at the northwest trending Tinjar lineament. To its west, the Neogene folds and strike ridges are at an acute angle to those of the Paleogene-Upper Cretaceous Rajang Group of sediments, but to its east structures of the Neogene are NE and parallel to those of the Paleogene sediments. While the Tertiary trendlines generally change rather smoothly across Sarawak, distinct kinking of the structural grain is exhibited by the NE-striking Sekiwa and SE-striking Dulit ridges — together forming the so called Dulit Triangle — and an 80-km wide, roughly N-S zone to its south as far as the Quaternary volcanic edifices of the Linau-Balui basalt and dacite lava flows (Regional map of Sarawak, Geological Survey of Malaysia, 1992). Liechti *et al.* (1960a; p. 281 etc.; Tectonic map) explained the SE-strike of the Dulit syncline in terms of interference of an older E-W structural trend with a younger NNE to NE trend and decollement at some depth. Liechti *et al.* applied the term *Rahmenfaltung* (frame folding) to the development of the NW Dulit trend and suggested that the linear NW Tinjar river course represented a basement fault zone that controlled this trend. Liechti also referred to other cases of Neogene structures of mainly NE-SW strikes being influenced by pre-Neogene structures of northerly trends, such as in the Brunei-Limbang area. He further asserted that NE-SW structures developed only where the Neogene strata were deformed independently from the older formations, a deformation process of *tectonique de couverture* in Liechti's terms; or detachment tectonics.

The present paper is based on several field trips in the general area of Bintulu-Dulit ridge-western Brunei, and a study of synthetic aperture radar (SAR) imagery acquired by PETRONAS in the early 1990s. A SAR image of a fragment highlighting the SW corner of the Dulit triangle was published by Light *et al.* (1994; their Fig. 3). These authors also described the technical details of the SAR acquisition. This particular SAR data set covers the whole of Sarawak and Sabah. Hard copies are of scales 1:50,000, 1:100,000 and digitially produced mosaics of smaller scales. In my experience with this data set is that, most probably due to the E-W flightlines and south-look mode of acquisition, N-S and near N-S trending faults are not represented. For instance the N-S Tubau trend/ lineament to the west of the Sekiwa ridge was only established in the field as an important fault zone, but was not apparent on the SAR image, even at its largest available scale of 1:50,000.

Tertiary Geological Development

Figure 2 shows the generalised stratigraphy of the part of Sarawak under discussion and is mainly based on published work by the Geological Survey of Malaysia (Sarawak) with minor changes. The

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Upper Cretaceous-Middle Eocene Belaga Formation consists of turbidites and belong to the Rajang Group, widely considered to represent an accretionary prism. On the SAR image-mosaic, well developed curvilinears enclose several E-W zones with structural strikes oblique to the curvilinears (Fig. 1). The long curvilinears are interpreted as important reverse or thrust fault zones within the prism, possibly representing particularly active subduction episodes. The Rajang Group is strongly deformed into isoclinal folds and overturned folds and reverse-normal faults. The latter were originally reverse faults verging north consistent with subduction from that direction but now appear as wide, normal fault zones hading north. This strong deformation episode occurred in the Late Eocene (Tb). This was probably accompanied by felsic volcanism that produced the Arip volcanics. Upon this angular unconformity was deposited a succession comprising regressive cycles of shallow marine (occasionally deeper marine: Temburong and Setap formations) to coastal and lower coastal plain depositional environments. Carbonate buildups occurred in the Tatau and Lambir formations, and as the significant Subis Limestone Member of the mainly Upper Oligocene sequence. The next younger deformation phase onshore Sarawak and adjacent Brunei was evident in Early Miocene, or within Te5, according to James (1984). The Oligocene Meligan, Temburong, Melinau and equivalent stratigraphic units were deformed into folds with very steep flanks. The third noticeable unconformity separates the generally near-flat-lying Pliocene (Liang Formation) and younger beds, from Miocene strata that display open folds. Two Miocene formations possess exceptional structural styles. One of these, the Setap (shale) Formation is mainly massive mudrock, noticeably with conchoidal fractures and lustrous fracture planes, and where accompanied

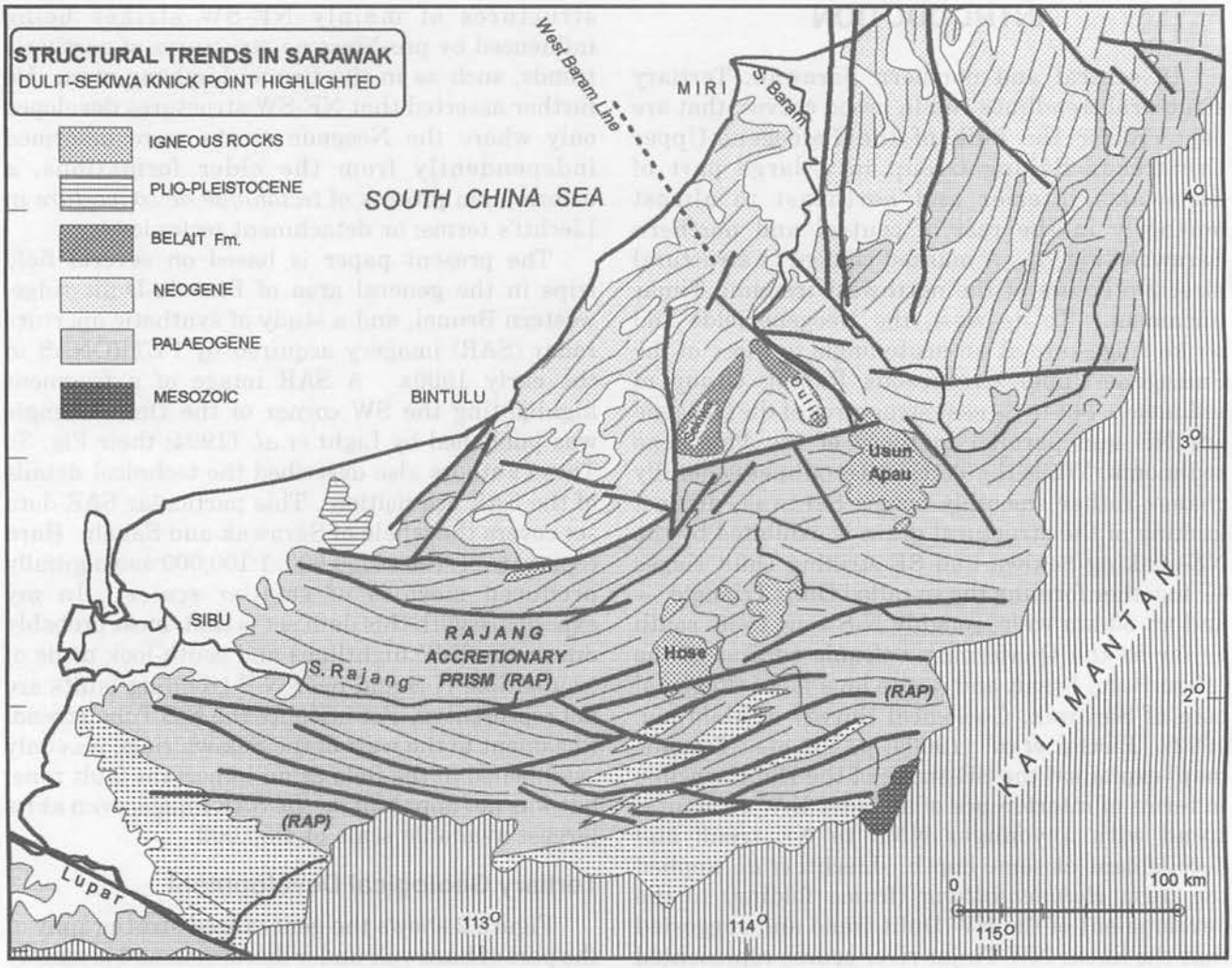

Figure 1. Structural trends in central and northern Sarawak interpreted from radar images of 1:100,000 scale. All N-S lineaments were added from geological maps and one (Tubau, to west of Sekiwa ridge) as result of fieldwork. The radar images are devoid of N-S lineaments.

by thin siltstone layers, a chaotic structure may be seen. Fieldworkers have noted that the Setap shales are associated with mud diapirs (mud volcanism) such as in the Bakong area south of Miri and in the Klias peninsula, Sabah, or formed the cores of comparatively narrow anticlines (e.g. the Jerudong anticline in Brunei). The other structurally different Miocene formation is the Belait, a very thick (probably in excess of 6 km) shallow marine to paralic sandstone-shale unit that usually occurs as large and broad synclines creating cuestas and homoclinal ridges. The Sekiwa and Dulit ridges consist of Belait beds. The Belait syncline in Brunei is an almost 50 km wide elongated basin formed by the same unit. In short, disharmonic structural style marks the Miocene beds in this part of Borneo. Schematically, H. Widmer (in Liechti *et al.*, 1960a, p. 151) ascribed the difference in structural styles of the Belait and Setap formations to high ductility of the latter. Clay diapirs are shown in structural cross sections (A. Koopman in Chapter 3, Sandal, 1996).

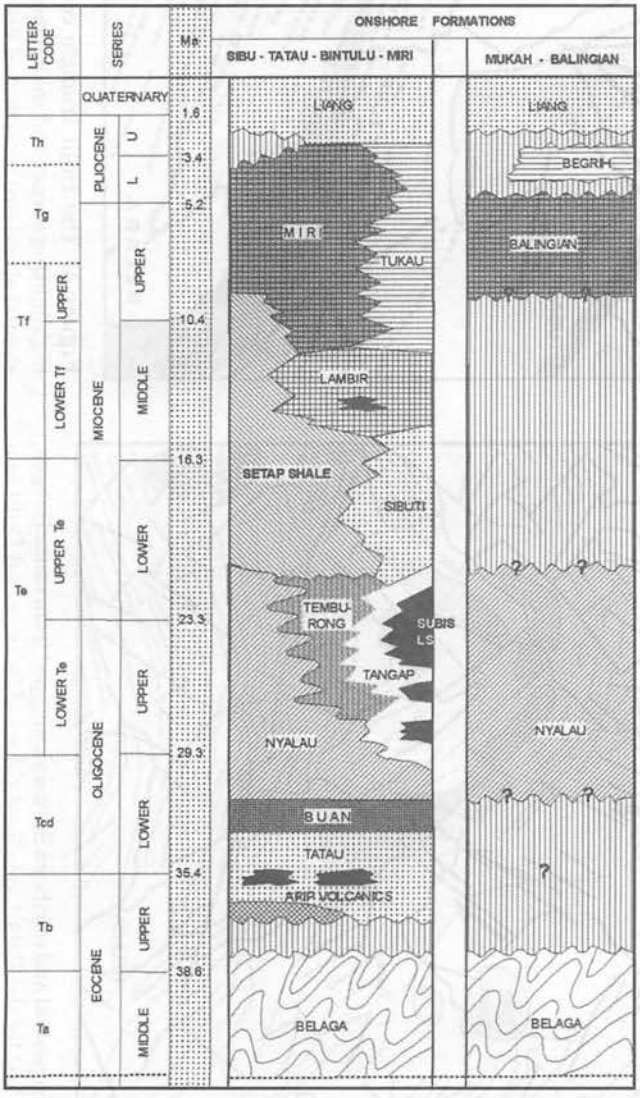

Figure 2. Generalised stratigraphy of central and northern Sarawak based on various sources, especially the Geological Survey of Malaysia (1992) and James (1984). The Temburong Formation corresponds with "Older Setap" in some publications. The Letter Code stratigraphy is the Tertiary subdivisions used in the Indonesian Archipelago *sensu lato*.

THE DULIT TRIANGLE

Figure 3 is a structural map of northern and central Sarawak interpreted from several 1:100,000 scale SAR images. Among the highlighted structures are the Belait synclines (Sekiwa and Dulit ridges) forming the Dulit triangle. The figure clearly shows the Dulit triangle to form a "knot" in the generally smooth structural trendlines across this part of Sarawak. The Dulit syncline and other NW-striking Belait ridges run parallel to the Tinjar fault zone. Fieldworkers have recognised the more than 50-km linear Tinjar river course as an important fault zone. Small igneous intrusives were mapped along this river stretch. On the SAR images, the Tinjar fault zone can be recognised as a 25-km wide corridor of fractures extending from the Pliocene-Pleistocene Usun Apau volcanic plateau up to the Sarawak coastline between Tanjung Bungai and the Niah river mouth (Fig. 3). The similarly NW-striking West Baram Line interpreted by petroleum geologists from offshore Sarawak is not in direct extension of the Tinjar lineament. The West Baram Line appears to intersect the Sarawak shoreline about 40 km more towards Miri. Another regional fault recognised on SAR images is the WSW trending Dengan fault forming the base of the Dulit triangle and being a segment of the Bukit Mersing Line. This line separates Paleogene-Cretaceous strata to its south from Neogene beds to its north (Liechti *et al.*, 1960b; regional tectonic map). Lateral separations of several kilometres were also shown on the images and are indicated by the half arrows on Figure 3. Figure 4 shows angular variations between structural trends that change in the area of the Dulit triangle. The north apex of the triangle consists of structural trends that change from NE to SE making an angle of 100°. From this apex southward the angles at the structural kink become progressively sharper. The strikes of the Sekiwa and Dulit ridges intersect at 75°. In the central part of the triangle the intersect is 62°, but further to the south it flares out to 130°. In the Rajang Group south of the Dengan fault, the change in trendlines is smoother at 150°. A structural

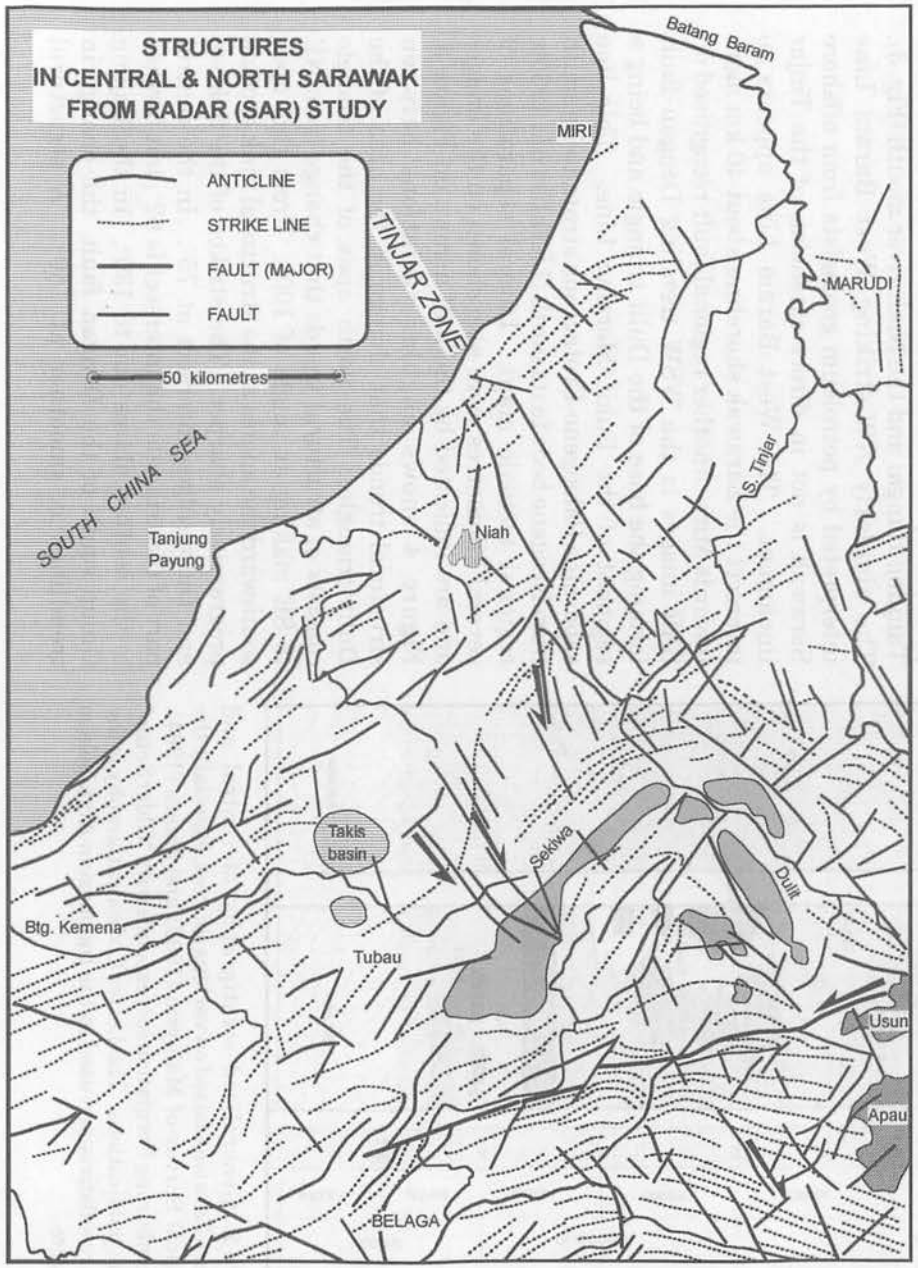

Figure 3. Structures in central and northern Sarawak mapped from radar images. The Dulit triangle marked by the Belait synclinal ridges of Sekiwa and Dulit is a conspicuous anomaly in the structural pattern.

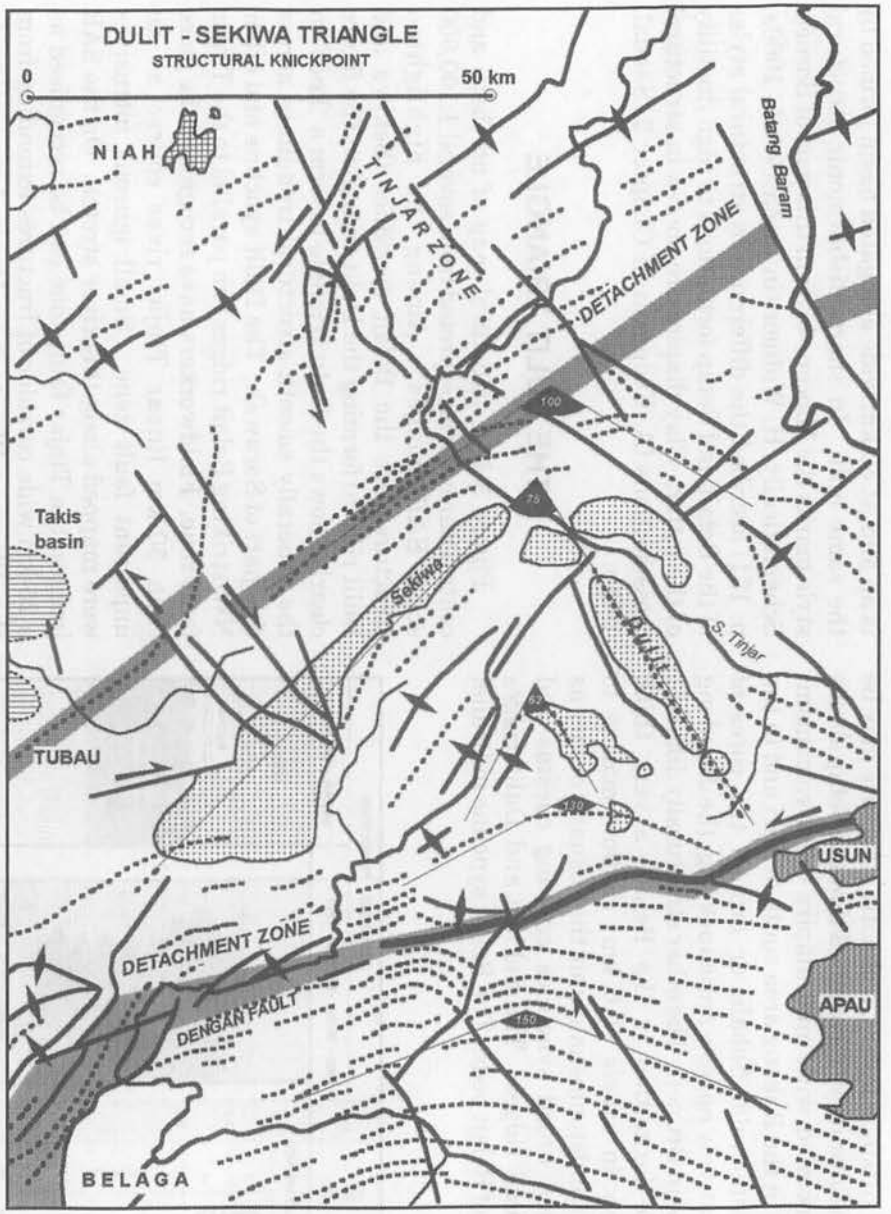

Figure 4. The Dulit triangle comprises structural kinks of varying angles highlighting structural disharmony even within the triangle. The elongated shaded strips are interpreted detachment zones.

separation, most probably a steeply dipping fault zone, striking NE is indicated to the north of the Sekiwa ridge. Structural trends farther than about 15 km remote from the ridge maintain their NE strikes. Closer to the Dulit triangle, structural strikes bend parallel to subparallel with the outlines of the triangle. This interpreted detachment zone is given the name Sekiwa line and runs parallel to the Jelalong river valley. The east by north lineament displayed by the Tubau valley on the west of the Dulit triangle has been recognised by geologists working in Sarawak. Liechti *et al.* (1960b) indicated this as the "Tubau trend" on the regional tectonic map. The map further shows this "trend" to continue northward as the long axis of the so called Ulu Suai dome. Farther towards north along this "trend", the regional geological maps of Sarawak show it as the west limit of Neogene sediments of northern Sarawak. Southward, the trend continues as a 15-km left-lateral displacement of the Bukit Mersing line, which is also the northern limit of the Rajang Group of sediments. This traceable length of the Tubau "trend" between Sibuti on the coast to Belaga in the interior is about 150 km. In a most recent fieldwork in the Ulu Suai dome, the "trend" is established for the first time as a regional fault zone with left-slip movement (Fig. 5; Tjia *et al.*, 1998).

Striking is the contrast in structural styles in the triangle. While its frames are only large open synclines of the Neogene Belait strata, within the triangle the upper Oligocene-lower Miocene Nyalau Formation and argillaceous Setap Formation were deformed into a series of tight folds with steep flanks (Fig. 6).

INTERPRETATION AND CONCLUSION

The disharmonic structures exemplified by the Dulit triangle are best explained as the result of

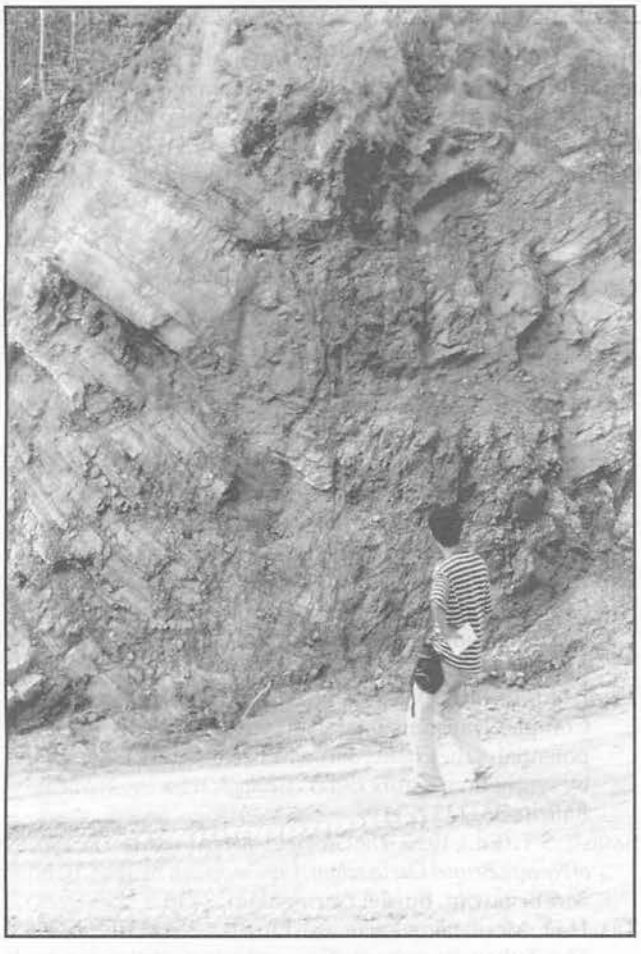

Figure 5. A strand of the Tubau fault zone in the Ulu Suai dome. View is towards south parallel to fault strike. On the left is folded flaggy sandstone, its fold axis pitching 32° northward. On the right are interbedded siltstone-mudstone beds of the Nyalau Formation.

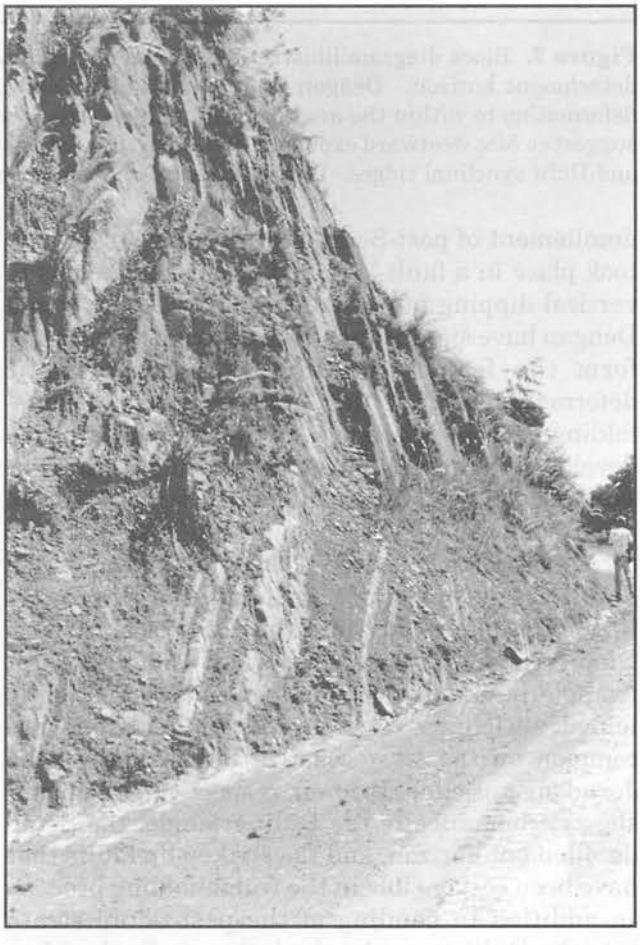

Figure 6. Near-vertical Nyalau strata forming a fold limb within the Dulit triangle south of its apex.

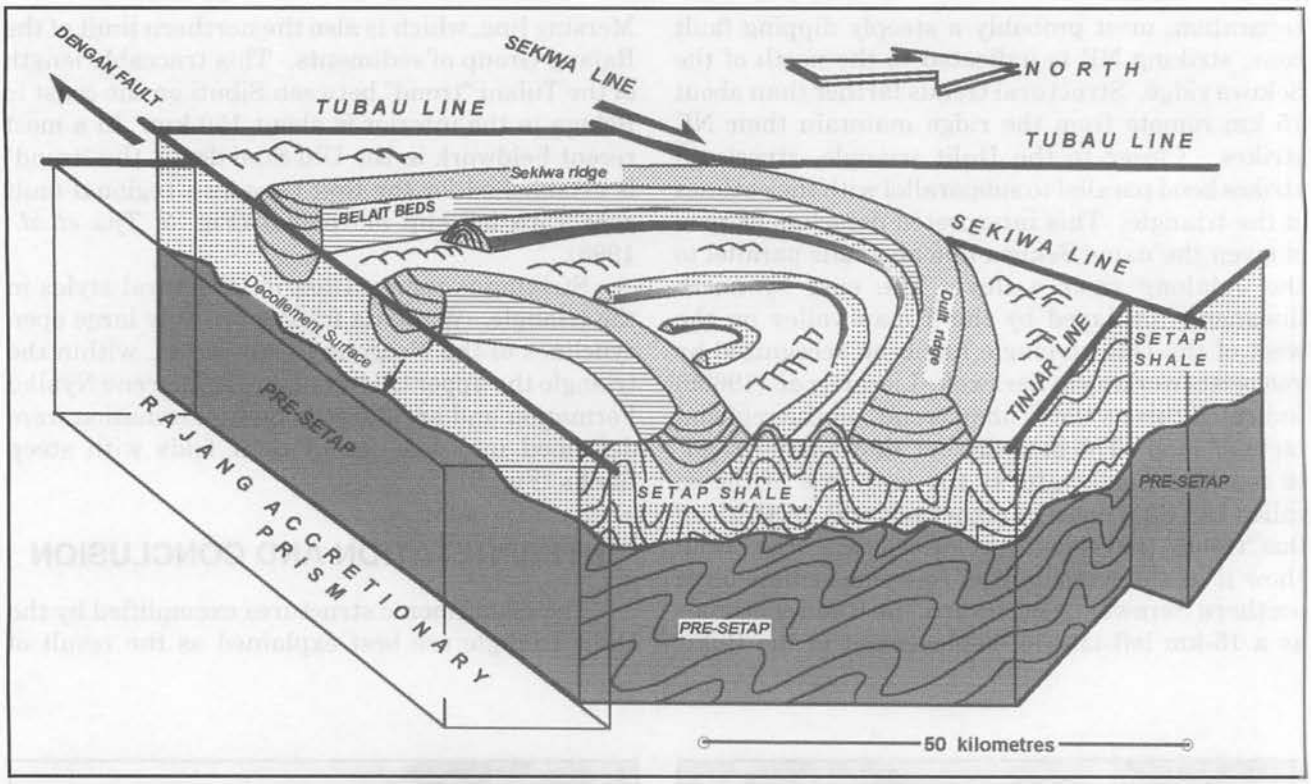

Figure 7. Block diagram illustrating detachment tectonics at the Dulit triangle. The mobile Setap mudstone is the detachment horizon. Dengan fault, Tubau line, Sekiwa line and Tinjar fault constrained disharmonic structural deformation to within the area framed by these structures. Lateral slip senses on the Sekiwa line and Dengan fault suggest *en bloc* westward expulsion of the area framed by the faults. Morphological inversion has resulted in the Sekiwa and Dulit synclinal ridges. Bar scale refers to near-side of the block diagram.

decollement of post-Setap sedimentary strata that took place in a fault-bounded area. The steeply to vertical dipping faults Tubau, Sekiwa, Tinjar and Dengan have significant strike-slip components and form the frame containing the disharmonic deformation within the Dulit triangle. Frame-folding (*Rahmenfaltung*) of the triangular area developed tight anticlines alternating with tight synclines of Nyalau and equivalent strata that are separated by mobile Setap mudstone from pre-Setap formations, the Setap Formation acting as a decollement horizon and sometimes probably intruding diapirically into the cores of anticlines. Diapirs have yet to be reported from the Dulit triangle, but mud cones (mud-volcanoes) and tightly folded anticlines cored by Setap mudstone are common on the west coast of Sabah and as the Jerudong anticline (Brunei), respectively. Figure 7 shows schematically the Dulit triangle, the Setap decollement horizon, and the strike-slip faults that have been responsible in the frame-folding process. In addition to bending of the post-Setap strata into the Dulit triangle, the latter as displaced *en bloc* towards west along the Sekiwa and Dengan faults.

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