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Asymmetrical deformation, thrusts and mesoscale fracturation of the Nyalau Formation at Bintulu

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Abstract: The Nyalau Formation (Oligocene-Miocene) was deposited in a coastal deltaic environment. It is a succession of sandstones and shales. In Bintulu the sequence has registered an episode of deformation which has structured the area into asymmetrical folds, thrusts and mesoscale fracturation.

The folding is a succession of asymmetrical synclines and anticlines ENE-WSW orientation. The Nyalau anticline and the Bintulu syncline have axes plunging gently to the WSW. The thrusts are widespread with vergence towards the south. The front of the thrusted unit is recognised by vertical to reverse dips, overturning of the sequence and intense fracturation.

The mesoscale fracturation show four main directions 010°, 030°, 150° and 170° which are conjugate shears and hybrids. Normal faults are oriented mainly E-W. The lithology of the sequence respond differently to the deformation; the clean sandstones are fragile, the shales and sandstones rich in organic matter attenuate the pressures with their compressive character and then show spectacular structures as movement accommodation.

This structuration is the result of the structural events that occurred during Late Early Miocene-Middle Miocene further north involving the collision of the Luconia with Borneo. This structural edifice probably continued to the offshore and may develop traps similar to those related to the thrust belts but at different scales.

GENERAL GEOLOGY

Bintulu is situated in the NW Sarawak and is geologically included in the Miri Zone (Fig. 1). This zone is underlined by crustal terrains Hutchison (1996). The Nyalau Formation (Oligocene-Miocene) covers all the area of Bintulu and extends from the Tatau horst to the Niah river occupying most of the area between the northern margin of the Belaga Formation and the coast. The Nyalau Formation is considered as the major transgression over the Eocene land mass. It rests conformably on the Buan Formation and with marked unconformity on the Belaga Formation (Liechti *et al.*, 1960). The Nyalau Formation has been deposited in a coastal deltaic environment; it is a succession of fine grained calcareous often argillaceous sands alterning with all gradation to clay and shales. The Nyalau Formation is sandy at the west becoming more muddy eastwards where it is known as the Setap Shales (Liechti *et al.*, 1960).

The ideal sedimentary sequence in the area of Bintulu represent a succession characteristic progradational tidal dominated sequence which shallows and coarsen upwards from offshore muds into silts and sands dominated facies. This sequence has been recognised in several localities, the most characteristic is situated at the mile 16 on the Bintulu-Miri road and at the Sungai Mas (Fig. 2).

The sequence starts at the base with unstructured dark gray or black muds and enriched in sand towards the top as thin layers; the muds pass to a tidal flat complex muddy or sandy developing then respectively flaser, lenticular, wavy and parallel laminated sandstone and mudstone facies, this is finely covered by fine to medium grained sandstones with low angle cross stratification, herring bones cross stratification, flaser and opposing direction of stratification characteristic of estuaries deposits.

Structurally, the area of Bintulu has been subject to deformation expressed by the different kinetic elements distinguishable on the field. As a result of this episode of deformation, this area has been folded, thrusted and affected by mesoscopic fracturation (Fig. 3).

THRUSTS

Sedimentary facies control on structural style

The lithology of the Nyalau Formation in Bintulu is a relevant factor in the occurrence of thrusts (Figs. 2, 3, 4 and 5). The shales act as the surface of slide along which the thrust movement is favored due to physical properties of shales. On the other hand sandstones which always occupy the

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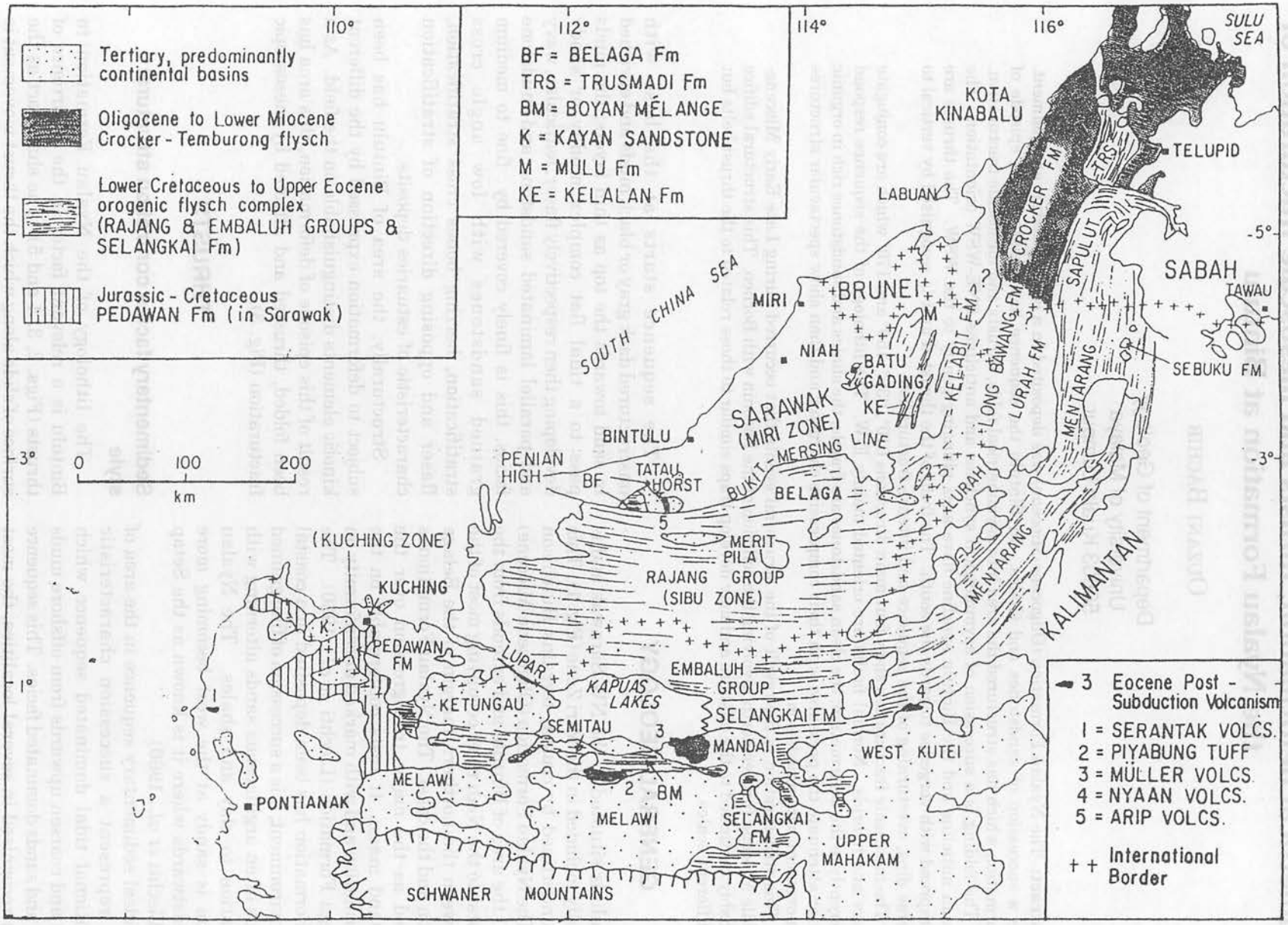

Figure 1. Sketch geological map of Sarawak, Sabah and contiguous Kalimantan (Borneo) to emphasize the Rajang Group. The eastern Miri Zone contains several inliers of Kelantan and Mulu Formations, interpreted to be equivalent to the Rajang Group. The Sibu Zone contains several large Pliocene volcanic massifs. Within the Embaluh Group outcrop they are known as the Metalung Volcanics. Based on Tan (1982), Lim (1985), Pieter *et al.* (1987) and Pieters & Supriatna (1989) (in Hutchison, 1996).

Figure 2. Lithology of Bintulu area.

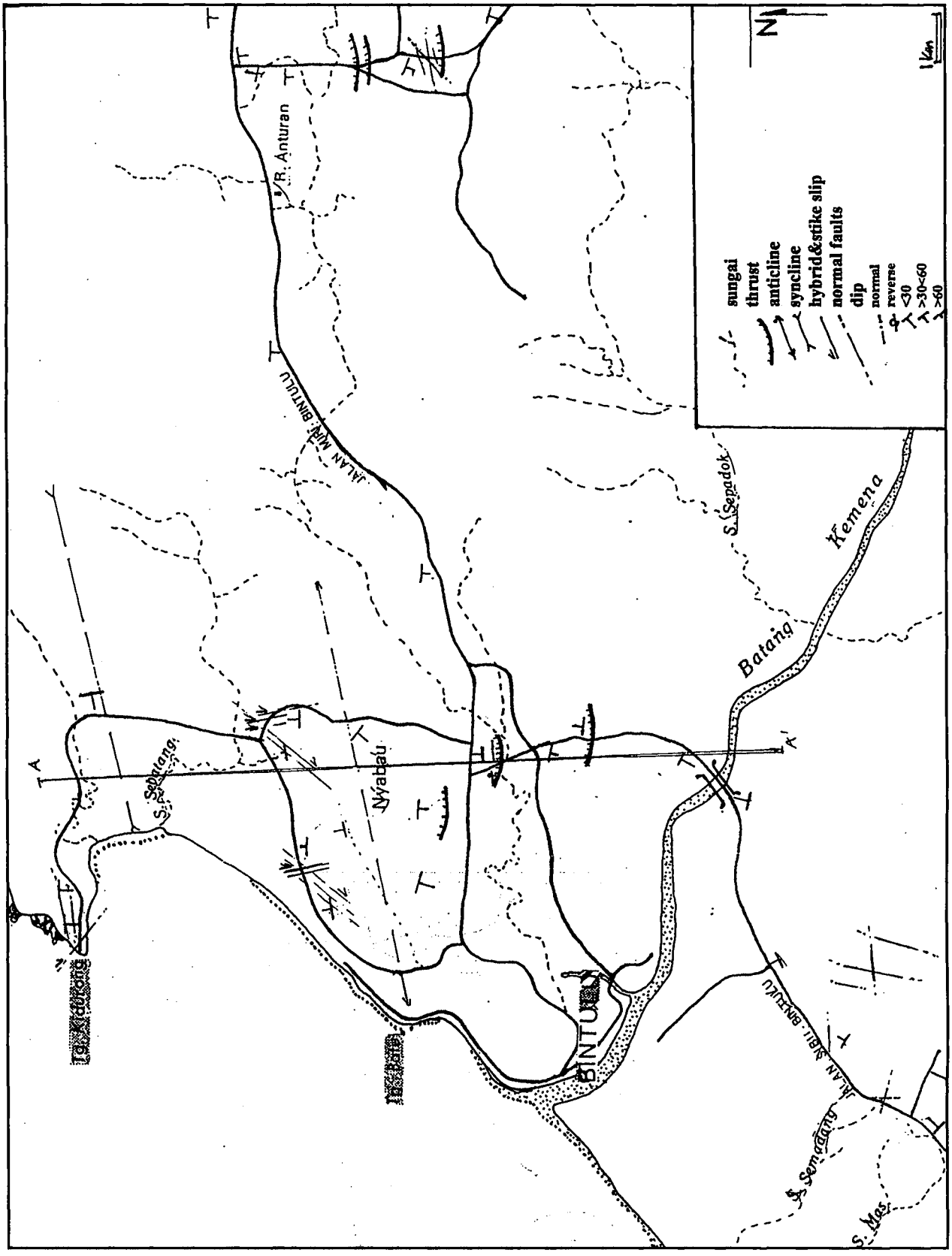

Figure 3. Structural map of Bintulu.

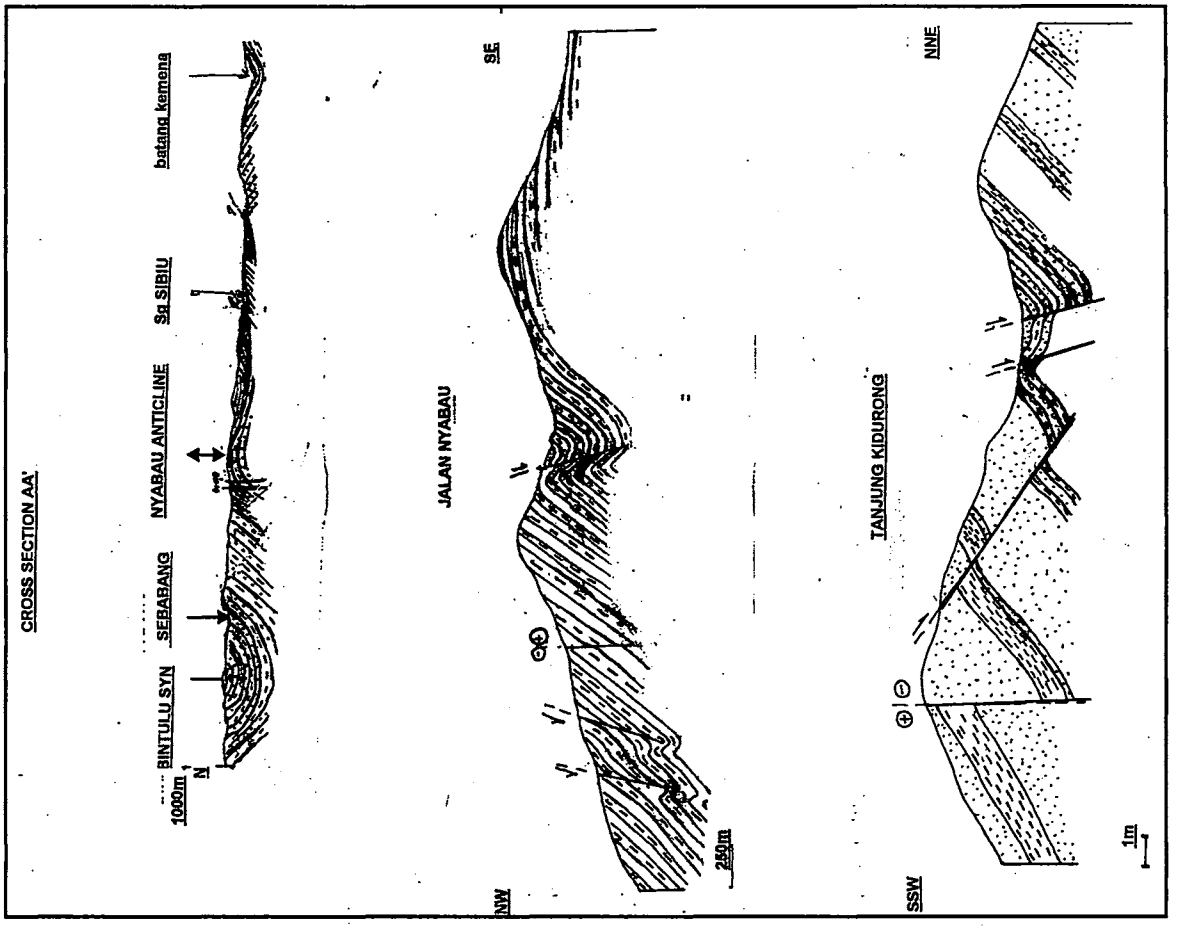

Figure 5. Cross section at N Bintulu.

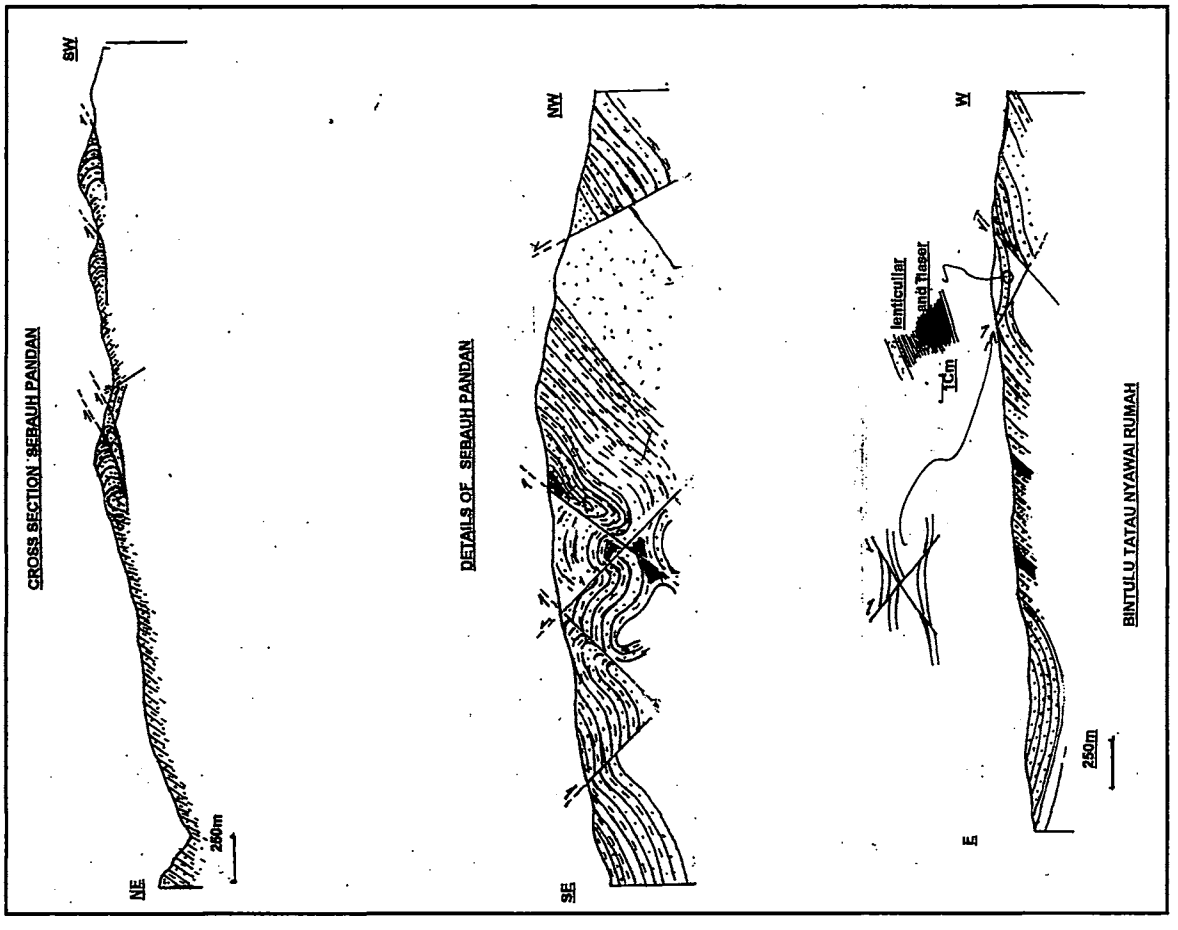

Figure 4. Cross sections at E and SE Bintulu.

front of the thrust units inhabit movement through frictional interaction with the substratum.

The thrusting is widespread in the area of Bintulu, dislocating the sequence and have produced parautochtonous units. The geometry of the thrust has been identified. It is gently dipping to the north and extends for hundreds of meters with a vergence towards the south. From the structural map of Bintulu area the front of the thrust line is easily pointed out which is nearly E-W and probably continue to the offshore. The megascopic features of the thrust are interpreted from the integration of the mesoscopic features recognised on the field. The fronts of the thrusted units are now occupied bounded by river valleys and are recognised by the overturning of the sequence, perpendicular to reverse dips and intense fracturation. The intensity of the deformation decreases from the front to the end of the thrust unit.

FOLDS (FIGS. 3 AND 6)

The projection of the strike and dips of the stratification of the Bintulu area indicate that the area has been folded. Axes of the folds are oriented ENE-WSW. These folds are asymmetric and show a southwards vergence. The structural map of the Bintulu area reveal the asymmetrical Nyabau anticline and Bintulu syncline with axes dipping gently to the WSW.

MESOSCALE FRACTURATION

The pattern of the fracturation strike have been analysed; four main families of fractures have been distinguished 010°, 030°, 150° and 170° (Figs. 3 and 7). These directions represent conjugate shears and hybrid resulting from forces in the north-south direction with a sense of movement towards the south. In the field some of these fractures are closed (joints) and have no measurable slip or dilation at the scale of observation but the parallelism with nearby kinetic indicators (shears and hybrid fractures) and the exhibition of a few millimeters of slip allowed to group them together.

The direction of the normal faulting is dominated by the E-W direction like shown by the rosace of the strike of the normal faults. An internal shear is recognised in the sandstones rich in organic matter which induce the appearance of spectacular structures to attenuate the pressure.

The lithology of the Bintulu area respond differently to the deformation; the clean sandstones are more fragile and the deformation is dominated by the fracturation. Shales and sandstones rich in organic matter are more plastic and attenuate or accommodate the deformation by showing more folding, shears.

Geomorphological expression of the structure

The geomorphology of the area of Bintulu area is interpreted to express the different structures related to the deformation; rivers are not meandering and the system of rivers is very dense formed by small rivers joining more important ones in the region like Batang Kemena and Sungai Sibiu. The thrust front line delimit an area towards the north characterised by a succession of hills between which are developed small lakes. The Bintulu syncline and Nyabau anticline are expressed by the embayment for the former and the extension of the headland into the sea for the later.

CONCLUSIONS

Bintulu area has been structured by an episode of deformation expressed by the kinetic elements recognisable on the field:

- Thrusts widespread with a vergence towards the south their nucleation is favored by the lithology of the Nyalau Formation in Bintulu. The thrust front line is E-W and probably continue to the offshore.
- Folds are asymmetric and oriented ENE-WSW with gently plunging towards the WSW and their vergence is southwards.

Mesoscale fracturation are characterised by the dominance of four families of conjugate shears and hybrid at 010°, 030°, 150°, 170°. Normal faults are globally E-W. Internal shears and faults occur in the rocks rich in organic matter.

The southwards vergence of the thrusts and the asymmetric folds, the mesoscale conjugate shears and hybrid, normal and reverse faults orientation are all compatible in a single model for one episode of deformation generated by forces from the north these forces are to relate to the tectonic event that occur during Late Early Miocene-Mid Miocene further in the north due to the collision of the Luconia and the Borneo island, Hayes (1983), Hutchison (1996). This structural edifice is probably continue to the offshore and may develop traps similar to those occurring in the thrust belts by back pressures but at different scales.

The style of deformation of the Nyalau Formation in Bintulu is probably identical to the deformation of formations deposited in the same coastal deltaic or deltaic environment characterised by the relevant presence of important thicknesses of shales in their stratigraphic column.

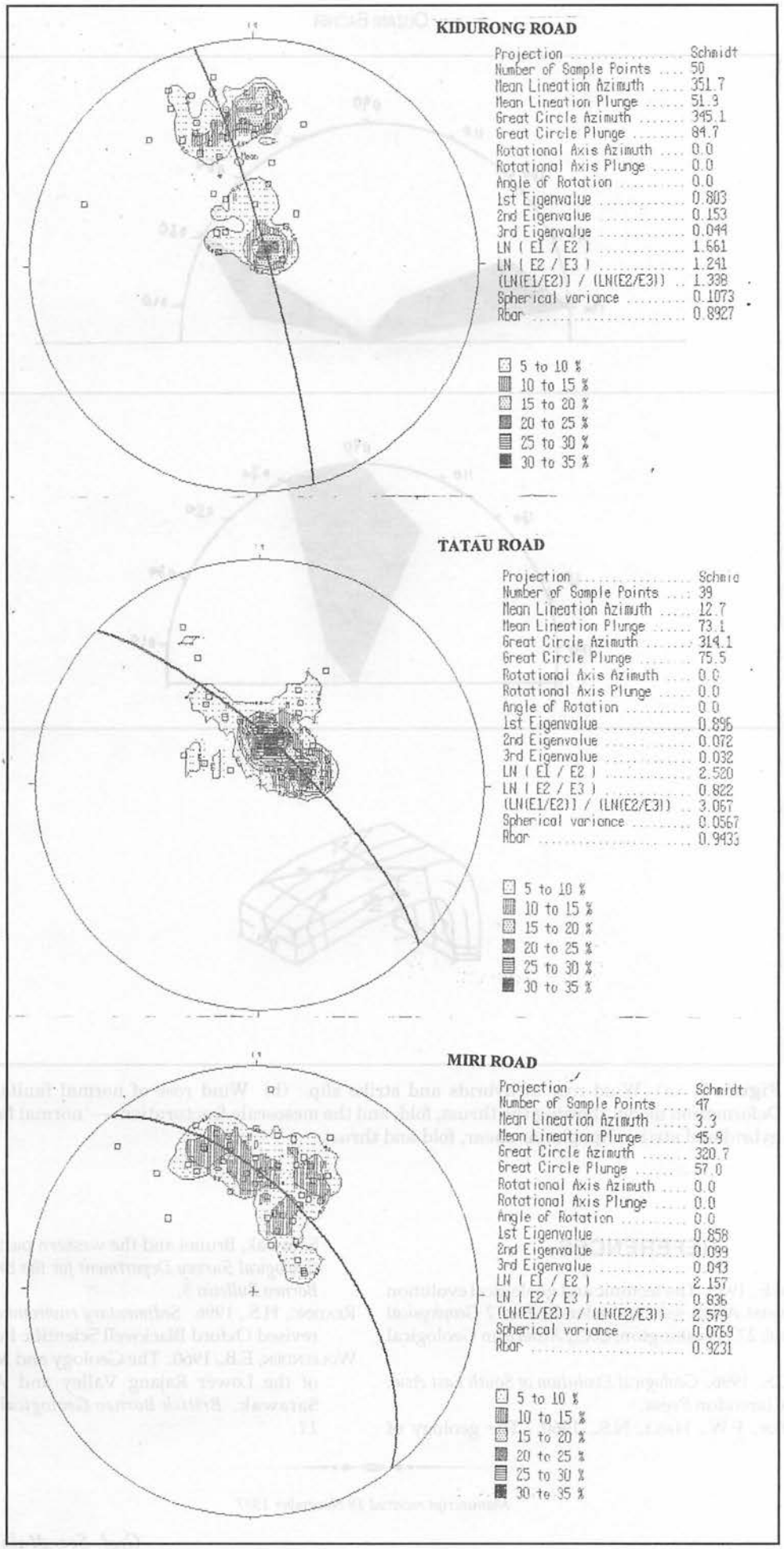

Figure 6. Patterns of stike and dip around Bintulu.

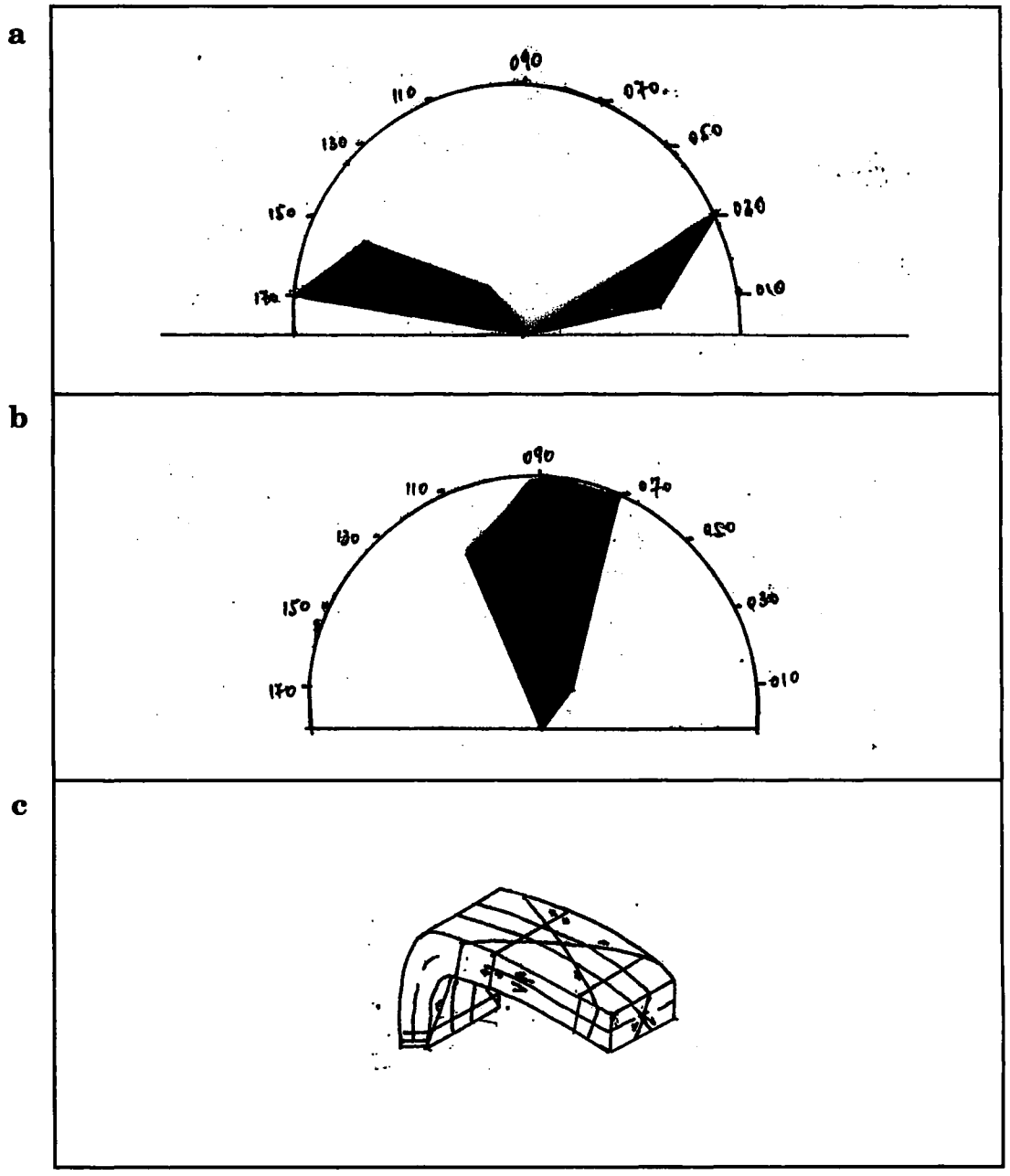

Figure 7. (a) Wind rose of hybrids and strike slip. (b) Wind rose of normal faults. (c) Deformation model showing the thrust, fold, and the mesoscale fracturation — normal faults, hybrid and strike slip, planar shear, fold and thrust.

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