Nature and Significance of the West Baram Line, NW Borneo*

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Abstract

The boundary between the Luconia-Balingian (SW) and Baram (NE) basins is placed along the West Baram Line (WBL, offshore) and Tinjar Line (TL, onshore). These "lines" are enigmatic features of Borneo's geological framework; their tectonic significance is unclear. Most reconstructions composite the two lines into a single entity that marks the NE edge of the Luconia microplate. Some tectonic reconstructions link the WBL with the East Vietnam-Red River fault systems to help accommodate extrusion of the Indo-China Block and opening of the South China Sea, ca. 32-16Ma (SCS); other reconstructions depict the WBL-TL as a transform fault separating Luconia from the Dangerous Grounds as the latter was subducted beneath NW Borneo.

Our interpretation of 2D seismic data across the WBL indicates the following:

1. The WBL is a fault zone, 50 km wide, composed of several large normal faults that dip steeply NE.
2. The WBL does not project directly into the TL.
3. Seismic sequences correlated across the WBL include a sequence that ties to Late Oligocene to Early Miocene (Cycle I-Cycle II) clastics in the Luconia-Balingian Province.
4. The Oligo-Miocene sequence (OMS) isochron map shows no evidence for large-scale differential displacement across the WBL. Thus, it is unlikely that WBL was a major Early Miocene strike slip fault.
5. The OMS is a post-rift sag sequence. It exceeds 3 km thickness NE of the WBL, but thins abruptly to the NW, onlapping rifted crust of Dangerous Grounds. Therefore, a major phase of extension on the Dangerous Ground (Late Eocene?) pre-dates opening of the SCS.

When we consider our observations in light of regional heat flow, gravity, and geological data, we favor interpreting the WBL and TL as an ancient suture along which deep structures have been reactivated. The Dangerous Grounds and the Luconia-Balingian Province are linked by the OMS and share an episode of Late (?) Eocene rifting. NE of the WBL the percent of crustal thinning during that rifting appears to have been much larger than in the Luconia-Balingian Province; a circumstance that may be related to rheological contrasts across the old suture. We see no evidence to support large-scale Oligo-Miocene strike slip faulting along the WBL, which implies less Neogene subduction beneath NW Borneo than is shown in most proposed tectonic models.

Discussion

The boundary between the Luconia-Balingian (SW) and Baram (NE) basins is placed along the West Baram Line (WBL, offshore) and Tinjar Line (TL, onshore) (Figure 1). These "lines" are enigmatic features of Borneo's geological framework; their tectonic significance is unclear. Most reconstructions composite the two lines into a single entity that marks the NE edge of the Luconia microplate. Some tectonic reconstructions link the WBL with the East Vietnam-Red River fault systems to help accommodate extrusion of the Indo-China Block and opening of the South China Sea, ca. 32-16Ma (SCS); other reconstructions depict the WBL-TL as a transform fault separating Luconia from the Dangerous Grounds as the latter was subducted beneath NW Borneo. Interpretation of 2D seismic data across the WBL, regional geologic features, and filtered Bouguer gravity data indicate the following:

1. The WBL is a fault zone, 50 km wide, composed of several large normal faults that dip steeply NE.
2. The WBL does not project directly into the TL, but may be part of a larger fault zone that has developed and persisted along and ancient suture in the Dangers Grounds terrane.
3. Seismic sequences correlated across the WBL include a sequence that ties to Late Oligocene to Early Miocene (Cycle I-Cycle II) clastics in the Luconia-Balingian Province. Early Miocene gross depositional environments suggest the WBL-TL controlled the shelf slope break.
4. An isochron map of an Early Miocene sequence that can be carried across the WBL shows little evidence for large-scale lateral displacement across the WBL.
5. The Early Miocene sequence appears to be a late rift sag sequence (LRSS). It reaches at least 2 km thickness NE of the WBL, but continues to thicken to the SE as it passes below the NW Borneo deepwater thrust belt (and seismic record length). The LRSS thins abruptly to the NW and NE as it onlaps rifted crust of Dangerous Grounds.

6. Free air and Bouguer gravity data suggest the LRSS may be filling accommodation space created by a high percentage of crustal thinning beneath the Baram basin, which suggests that a major phase of extension on the Dangerous Ground occurred in the Early Oligocene to Late Eocene prior to rifting in the SW part of the SCS.

The linkage of the LRSS across the WBL, lack of offset of folded Early Miocene rocks onshore, and the continuity of N-S trending gravity anomalies, all argue against large-scale strike slip faulting along the WBL in the Oligocene to Early Miocene. After considering these observations in conjunction with regional heat flow data and Pliocene volcanism of the Usun Apau Plateau, the WBL-TL appears to represent an ancestral suture in the Dangerous Ground terrane that has been episodically exploited and reactivated during the Cenozoic.

- Dangerous Grounds DGs, including Luconia, collides with SE Asia sometime between ~110 (Hall et al. 2009) and ~ 40 Ma (Fhynn et al. 2010).
- Proto-SCS is paleo-Pacific oceanic lithosphere that arrives with Dangerous Ground.
- WBL and TL are generally considered a composite feature that acted as a dextral transform during subduction of proto-South China Sea beneath Sabah.
- Subduction ended with collision of DGs rifted continental crust with NW Borneo.

Luconia is comprised of multiple provinces (Figure 2). Fault trends align and pass from DGs to Luconia. Baram Basin: thick clastic foreland basin wedge derived and re-worked from interior highlands Upper Cretaceous to Lower Tertiary flysch sequences. Dangerous Grounds and rifted continental crust extends onshore beneath Baram Basin and Luconia. Most tectonic models (Hall, 2002, Fhynn et al., 2010) treat WBL-TL as right lateral transform fault relating to SE directed subduction under NW Borneo (Figure 3).

1. Strong contrasts in heat flow and geothermal gradient.
2. Marked break in bathymetry.
3. SW end of NW Borneo deepwater thrust belt and NW Borneo trough.
4. Onshore oroclinal bend in Paleogene flysch deposits (60 km displacement; no distinct break).
5. Onshore alignment of Dulit plateau and Usun Apau plateau (Figure 4).

TL (down to NE) may be SW limit of WBL fault zone, w/ right stepping bend. Pre-MMS late rift sag sequence thins onto Dangerous Grounds and extends across WBL; correlates to Early Miocene clastics in wells (Figure 5). Late rift sag sequence thickens to SE. True base cannot be defined as it extends deeper than seismic records. WBL may have acted a hinge, but sequences do not appear to be laterally displaced (Figure 6). Minimal strike-slip faulting occurs in coastal fold belt in E. Miocene sediments.

Overall shelf-slope-basin geometry is not compelling for large-scale strike-slip displacement along WBL-TL. WBL-TL more likely acted as a hinge line accommodating subsidence and normal faulting as the shelf slope break (Figure 7).

Areas shaded light blue outline in white dashes (Luconia) has a subdued Bouguer response relative to areas to the NE that appear more intensely faulted (Figure 8). N-S striking gravity anomaly on G10 ridge extends from Luconia across WBL with no significant offset. Onshore a major NE-SW gravity high (Anau-Nyalau Block) is not offset by the Tinjar line; nor are NE trending folds in the Nyalau Formation (Oligocene-Early Miocene). Bouguer gravity high underlies Baram Basin; possibly representing highly attenuated crust and generation of accommodation space for the late rift sag sequence.

Conclusions

The West Baram–Tinjar Line is not a large-scale Early Miocene transform fault, but rather an ancient crustal discontinuity that was persistently re-activated in the Cenozoic.

Selected References

Hall, P., L.B. Cooper, and T. Plank, 2009, Evolution of mantle flow and melting beneath a migrating back-arc spreading center: EOS Transactions, American Geophysical Union, v. 90/52, Abstract T31D-05.

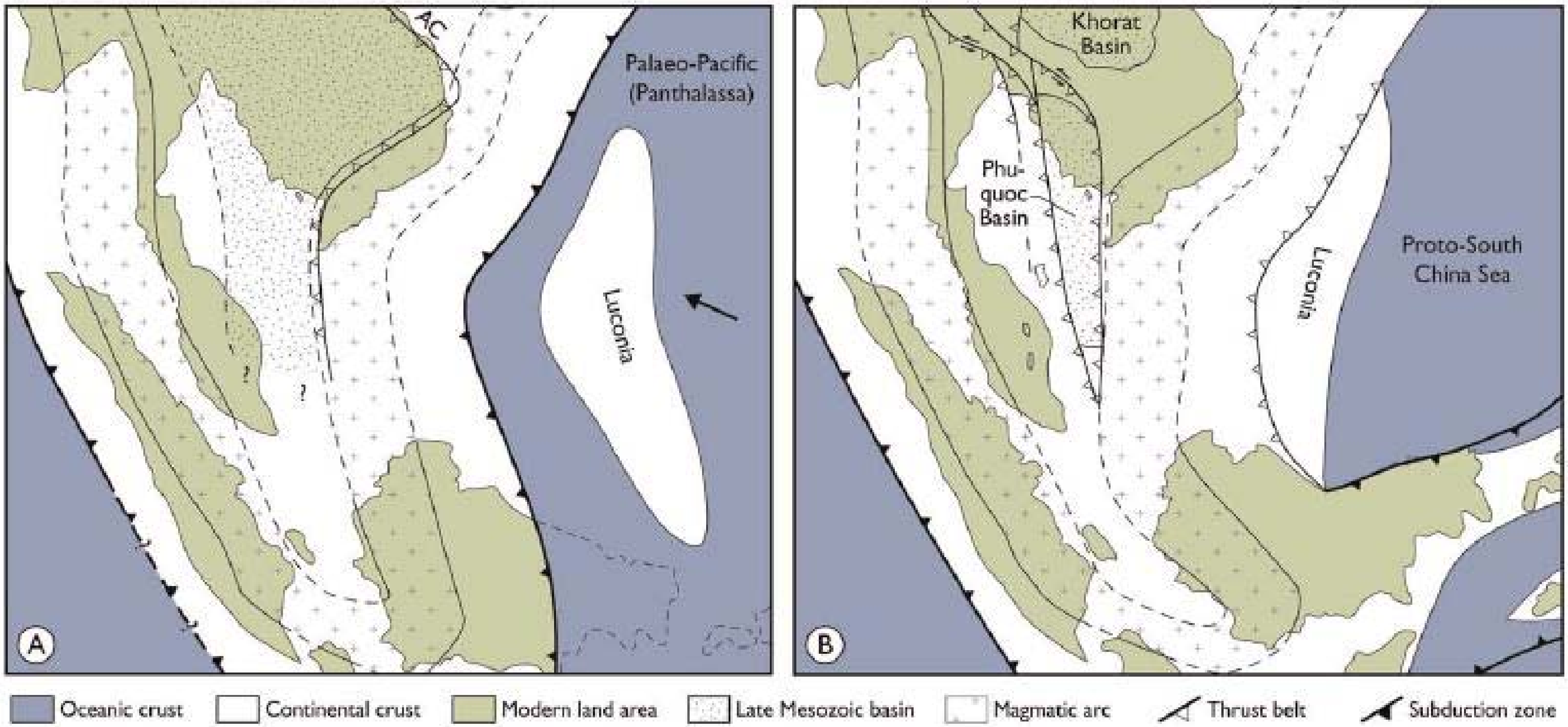

Fig. 10. Simplified reconstruction of the palaeogeographical outline of SE Asia (**a**) immediately before the accretion of Luconia to SE Asia and (**b**) immediately after accretion. Prior to the Luconian suturing a large epicontinental foreland basin formed in association with the rise of a magmatic arc behind the subducting palaeo-Pacific Ocean and uplift along the Annam Cordillera (AC) farther north. Basin inversion associated with the Luconian collision resulted in basin segregation as a result of uplift along well-constrained deformation belts. Compressional folding and faulting dominated along the roughly north–south-trending fold belts, whereas left-lateral transpression took place along the more NW–SE-trending deformation belts.

Figure 1. West Baram (WBL) and Tinjar Lines (TL): Tectonic Elements.

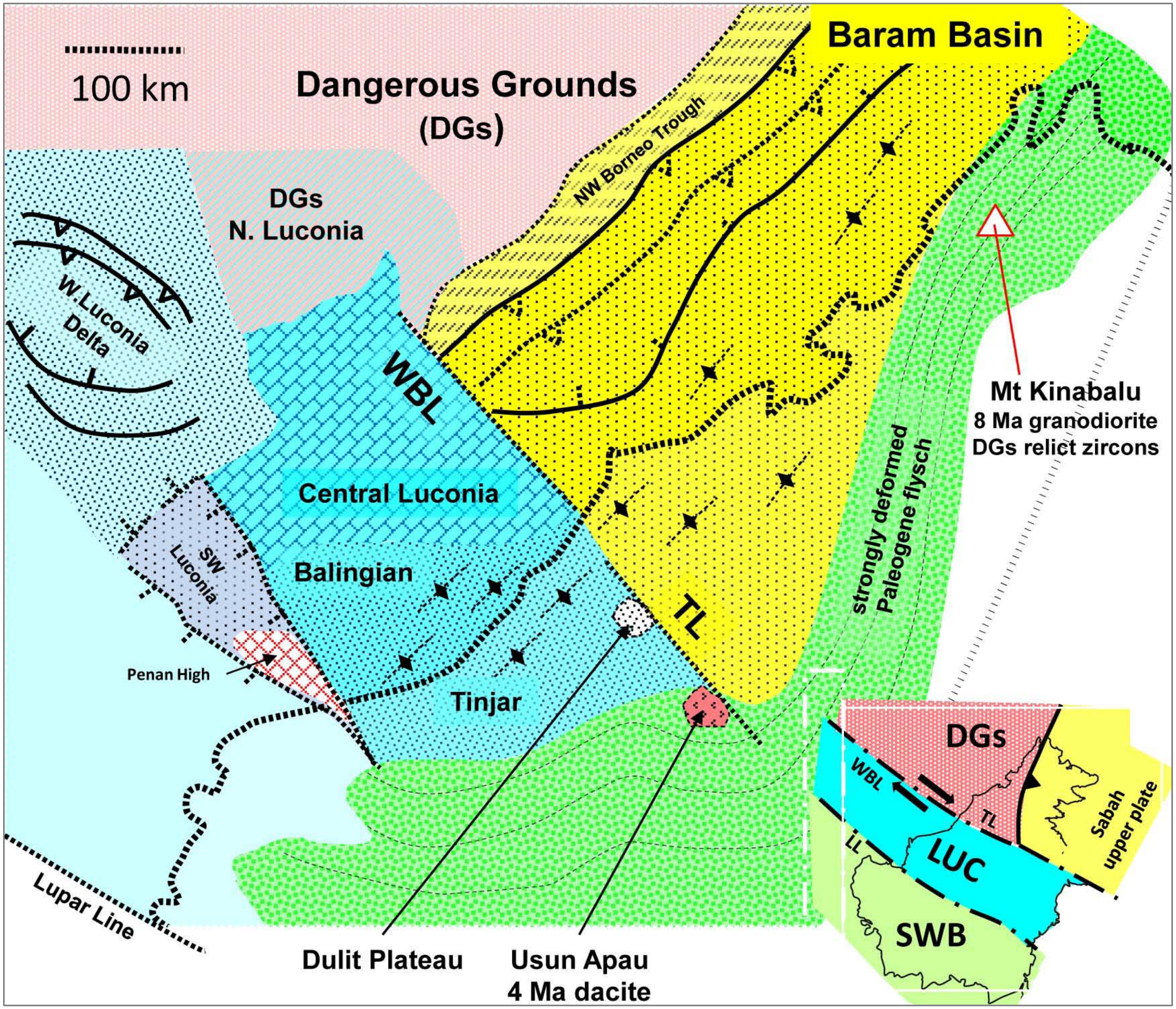

Figure 2. West Baram –Tinjar Lines divide two rich petroleum provinces: Luconia (carbonates> clastics, gas > oil) and the Baram Basin (no carbonate production, oil > gas).

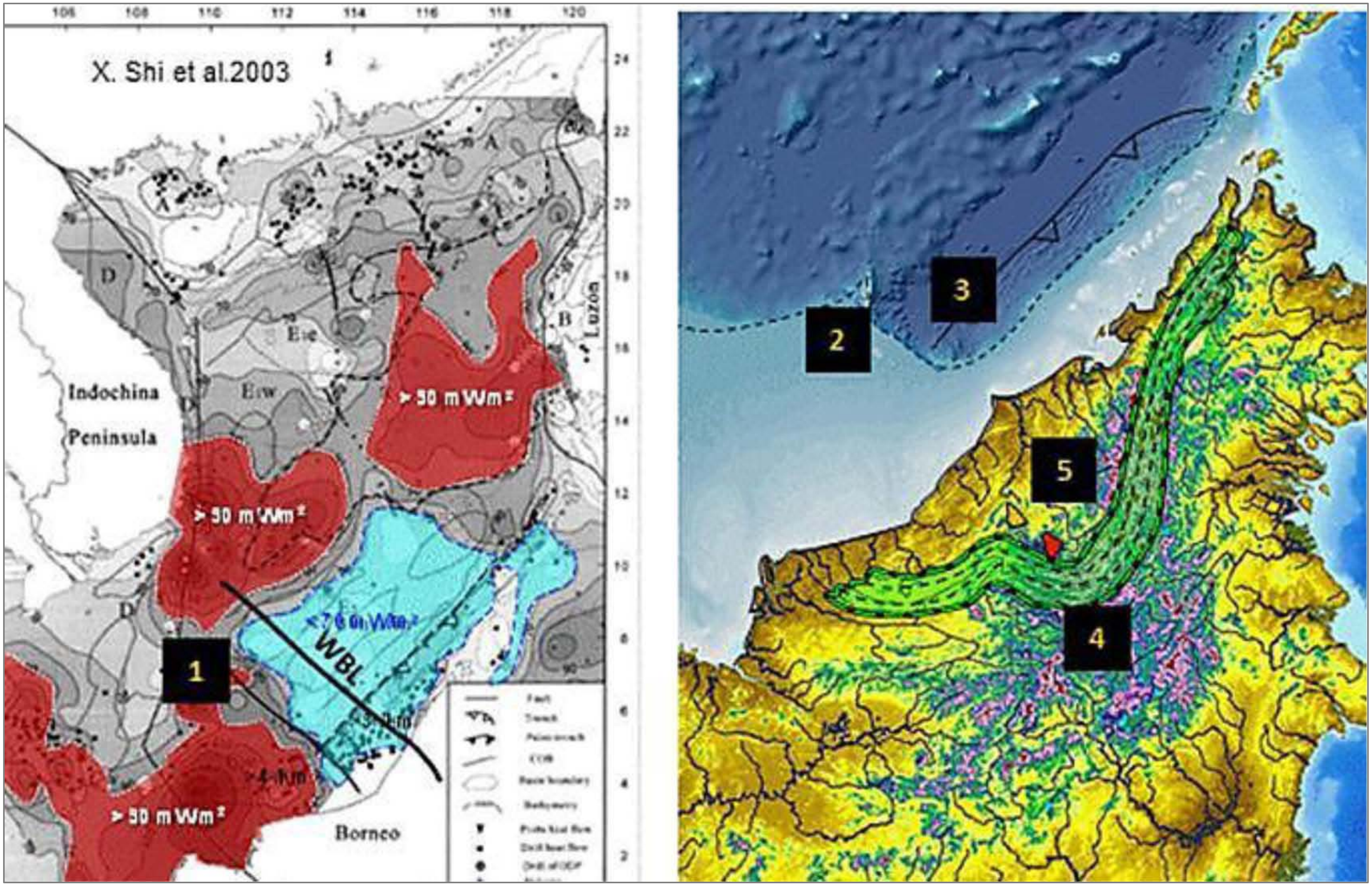

Figure 3. Expression of the West Baram and Tinjar Lines.

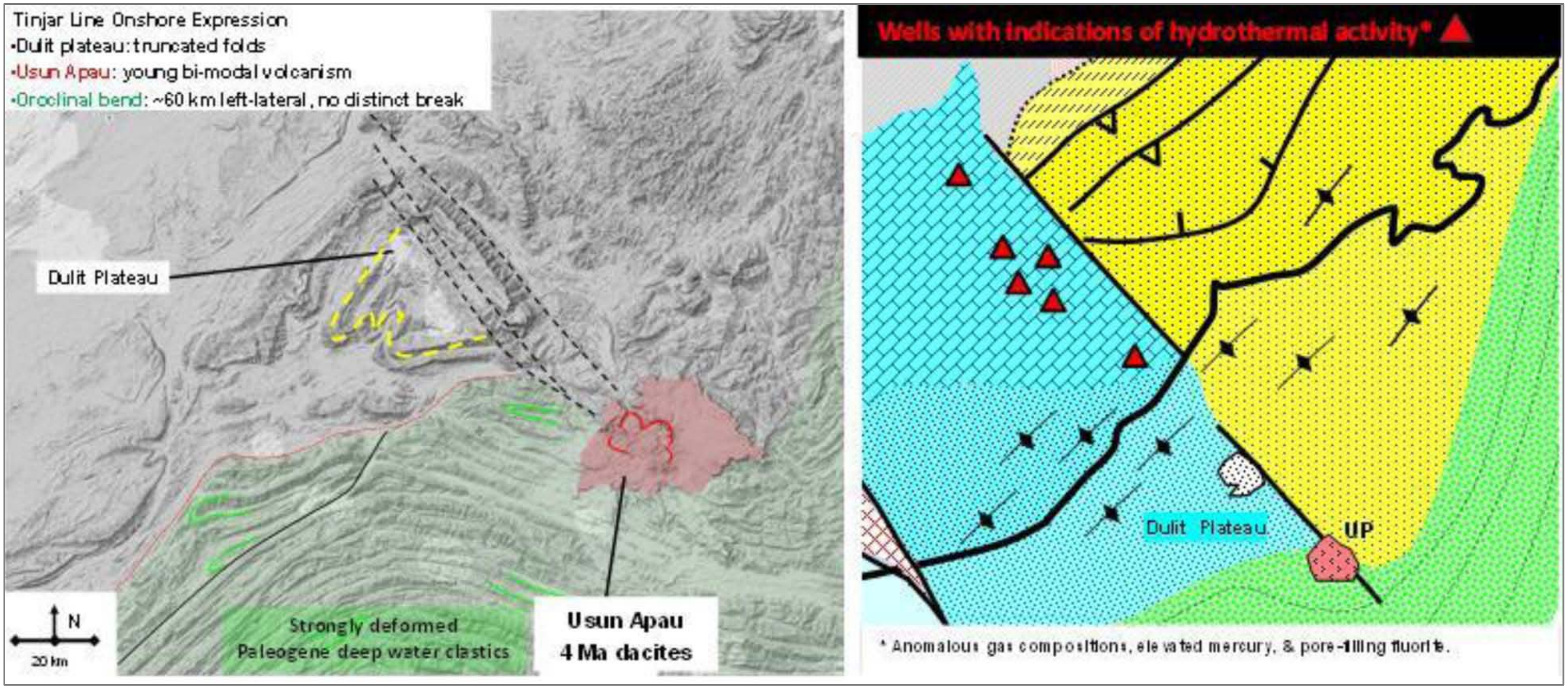

Figure 4. Dulit plateau, Usun Apau Volcanics, and an oroclinal bend in fold belt of Paleogene turbidites define the Tinjar Line onshore. The Tinjar Line projects (NW) offshore towards anomalous wells with evidence of hydrothermal thermal activity, NE-SW trending folds in Early Miocene Nyalau Formation are not offset.

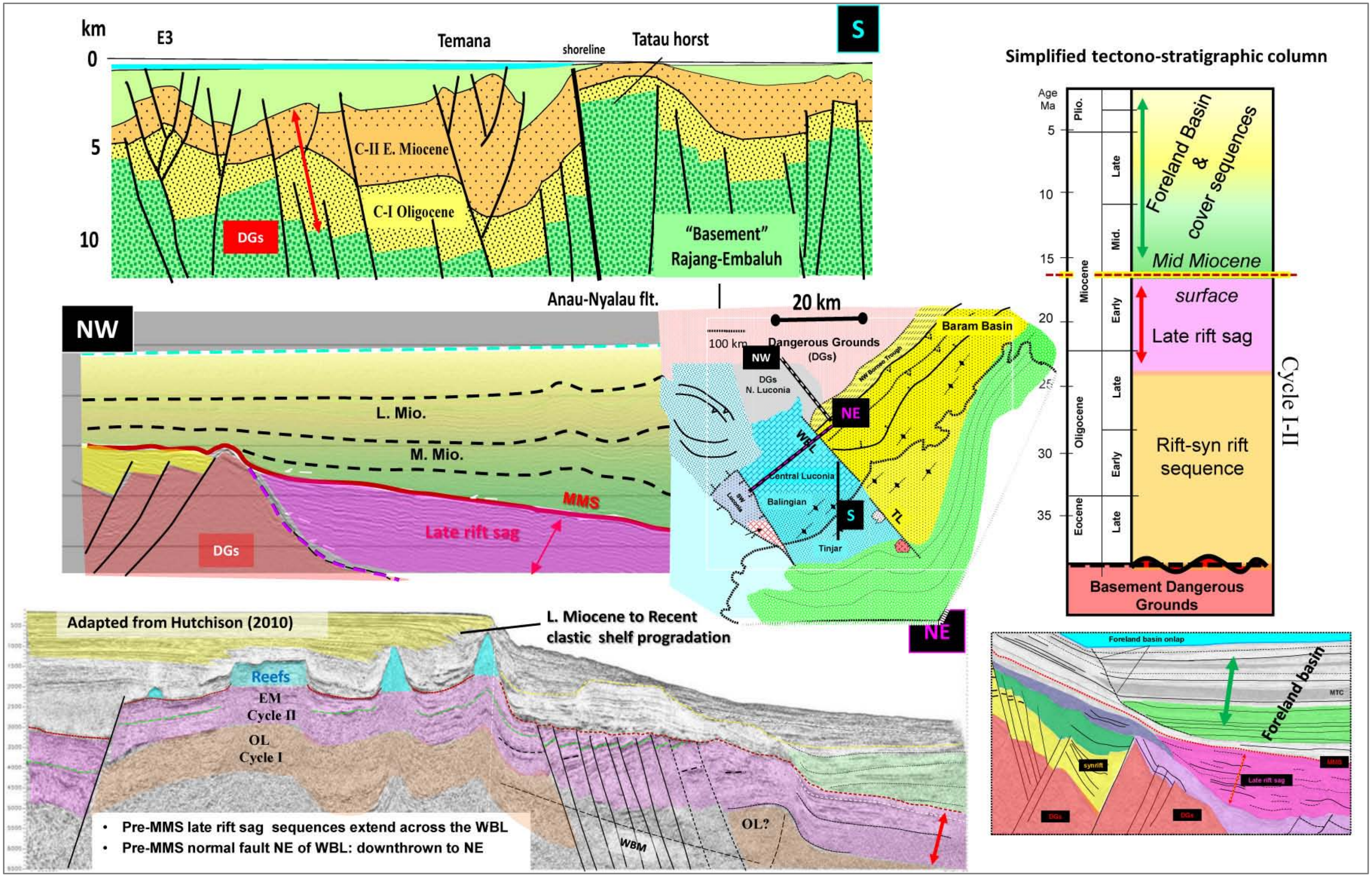

Figure 5. Provinces share similar tectonostratigraphic history: Eocene extension, Oligocene-Early Miocene rift and syn-rift fill, and post-rift cover sequences above a Middle Miocene Surface (MMS represents an unconformity in some areas and a condensed section in other areas). Pre-MMS sequences can be mapped across WBL.

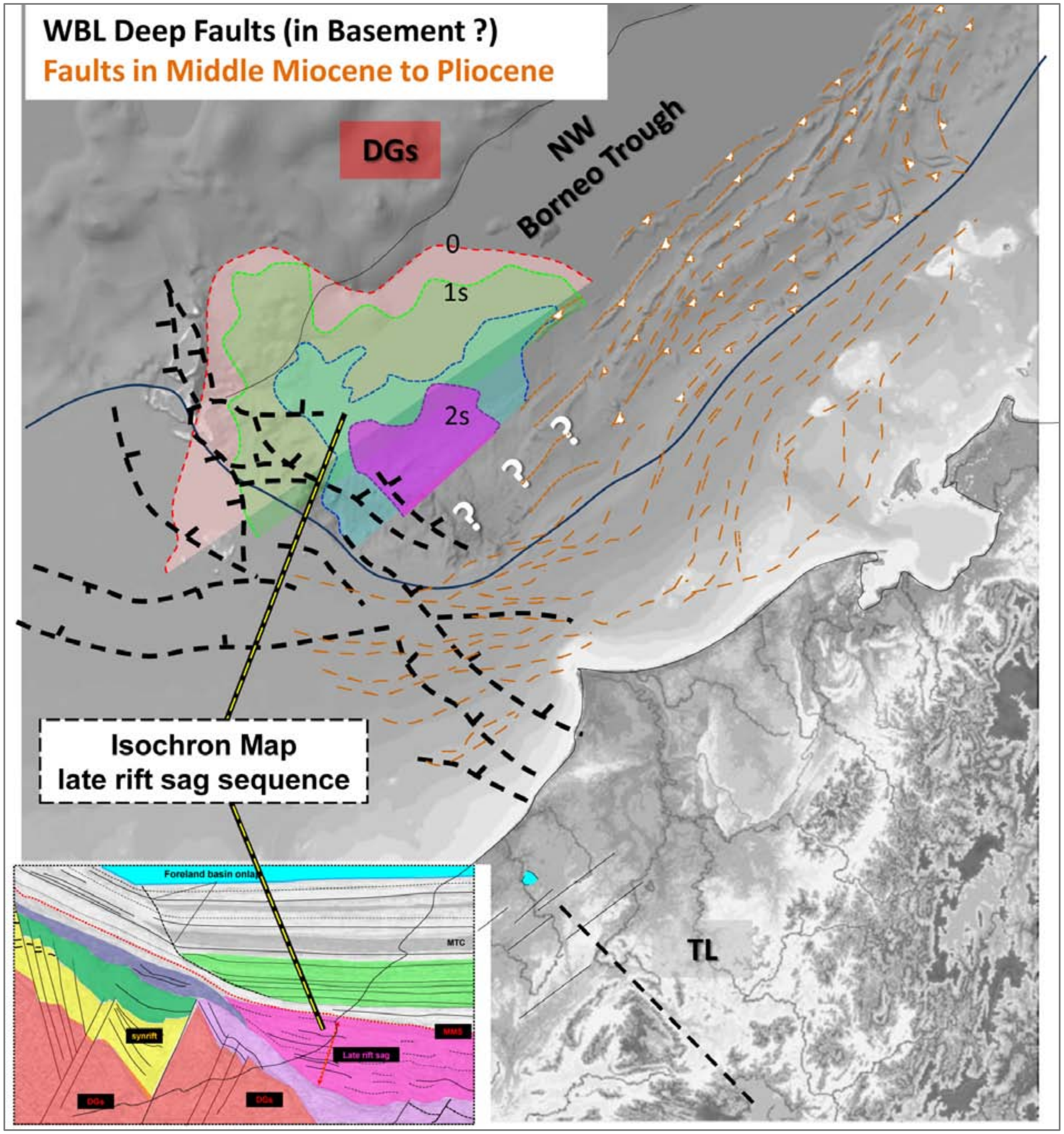

Figure 6. Many short segment normal faults along WBL (down to NE); no thru-going master fault.

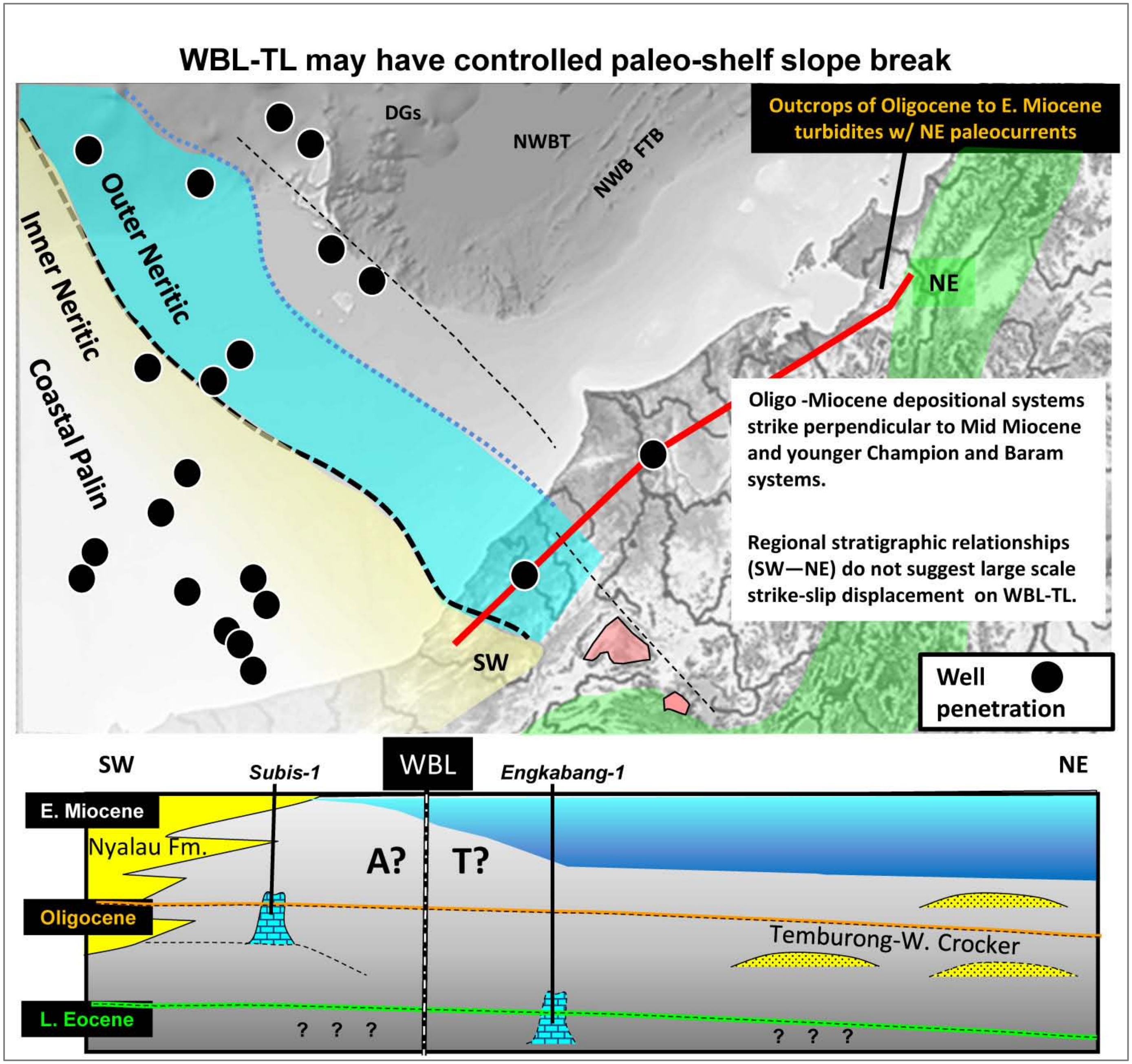

Figure 7. Nyalau Formation: Oligocene - Early Miocene depositional trends parallel WBL-TL.

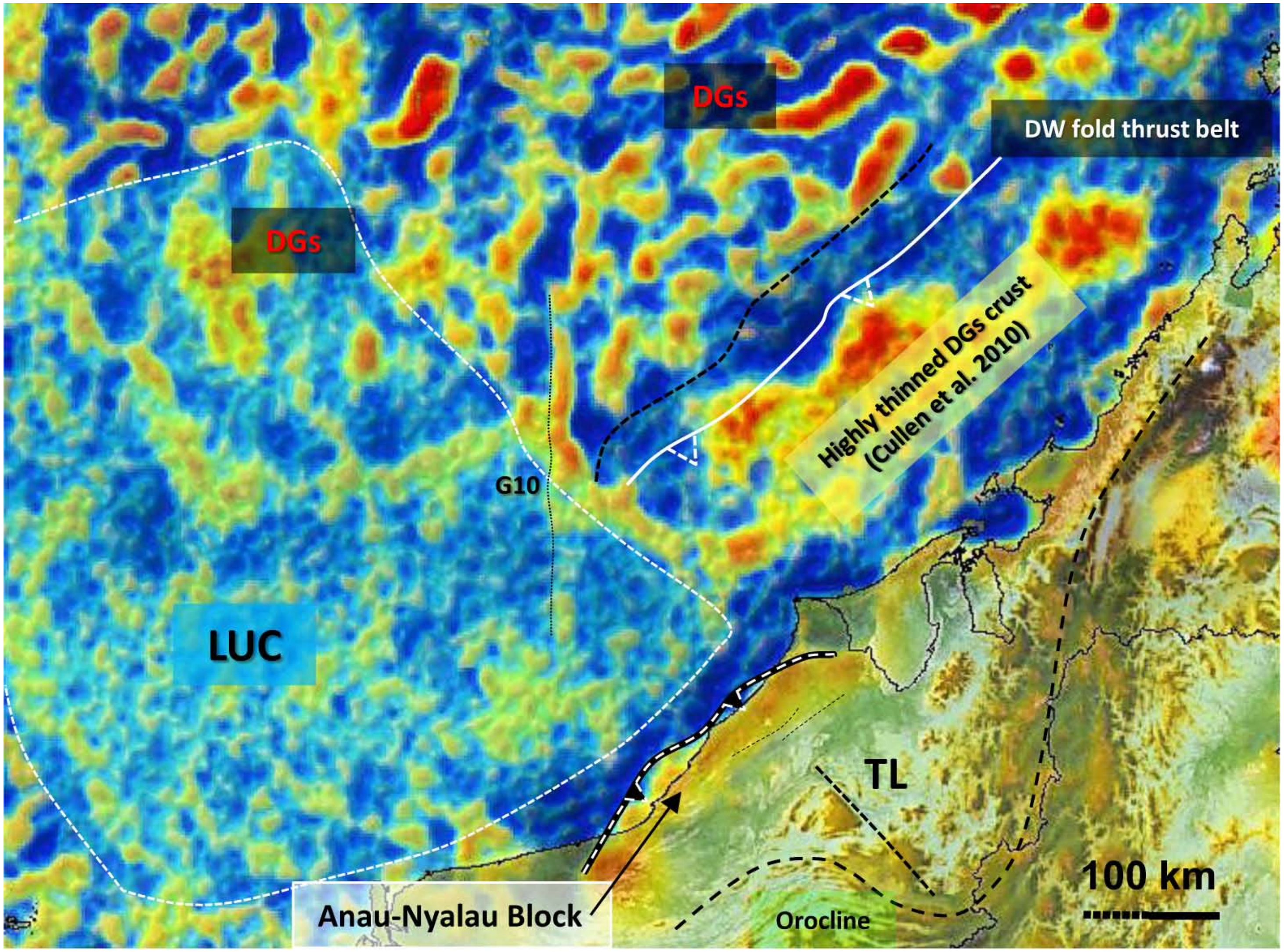

Figure 8. Bouguer Gravity: 500 km high pass filter draped with first vertical derivative.