INDONESIAN JOURNAL ON GEOSCIENCE
Geological Agency
Ministry of Energy and Mineral Resources

Journal homepage: http://ijog.bgl.esdm.go.id
ISSN 2355-9314 (Print), e-ISSN 2355-9306 (Online)

Wrench-Slip Reversals and Structural Inversions: Cenozoic Slide-Rule Tectonics in Sundaland

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Manuscript received: January 17, 2014, revised: March 12, 2014, approved: April 10, 2014

Abstract - Most of continental Southeast Asia, that is, Sundaland and Indosinia, achieved a relative tectonic stability by the beginning of the Cenozoic. Since then a strong tectonic activity in Sundaland has been restricted to existing regional fault zones and to regional slow, vertical crustal movements elsewhere that produced small to very large sedimentary basins. On the other hand, regional deformation of Indosinia as a consequence of ductile shearing has continued into the Paleogene. Since the Oligocene, the northern part of Sundaland and Indosinia have been extruded differentially towards southeast along the Red River, Wang Chao (or Mae Ping, or Tonle Sap), and Three Pagodas - Axial Malay fault zones. The initial cause has been attributed to hard collision between Subplate India with Megaplate Eurasia. Plate dynamics in the region have changed substantially since Mid-Miocene as to force wrench-slip reversals along the major fault zones in Sundaland as well as in Indosinia. Concomitant structural inversions are demonstrated on seismic sections. In the core of Sundaland, earlier transtensional wrenching was succeeded by transpressive strike-slip faulting that on major faults of the Malay Basin manifested in reversals of sense. From the Hinge-line fault eastward, the transtensional left wrench slip was succeeded by transpressional dextral slip, while in the region to its west the wrench-slip kinematics was an earlier transtensional right slip followed by transpressional left slip. In the Strait of Malacca and eastern margin of Sumatra, right-lateral wrenching in the Neogene has been common. In certain places it could be established a wrench-slip of transtensional character in Oligocene-Early Miocene, and the transpressional wrench movement occurred mainly during the Middle to Late Miocene. The remarkable coincidence of termination of spreading of the South China Basin in Langhian, and that of the West Philippine and Caroline basins during Mid-Miocene invites further study.

Keywords: transtensional vs. tranpressional wrenching, sequence, domains delineation

Introduction

Sundaland forms the southern part of the Southeast Asian Subplate, whilst the northern portion of the subplate is usually referred to as Indosinia (Figure 1). Pre-Tertiary outcrops are widespread. The two geological terrains can be artificially separated by the 9 degrees northern latitude. The Red River fault forms the northern border; the Sagaing demarcates the western limit, and the Vietnam Shear separates Indosinian continental block from the oceanic and thinned continental crusts of the South China Sea region. The three regional wrench faults, all striking North-west, cut Indosinia into large elongated crustal slabs. These faults are the Red River, Wang Chao (or also called Mae Ping or Tonle Sap), and Three Pagodas. Tapponnier *et al.* (1982) suggested that these regional fault zones possessed left-lateral strike-slip that facilitated extrusion of the crustal slabs towards southeast. This hypothesis attributes sustained collision of the Indian Subplate against the Eurasian megaplate at the Tibetan region as the cause. The tectonic extrusion of Indosinia has been adopted as a working model by many practicing geologists of the region.

Further investigations showed that wrench-slip reversals had occurred on the three fault

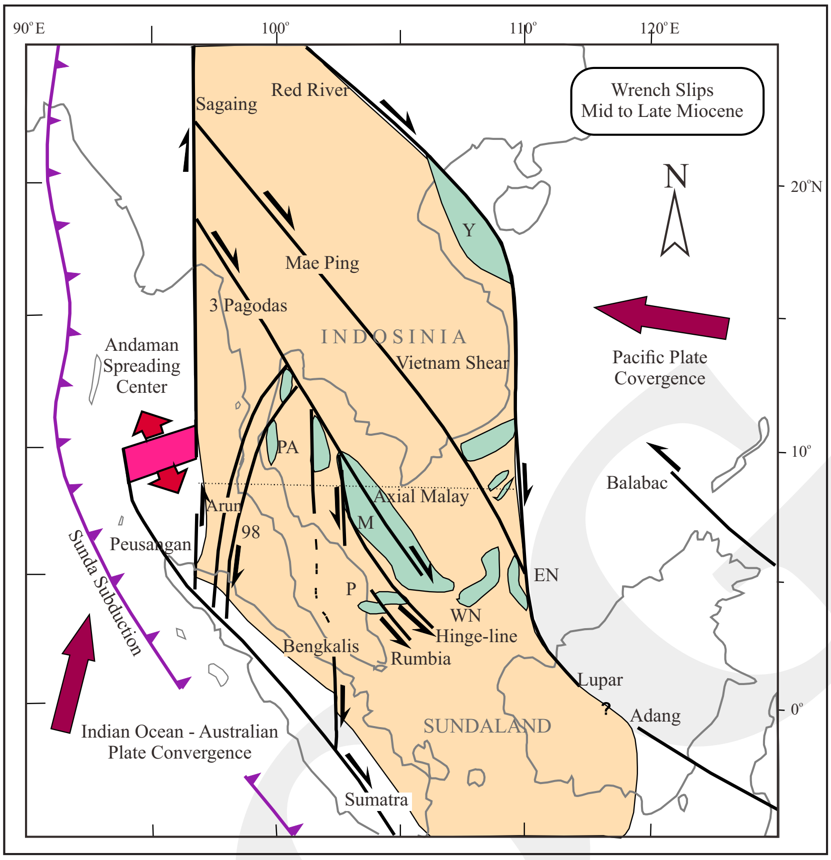

Figure 1. Index map of the Southeast Asian Subplate comprising Sundaland and Indosinia. Pre-Tertiary outcrops are widespread. Wrench-slips in Sundaland during Middle to end of the Miocene. Sundaland is arbitrarily separated from Indosinia by the 9 degrees northern latitude. Wrench-slips in the main Malay Basin and in its western ramp have been different. The Hinge-line Fault acts as an important tectonic boundary. Major faults are named; basins are: Y (Yinggehai), M (Mekong), NC (Nam Con Son), EN (East Natuna), WN (west Natuna, P (Penyu), M (Malay), Pa (Patani).

zones. Lacassin *et al.* (1997) supported wrench reversals and structural inversions with 40Ar/39Ar dated metamorphic rocks, which were interpreted to imply that left-lateral slips occurred in Oligocene - Early Miocene, while dextral wrench slips of the faults occurred in the Pliocene-Quaternary time span. A major argument supporting the changes concerns continuous northward progression of the Indian Subplate collision that has produced a clockwise rotation of over 100^o of the regional stress fields of Indosinia. Rhodes *et al.* (2005) interpreted three tectonic stages for the Three Pagodas Fault zone: (1) initially as a wide ductile left-lateral shear zone in a transpressive environment; (2) followed by individual fault strands of the TPFZ becoming right-slip transtensional; and (3) renewed activity (Holocene?) right-lateral transpressional with small dextral slip in the Northwest of the TPFZ. Exploration for hydrocarbons in the Malay, West Natuna and Penyu basins in the core of Sundaland and also in Tertiary basins located along its western and southern fringes produced a plethora of relevant data pertaining to regional stress field changes (Tjia and Liew, 1996). The main objective of the current article is to deal with Cenozoic kinematics of wrench faulting and structural inversions in Sundaland. A few unpublished/lesser known indicators from Indosinia are included. Relevant structural information is also scattered in the petroleum geology book of Petronas (1999).

Note: Before the age of electronic calculators, a wide range of computations was performed by sliding back-and-forth parts of a slide rule (*mistarhitung*). Elongated crustal slabs of Sundaland moved in similar fashion along wrench faults. The term “slide rule tectonics” is here introduced to encompass the development of regional wrench-slip reversals and associated structural inversions.

Regional geology

Indosinian Slide-Rule Tectonics

Tapponnier *et al.* (1982) proposed a tectonic model of large scale extrusion of the Indosinian continental plate by left-lateral wrenching along regional fault zones: Red River, Mae Ping/Wang Chao, and Three Pagodas. This model is purportedly consistent with the Indian Subplate colliding with the Eurasian Megaplate. The proposers supported their hypothesis with laboratory experiments using plasticine. Lacassin *et al.* (1997) showed that the three regional fault zones were subject to wrench reversals and inversions. Since the Late Neogene the three named faults produced right-lateral wrenching (Figure 2). The effects of initial left-lateral wrench slip have not been fully restored by the later reversals.

Right-lateral wrenching on the Three Pagodas Fault Zone is also indicated in Figure 3. This map fragment is simplified from the Geological Surveyof the Department of Mineral Resources (Thailand) regional map published in 1983. The Three Pagodas Fault Zone (TPFZ) along the Khwae Noi segment has several Neogene (Tertiary-Quaternary) depressions. The Hao Tha Khanun (or Pracham) Basin has a rhombic plan that suggests a pull-apart 40 - 45 km long filled with Neogene-Quaternary sediments. This pull-apart basin is consistent with dextral wrench on the TPFZ, a clear reversal of the sinistral sense (black half-tipped arrow) that characterizes its earlier activity. Fenton *et al.* (2003) believed that faults in northern and western Thailand (including the Three Pagodas Fault Zone) indicate a recent activity. Lateral slip rates were estimated at 0.5 to 2 mm.

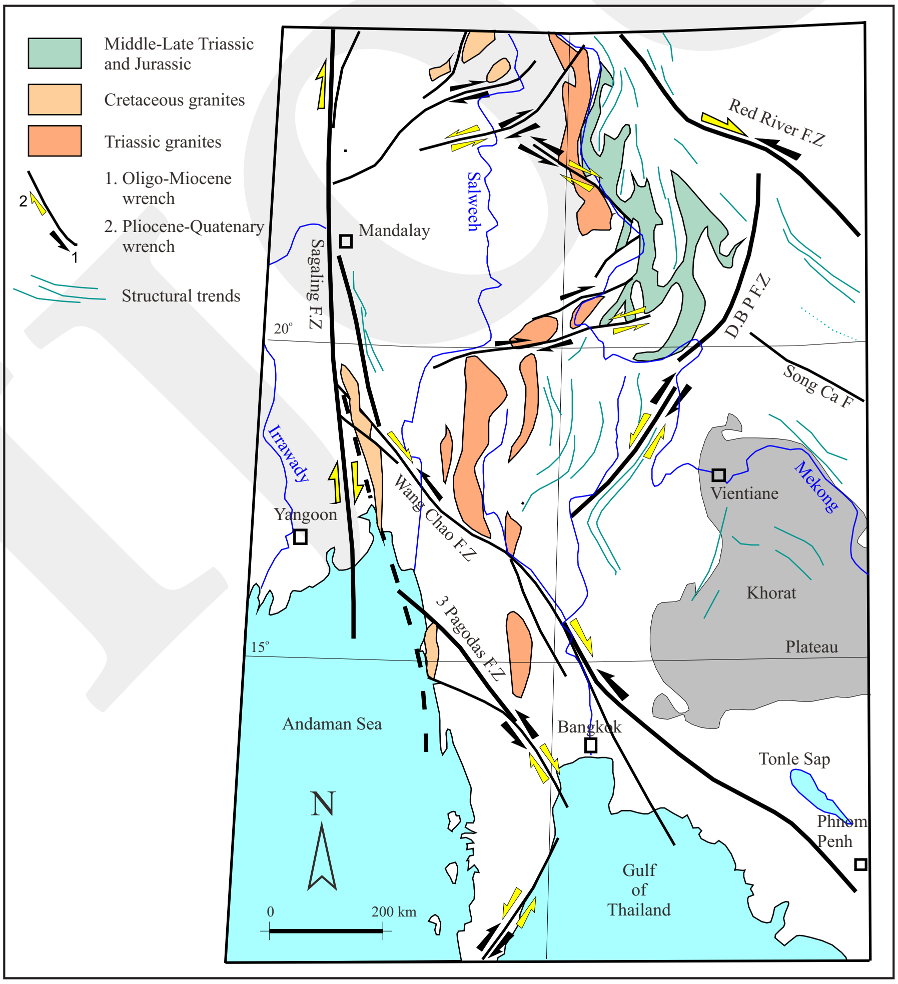

Figure 2. Major structures, especially fault zones in Indosinia. The geology is simplified from Lacassin *et al.* (1997) that highlight regional drag effects by the major faults. These effects show case the significance of Paleogene wrench faulting, while later wrench reversals appear much more subdued.

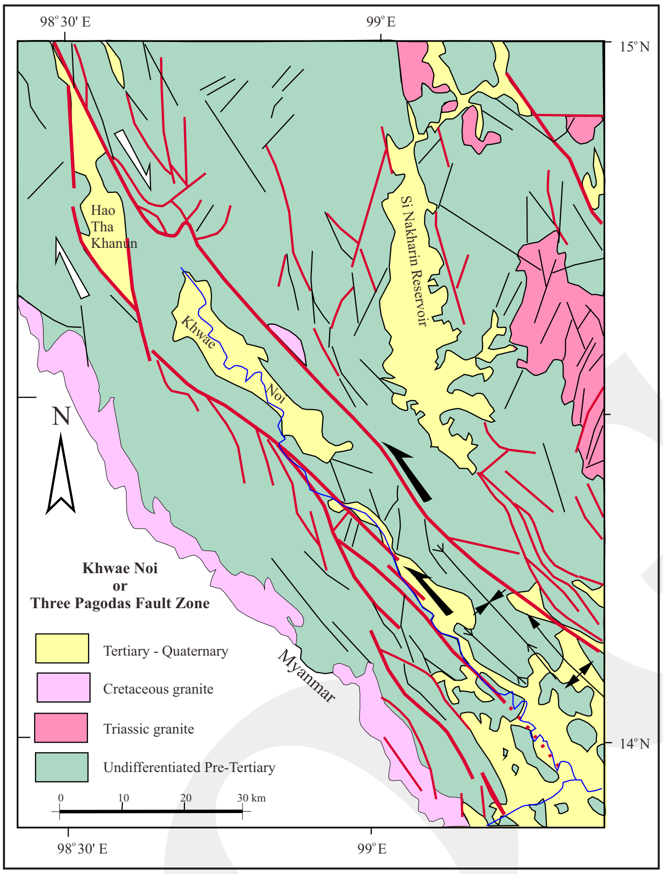

Figure 3. Simplified regional geology of western Thailand based on the Geological Survey of the Department of Mineral Resources (1983). Half-tipped black arrows indicate strike-slip sense on the Three Pagodas Fault Zone in pre-Mid Miocene. The Hao Tha Khanun basin has typical pull-apart outlines representing right-lateral wrenching (white half-tipped arrows) that has transpired since Mid(?) Miocene.

Along its SE-strike, the Three Pagodas Fault Zone is likely to extend into the Malay Basin as its Axial Malay Axial Fault Zone. Wrench reversal from an earlier sinistral sense into dextral strike slip has been demonstrated (Tjia and Liew, 1996). However, the wrench kinematics of the TPFZ and AMFZ has been in opposite sequence.

The Yinggehai depression marks the transition between the Red River Fault Zone and the Vietnam Shear (Figure 4). The rhombic outline of the depression suggests a pull-apart produced by right-lateral wrenching. The outline is based on a map by CCOP (1991). The Vietnam Shear separates a combination of oceanic and thinned continental crust of the South China Sea Basin from normal continental crust of Indosinia-Sundaland (Taylor and Hayes, 1983; Roques *et al.*, 1997). The shear is most likely a transform fault (Sandal, 1996, Figure 2.1; and Tjia (1998). The shear's activity may have begun with the opening of the South China Sea Basin dated at 32 Ma, or within the later part of the Oligocene. Tapponnier *et al.* (1982) assigned left slip exceeding 500 km on the Red River Fault Zone. This probably occurred during the Paleogene. A morphotectonic study by Zuchiewicz and Cuong (2009) cite earlier results on the RRFZ and note that left slip overlaps with the opening of the South China Sea Basin in the 34 to 17 Ma period, with estimated total displacement of 300 + 60 km to as much as 500 - 700 km. Since the end of Miocene, right-lateral slip may have reached a total of 200 - 250 km. Quaternary dextral slip has been in the 300 m to 2 km range representing an average annual rate of 5 mm.

Four recent earthquakes have epicenters at the ends of the Red River and the Mae Ping fault zones (Figure 5). The two shallow earthquakes (focal depths < 33 km) near Hainan Island show first-motion solutions of right-lateral wrenching

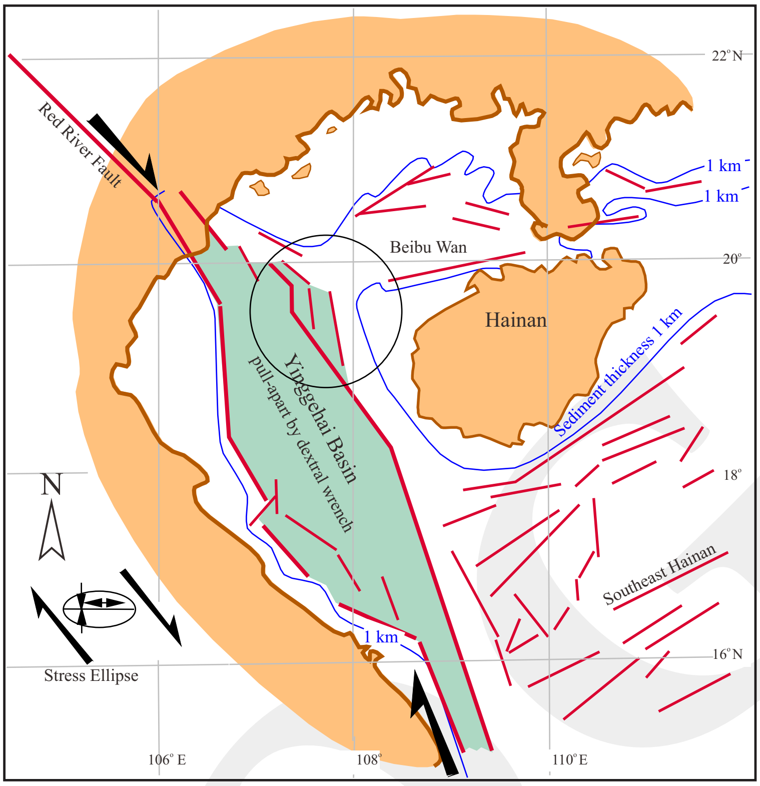

Figure 4. The Yinggehai depression marks the transition between the Red River Fault Zone and the Vietnam Shear. Its outline suggests a pullapart produced by right-lateral wrenching. The outline is based on a map by CCOP (1991).

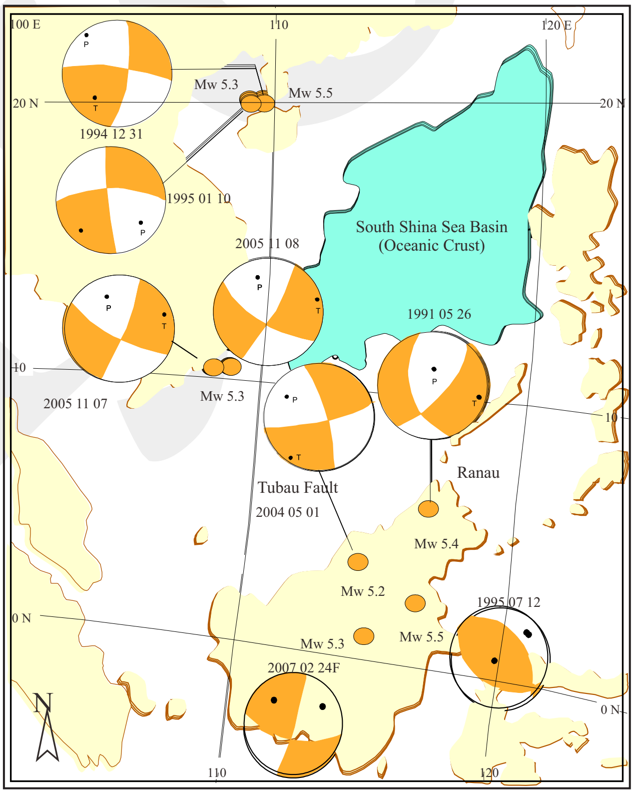

Figure 5. Recent earthquakes at the Red River and Mae Ping fault zones. First motions of recent earthquakes associated with the Red River and Mae Ping fault zones are consistent with right-lateral sense of wrenching. Data from USGS-NEIC.

on NW-trending segments of the Red River Fault Zone. Two of the moderate-magnitude earthquake epicenters are located at the end of the Mae Ping Fault zone and also possess shallow foci of < 33 km. The "beach balls" are consistent with right lateral slip on NW - SE striking faults. Both the RRFZ and MPFZ are active.

Sundaland Slide-Rule Tectonics Malay Basin, West Natuna, and Penyu Basins

Malay Basin (1)

In Figure 6, the Malay Basin occupies the grey-shaded region. Regional faults striking within the NW to N sector form the western limit of the basin. Black half-tipped arrows indicate initial wrench sense on the Dungun, Hinge-line, and Tenggol Faults. Dextral slips produced relatively small pull-apart depressions, each associated with the faults. In other words, the wrenching was transtensional (see further below). Later, in Late Oligocene to Early Miocene time the wrench slip reverted within a transpressional stress regime that produced compressional structures in the basin-fill sediments. The Malay Basin proper is traversed by major North-South faults that dextrally displaced East-West trending anticlines -most containing commercial hydrocarbons for distances up to 35 km. However, the East-West disposition of the large folds was derived from Paleogene pull-aparts associated with left-lateral wrenching of a 30 - 35 km wide fault zone marking the axis of the basin (Tjia and Liew 1996; Tjia, in Petronas, 1999).

Lateral fault slip reversals on this Axial Malay Fault Zone (Figure 7) are also accompanied by structural inversion. Severity of inversion in-

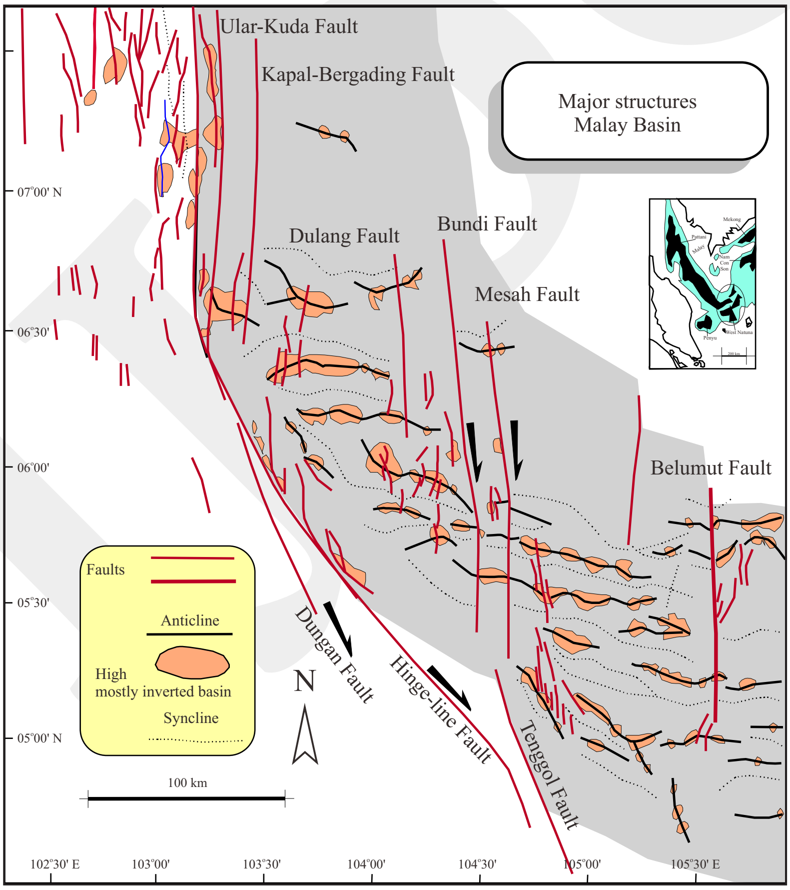

Figure 6. Malay Basin occupies the grey-shaded area. Along its western border are major faults trending within the NW to N sector of which Dungun, Hinge-line and Tenggol are prominent. Black half-tipped arrows correspond to transtensional wrenching that produced pull-aparts along the faults. The pull-aparts became depositional loci for Lower Oligocene to Lower Miocene sediments. By Middle Miocene, wrench sense reverted and became transpressional resulting in folds of the sedimentary fill and structural inversion. Within the Malay Basin proper initial wrench sense was left-lateral that resulted in large East-West oriented pull-aparts.

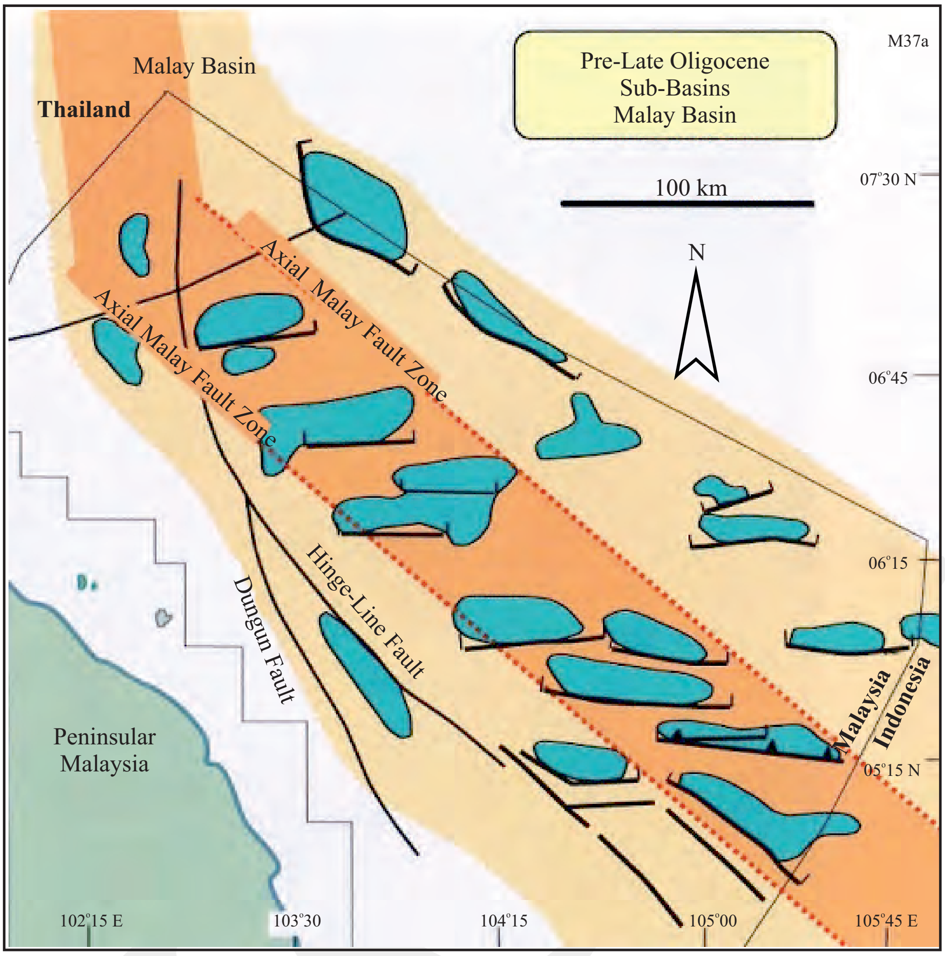

Figure 7. East-West pull-aparts at the base of the Axial Malay Fault Zone (AMFZ) developed during sinistral wrenching. Subsequent wrench-slip reversal produced transpressional stress regime. Since the Middle Miocene dextral slip on the AMFZ resulted in structural inversion of the pull-apart sedimentary fillings into large folds and associated reverse faulting amounting to as much as 550 m (Ledang field).

creases progressively towards the southeast end of the Malay Basin. For instance, at the Ledang field structural inversion amounted to 550 m (Petronas 1999); at the Peta field structural inversion has exceeded 250 m (Figure 8). A large half graben containing Lower Oligocene sediments was inverted by the Middle Miocene. The inversion was also accompanied by reverse faulting that involved the seismic basement, which may be of pre-Tertiary age. Farther southeast is the West Natuna Basin where transpressional effects are significant (Wongsosantiko and Wirojudo 1984). Tectonic compression directed NW - SE has produced the Udang asymmetrical anticline that borders a reverse fault striking NE - SE (Daines, 1985). The kinematic plan is completed by conjugate wrench faults, one of sinistral slip striking a few degrees east of North; the second consisting of a dextral slip wrench striking WNW - ESE.

The structural evolution of the central zone of the Malay Basin is diagrammatically shown in Figure 9. In Oligocene - Early Miocene, left-lateral transtensional strike-slip faulting occurred on the wide Axial Malay Fault Zone that produced East-West trending pull-aparts. The depressions accommodated deposition of sediments. Slip sense on the AMFZ reverted since the Langhian (Early to Middle Miocene transition) in a transpressional stress regime producing the large East-West striking anticlines from the pull-apart sediment fillings.

Changing wrench kinematics in the northeastern edge of the Malay Basin is illustrated by Figure 10. The top of basement surface possess folds that can be interpreted to have developed as drag

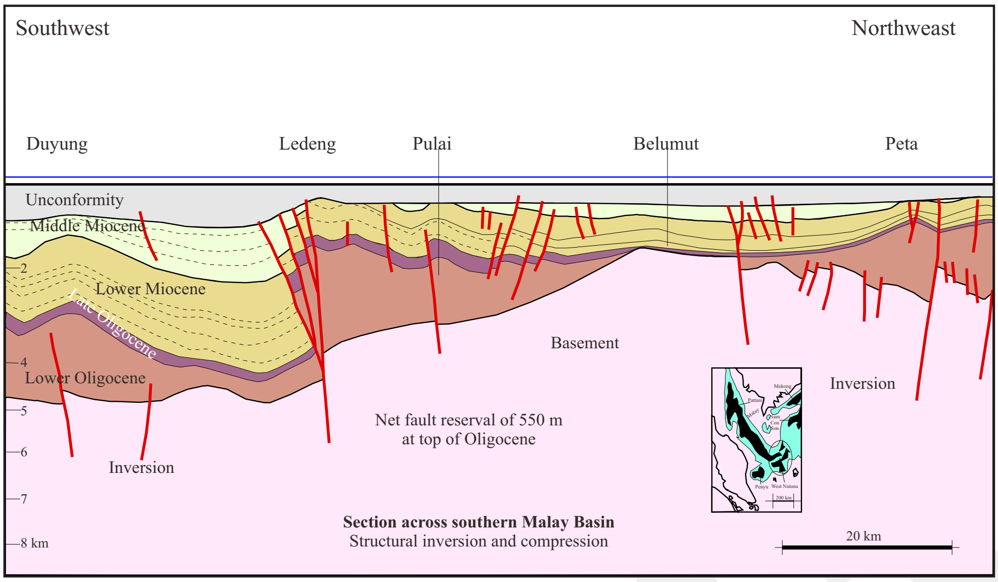

Figure 8. Peta structural inversion has involved over 250 m vertical uplift including basement-involved reverse faulting. In the southeast, a smaller inverted half graben indicates the tectonic event to have occurred in post-Early Miocene time.

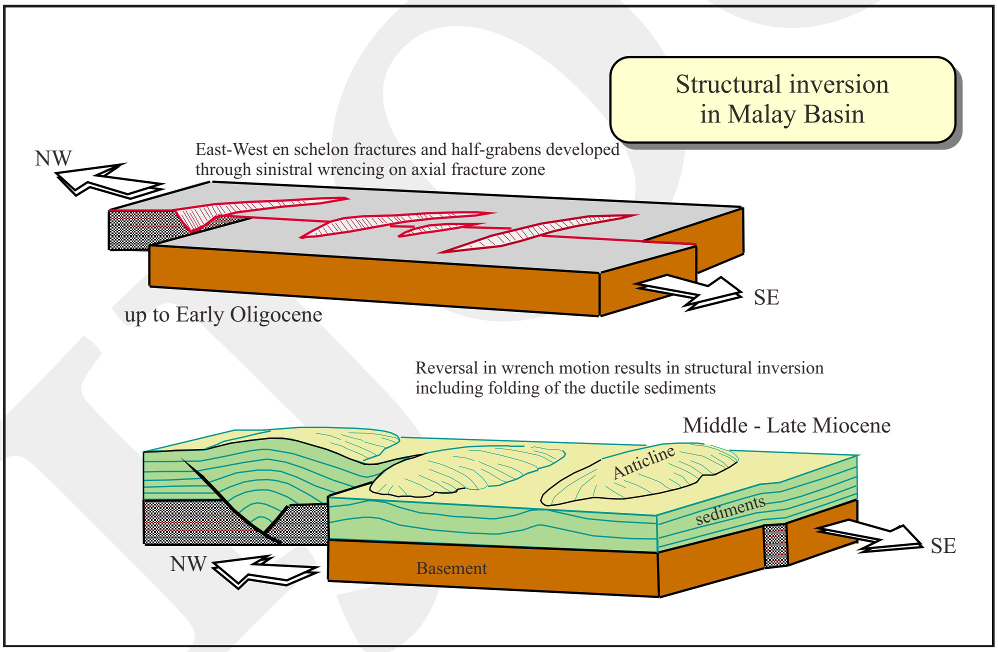

Figure 9. Diagram shows the development of the AMFZ: initially by sinistral wrenching creating transtensional depressions (pull-aparts) in systematic pattern, followed by dextral wrench-slip associated with transpression.

structures associated with left-lateral slip along a curving fault zone trending NW to WNW. A relatively small rhombic pull-apart in the southeast of the map correspond to right slip of the wrench zone. Which of the wrench regime was older is not definitive as age control is wanting. At this stage of knowledge it is speculated that the initial wrench regime was, probably transpressional, left lateral sinistral. The rather limited extent of wrench transtensional effect in the Southeast corner was possibly a younger event.

West Natuna Basin

Figure 11 illustrates effects of strong compression (folds and reverse faults) and at least one wrench-slip reversal among the WNW - ESE

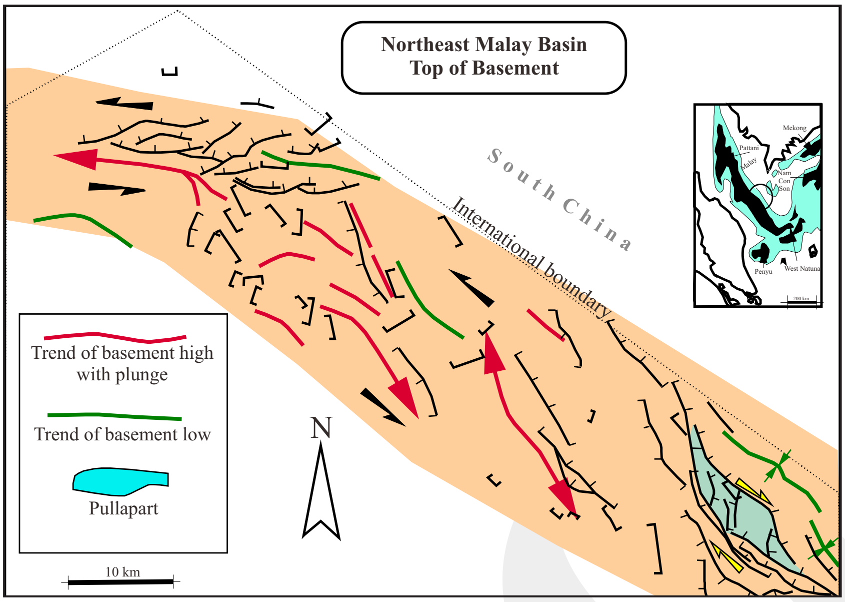

Figure 10. Wrench reversal is also demonstrated by structure patterns at basement top at the northeastern ramp of the Malay Basin.

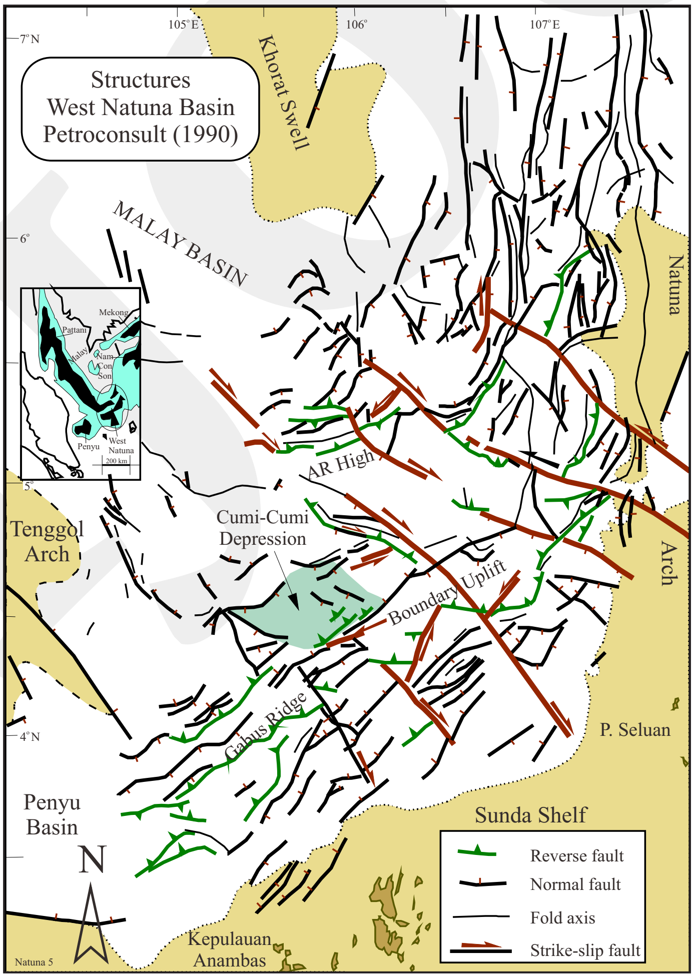

Figure 11. West Natuna Basin at the SE end of the Malay Basin possesses strong compressional structures comprising reverse faults and wrench-slip reversal.

striking major faults. The Lower Oligocene graben infill (Belut Formation) up to the Lower Miocene (Gabus Formation) shows structural inversion in the form of anticlines (Figure 6; Daines, 1985).

Malay Basin (2)

Wrench-slip reversal along the Tenggol Fault along the SW side of the Malay Basin is illustrated in Figure12 (Shahar, 2008). This composite fault map at levels representing Oligocene and several horizons of the Miocene shows en echelon faults (red) at the basement top and at the various Miocene levels. The en echelon arrangements are opposed to each other. The red-coloured older fault system represents left wrench slip; all the Miocene levels, and especially in a well-defined zone of the Tenggol Fault, indicate later right-lateral wrench slip.

Wrench-slip reversals along the Hinge-line fault and its subsidiary Dungun Fault from an initial right-slip to left slip have been documented by pull-aparts whose sedimentary fillings were folded in the subsequent transpressional stress regime, respectively. Examples were published in Tjia and Liew (1996), Liew (1996), Tjia (1998), and Petronas (1999) . Figure 13 shows wrench reversal along a northern segment of the Hinge-line Fault in the Kabut area. Right-lateral wrenching (black half-tipped arrows) most likely occurred in the Early-Mid Miocene time span producing a partitioned pull-apart depression. Middle to Upper Miocene sediments filled the compartmentalized pull-apart that since the Late Miocene experienced transpressional deformation through wrench-slip reversal (red half-tipped arrows).

Figure 14 shows time structure at approximately pre-Tertiary basement level of the Dungun Graben and two smaller depressions along the Dungun Fault, a splay to the west of the Hinge-line Fault (Figure 6). The somewhat streamlined outline of the Dungun Graben suggests an origin as a pull-apart produced by transtensional right-lateral wrenching (black half-tipped arrows). The lower Neogene sedimentary graben filling has been folded indicat-

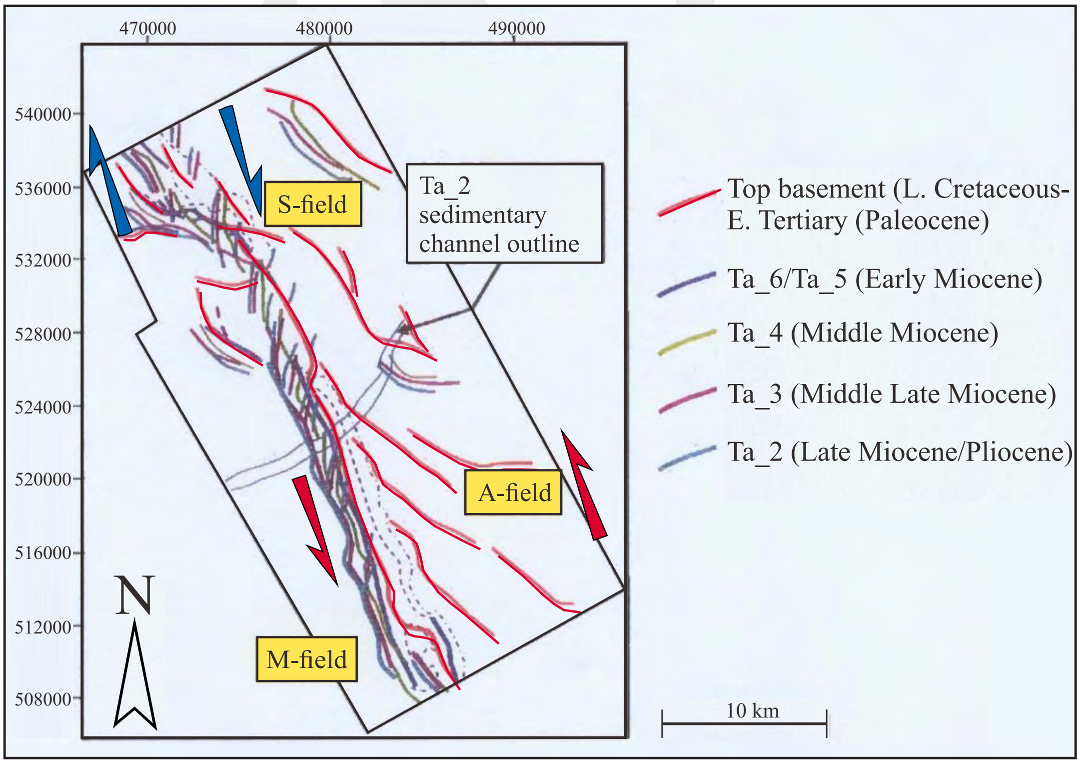

Figure 12. A composite fault map of the Tenggol Fault zone highlighting en echelon fault patterns (red coloured associated with left-lateral wrench slip) and along a narrow zone indicating right wrench-slip in Miocene beds. Shahar (2008) also pointed out that the trend of channel sands was not disturbed by dextral wrenching.

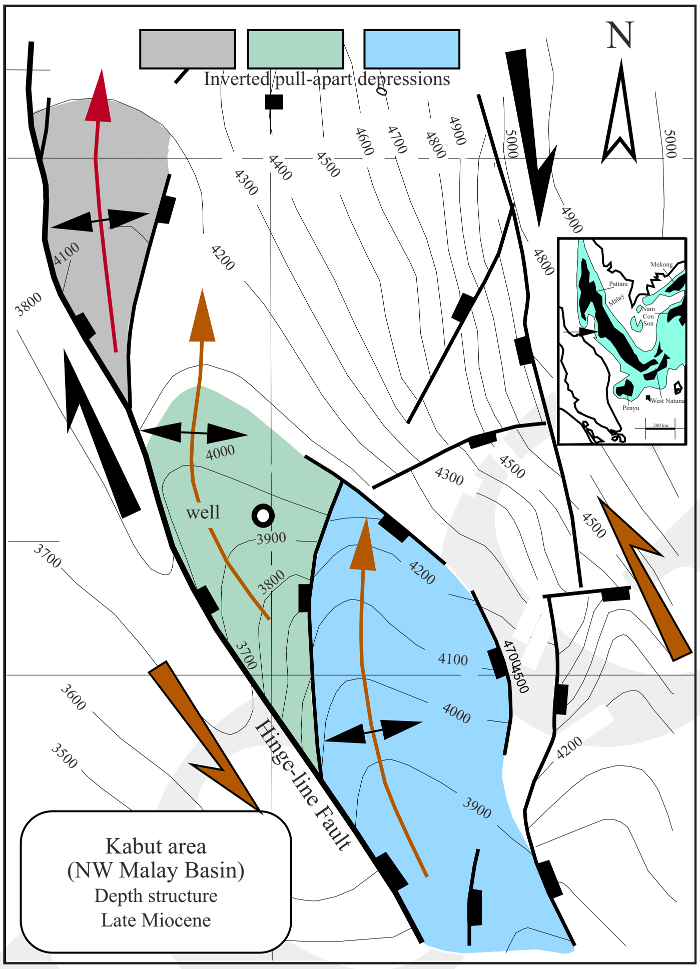

Figure 13. In the Kabut area on the northern segment of the Hinge-line Fault Zone wrench slip reversal is demonstrated by an earlier right-lateral transtensional stage when the pull-apart was developed, most likely in Early to Middle Miocene when sediments were filling the depressions. In the succeeding tectonic episode, wrench-slip reversal generated transpression in which the basin-filling deposits were deformed into folds.

ing lateral left-lateral transpressional strike-slip motion (yellow half-tipped arrows), possible since the Middle Miocene.

Penyu Basin

At the base of the Tertiary, structures of the Penyu Basin are shown in Figure 15. The large half-grabens are up to 4000 m deep and contain the larger portion of the Intra-Oligocene Penyu Formation (Figure 16). The great thickness of sedimentary basin fill demonstrates a long-lasting tensional stress regime. Ngah *et al.* (1996) published the Penyu Basin stratigraphy. Other geological information is by Madon and Anuar (1999). Basement is pre-Oligocene; Penyu Formation and the Terengganu Shale are Oligocene; the Pari Formation is Early-Middle Miocene; the Pilong Formation includes sediments from Late Miocene to the present. The Rumbia Fault is a prominent fault striking northwest. Subsidiary faults are arranged en echelon implying sinistral wrench slip. The section clearly indicates that the basin experienced two separate episodes of tectonic events. The deep half grabens were associated with an older pre-Oligocene event. Structural inversion is expressed by the uppermost Oligocene Terengganu Shale. Figures 15 and 16 combined suggest that the wrenching shown by the Rumbia Fault system had been transpressional and represents the younger tectonic event.

Concluding remark on the Hinge-line Fault Zone

In the Malay Basin, the major wrench faults to the East of the Hinge-line experienced ini-

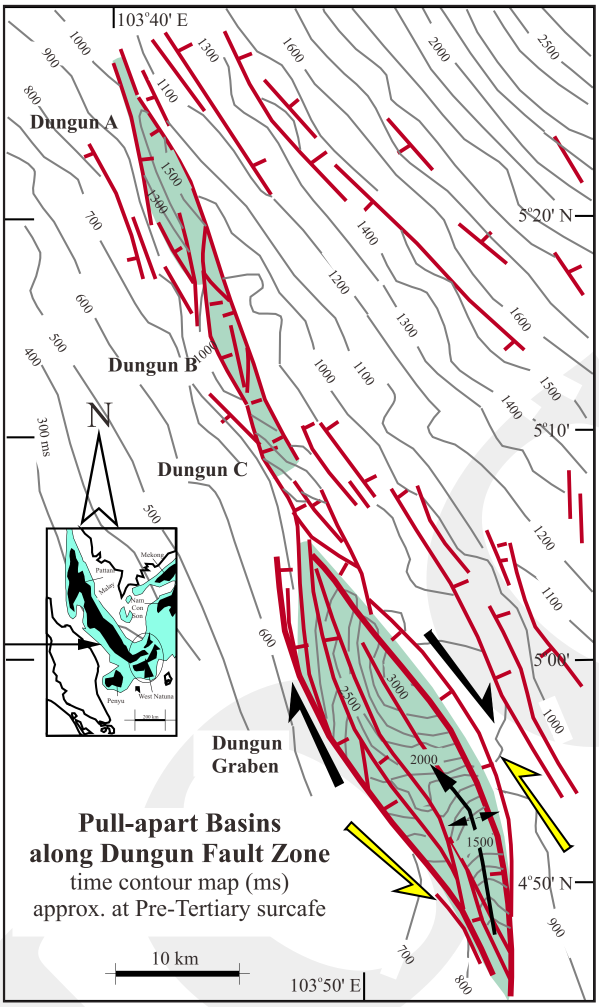

Figure 14. Dungun Graben is the largest depression along the Dungun Fault, a splay of the Hinge-line Fault. The streamlined rhombic outline suggests a pull-apart origin that accommodated Lower Miocene (and Oligocene?) deposition of some 3000 m thick sediments.

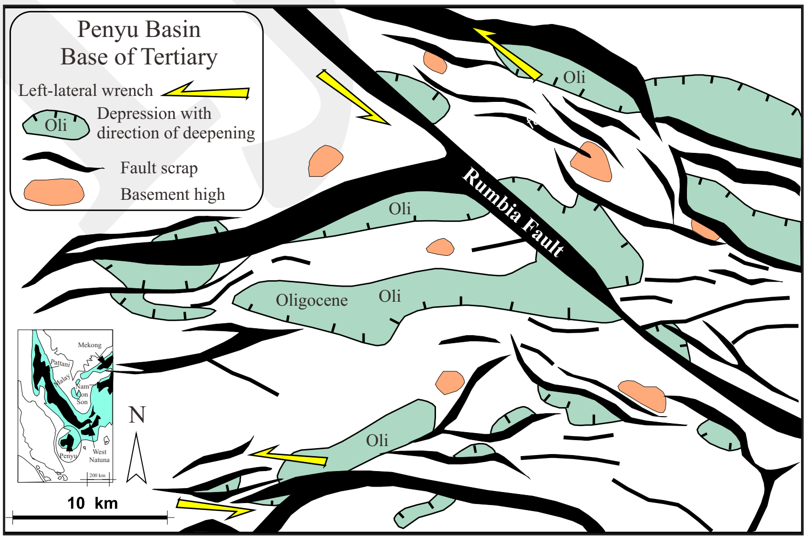

Figure 15. Near Tertiary base level structures of the Penyu Basin are illustrated. The large half grabens host Oligocene-Quaternary sediments.

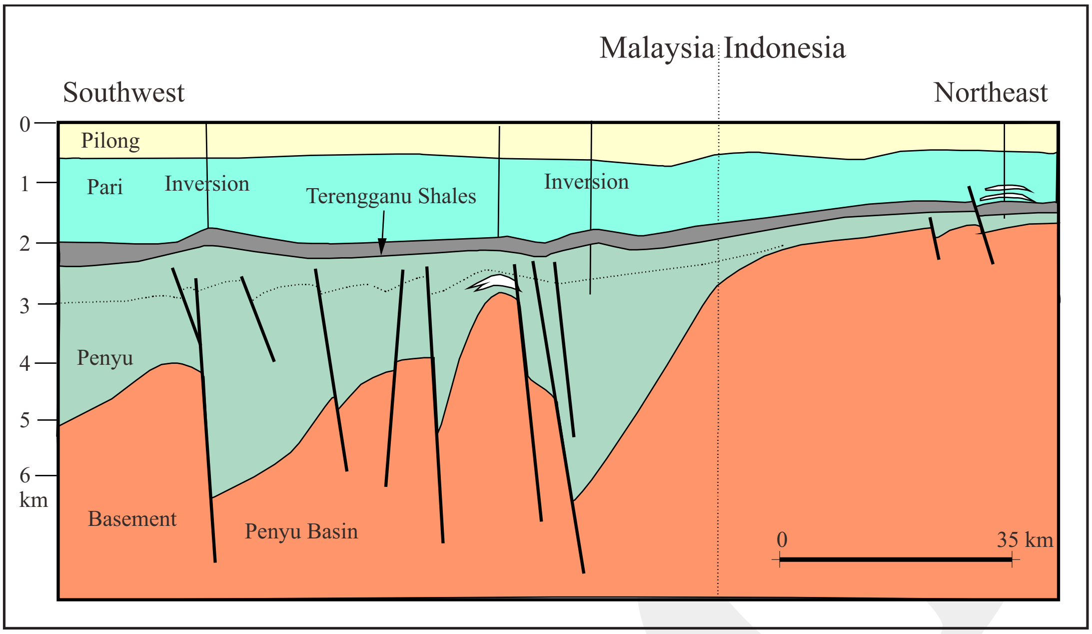

Figure 16. The Penyu Basin section shows the deep half grabens; inversion distinctly expressed by the Terengganu Shale.

tially transtensional sinistral wrenching that was succeeded by strike-slip reversal, predominantly beginning around Langhian, or transition from Early to Middle Miocene. The reversal was associated with transpression. To the West of the Hinge-line Fault, also referred to as the western ramp of the basin, wrench kinematics progressed in opposite fashion: pre-Langhian dextral transtension succeeded by sinistral wrench slip. Tectonic history interpreted from published evidence of the Penyu Basin - located to the west of the Hinge-line Fault- are in general agreement

Peninsular Malaysia

Major strike-slip faults traversing the onshore area of Peninsular Malaysia have been mapped in some detail. Most of their kinematics appears to have been restricted to the pre-Tertiary. The main reason for the lacunae in knowledge about their Tertiary tectonic activity is the paucity of relevant rocks. Two Lower Tertiary basins, the Batu Arang and Lawin, lie adjacent to the sinistral Kuala Lumpur wrench zone and the similarly sinistral Baubak (also spelled Bok Bak) wrench fault, respectively (JMG, 1985). Raj (1998) published a well documented discussion on tectonic evolution of the Batu Arang Basin. A series of northerly striking fault zones in Terengganu (Tjia, 1998) can be projected to extend offshore to join the Hinge-line fault and faults in the border region of Malaysia-Thailand. At this stage, in both cases age control of their Cenozoic activity is still speculative.

GPS study of coseismic vertical displacements associated with the mega-earthquake of the Indian Ocean in 26 December 2004 shows up to 11 mm uplift in the northwest part of Peninsular Malaysia and as much 7 mm for the region neighbouring Singapore Island (Din *et al.*, 2012).

Towards the end of the first decade of the 21st century, weak earthquakes (less than 3.8 magnitude) of uncertain origin were recorded in the west-central parts of the Peninsula.

The cited evidences point to crustal disturbances during the Cenozoic, possibly associated with major faults in Peninsular Malaysia. However, their tectonic association to known major faults has not been confidently proven. The present discussion has excluded their possible role until reliable age control can be established.

Strait of Malacca and Northern Sumatra

The dominant fault structures in the Strait of Malacca strike North-South. The structural geology is published in Liew (1995) and Madon and Ahmad (1999). Liew recognizes four belts of N-S elongated fault depressions bridging the strait between the coastal zone of Sumatra into the Malaysian shelf area (Figure 17). Three domains of Cenozoic wrench kinematics are recognized: (1) Malay Basin region, (2) western ramp of the basin, and (3) Strait Malacca zone. Many of the fault depressions are half grabens whose bottom sediments are considered Pematang equivalent of Upper Oligocene-Lower Miocene. Strata of the Sihapas equivalent (Middle Miocene) suggest structural inversion in the Central and Southern Grabens, Port Klang Graben, and Johor Graben. Seismic indicates that inversion gradually expires towards the beginning of the Pliocene. The graben-bounding, basement- involved faults are associated with flower structures in the Central, Angsa, Port Klang, and Johor Grabens. The Bengkalis Trough is drawn in its proper position. Dextral offsets of Neogene structures are shown in Figure 18, which is simplified from Heidrick and Aulia (1993).

Figure 19 is a structural plan of the seismic basement surface below the Upper Oligocene strata of the Northern Graben. The sigmoidal en echelon pattern of faults indicate the depression to have been subjected to right-lateral transtensional wrenching parallel to its longer N-S axis. The transtensional stress environment created the graben as a pull-apart, most likely in the Late Oligocene-Early Miocene time span. The succeeding compressive stress episode of the Mid- to Late Miocene produced structural inversion that appears to have been associated with transtensional wrenching. The basement-involved flower structures suggest that this may be the case.

Northerly trending faults in the western margin of Sundaland are below the coastal zone of northern Sumatra. Two regional stress domains relate to the Andaman Basin and Indian Ocean- Australian tectonic entities (Figure 20). Significant right-lateral displacement of pre-

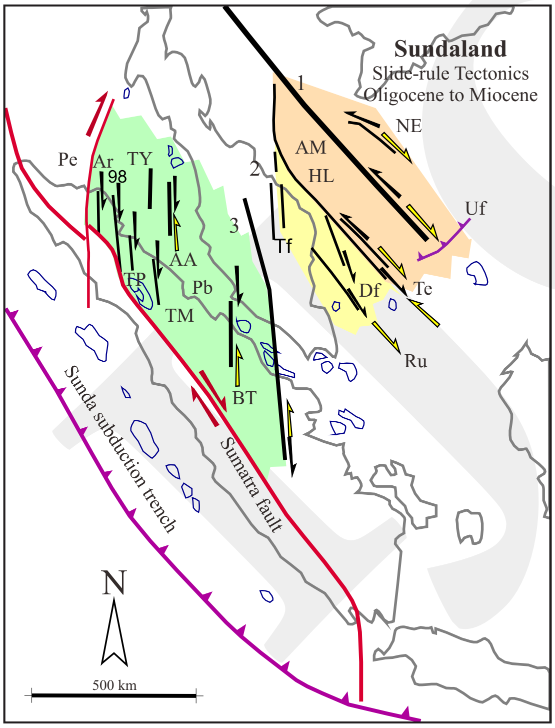

Figure 17. Slide rule tectonics in Sundaland - Major faults: NE (NE Malay Basin), Uf (Udang reverse fault), AM (Axial Malay Fault Zone), HL (Hinge-line Fault Zone), Te Tenggol Fault), Df (Dungun Fault), Ru (Rumbia Fault), Tf (Terengganu faults), BT (Bengkalis Trough), Pb (Pematang Balam zone), AA (Asahan-Aruah zone), TY (Tamiang-Yang Besar zone), Ar (Arun fault), 98 (98 Fault), TP (Tanjung Pura Fault), TM (Tanjung Morawa Fault), and Pe (Peusangan Fault). Note three wrench-fault domains have been identified.

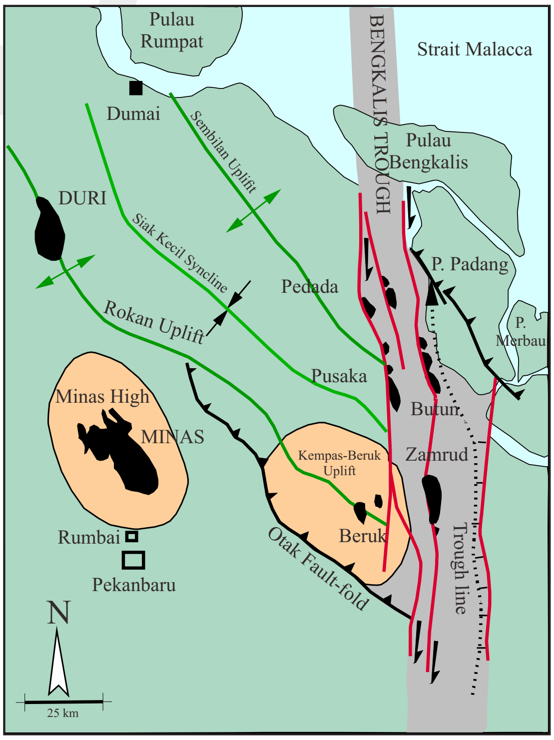

Figure 18. Bengkalis Trough with structures and some hydrocarbon fields exhibiting effects of dextral wrenching of the trough. Simplified from Heidrick and Aulia (1993).

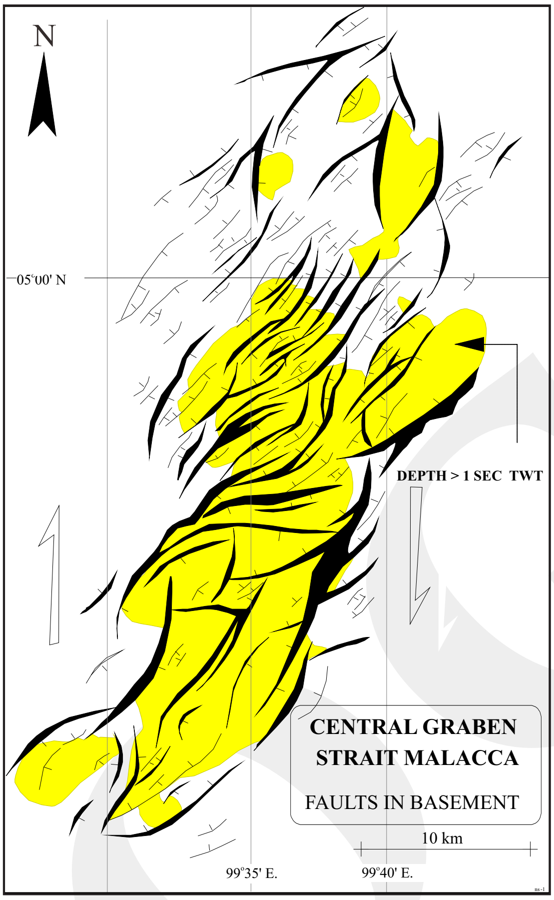

Figure 19. Systematic en echelon fault pattern in the Tertiary sediments filling the Central Graben of the Aruah-Asahan deformation zone, Strait of Malacca (AA on Figure 17).

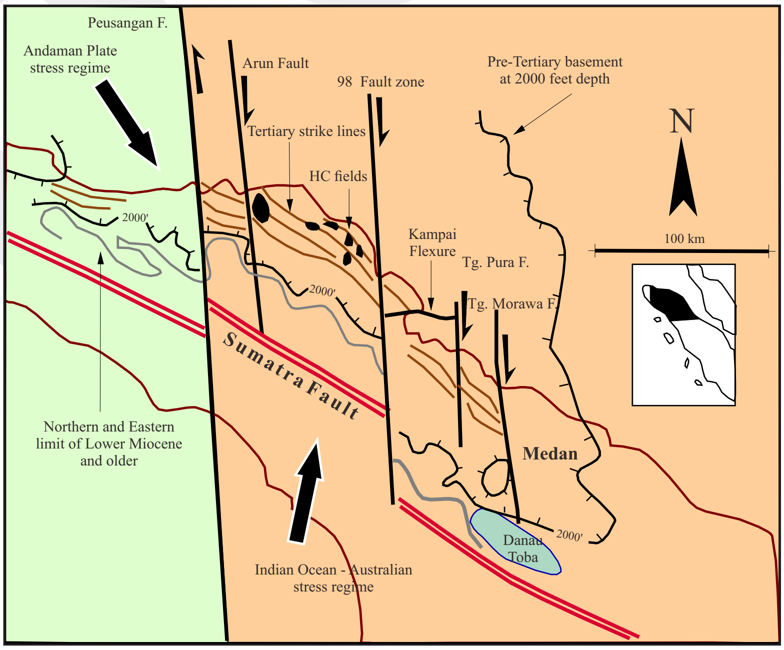

Figure 20. Northern Sumatra slide-rule tectonics. The area of northern Sumatra from the Peusangan Fault westward is under the influence of spreading of the Andaman Sea Basin (large arrow shows compression direction). To the East of the Peusangan Fault, wrench faulting responds to collision of the subducting Indian Ocean-Australian Plate with Southeast Asia.

Tertiary basement and drag effects on strikes of Tertiary structures is indicated. The distinct dislocation of the Sumatra Fault Zone between the Peusangan and the 98 Fault from its general trend was observed earlier (Tjia, 1977).

Discussion and Conclusions

Mainly, Oligocene to Miocene 'slide-rule' tectonics are different for three domains of Sundaland (Figure 17). However wrench reversals appear centered about Langhian (17 to 15.5 Ma; or transition from Early to Mid Miocene). Domain 1 from and including the Hinge-line Fault (HL) eastward was subject to transtension prior to Langhian and wrenching has since reverted to transpression. Wrench kinematics had the opposite sequence in Domain 2, that is, westward from the Hinge-line fault and perhaps including major faults in the Malay Peninsula. The paucity of Cenozoic sediments associated with onshore wrench faults prevents inclusion of possible wrench kinematics in the discussion. Radiometric dates of 3 mylonites of major onshore wrench faults indicate a latest activity in the later part of the Eocene (Harun, 1992). Weak magnitude seismicity (around 3 and maximum 3.8) in the past decade could not be satisfactorily related to renewed displacement along some of the major faults in the western zone of Peninsular Malaysia. For these reasons, Peninsular Malaysia is left out from the current discussion. Cenozoic Domain 3 is bordered by the Bengkalis Trough, the Peusangan Fault, and the active transcurrent Sumatra Fault Zone on the southwest side. Geographically the Bengkalis Trough extends into the Bentong Suture, but the latter activity during the Cenozoic is not known. Domain 3 contains North-South faults and zones of aligned fault depressions. Wrench-slip reversals were only determined for structures shown in seismic sections.

The Hinge-line Fault distinctly separates two areas of the Malay Basin that have had separate wrench kinematics during the Cenozoic: in the main basin area to the east and of the western basin ramp to the west. Figure 1 shows the convergence of the two megaplates onto Sundaland-Indosinia after the Langhian - Early Miocene to Middle Miocene transition time. Wrench-slip reversals, although not always in tandem, during the Cenozoic history of Sundaland and Indosinia may have had common causes. The Langhian time threshold of change in wrench kinematics (and structural inversions) invites further study. Around the same geological time, seafloor spreading ceased in the South China Sea Basin and also in far-field regions such as the West Philippine and Caroline Basins.

Acknowledgements

The material and idea for this article were gathered over many years. Inspiration originated from talks with fellow geologists: the late John Ario Katili, G.A.S. Nayoan, C.K. Burton, Khalid Ngah, and Liew Kit Kong.

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