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PALINSPASTIC RECONSTRUCTION OF STRUCTURAL EVOLUTION IN THE SEMANGKO PULL APART BASIN, SUNDA STRAIT: TIMING AND KINEMATICS

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Abstract

Structural evolution of the Semangko pull apart basin in the Sunda Strait is analyzed based on palinspastic reconstructions of re-interpreted seismic reflection data to understand the timing and kinematics of structures in such basin. We use more than seven multichannel seismic reflection data combined with swath bathymetry and seismicity data available in this area. A package of NW-SE trending planar- and listric-normal faults appear to have formed as graben and half graben system. Sunda Strait. These structure packages are defined as graben and half-graben structures which are developed in this zone. The main graben is West Semangko and East Semangko Grabens, whereas another graben system is recognized farther east, the Krakatau Graben. The Semangko Grabens were developed due to the overstepping of the Sumatra Fault in the northwestern area, and Ujung Kulon Fault in the southeast.

Palinspastic reconstruction shows kinematic evolution of the Semangko Grabens commenced in Middle Miocene, marked by the initiation of basement faulting with 0% to 4.77% extension, deposition of stratigraphic Unit 1 and Unit 2 started at 4.77% to 10.90% extension contemporaneously with the initiation of uplift of NW-SE trending ridges due to the development of cross-basin fault in a transtensional system. The Plio-Pleistocene Unit 3 deposited during 10.90 to 11.62% extension, accompanied with the uplift of ridges and eroded all rock units. Based on those observations, Unit 3 was developed as a syn-transtensional deposit. The western graben appears to be more active and developed as compared to that in the eastern part, possibly due to the activity of Ujung Kulon Fault.

Keywords: *Semangko pull apart basin, transtensional, graben, Palinspastic, Kinematic, Cross-basin fault*

1. Introduction

The Semangko pull apart basin is one of the active deformation zone in the southeastern part of Sundaland. This zone is part of the Sunda Strait, which is a transition zone between two subduction systems; normal subduction off Java and oblique subduction in the west of Sumatra (Hamilton, 1979; Malod et al., 1995) (Figure 1). The activity of the deformation zone is evidenced by the high intensity of seismicity along the north-south trend structures (Harjono et al., 1991). The Semangko pull apart basin is a extensional opening zone due to movement of the southeastern part of Sumatran Fault segment (Natawidjaja and Sieh, 2000) with Ujungkulon Fault in the southeastern part of the Sunda Strait. This opening zone have also been accommodated by the movement of the Sumatra plate sliver (Huchon and Le Pichon, 1984), that induced a transtensional basin (Lelgemann et al., 2000; Susilohadi et al., 2009). The structures in the Sunda Strait had been formed since at least Middle Miocene. A palinspastic study is conducted to determine the structures and kinematic evolution process of the graben system in the Semangko pull apart basin.

2. Data and Method

This study used multichannel seismic reflection (MCS) data of Susilohadi et al, (2009) combined with swath bathymetry data, which has resolution of 30 arc second. Interpretation of sedimentary strata is based on the concept of seismic stratigraphy Vail et al, (1977) to determine the horizon and structures. A palinspastic reconstruction is conducted to determine kinematic evolution of the graben and timing of the deformation. This palinspatic method is focused on the layer thickness and geometry of the faults in order to balance the cross sections.

3. Stratigraphy of Semangko Pull Apart Basin

Re-interpretation of the seismic reflection data resulted three stratigraphic units, which were deposited since Late Miocene.

3.1 Unit 1

Unit 1 is divided into two sub-units: lower and upper unit. the Lower Unit 1 is interpreted as of upper Miocene deposits (Susilohadi et al., 2009). Reflectors in the lower part of this sub-unit show onlap to top basement. The boundary between of the basal part of this unit and the basement appears to be an unconformity. In the Semangko horst and Tabuan ridge, lower Unit 1 is characterized with parallel reflectors with lateral continuity, high-medium amplitudes and low frequency (Figure 2). The Upper Unit 1 is characterized with low-medium amplitudes, medium frequency, parallel-sub-parallel, and lateral continuity along Semangko horst, Tabuan ridge and Krakatau ridge (Figure 2 & 3).

3.2 Unit 2

Unit 2 is observed to be conformable overlying Unit 1. This unit had been interpreted to have deposited during Early Pliocene (Susilohadi et al., 2009). This unit is observed in the whole part of the basin, and is characterized by medium-low amplitudes, medium frequency, parallel-sub parallel, lateral continuity in Semangko horst. The deposition of Unit 2 is interpreted to have influenced by the increased of magmatic intrusions that penetrate this sedimentary layer (Figure 3).

3.3 Unit 3

Unit 3 is observed unconformably overlying Unit 2. The lower of this unit shows downlap termination and is interpreted to be a sequence boundary between Upper Miocene-Lower Pliocene sediments. Unit 3 had been interpreted as Upper Pliocene-Pleistocene sediments (Susilohadi et al., 2009) that is characterized by onlap fill, medium-low amplitudes, medium frequency, sub-parallel (Figure 2 & 3). The thickness of this unit is highly variable ranging from 0.1 TWT in the West Semangko graben that thicken towards N-E in the depocenter of Krakatau graben. Exploration well C-1 SX data show that at depth of 3,005 meters, the drilled rocks comprised the Upper Pliocene sediments with claystone lithology associated with volcaniclastics that were deposited in a sublittoral-upper bathyal environments (Noujaim, 1976).

4. Structural Geology

Re-interpretation of seismic data (SO137-21 and SO137-23) revealed the NW-SE and N-S patterns of the main structures. The Semangko pull apart basin formed as half graben in the western and eastern part of the basin. Structural package of western half graben exhibit planar normal fault, whereas in the eastern part of the basin, the structures show varied geometry of planar and listric normal faults.

The major faults formed in the western part (West Semangko Fault) and eastern part (East Semangko fault) marked the ridges and appear to be active until top Unit 2. The western part of the basin is bounded by Semangko horst that formed by the up-thrown block of a NW-SE trend planar normal faults package.

The eastern part of the basin is bordered by the Krakatau ridge that formed by a package of NW-SE trending planar-listric normal faults. In the central part of Semangko basin a set of ridges is observed along a NW-SE trend that is interpreted to have formed due to magmatic intrusion. A tilted block appears to have formed due to the East Tabuan Fault, subsequence to the deposition of Unit 2 (Figure 3).

5. Palinspastic Reconstruction

Balanced cross section reconstruction of line SO137-23 shows that 12.38% extension had been occurred during Middle Miocene-Recent, followed by 1.12% contraction ratio (Figure 4). 4.77 to 10.9% extension and 1.04 to 1.10% contraction ratio are interpreted to have formed in late Miocene-early Pliocene during the deposition of Unit 1 and Unit 2. These units were deposited laterally with a constant thickness in the Semangko basin. An 11.62% extension ratio and 1.11% contraction were calculated prior to deposition of Unit 3, which occurred in the whole Semangko Basin.

6. Interpretation and Discussion

Based on interpretation of a compilation of 2D seismic reflection, swath bathymetry and seismicity data we argued that the formation of Semangko basin is related to a transtensional zone due to the activity of Sumatra and Ujungkulon Faults. Middle Miocene is interpreted to be the initial phase prior to the deformation caused by "basement" block faulting. During this phase, a slope geometry is interpreted to have formed farther southwest. A 4.77% to 8.59% extension is calculated prior to deposition of Unit 1 in the Late Miocene. This unit is observed within the present-day basin and ridges with similar thickness, suggesting that this unit 1 had been deposited as a pre-transtensional sediments.

Unit 2 had been deposited during Early-Late Pliocene, in which 10.9% extension is calculated to have occurred. Subsequently, reactivation of old structures as suggested by difference of throw on hanging wall side and antithetic faults emergence is interpreted due to the activity of the NW-SE trending cross-basin faults. The SE-NW and N-S trending grabens are interpreted to have form after the deposition of Unit 2. Therefore, Unit 2 is categorized as a pre-transtensional deposit.

Deposition of Unit 3 is interpreted to have initiated in the late Pliocene, during a 11.62% to 12.38% extension. This unit is not observed in the Semangko horst. Whereas in the Tabuan-Panaitan ridges Unit 3 is argued to been eroded. Deposition of Unit 3 is closely associated with the formation of the pull apart basin as indicated by different thickness in the horst and in the graben. Therefore, it is interpreted that this unit is a syn-transtensional deposit.

Structural evolution of the Sunda Strait was started at least from the Middle Miocene, as recognized by the activity of the Sumatra Fault Zone (Figure 5). In the Late Miocene-Early Pliocene, en-echelon faults formed along the central basin, eastern and western flank. The en-echelon faults merged with the Principle Displacement Zone (PDZ) and formed the West Semangko and East Semangko Faults during Pliocene-Pleistocene. Faults in the PDZ formed a weak zone that now occupied by intrusion that lead to the emergence of Tabuan and Panaitan highs.

Conclusions

The Semangko pull-apart basin is formed by overstepping of SFZ and UKFZ. Two major structural patterns developed as a N-S and NW-SE trending normal faults. Three sedimentary units are observed: the pre-transtensional deposits of Unit 1 and Unit 2, and the syn-transtensional Unit 3. Total strain formed during Middle Miocene-Recent are of 0.123, with 12.38% total extension and 1.12 contraction ratio. The western graben appears to be more active as compared to that in the eastern part, possibly due to the activity of Ujung Kulon Fault.

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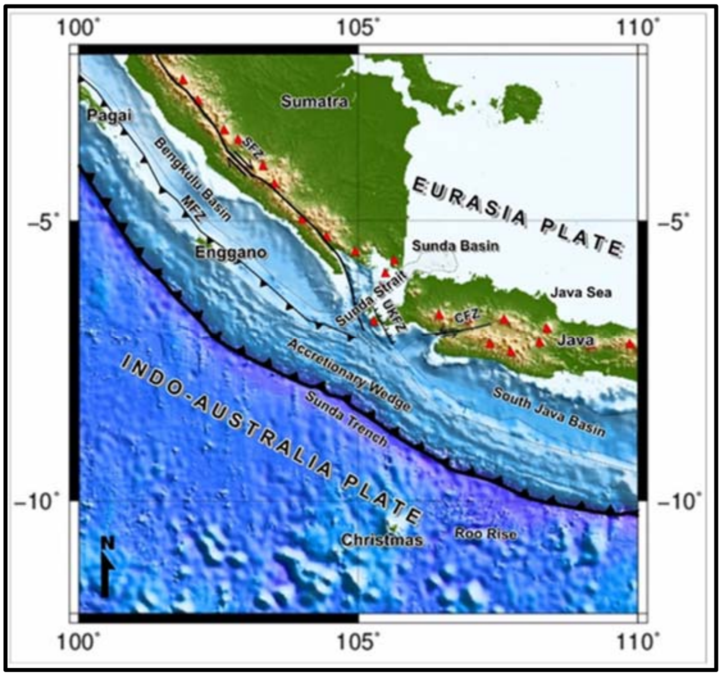

Figure 1 : Tectonic map of Western Sundaland. SFZ after Sieh and Natawidjaja (2000), MFZ (Susilohadi et al., 2005), CFZ (Malod et al., 1995), Sunda Trench (Hamilton, 1979). Research area is located in the Semangko Basin, Sunda Strait.

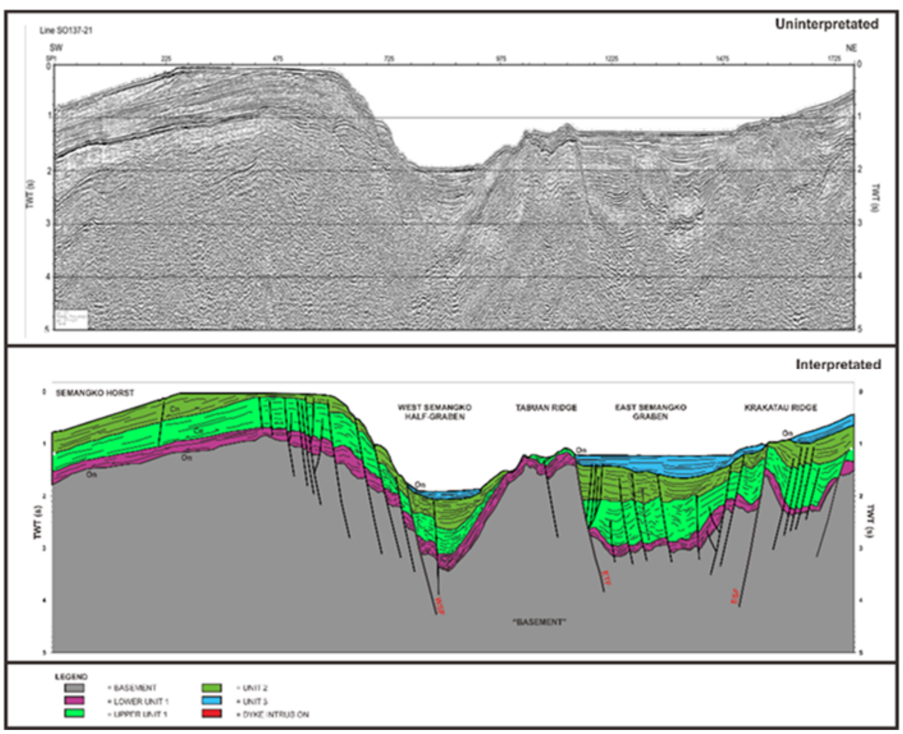

Figure 2 : Re-interpreted seismic section Line SO137-23 of Susilohadi et al., (2009).

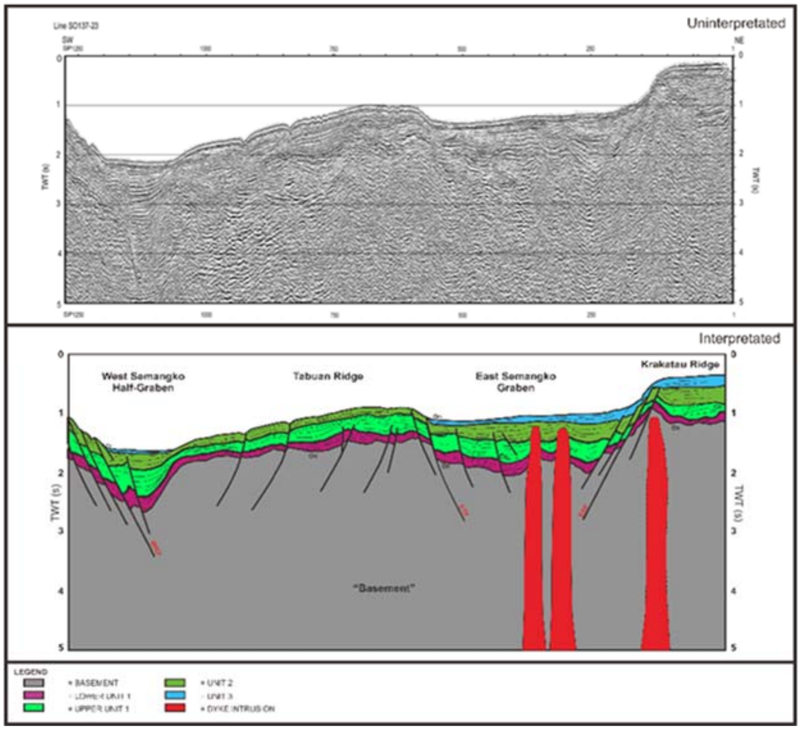

Figure 3 : Re-intrepreted seismic section Line SO137-23 of Susilohadi et al., (2009).

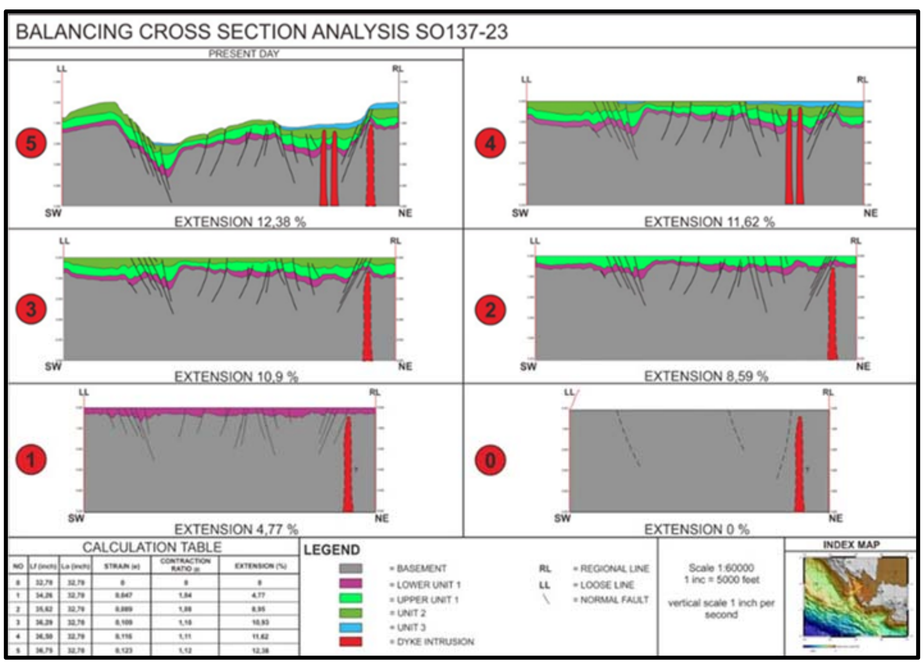

Figure 4 : Result of palinspastic reconstruction of Line SO137-23.

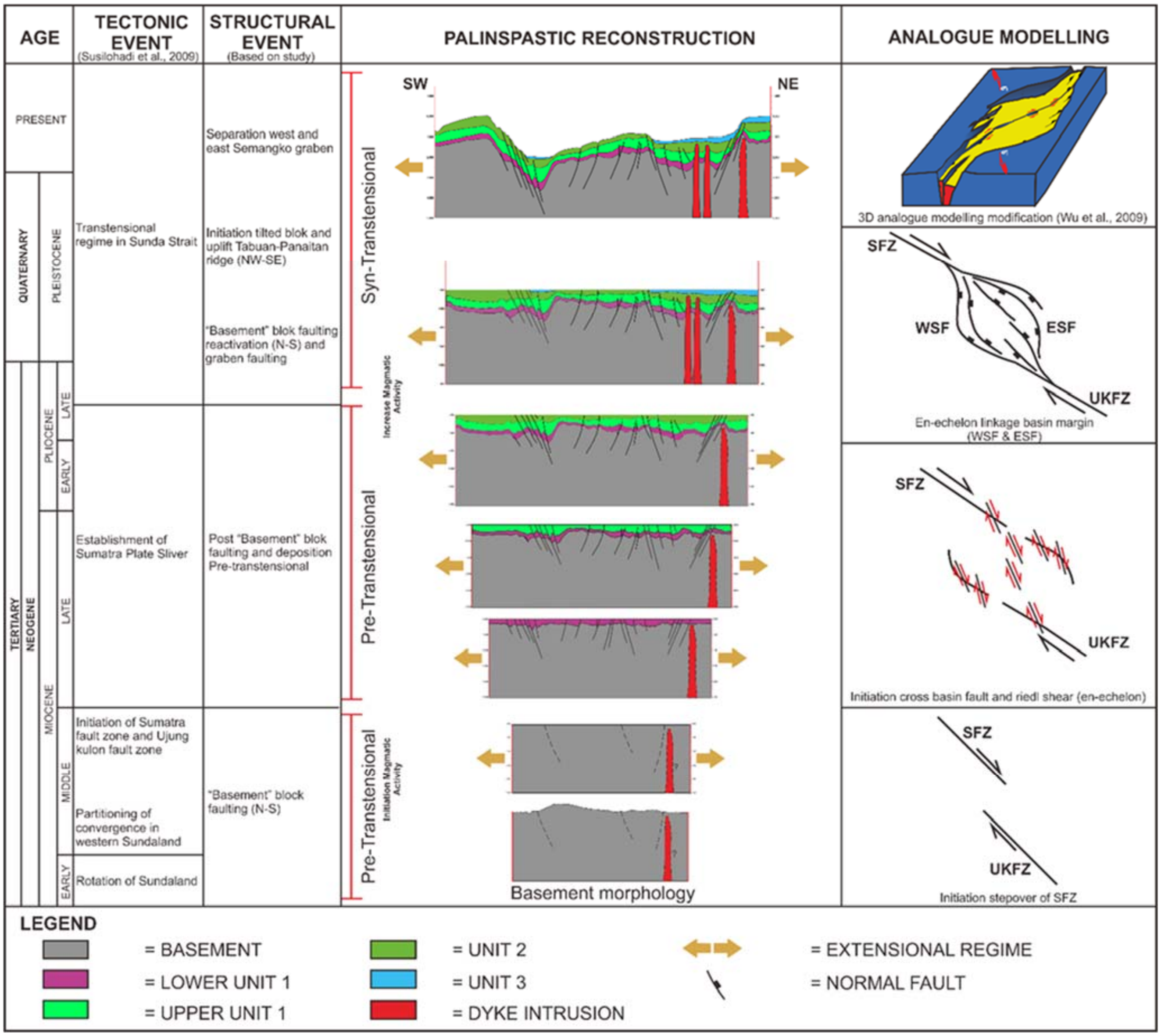

Figure 5 : Structural evolution of the Semangko Basin. Tectonic event is based on Susilohadi et al., (2009), 3D analogue modeling is based on Wu et al., (2009).