5th World Conference on
Applied Sciences, Engineering & Technology
02-04 June 2016, HCMUT, Vietnam

Mechanism of Phu Khanh Basin Formation and Related Tectonic Context in the Southeast Asia Sea

NGUYEN XUAN TRUONG, NGUYEN XUAN HUY*, TA QUOC DUNG, DO QUANG KHANH
Faculty of Geology and Petroleum Engineering, Ho Chi Minh City University of Technology, Vietnam
Email address: nxhuy@hcmut.edu.vn

Abstract: Phu Khanh basin is a deep-water area lying offshore along the central Vietnamese East Sea, with 250km of North-South extension and 50 – 75 km wide opening. The area is steeply towards the basin floor to the Eastern (more than 4.000 m water column), whereas the shallow coastline is lying to the West (300 m deep). Gravity survey has been conducted since 1972 to assess the West flank of Phu Khanh Basin. Seismic acquisition just performed in 2008, covering 14,500 km 2-D seismic line by GeoStreamer™ along with the Aeromagnetic Survey (Maringarm, 2012). Further research has been investigated into the area in such of three well were drilled (124-HT-1X, 124-CMT-1X in 2009, and 123-TH-1X in 2011) in the shallow water and uplifted block. The 124-CMT-1X well has been recognized with the the oil show in Miocene Carbonate strata, which make the area potential for Petroleum Exploration.

Tectonic activity of the Southeast Asia Sea (SAS) is believe to lead to the formation of Phu Khanh basin. In fact, the study basin is lying next to the opening zone of the SAS, where tectonic framework governs the basin development. It is recognized that two extension phases of the SAS have been recorded in Palaeocene-Eocene and Late Miocene-Early Miocene. The post rift phase experienced a thermal subsidence started in Middle Miocene which affected the deposition settings of Phu Khanh basin, ranging from shelf slope to deep-sea environment. In addition, the opening of SAS has initiate the heat flow regime of the region, in the time, which closely influenced the thermal maturation of the organic content. Therefore, this paper will examine and reason how the Phu Khanh basin has been formed under the tectonic happen of the SAS.

Keywords: *Phu Khanh basin, Tectonics, Southeast Asia Sea, Basin Research, Asia Earth Science*

Introduction:

Southeast Asia Sea is an enormous sediment basin, consisting of many mini-basins. The area is located to the East of Central Vietnam, adjacent to Phu Khanh Basin. The Southeast Asia Sea is formed in combination of tectonic activities, where the collision of the India Plate towards the Eurasia Plate, as long as the subduction happening of the Pacific Plate to the west. The East Sea, however, has experienced stages of sea floor spreading, separating many mini-plates, mainland, oceans, and islands apart from each other. Such formation in the region has initiated the formation of Phu Khanh Basin, where subsidence, faulting and sedimentation happening to make the basin as it is at present day. In this framework, Phu Khanh Basin has been limited to the north by the extension of South Song Hong Basin; to the South by Cuu Long Basin and Nam Con Son Basin (Figure 1).

Also noted that the Cenozoic evolution of Southeast Asia Sea has included many rifting, subduction, collision and strike-slip faulting occurring (Andrew Cullen, 2010), and continental crust attenuation is a result to form the flexural back-stripping feature to form the Phu Khanh ultra deep water basin. Many other features are the consequence of the activity, where there are Pearl River Mouth (Ru & Pigott, 1986), Dangerous Grounds (Thies et al., 2005), onshore Kalimantan (Barito, Kutei, and Tarakan basin, Satyana et al., 1999), Makassar Straits (Guntoro, 1999; Hall et al., 2009), Macclesfield Bank, Luconia Balingian Basin, Baram Balabac Basin, Reed Bank, and so on. The studied basin setting is to recognize what type rift or sag basins, which linked to continental-scale strike-slip faulting or to an Atlantic-type continental, break up by my European Geoscientists (Michael B.W. Fyhn, 2009).

Figure 1. Location of Phu Khanh Basin and Southeast Asia Sea

Materials and Methods:

Many deep ocean-drilling programs has been conducted to confirm the evidence for the tectonic activity of the sea regions, such as the International Ocean Discovery Program (IODP) Expedition 349 recently reported in 2014, to be drilling five sites in the oceanic basin (Weiwei Ding and Jiabiao Li, 2015). Dating age using isotopes along with microfossils and palaeomagnetism measurements have also been performed with an attempt to refine the absolute age of the area. The argument on such issue has come to a compromise lately. Therefore, the setting and formation of Phu Khanh Basin can be refined more clearly.

Decades ago, back to 1980, Taylor and Hayes have reconstruction the magnetic anomaly data of the SAS region with a certain degree of confidence. The work has completed the correlation of the magnetic reversal time scale with the mapped anomalies, which can be utilized to derive the age of magnetic zoning which supported the tectonic modelling from the earlier proposal of the SAS. Lately, a database of seismic lines and magnetic/gravity profiles have been continuously recorded and reviewed to investigate the continent-ocean transition between Reed Bank and Palawan and Calamian (D. Franke, 2011). He described the ceasing and termination of the magnetic spreading anomalies to be the feature of the continent-ocean transition at the seaward limit where there are presence of relatively thick continental crust of low density and relatively thin oceanic crust of high density. This would be influenced by the pre-rift lithospheric configuration. Consequently, many structures have been recognized, including gradual deepening of the rift towards the oceanic crust, seaward-dipping listric normal faults, half grabens, rotated fault blocks, fault ramp and detachment.

Many unconformities in the stratigraphy column have been described by seismic interpretation and seismic section with the recognition of acoustic basement underlying the SAS. These work illustrated the beak of sedimentation due to uplifted blocks and / or the lowering of sea level due to tectonic happens (Holloway, 1982). Such thing might coincide (or not) with major orogeny recorded in the Sundaland and spreading and rotation of the SAS. The Cretaceous-Palaeocene boundaries were described by Holloway to analyse the presence of sediment package in conjunction with tectonic periods. Also, related to the faulted blocks of the shelf areas (Falvey, 1974) to be described as a representative feature of the rift-onset event in latest Cretaceous-early Palaeocene. And the supposition law has strongly supported that there is no conterminous in Neogene times in SAS (Holloway, 1982).

A more detailed study on the seafloor spreading due to non-uniform hyper-extension process in the SAS also denoted the tectonic model happening in between 32 and 16 Ma (Li, Clift, Stephenson, & Nguyen, 2014). The initiation of syn-rift subsidence possibly prior to the seafloor spreading has been forming banks offshore Sunda continental Shelf and surrounded by hyper-extended crust of the transition crust during the time. This pretty much fits in the polarity chronology of the magnetic anomalies at the SAS (Sorkhabi, 2013).

Results and Discussion:

SAS tectonic model of formation

Southeast Asia Sea or East Sea has been described as beginning of a transition from the Indochina continental block to the deep ocean basin (P. Tapponnier, 1986). The activity of pushing up the Himalaya range created the shear zone running through the North of Vietnam Territory. When offset towards the continental shelf, the shear zone run southwards to the Sunda Shelf, while the rotation activity and spreading plate of the East Sea occur. In the meantime, the subduction of the Pacific Plate from the East towards the West also provides many influences to the SAS opening. It has been studied that there are quite a few models of tectonic happening in the area to be suggested observed from data and experiment available. To accommodate the purpose of this research, this paper examines two proposed kinematic-tectonic models applied to SAS (Andrew Cullen, 2010), which is the collision-extrusion model (Briais et al., 1993; Replumaz & Tapponnier, 2003) and subduction-collision model (Hall, 2002; Hall et al., 2008).

- *Collision-extrusion model*

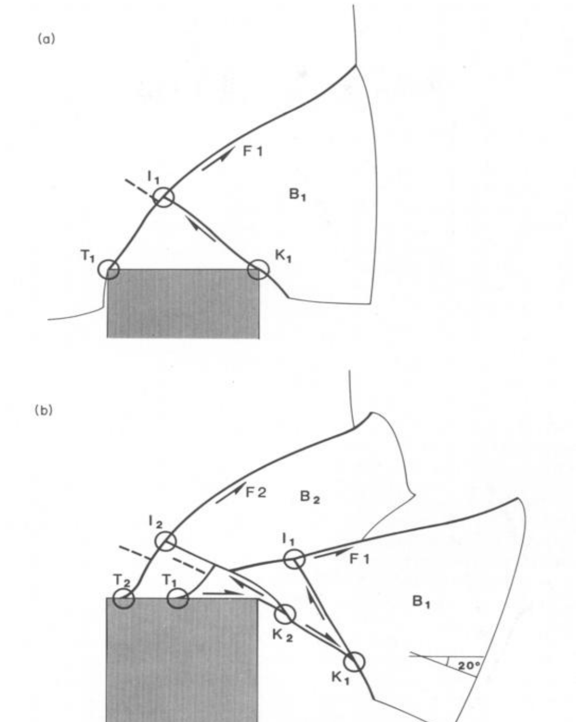

Figure 2. Collision Extrusion Model with rotation of two major blocks of plasticine (B1 and B2), penetration of the indenter. F: faulting; K, T, I: sharp rheology point. Adapted from P. Tapponnier, 1986.

The Sundaland has experienced a collision to the north of the plate margin, where India plate crushing the Asia plate, pushing the Sundaland plate to the E and SE (P. Tapponnier, 1986). This activity creates an intense stress field to result in the continental crust shearing at the Indochina block forming the Red River fault zone, whereas the SAS with its transition to the thin ocean crust undergoes a stretching episode. The SAS seafloor spreading is terminated at the time when the India plate penetrates enough into Asia plate, halting the pushing Indochina force. There are some requirement when considers this model, such as the amount of seafloor spreading needs to equal to the lateral displacements along the intercontinental strike-slip and a 25^O clockwise rotation of Indochina and Borneo occur. In this model, deep fault systems need to be clearly and carefully modelled for better understanding of the mini-plates behaviours, i.e. the Ailao Shan-Red River fault zone, the Mae Ping fault and the West Baram Line, the East Vietnam Fault with linking to the SW side of the oceanic spreading (Figure 2) (Replumaz & Tapponnier, 2003).

- *Subduction-collision model*

The idea of Hamilton (1979) and Holloway (1982) considers the spreading of SAS is due to the subduction activity with the features of long-lived subduction beneath NW Borneo (Lee & Lawer, 1995; Hall, 1997). Proto-plate of SAS has experienced a subduction process where the oceanic crust immerses under the NW Borneo between Palaeocene to Middle Eocene and ended in Early Miocene at the Baram-Balabac basin. At the time, the Dangerous Grounds attenuated continental crust becomes buoyant (Hall, 1997; Longley, 1997); Murphy, 1998; Morley, 2002; Hall, 2002). As a result, the Sabah Orogeny has been built up 18 Ma (Hutchison et al., 2000). Recent study has been argued the presence of the subduction zone (Hall, 2013) to confirm the model (*Figure 3*).

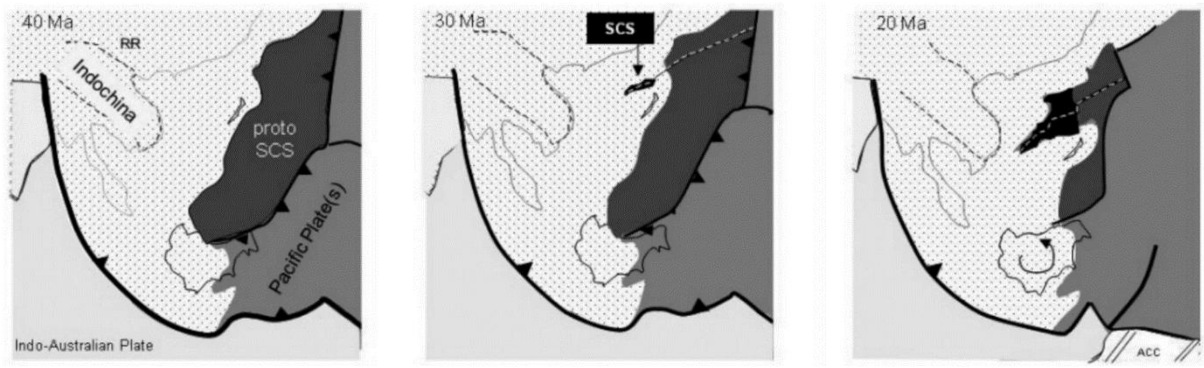

Figure 3. The subduction model suggested by Hall, 2002. Adapted from Andrew Cullen, 2010.

It would be undoubted that many models have been proposed to accommodate the situation at SAS. However, every model reveals pros and cons towards the situation, which is complicated and possibly a result of all suggested activities. However, the formation of Phu Khanh Basin during the development of the SAS is greatly influenced and reflected the seafloor spreading activity.

SAS opening history

Many research, although showing a ranging of absolute age of this tectonic activity, emphasize the opening of the SAS consisting of many phases during the Oligocene and Early Miocene, 32 Ma to 16 Ma, with at least one ridge jump occurred (Figure 4) (Andrew Cullen, 2010) .

- **37 Ma to 25 .5 Ma (anomalies 16 to 7A):** initiated to the west of Luzon transform fault, the anomalies 14-16 open to the west showing an east-west spreading ridge which is linked to north-south striking transform faults. It can be observed at Xisha Trough as a narrow EW trending bathymetric low on the northern side of Paracel Islands. A failed rift arm is also interpreted from 2D seismic data (Qui et al., 2001) marking the thinking of pre-rift continental crust.
- **25.5 Ma to 24.7 Ma (anomalies 7 to 6B):** a jump of the spreading ridge is recorded from east of the Xisha Trough to roughly 50 km south. The spreading trend becomes WSW orientation seeing with the anomalies 7 and 9 to the southern side of the rift and eventually initiate rifting phase at previously formed oceanic crust. The presence of the Reed and Macclesfield banks are believed to inhibited the propagation of the rift to the SW.
- **24.7 Ma to 20.5 Ma (anomalies 6B to 6A1)**: Another jump happens across a transform faults seeing at 24.7 Ma while the rift entering the continental crust, splitting the Reed and Macclesfield banks. The spreading ridge of SAS seafloor now is NW to SE. The limit point of the spreading rift is a mystery as it is unknown whether the underlain is oceanic crust or exhumed mantle. Huchon et al. (2001) has documented the dextral oblique faulting near the rift tip and Bouguer gravity data indicates that to the SE there is much wider attenuated continental crust present on the Vietnamese margin.

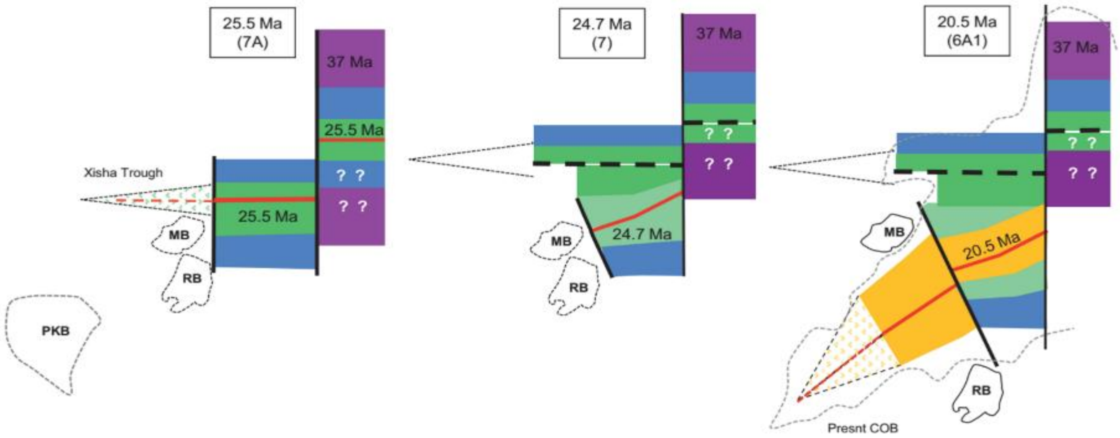

Figure 4. Schematic opening history of the Seafloor Spreading activity observed at SAS with Magnetic anomalies 7, 7a, and 6A1. (Adapted from Andrew Cullen, 2010)

The formation of Phu Khanh Basin

Aeromagnetic and gravity survey are applied to understand the crust structure and examine the characteristics of the acoustic basement within the sedimentary basin. From the study of seismic cross section, it can be extrapolated the structure of deep faults in the old crusts (Figure 5). There are 17 magnetic anomalies divided at the SAS region. The central is located the East Sea with the oceanic crust underlying. There can be classified into three phases of spreading the seafloor as following:

- **Phase 1:** Palaeocene – Late Oligocene (65 Ma to 36.6 Ma): the initiation of rifting phase when the basin has experienced the extension. It can be observed there are lateral moving blocks with many transform faults.
- **Phase 2:** Late Oligocene – end of Early Miocene (36.6 Ma to 15.5 Ma): the formation of fore-arc basin. When the spreading seafloor of the SAS ends in Early Miocene, the continental crust is cooled down and shrinking until Middle Miocene.
- **Phase 3** (10.5 MA): recognized by the separation between Middle Miocene and Upper Miocene.

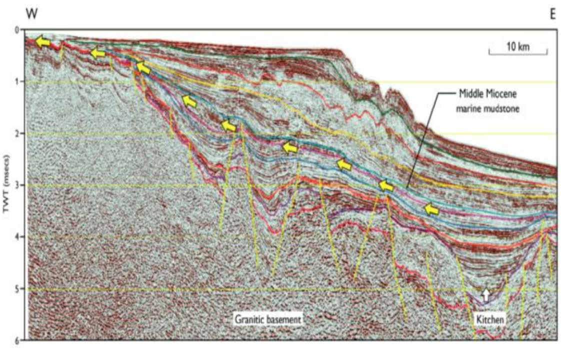

Figure 5. Seismic Cross Section of Phu Khanh Basin (PVEP)

The three rifting phases have formed the 2 main extension orientations: North – South and North West – South East. Most of the faults and rifts are overlain by the unconformities dating back to 10.5 Ma. The volcanism activity during Neogene also become abundant, which results in the intrusion of magmatism along the Central and South of Vietnam margin. Such activity has an impact on the ancient rifting and faulting phases at Phu Khanh basin. The tectonic activity has formed uplifted blocks, which are eventually eroded during later. Many sources of sedimentation are come from this erosion, where graben and deep sea trough basin are filled by this kind of sediment in many different process, ranging from continental to shallow water and deep sea basin. The transition zone marking with the presence of carbonate build-ups. Following is the cooling and shrinking of the thermal subsidence stage to form the Phu Khanh basin.

Conclusion:

It is clearly that tectonic activity has play important role in forming Phu Khanh basin as well as developing the regional structures. The seafloor spreading at SAS has been recorded from Eocene – Oligocene, governing the formation of the Phu Khanh basin. Many of tectonic models have been proposed and under researching for refinement.

References:

[1] Andrew Cullen, P. R. (2010). Rifting of The South China Sea: New Perspectives. *Petroleum Geoscience, 16*, 273-282.

[2] D. Franke, U. B. (2011). The Continental-Ocean Transition at the Southeastern Margin of the South China Sea. *Marine and Petroleum Geology, 28*, 1187-1204.

[3] Holloway, N. (1982). North Palawan Block, Philippines-Its Relation to Asian Mainland and Role in Evolution of South China Sea. *AAPG Bulletin, No. 9*(SEPTEMBER), 355-383.

[4] Li, L., Clift, P., Stephenson, R., & Nguyen, H. (2014). Non-uniform Hyper-extension in Advance of Seafloor Spreading on the Vietnam Continental margin and the SW

South China Sea. *Basin Research, 26*, 106-134.

[5] Michael B.W. Fyhn, L. O. (2009). Geological Development of the Central and South Vietnamese Margin: Implication for the Establishment of the South China Sea, Indochinese Escape Tectonics and Cenozoic Volcanism. *Tectonophysics, 478*, 184-214.

[6] P. Tapponnier, G. P. (1986). On The Mechanics of the Collision Between India and Asia. *Geological Society of London, Special Publications, 19*, 113-157.

[7] Peel, F. J. (2014). The Engine of Gravity-Driven Movement on Passive Margins: Quantifying the Relative Contribution of Spreading vs. Gravity Sliding Mechanism. *Tectonophysics, 633*, 126-142.

[8] Peel, F. J. (2014). The Engines of Gravity-Driven Movement on Passive Margins: Quantifying the Relative Contribution of Spreading vs. Gravity Sliding Mechanisms. *Tectonophysics, 633*, 126-142.

[9] Sorkhabi, R. (2013). The South China Sea Enigma. *Geo ExPro*, 50-56.

[10] Weiwei Ding and Jiabiao Li. (2015). Conjugate Margin Pattern of the Southwest Sub-Basin, South China Sea: Insights from Deformation Structures in the Continent-Ocean Transition Zone. *Geological Journal*.

Proceedings of the 5th World Conference on Applied Sciences, Engineering and Technology
02-04 June 2016, HCMUT, Vietnam, ISBN 13: 978-81-930222-2-1, pp 133-137