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Non-structural traps in the post-rift succession of Phu Khanh Basin: Classification and Depositional History

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ABSTRACT

The Phu Khanh basin is a rifted continental margin basin that was formed by Paleogene rifting and subsequent post-rift subsidence. The basin is situated along the narrowest part of the Bien Dong Sea's shelf and is characterized by a water depth ranging from a few tens of meters to abyssal depths towards the east. Oil and gas discovered from 2 wells 124-CMT-1X and 123-TH-1X are evident for approving petroleum system of the Phu Khanh basin. Besides structural play, non-structural play is also a potential reservoir. The Carbonates, Fans, Turbidities in the post-rift succession are prospective non-structural play. This play was formed in subsidence and sagging phase during the Miocene - Pliocene period as a resulted of increased sediment accumulation rates and transgression in the Phu Khanh Basin.

1. Introduction

To maintain and increase oil and gas reserves, along with oil and gas exploration in the form of structural traps, necessary to conduct the search of oil and gas on the form of non-structural traps.

To the present time, the exploration activities have been deployed on a large area of Phu Khanh Basin. With the existing database, geological structure Phu Khanh basin has gradually been clarified, and petroleum potential of the basin has been evaluated as positive with the assertion petroleum system exists through the results of wells drilled 124-CMT-1X and 123-TH-1X. But these wells are drilled on the structures. Besides structural play, non-structural play is also a potential reservoir.

The Phu Khanh Basin is situated along the narrowest part of the Bien Dong Sea's shelf (Fig. 1) and occupies much of the continental margin of central Vietnam and is characterized by a water depth ranging from a few tens of meters to abyssal depths towards the east. Stratigraphic evolution and structural analyses of the Phu Khanh Basin indicate that the initial rifting began during the Paleogene (Fig. 2). Thick sequences of lacustrine and alluvial sediments were deposited during the Paleogene rift periods. The Late Oligocene rifting ended due to inversion, triggered by right-lateral wrenching near the Paleogene - Neogene

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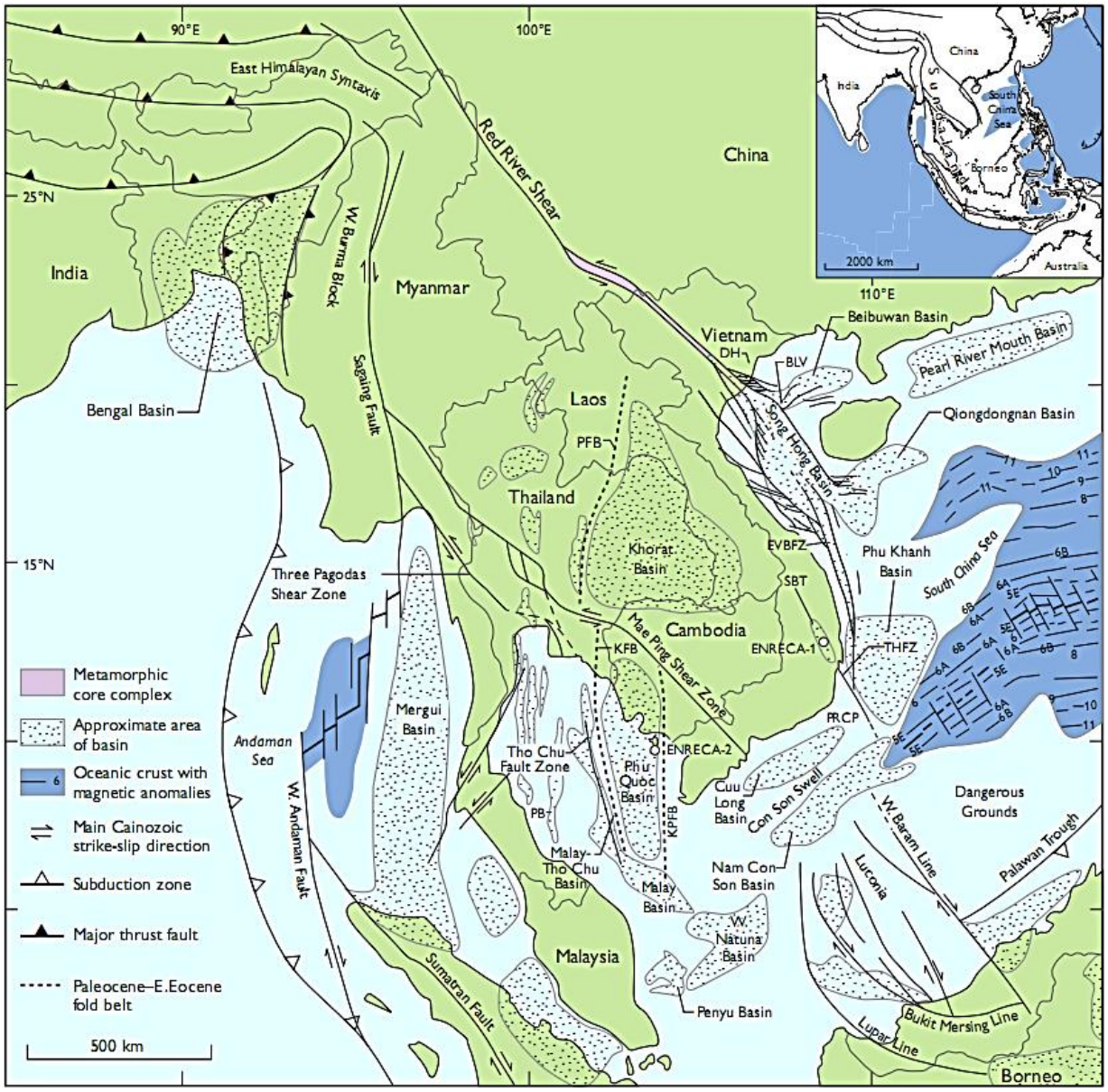

Figure 1. The Phu Khanh Basin is situated along the narrowest part of the Bien Dong Sea's shelf (Fyhn, 2009).

boundary. Following the onset of this inversion regional uplift and volcanism took place in the southern half of the study area and contemporaneous subsidence and transgression took place farther north, leading to wide spread carbonate deposition. As the right-lateral wrenching decreased during the early Neogene, thermal subsidence and siliclastic sedimentation became dominant, resulting in the buildup and south ward propagation of the shelf slope. Sediment accumulation and subsidence rates increased after the Middle Miocene times due to east ward tilting of Central Vietnam and the adjacent offshore area. Very large and rapidly sediments deposited within the tectonic development have generated various types of structural and stratigraphic traps with potential reservoirs including Paleogene fluvial sandstones, Neogene turbidities, shelf, lowstand delta, and coastal sandstones as well as Miocene carbonate and fractured basement (Fig. 3).

The purpose of this paper is to present the theory of base for non-structural trap classification and geological condition as well as its influences of non-structural traps in the post-rift succession of the Phu Khanh Basin.

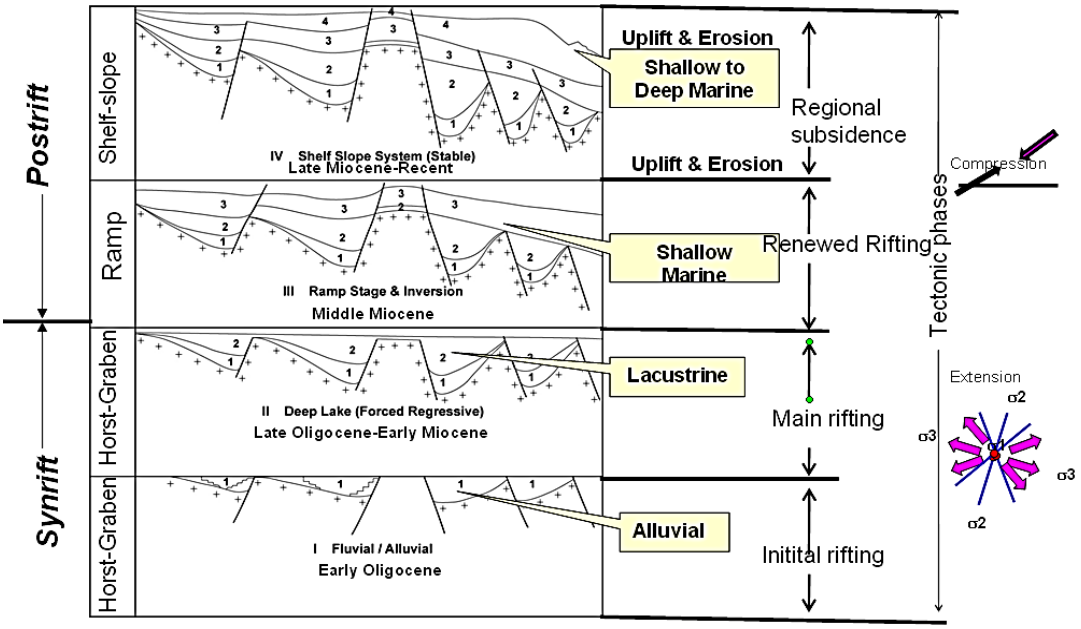

Figure 2. Schematic section illustrating the Tectono- Stratigraphy of the Phu Khanh Basin.

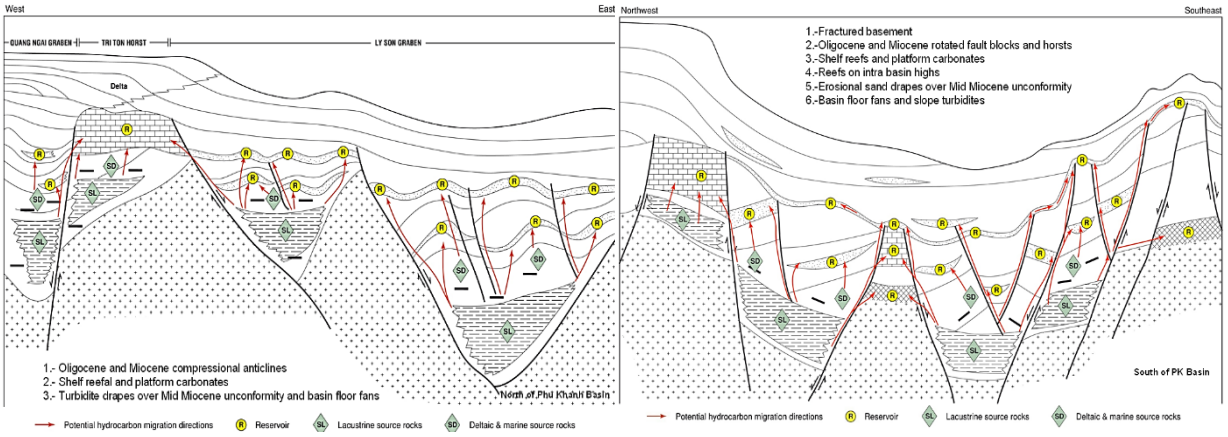

Figure 3. Schematic section illustrating structrural and non strucrural traps of the Phu Khanh Basin.

2. Non-structural trap classification

Currently, in the world as well as in Vietnam, non-structural traps are classified on the basis of the following (Gordon, 2001; Nguyễn Thu Huyen, 2014):

1. Time of trap formation: Primary - a direct product of the depositional environment; Secondary –Development after deposition and diagenesis of the reservoir: mainly unconformity trap.

2. Kind of reservoir rock.

3. Kind of porosity.

4. The genesis of the reservoir rock.

5. Relation of the regional dip.

6. The geometry of the reservoir rock.

7. The way the impermeable barrier formed.

From the classification above, can be classified into 3 types of non-structural traps groups as follows:

- Stratigraphic trap;
- Architecture intrusive trap;
- Combination trap.

A stratigraphic trap is fairly common and plays an important role in the process of finding non-structural traps. This trap type is usually distributed in a separate area, which was created by one of the causes: a change of facies; weathering phenomenon; chemical interaction,…

Based on the time of trap formation can be classified into two categories: primary

stratigraphic traps and secondary stratigraphic traps.

Primary stratigraphic trap formed during the deposition and/or diagenesis of the rock.

A secondary trap results from some stratigraphic anomaly or variation that developed after deposition and diagenesis of the reservoir rock; almost everywhere associated with unconformities.

Architecture intrusive trap formed mainly from the viscous rocks as salt, magma, mud-diapire.

Combination trap formed by many factors such as tectonics, stratigraphy, sediment, which can not be classified, considering one of the classification criteria above.

In the Phu Khanh Basin, based on the previous studied, some non-structural traps in the form of stratigraphic traps in the post-rift sediments were predicted (Fig. 3).

In the Phu Khanh basin, a stratigraphic trap is an important play for Oil and Gas exploration [] Fig 3. The primary and secondary traps that created as the product of the erosion, filled by wind, river or sea, with different environmental conditions, will be forming different types of stratigraphic traps as following:

- Reefs and carbonates;
- Erosional sand drapes over the unconformity;
- Basin floor fans;
- Turbidites.

3. Tectonics and Structural Development of the Phu Khanh Basin

The Phu Khanh Basin (Fig. 1) occupies much of the continental margin of central Vietnam. It is a long, wide basin extending north-south approximately 350 km and its width ranges from 125 to 150 km. It is bounded to the west by a narrow shelf, separated from the Quang Ngai Basin to the north by the Da Nang shear zone and from the Cuu Long Basin to the south by the Tuy Hoa shear zone (Fyhn, 2009).

The evolution of the Phu Khanh Basin is closely related to the development of the Bien Dong Sea (Hall, 1996; Hutchison, 1989; Longley, 2003; Fyhn, 2009; Tapponier et al., 1988) (Fig. 1). Mesozoic subduction along the northwest margin of the Pacific Ocean led to the dominant ENE structural grain prevalent throughout the Bien Dong Sea. Approximately 500 km - 600km of displacement was recorded during Late Oligocene to Miocene time related to the rifting and sea-floor spreading in the Bien Dong Sea. Basin as a consequence of the separation of the Palawan micro-continent from the mainland of China. Rifting and extension started around the late Eocene - Early Oligocene (~36Ma) times during the opening of the Bien Dong Sea.

Rifting and extension weakened the continental crust in the Bien Dong Sea area to the point where oceanic crust and sea floor spreading began sending the Phu Khanh Basin into compression for a short period of time during the Late Oligocene (Fig. 1, Fig. 2).

During the Early Miocene (21Ma), spreading of the Bien Dong Sea switched from N- S to NE-SW, whilst left lateral movement continued along with the Red River transfer fault system (Tapponier et al., 1988; Fyhn, 2009). A volcanic phase occurred regionally and commenced offshore during the early Miocene time. Magmatic activity later widened and caused basaltic volcanism onshore. In parts of the Phu Khanh basin, particularly intense magmatism re-activated older faults and caused the buildup of major volcanoes that now under-lie the Vietnamese margin. A subsequent Late Neogene intensification of volcanism onshore lead to regional uplift and denudation of southeastern Indochina. This, in turn, enhanced the offshore siliciclastic accumulation rates and, thereby, repressed offshore carbonate deposition (Tapponier et al., 1988).

The upper Middle Miocene (10.5Ma) marks a major eustatic sea-level fall associated with the termination of spreading in the Bien Dong Sea [. Pronounced turbidite sedimentation on the slope and basin floor occurred at this time during a tectonic sag phase. During the Early Pliocene (5.5Ma), movement along the Red River Fault Zone ceased. Counterclockwise movement of the Philippines plate led to an inversion episode and initiation of the compressional regime that continues to the present day.

4. Depositional history of the non-structure trap in post-rift succession

The most common definition of the sedimentary strata of the Phu Khanh Basin is

facies change sharply between regions, especially between the north and south, as well as the east and west. Thick Cenozoic sedimentary possible to 10.000m at the center trough and thinner in the western and the southern part, including the syn-rift sediments are separated from the post-rift succession above by the major unconformity, the unconformity is believed related to the start of the Bien Dong's spreading phase (Fyhn, 2009).

Rifting with syn-rift sediments that original was formed along the continental environment, and created graben simultaneously with the extension in deep waters of the Bien Dong Sea (Fyhn, 2009) is the key factor affect the structural trap types (Fig. 3). Subsidence and sediment accumulation rates increased significantly around the early Late Miocene, responding to sea-ward tilting to the east and led to progradation of the shelf as well as to increased water depth towards the basin center in the east and a depositional regime dominated by mass flow deposits east of the shelf slope are favorable conditions to create non-structural trap types (Fig. 3).

Up to the late Oligocene, this period is characterized by rifting, where extensional faults controlled the sedimentation in the small grabens during the initial part of the opening. During the Late Eocene, the sediments were deposited within a very continental environment with possible alluvial fans and conglomeratic reservoirs. During the Oligocene, as the basins create more accommodation space, a more fluvial - lacustrine - deltaic environment dominated. The sediments deposited during this time are believed to contain the main source rocks for the basin - coals, and shales. A fluvio-deltaic sheet-like sands and sand bars belonging to the syn-rift sequence can also be expected during this time and would potentially make good reservoirs. At the end of the Oligocene, rifting stopped with the onset of seafloor spreading in the Bien Dong Sea and this is characterized by uplift and erosion which marks the end of the main rifting phase and initiation of a marine transgression (Fig. 2).

While phase subsidence and sagging, a marine transgression began, resulting in widespread carbonate deposition during the Early Miocene. Carbonate build-ups within the Early-Mid Miocene sequences are considered the most prospective non structural play on the margin of the Phu Khanh Basin (Fig.3). Well 124-CMT-1X tested a carbonate prospect on the edge of the platform (Fig.4), discovered 22m of light oil within the carbonate. In addition to those,

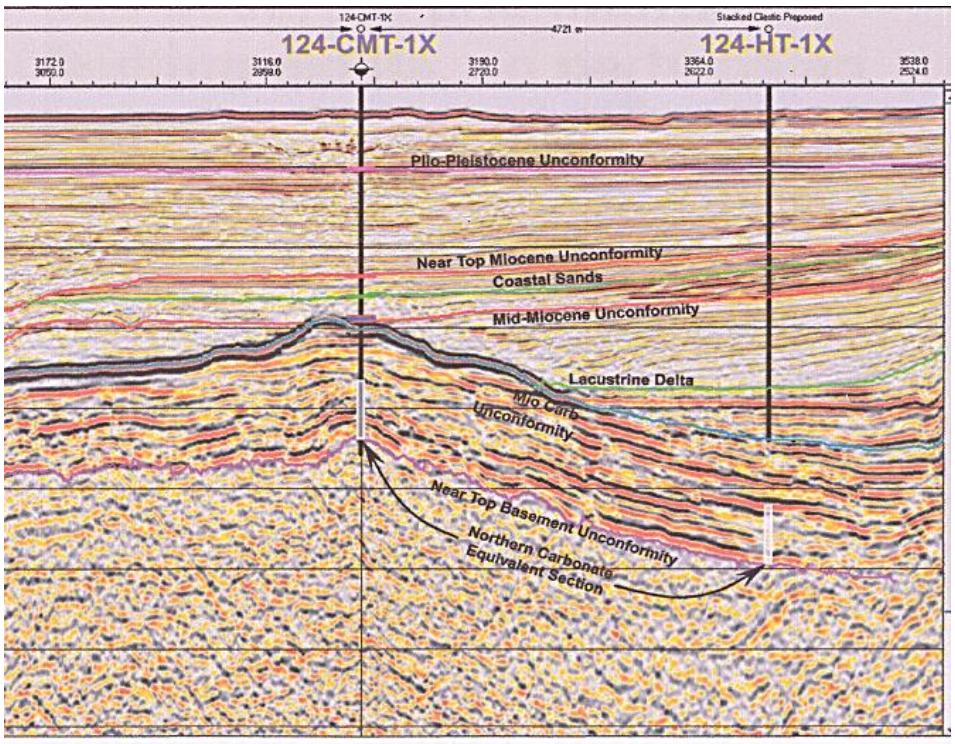

Figure 4. Well 124-CMT-1X: a carbonate prospect on the edge of the platform.

the other type of carbonate - reefs may be present in the deep waters of Phu Khanh. This carbonate seems to be associated with intra-basin highs in areas where large basement blocks have remained high through the Tertiary period of the basin (Fig. 5) where it can be appreciated that this type of target could also be drilled by a well testing multiple stacked.

Besides a widespread buildup of carbonates on the shelf and basin highs occurs during the Early and Middle Miocene, terrigenous influx due to the inversion at the top Oligocene resulted in both shallow marine siliciclastics and turbidites being deposited to the east of the continental shelf (Fig, 6). The Early Miocene package indicates a period of renewed rifting in some parts of the Phu Khanh Basin, as evidenced by extensional faults which cut into the Early Miocene sequence as well as the characteristic syn-depositional shape of this package. The transition from Lower to Middle Miocene is characterized by an angular unconformity. The top of the Middle Miocene is characterized by a regional unconformity which locally exhibits great amounts of erosion and simultaneously occurs in the Song Hong and Nam Con Son basins (Tapponier et al., 1988). This aerial unconformity is associated with a eustatic sea-level fall associated with the termination of spreading in the Bien Dong Sea (Fig. 2).

As the transgressions continued, a shelf slope started to build in the northern part of Phu Khanh Basin, and siliciclastic deposition gradually became dominant. Several large fan complexes which were deposited over most of the northern half of the Phu Khanh Basin (Figure 7, 8). The fans are up to 500 ms thick and show an internal configuration which indicates that different sediment flows have occurred over time stacking multiple sand bodies on top of each other (Fig. 7). The package sits above the Middle Miocene unconformity and presents multiple trapping opportunities as the sediments are draped over many of the inverted Lower and Middle Miocene blocks and roll-overs. This is one of the most attractive plays in the northern area, given the multiple occasions in which it is found within a structural closure at different levels presenting an opportunity for multi-target drilling.

From Late Miocene onwards, there was an eastward tilting of the region as a consequence of the increased volcanism onshore Vietnam (Fyhn, 2009). This resulted in increased sediment accumulation rates, increased water depths, and transgression in the Phu Khanh Basin. To the west of the basin, there was a rapid progradation of

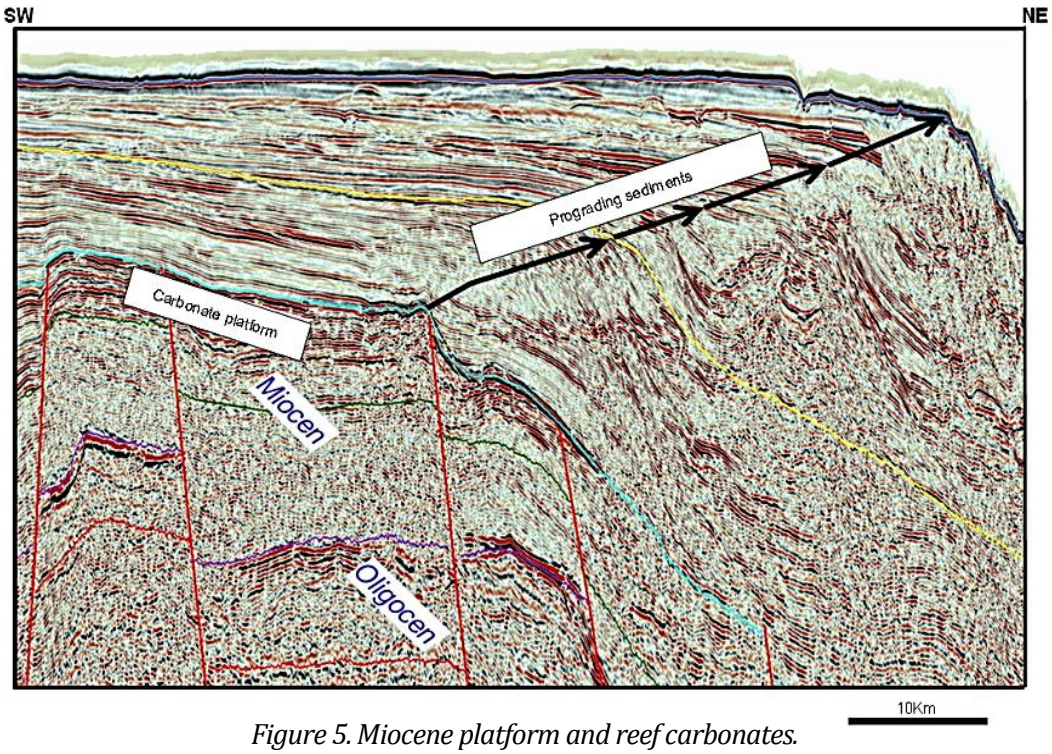

Figure 5. Miocene platform and reef carbonates.

deltaic sediments to the shelf edge, which drowned and buried the platform carbonates and reefs (Fig. 5). A series of very large Late Miocene submarine slope fan complexes developed to the east of the slope and can be seen deposited immediately above the Middle Miocene unconformity. The Pliocene and Pleistocene shelf sediments are characterized by prograding deltaic clinoforms which, through time, migrated the shelf break further to the east (Fig. 5). The sedimentary section observed to the east of the shelf would mainly comprise deep water shales with discrete intercalated turbidite bodies. Various turbidites are seen in the younger sedimentary section of the Phu Khanh Basin. The potential turbidite reservoirs are interbedded or

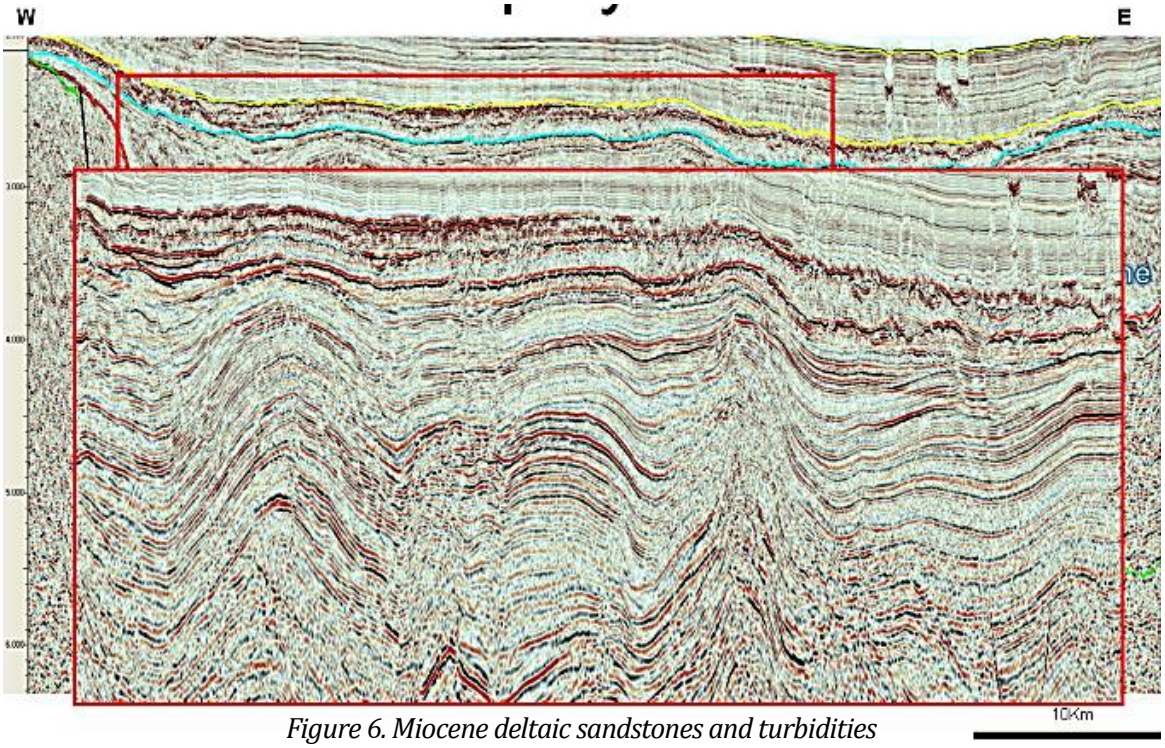

Figure 6. Miocene deltaic sandstones and turbidities

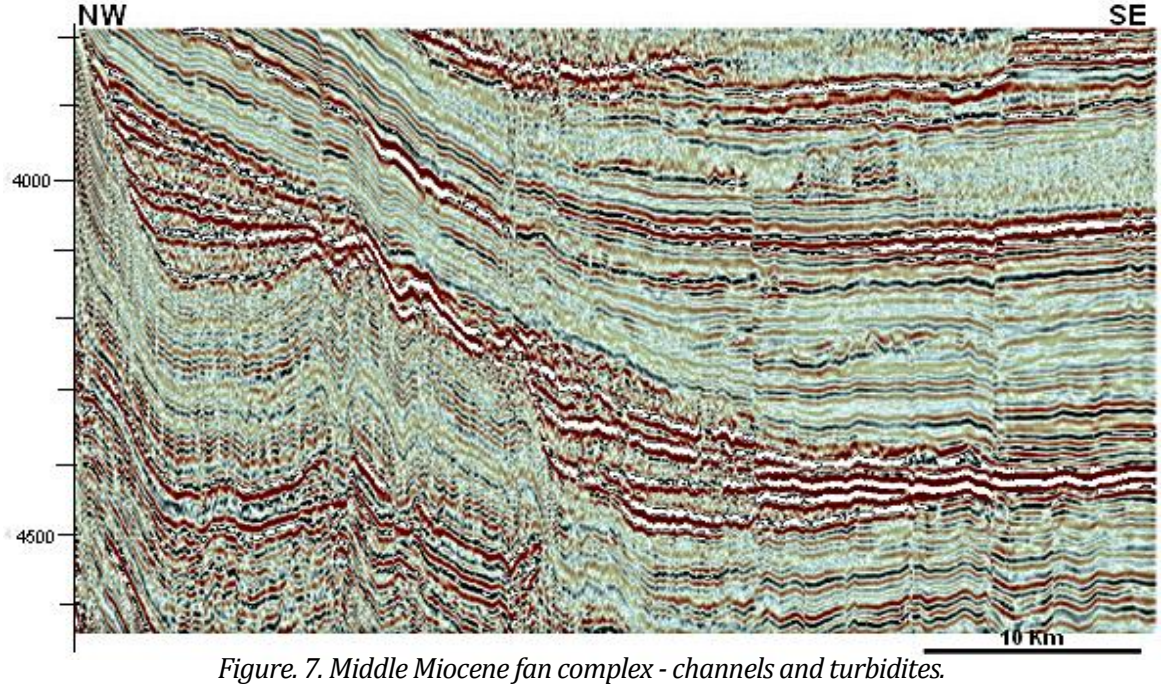

Figure. 7. Middle Miocene fan complex - channels and turbidites.

overlain by shales and, as such, seal risk is quite low. The Late Miocene/Pliocene facies analyses (Fyhn, 2009) shows a series of channels which run down the slope into the basin floor. The age of these channels seems to correspond with the time when the Vietnamese region tilted eastwards, generating a great influx of clastic to be shed down the slope and possibly depositing as the large fans above the Middle Miocene unconformity (Fig. 7, Fig. 8) that today we see on the data. It could be speculated that the large sand dunes seen today onshore East Vietnam acted as the clastic provenance for the fan complexes (Fig. 9).

5. Conclussions

Non structural trap plays an important role in Oil and Gas exploration in the Phu Khanh basin. Various types such as Carbonates, Fans, Turbidites are predicted mainly in the northern part of basin that formed in subsidence and sagging phase during the Miocen - Pliocen period as a resulted of increased sediment accumulation rates, increased water depths and transgression.

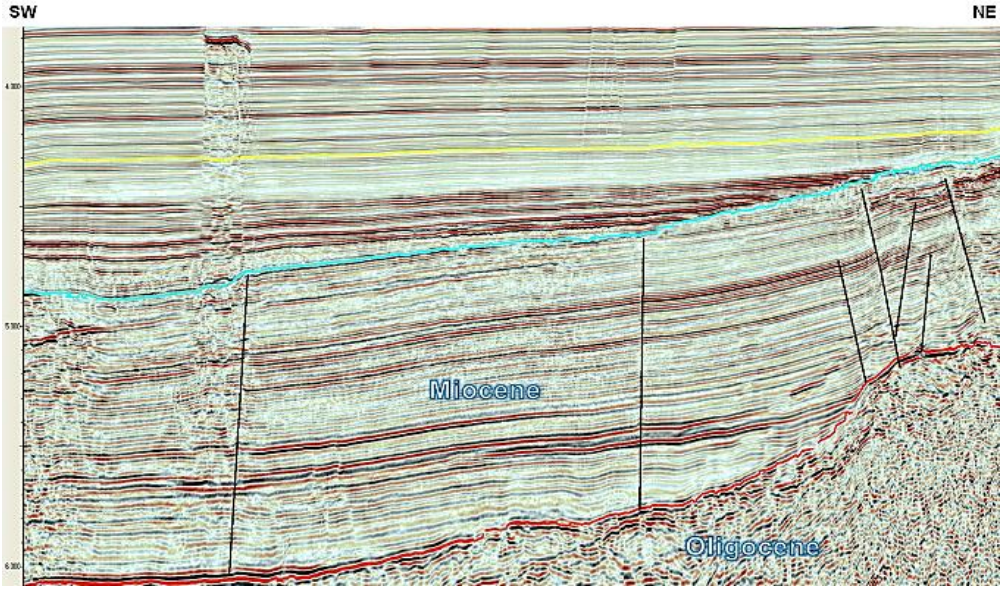

Figure 8. Upper Miocene fan - above the Middle Miocene unconformity.

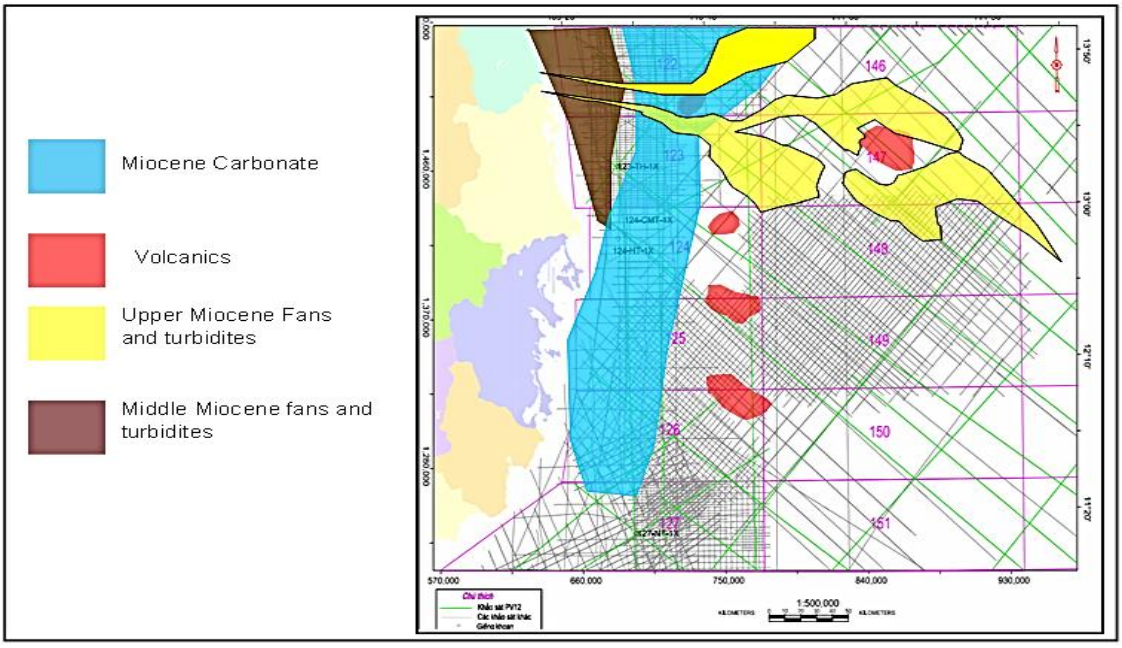

Figure 9. The non structural traps distribution map.

One of the main non structural play in the Phu Khanh basin is siliclasclastic sand bodies that presented multiple tpyes depending to the sediment accumulation rates and sediment supply tilting: Several large fan complexes which were deposited over most of the northern area besides various turbidites are seen in the younger sedimentary section of the Phu Khanh Basin.

Erosional sand drapes over the unconformity occurs during the Early and Middle Miocene, terrigenous influx due to the inversion resulted in both shallow marine siliclastics and turbidites being deposited to the east of the continental shelf. The transition from Lower to Middle Miocene is characterized by an angular unconformity which locally exhibits great amounts of erosion as well as the characteristic syn-depositional shape of straigraphic trap.

Carbonate build-ups within the Early-Mid Miocene sequences are and the other type of carbonate that was associated with intra-basin highs in areas where large basement blocks have remained high through the Tertiary period of the Phu Khanh basin can be appreciated as a type of Hydrocarbon exploration target.

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