Geological Controls on Evolution of Submarine Channels in Song Hong Basin, Offshore Vietnam

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Abstract

Song Hong basin is a very large basin with complicated onshore to offshore geological structure. The basin comprises the pre-Tertiary basement and Kainozoi sequences. This study focused on the evolution of submarine channel in Miocene sequence. The study interval is the major reservoir of the basin characterized as submarine channel complex and lower to Middle Miocene carbonates with the porosity of 15–25%. The channel is highly eroded into the substrate with c. 7 km wide and 20 km long, trending northwest-southeast. They are 'U' to 'V' shape, sub-parallel to deep faults which reactivated in the Early and Mid-Late Miocene. The channel deposit is characterized by cut and fill architecture and can be seen as high amplitude, bi-directional downlap. The channels are likely to be controlled by the two inverted phases in Late Oligocene and Middle-Late Miocene. The tectonic events are not only controls the flow directions but also modified the shape of the channels. The occurrence of well-developed submarine channel give a great hydrocarbon potential for the Song Hong basin.

Keywords: *Song Hong basin, submarine channels, channel complex, 3D seismic*

1. Introduction

During the past few years, submarine channel has been significantly getting interest from scientists due to the development of 3D seismic techniques. This advance techniques allow us to get inside the channel image and thus understand the channel evolution and also its spatial and temporal distribution (Gee et al., 2007; Posamentier and Kolla, 2003; Kolla et al., 2007). Despite this, many elements of channel development and the processes that define their geometry remain unconstrained (Gee et al., 2007).

Submarine channel evolution is a result of sea-level change, sediment gravity flows, tectonics, and climate and plays an important element in the sedimentary basins (Satterfield and Behrens, 1990; Covault et al., 2016). The channel can extend up to thousands of kilometers. The channel fills reveal different stages from early channel incision to lateral migration to late-stage aggradation (Covault et al., 2016). They were proved to be very important in oil and gas exploration as the sand-rich channel filled that have high porosity and thus can store large amount of hydrocarbon (Kolla et al., 2001).

Submarine channels have been documented in the Song Hong basin (Hiep, 2019). The channels are not just simple with straight planform, they are highly complex with deeply incised channels. Due to this complexity, many aspects of channel evolution and the processes that control channel geometry remain unconstrained and have not been studied. In this paper, we use 3D seismic data to investigate the channel evolution and its associated depositional elements in conjunction with the tectonic regime in the northern part of the Song Hong basin. The channels are in Mid-Miocene in age and buried a few hundred meters below the present-day seafloor.

2. Geological setting

The Song Hong basin, situated on the northern part of the Vietnam continental shelf, is an extended basin trending NW--SE direction containing a small onshore area (Hanoi trough) and a large offshore area in the Gulf of Bac Bo from the NE to offshore Central Vietnam with more than 10 km of sediment thickness in the central basin area (Fig. 1).

Song Hong basin is the second largest sedimentary basin in Vietnam with complicated onshore to offshore geological structure, varying from the NW to the SE and from North to the South. The rhombic shape extended along the basin axis suggests that the basin had a strike-slip origin related to the Red River fault system, which was initiated by the collision between the Indian and the Eurasian plates in Eocene - Early Oligocene times (Tapponnier et al., 1986, 1990, Nguyen et al., 1999). Left-lateral strike-slip movement and pull-apart extension are the main geodynamic factors that form the Song Hong basin. After that, tectonic inversion in Late Oligocene

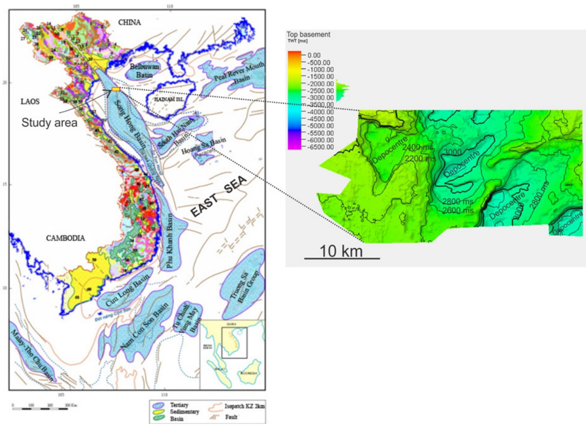

Fig. 1. (a) Study area in the Song Hong basin, one of the tertiary Sedimentary Basins in Vietnam, (b) Time structure map of the top basement of the study area – visible 4 depocentres with a thickness of up to 400 ms TWT

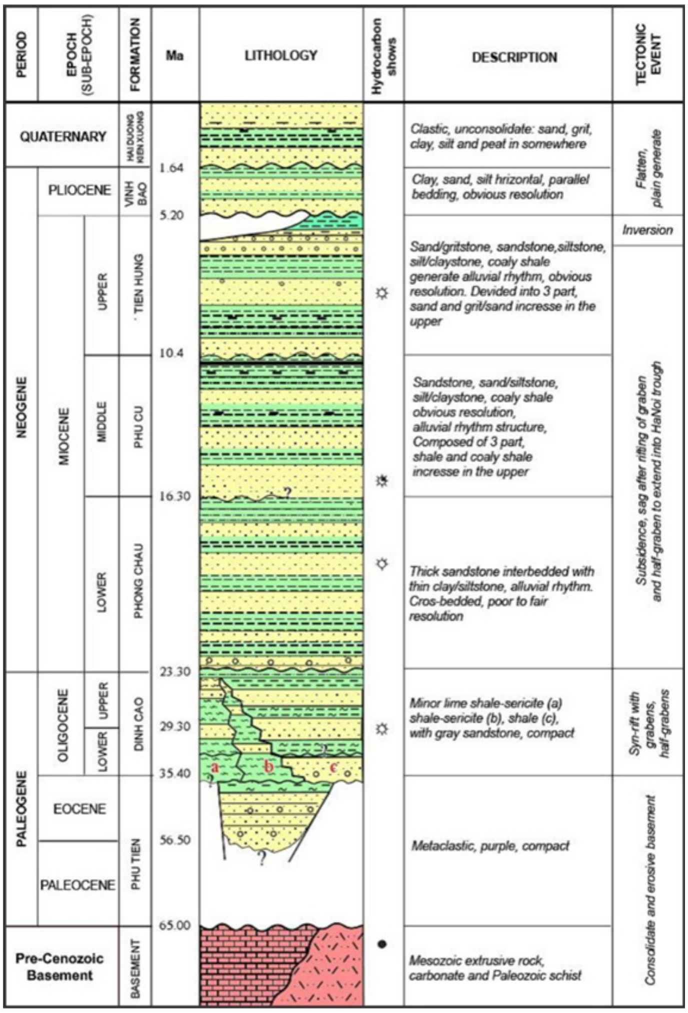

Fig. 2. Generalized stratigraphic column of NW Song Hong basin (Hiep, 2019)

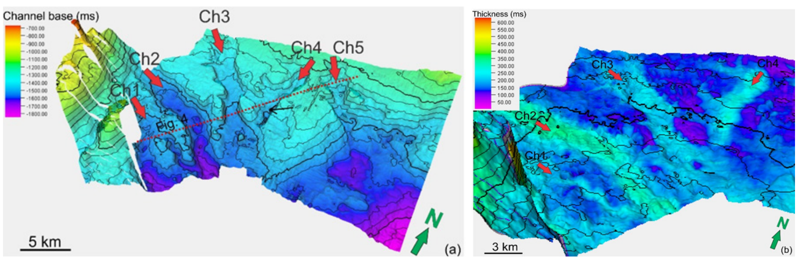

Fig. 3. (a) A map, 3D view of the channel base, shows the occurrence of five channel in the same stratigraphy level corresponding to Mid–Miocene in age. (b) Thickness maps between the channel base and the top of Mid–Miocene sequence reveal the channel thickness is up to 350 ms

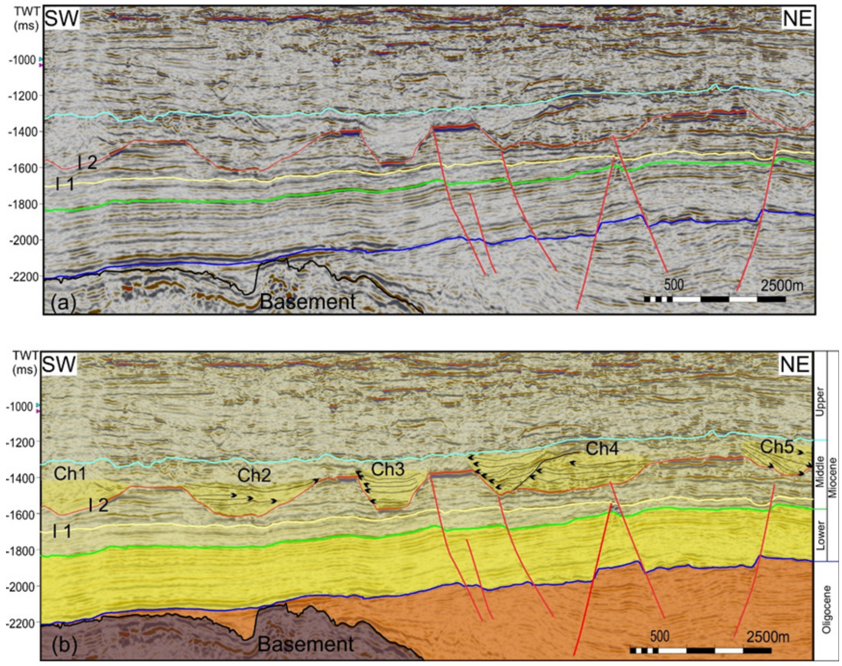

Fig. 4. The un-interpreted seismic section (above) and interpreted seismic section (below) to show the five channels in the cross section

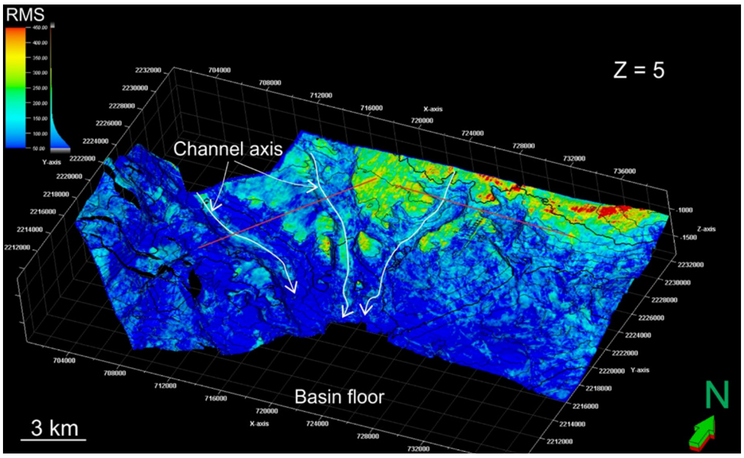

Fig. 5. RMS attribute map of the Mid Miocene channel base in 3D view

caused by northwest–southeast opening of East Vietnam Sea and the Middle-Late Miocene tectonic inversion partly contributed to the hydrocarbon trapping mechanism in the Song Hong basin (Vo et al., 1999).

The stratigraphy of the Song Hong basin is relatively complex, including the Pre-Tertiary basement and Kainozoic sequences – Paleogene, Neogene, and Pliocene-Quaternary sediments (Fig. 2).

Geological structures in the Song Hong basin, which involved the hydrocarbon accumulation, were formed in different stages, including (1) buried basements, (2) Oligocene tilted fault blocks or flower fault systems, and (3) Oligocene –Early Miocene inverted structures. Hydrocarbon migrated from Eocene–Oligocene source rocks vertically along faults, then secondary migration was mainly lateral. However, to some extent, fault systems would facilitate the leakage hydrocarbons from the traps (Hiep, 2019).

3. Dataset and methodology

In this study, we use high-resolution 3D seismic data covering an area of 936 km² (39 km long and 24 km wide) from the northern part of the Song Hong basin. The dataset has inline and crossline spacing of 12.5 m. Dominant frequency is c. 44 Hz and the velocity is 2000 m/s, the vertical seismic resolution defined as a quarter of the dominant wavelength, will be 11 m. The study focused on the Lower–Middle Miocene sequence, corresponding to the interval from 560 ms to 2740 ms.

The seismic interpretation have carried out using the Schlumberger™ Petrel software to determine the key sequence stratigraphy boundaries, geometry, and internal structure of channels. The seismic interpretation started with line by line interpretation, auto-tracking, and seismic facies identification. Detail time structural, thickness, gradient, and attribute maps were generated to visualize the channel image in 2D and 3D map view. The study used the sequence stratigraphy method of Vail and Mitchum (1977) to detect the channel. The reflection terminations are the key to breaking up the seismic sequences by identifying their unconformities and their correlative unconformity. Channel is recognized as a set of onlap or bidirectional down termination reflections onto the erosional base.

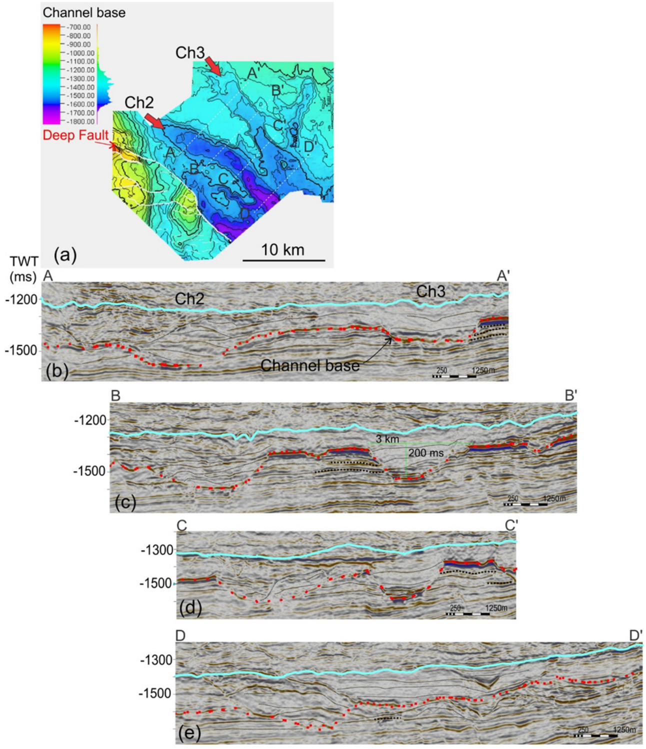

Fig. 6. (a) Time structure map of the base of the Mid Miocene channels, (b–e) seismic cross sections along the channel 2 and 3 to illustrate the channel variation and evolution downstream

4. Results and discussion

In the Miocene sequence, the channels are intensively developed at the Mid–Miocene level in which the channel base has been mapped to analyze the channel morphology (Fig. 3 & 4). Five channels have been detected, marked as channel 1 (Ch1) to channel 5 (Ch5) from West to East respectively. The channels are rather straight, derived from the north, and northwest, flowing down to the central of the basin to the southeast. The channels have ‘U’ to 'V' shape, up to 20 km long, 7 km wide, and 350 ms deep (Fig. 4). They intensively developed in the same stratigraphy level, spacing of c. 5 to 10 km. The channels tend to remain dimension until some of them join together downslope.

Three elements to describe channel characteristics include (i) channel axis, (ii) channel fills, and (iii) levees.

The base of channels is wide and relatively flat. The channel axis is often associated with high amplitude at the base of the channel and can be well observed in channel 2, 3, and 4 (Fig. 5). These high amplitudes change to low when the channel move further down toward the basin floor.

The channel fill is characterized as low to moderate amplitude with discontinuous to continuous reflections, complex geometries. This is interpreted to be sandy deposits. Among those channels, channel 3 is dominantly by low amplitude to transparent amplitude reflections, high amplitude reflections only observed at the channel base. This suggests that the channel had mainly been supplied by a muddy source system and thus gradually derived very fine-grained sediments. The internal architecture of the channels is progradation or aggradation fills which tends to convex up (Fig. 6 & 7). These folding shapes may be caused by a period of high sedimentation rate or more likely be a result of the inversion tectonic uplift in Mid-Late Miocene, leading to sediment compression.

Levee is the last channel element, it commonly shows aggradational and low to high amplitude reflections. High amplitude reflections appeared to be seen near the channel and decreasing amplitude away from it. The maximum levee height is approximately 20 ms, decreasing thickness away from the channel. The amplitude gradually changes to low away from the channel indicating the finer grain size in this direction.

The channels are highly incised into the substrate and conduit the sediment downward to the basin floor. These sediments were deposited in a deltaic or shallow marine setting (Hiep, 2019). The occurrence of all channels in the same stratigraphy level corresponds to the Mid-Miocene time. The basin experience an uplift and inversion in the Early Oligocene to Mid-Late Miocene, and even to the Early Pliocene in some places. Miocene sediments were strongly compressed, uplifted, and truncated. As a result, a thick section of approximately hundreds to thousands of meters was eroded; non-deposition possibly lasted for several million years (Hiep, 2019). The channel image of this study area confirmed for the tectonic inversion by the convex up of internal channel fill reflections.

Tectonic inversion was triggered by the right lateral movement of the Red River fault system at the end of the Miocene (Hiep, 2019). Therefore, channels developing in the highly tectonic area are experienced many phases of dynamic adjustment in their cross-channel geometry. The internal structure of the channel varies along the channel profile from aggradation to progradation. Channels are highly incised into the substrate with muti-stage of cut and fill (Fig. 6 & 7). The channels are straight indicating for high-energy environment. They are more likely to conduit turbidity current flows, transporting sediments further downslope to deposit in the depocentres.

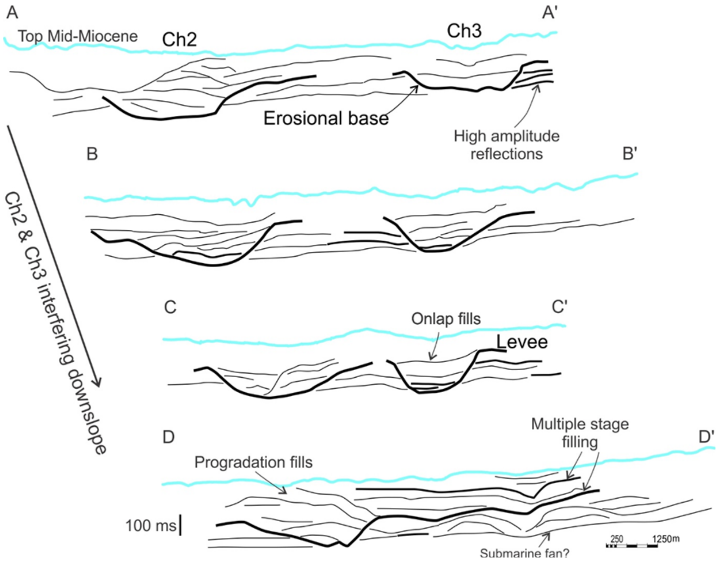

Fig. 7. Seismic facies diagram of the channels 2 and channel 3. Channels 2 and 3 tend to join together downslope, toward the basin floor (see seismic section in Fig 6)

The rifting phase creates the basin and forms many grabens corresponding to the four depocentres on the Basement map (Fig. 1b). These depocentres are overfilled in Oligocene time. Some deep basin opening faults dominantly in the eastern part of the study area (Fig. 6a) reactivate and penetrate through Oligocene and Miocene with the offset up to c. 50 ms, trending northeast–southwest. These faults tend to parallel with the channel paths. All of the channels are derived from the north and northwest which is the basin margin direction. The channel seems to follow the basement structure, the deep fault of the basin (Fig. 6a). There is no connection between the depocentre on the top basement and the Mid–Miocene channel system.

The amplitude attribute is an indicator to predict the strata lithology. In this area, the channels are filled by medium to high-amplitude seismic reflections, suggesting sandy channel deposits. Among those, channel 3 has muddy filled at the late stage with low to transparence amplitude. This indicates for more than one sediment source supplying for this channel system. Channel 3 is mainly supplied by the muddy sediment source.

According to Hiep (2019), the porosity of Miocene sandstones and sandstone-claystones usually varies from 15% to 25% increasing towards the upper section. The intensively developed channel system in the Mid-Miocene, which tends to be merged downslope, shows a widespread and stable distribution of the sand-rich channel deposits. This channel system may provide good reservoir quality for the Mid-Miocene sequence, giving a great hydrocarbon potential for the area.

5. Conclusions

Mid-Miocene channels are a complex channel system located on the margin of the Song Hong basin. The channels developed intensively on the same stratigraphy, highly incised along its pathway. The geometry of the channels almost remains ‘U’ to ‘V’ shape, channel width, and thickness along its profile. The channels have been built gradually by progradation or aggradation. The channels may have undergone some postdepositional deformation due to the mid to late Miocene tectonic inversion, resulting in the relatively doming channels. Channels run northeast–southwest which has a similar direction to the deep faults which have been reactivated in early and Mid-late Miocene time. The occurrence of submarine channels which are interpreted to be sand-rich deposits (except channel 3) at large scale give high-quality hydrocarbon reservoirs for the study area.

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