Facies Analysis and Depositional Environmental Interpretation of The Upper Oligocene, Block 09-2/10, Cuu Long Basin

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Abstract

The article presents the facies and environment of the Upper Oligocene sediments in the area of block 09-2/10 based on the analysis of seismic facies and well data of the neighboring areas. The results of the interpretation of seismic data indicate that the upper Oligocene sediments are limited by the top C, top D seismic reflectors. The environment is formed from lagoons, lakes to deep lakes. Seismological facies analysis identified 03 facies including seismic facies with medium to poor reflection amplitude, medium continuous, low frequency reflecting the lacustrine sediments (80%) in most of the lake center. Strong reflective seismic facies, sigmoidal clinoforms reflect the lakeside sediments (15%) distributed in the lakeside shelf. The seismic facies with average and continuous amplitude poorly reflect alluvial sediments (5%) in the Northwest region. The direction of sediment transport is mainly from the Northwest and Southwest in the area. The sandstone sequences are distributed on the slopes of the lake and the lake bottom, which is potential reservoir.

Keywords: *Cuu Long basin, upper oligocene, depositional environment, seismic facies, block 09-2/10*

1. Introduction

The Cuu Long Basin is one of the most detailed drilled and studied basins in the continental shelf of Vietnam. This basin is covered by a large volume of seismic profiles as well as many oils and gas exploration and production wells. The basin's sedimentary fill is dominated by Cenozoic sediments, with the Oligocene and Lower Miocene formations serving as the primary targets for hydrocarbon exploration and exploitation. These sediments are characterized by a diversity of depositional environments, including fluvial, lacustrine, peat swamp, brackish lagoon, and inner neritic settings.

Block 09-2/10 is located in the center of Cuu Long basin, Vietnam (Figure 1). Around the study area are large oil and gas fields such as Bach Ho, Te Giac, and Rang Dong. However, oil and gas research and exploration activities in 09-2/10 are still limited. In addition, in the study area, seismic explosion collection and drilling of an exploratory well have been carried out in the Middle Miocene sediments. The Lower Miocene sediments are not capable of generating hydrocarbons. Therefore, Oligocene sediments are the main study object for this paper. The deposition conditions of Upper Oligocene C are unclarified. The paper shows sedimentary facies and depositional paleoenvironment of the Upper Oligocene C based on analysis of seismic facies and well around block 09-2/10.

2. Geological setting

Cuu Long basin is a Cenozoic rift basin located in the Southeastern shelf of Vietnam. The geological evolution of the Cuu Long basin is divided into three periods: pre-rift, syn-rift and post-rift (Figure 2).

Pre-rift, especially from the Jurassic to Paleocene, is the period of formation and uplift of extrusive magmatic basement.

Syn-rift: This period commenced at the end of the Eocene - Early Oligocene under the influence of aforementioned tectonic events with the main extension direction being the NW-SE.

Post-rift: Near the end of the Early Miocene, the NW-SE East Sea spreading weakened, quickly terminated (17 Ma), and was immediately followed by crustal cooling period. Post-rift sediments were common in that they were all widely distributed, undisplaced, unfolded, and almost horizontal.

The stratigraphy of block 09-2/10 in the Cuu Long basin consists of Pre-Cenozoic basement and Cenozoic sedimentary cover. The characteristics of lithology and fossil assemblages of each formation unit are summarized in the generalized stratigraphic column of the basin (Fig 3). Pre-Paleogene basement: The Pre-Paleogene basement in the Cuu Long basin is composed of mostly magnetic intrusive rocks with main lithologies of granite, granite - gneiss, granodiorite, diorite, adamellite, monzodiorite, gabbro, monzogabbro. The metamorphic rocks are also encountered in some places [6].

Lower Tra Tan – Tra Cu formation – Oligocene E: This continental sediment consists of shale, siltstone and sandstone, which were deposited unconformably on the Pre-Paleogene basement. It is distributed widely across the southeastern area and divided into two sub-units:

Oligocene E Lower in the lower part and Oligocene E Upper in the upper part. The lower one is dominated by medium – to coarse grained sandstones composed of mostly granitic fragments and feldspars, interbedded with hard organic-rich black shale layers. The other one is composed majorly of fine to medium grained sandstones interbedded with gray shale layers. In addition, magma intrusions such as dykes, composed majorly of andesite/basalt were found occasionally [7].

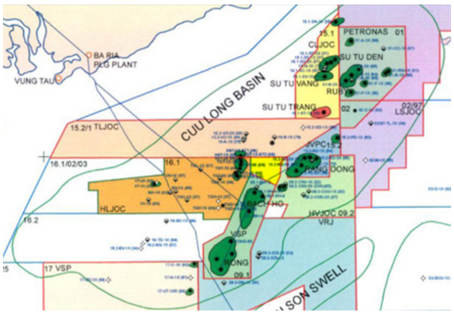


Fig. 1. Location of the study area

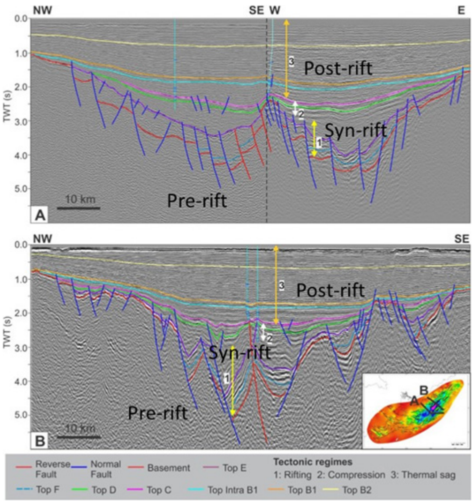


Fig. 2. The geological evolution of the Cuu Long basin (Modified after William J. Schmidt, 2018)

Upper Tra Tan Formation – Oligocene D: It is majorly organic rich brown shale deposited in lacustrine environment, occasionally interbedded with local layers of coal or sandstone. However, toward the Eastern boundary of the sub-basin (close to Con Son swell), thick layers of sandstone were deposited on top of Oligocene D shale. Upper Tra Tan Formation – Oligocene C: This section is the mixtures of fine-grained sandstones and lacustrine brown shale [6].

Bach Ho Formation – Miocene BI: This stratigraphic sequence is divided into two sub-units Miocene BI.1 (lower part) and Miocene BI.2 (upper part). Miocene BI.1 is composed mainly of sandstone dominant fluvial-deltaic deposits with small intercalation of shale deposited in floodplain or some brackish environments, while Miocene BI.2 is composed mainly of sandstone interbedded with shale/claystone, occasionally shallow marine siltstone and limestone. The top section of Miocene BI is Bach Ho shale, a thick and continuous shale layer, acting as a regional seal for the whole Cuu Long basin [6].

3. Material and methods

3.1. Materials

The seismic data used for this study is 250km2 PSTM 3D seismic cube of block 09-2/10. In addition, lithological, paleontological, and geophysical data from wells A1, A2, B1, B2, C1, C2, C3, D, E, F and G were also used to determine the environment of sediments (Figure 4). Seismic facies analysis was combined with petrographic and paleontological data to forecast the sedimentary environment of sequence C.

3.2. Methods:

Seismic facies analysis:

Seismic facies analysis is the description and interpretation of seismic reflection parameters, such as configuration, continuity, amplitude, and frequency, within the stratigraphic framework of a depositional sequence [1,2]. In seismic facies analysis, different seismic sequence has a different wave characteristics and is identified by the shape, amplitude, frequency, continuity of the seismic reflections. The external geometry and internal reflection of the reflected wave can reflect the deposition process as well as the direction of the source of the sedimentary material.

Log curve shape Analysis:

Based on the shape of the gamma ray curve, it is possible to determine the sedimentary environment (Figure 5). The shapes of well-log curves analysis serve as basic tool to interpret depositional facies because shape of log is directly related to the grain size of rock successions [4]. The log curve shapes were used to interpret the depositional environment, The study of core with relation to logs is also an important tool of facies interpretation in the subsurface [2].

Petrographic analysis:

Petrographic analysis identifies the mineral content for classification of a rock. Analysis usually comprises the description of the macroscopic aspects of the rock, such as fabric, color, grain size, and other relevant characteristics that may be visually observed in hand specimen or in outcrops, and chiefly the identification and description of microscopic characteristics of the studied material in thin sections such

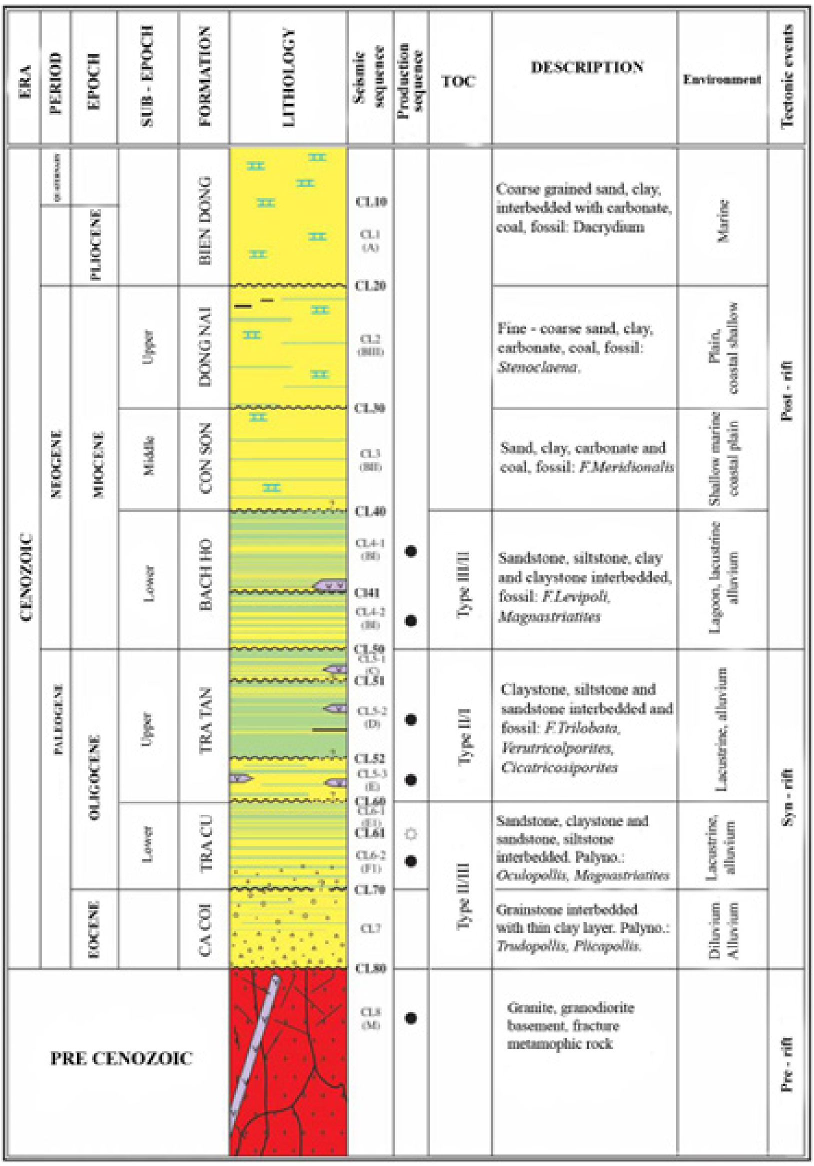


Fig. 3. Generalized stratigraphy of the Cuu Long basin [3]

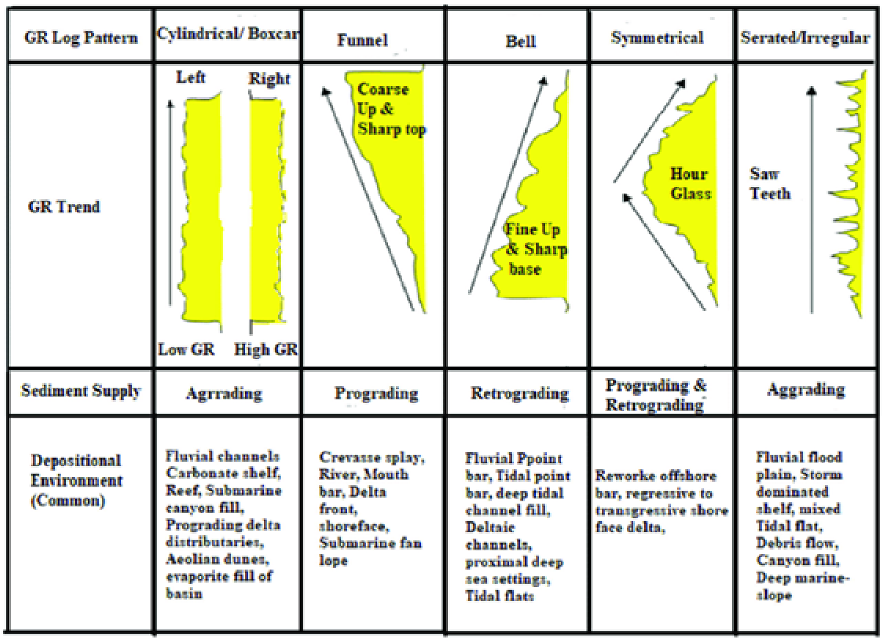


Fig. 5. Common sedimentological facies associated with various gamma-ray log shapes. Modified after Cant (1992)

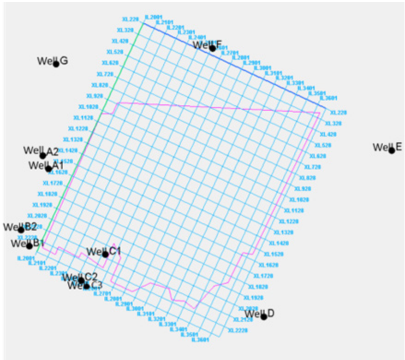


Fig. 4. A base map showing well sites relative to the seismic survey inlines and crosslines

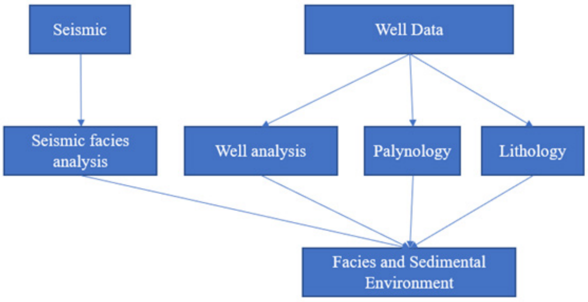


Fig. 6. The workflow for facies analysis and sediment environment study

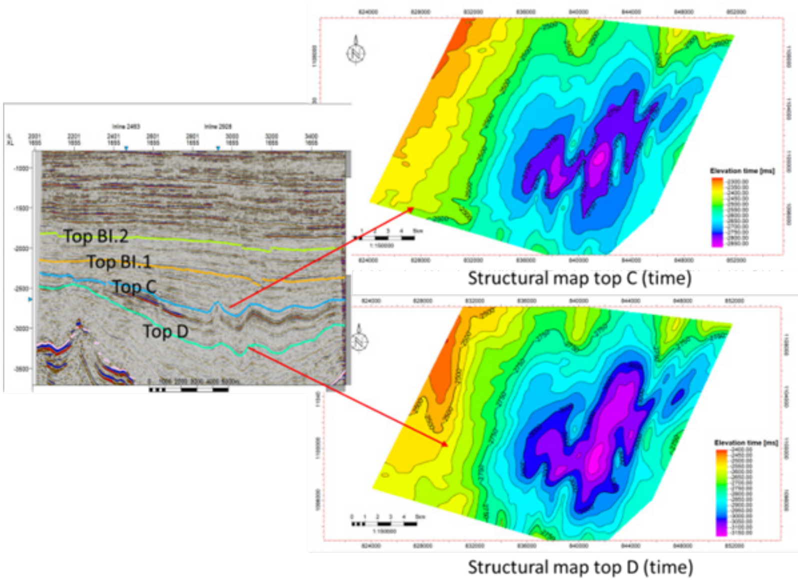


Fig. 7. The time structure map of Top C and Top D

as mineral composition, texture, grain size, and evidence of alteration and/or deformation [3]. The results of petrographic analysis are an important tool for determining the conditions of the formation of the rock.

Researching of the sedimentary environment of sequence C in the study area was carried out by the authors according to the following diagram (Figure 6).

4. Results and discussion

4. 1. Seismic interpretation

In block 09-2/10, The basement rock is deeply buried, so there is no potential structure. Therefore, seismic interpretation only focuses on the Upper Oligocene and Lower Miocene. The results of the seismic interpretation showed 4 horizons. Which are interprated including Top D (Lower Oligocene), Top C (Upper Oligocene), Top BI.1 (Lower Miocene) and Top BI.2 (Upper Miocene). The sequence C is limited by Top C and Top D (Figure 7). The structure map top C and Top D shows that this area same as subsiden. The west is a clearly an area of downslope sedimentation.

The thickness map (Figure 8a) shows the same as a deep lake. In the west, the sediment thickness is thin. In the middle, the sediment is more thicker. The models show the depositional environment and source rock deposition (Figure 8b).

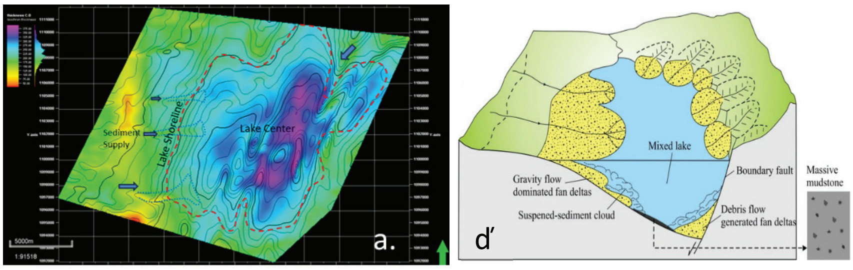


Fig. 8. a) Iso-thickness map of sequence C, b) Model of the sedimentary environment of sequence C [5]

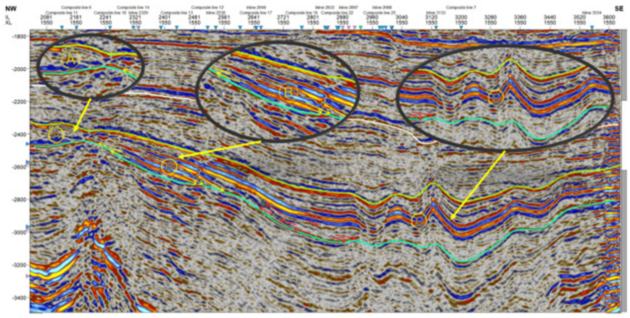


Fig. 9. Seismic section shows that sequence C has 3 main groups of reflections

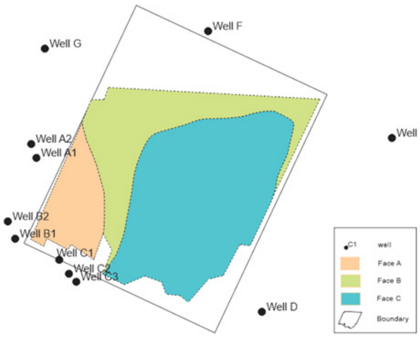
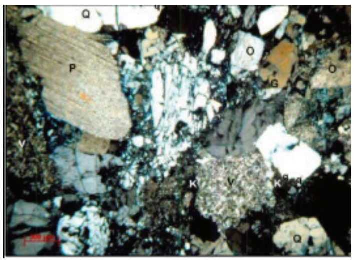
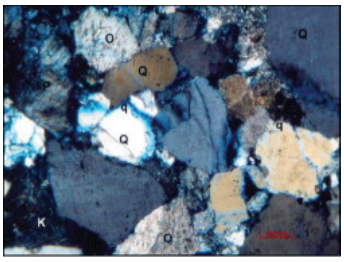


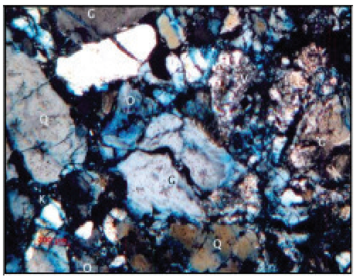
Fig. 10. Seismic facies map of sequence C



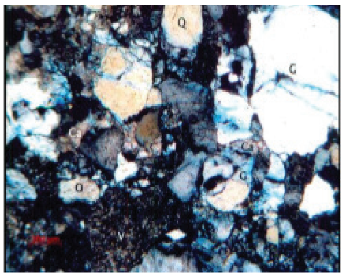
Sidewall core sample (at 3042m TVDss): arkose lithic sandstone with coarse grain, poor selectivity at well A1 (Q- quartz, P – Plagioclase)



Sidewall core sample (at 3182.5m TVDss): arkose lithic sandstone with fine grain, medium selectivity at well B1 (Q- Quartz, P – Plagioclase, k-feldspar)



Sidewall core sample (at 3012.5m TVDss): arkose sandstone with coarse grain, poor selectivity of well A2 (Q- Quartz, P – Plagioclase, k-feldspar)



Sidewall core sample (at 3026m TVDss): arkose sandstone with medium grain, poor selectivity of well A2 (Q- Quartz, P – Plagioclase, k-feldspar)

Fig. 11. Arkose sandstone of sequence C at wells A2, A1, B1 [10]

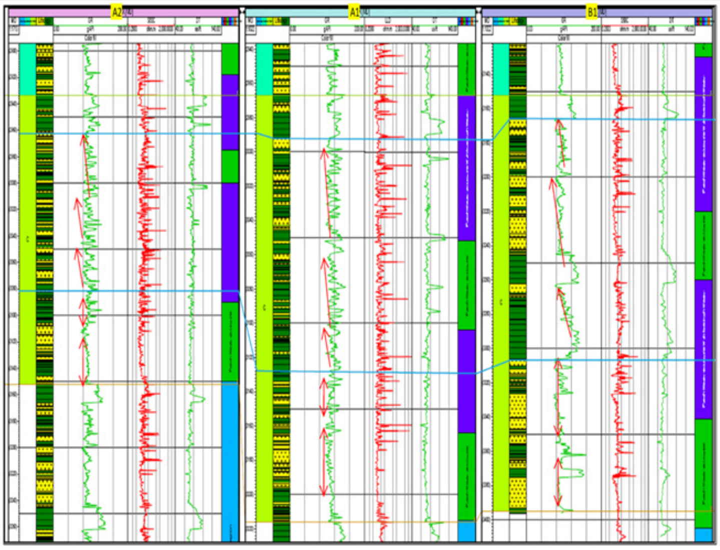


Fig. 12. Well correlation of Well A2, Well A1, Well B1

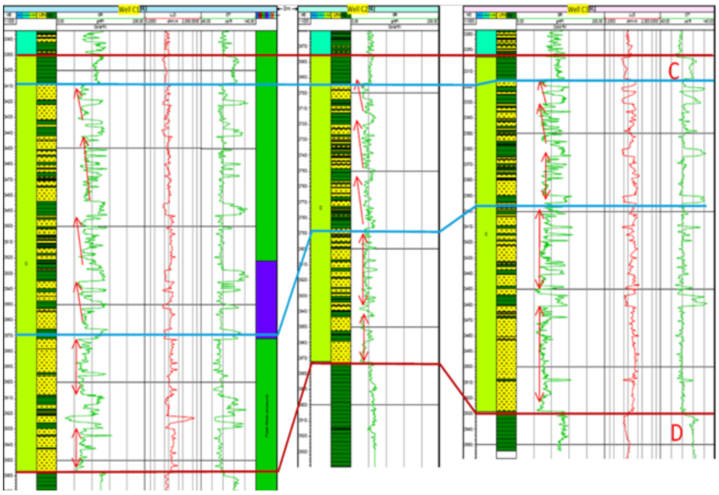


Fig. 13. Well correlation of Well C1, C2, C3

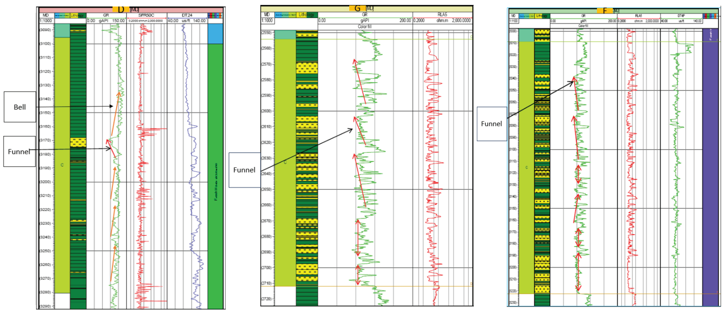


Fig. 14. Depositional environments in well area D, G, F

4.2. Seismic facies interpretation

Analyzing the seismic facies of Upper Oligocene "C" sequence, it shows that 03 seismic facies include (figure 9):

Seismic facies A shows subparallel reflection features with weak-medium amplitude, and poor continuity, reflecting medium-energy sedimentation. These seismic facies represent alluvial.

Seismic facies B has reflection with high amplitude, good continuity, and sigmoidal clinoform, which is typical for high-energy sedimentation. These facies show the shelf-slope sediments.

Facies C includes 2 groups with different characteristics. The first group is the high amplitude, good continuity, parallel reflections, shows sediments due to the change and decrease in energy gradually until completely weak. The negative phase reflections (in blue) reflect the sedimentary facies as the tails, the outermost parts of the lobe. The positive phase reflections (reddish brown) reflect the fine-grained facies of clay, formed in the period of still water, lacking sedimentary materials. The second group is a set of weak, discontinuous, chaotic. They reflect the sediment with coarser grain and poor selectivity. Which are rapidly deposited in a high-energy environment.

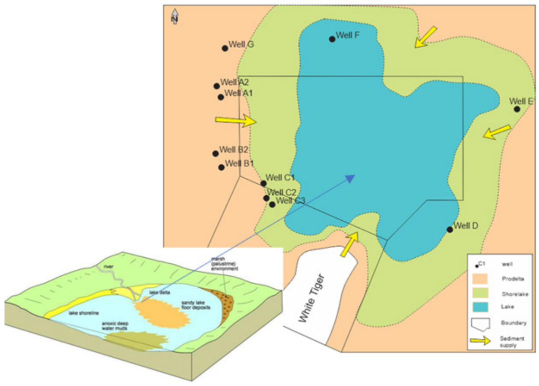


Fig. 15. Diagram of sedimentary environment of Late Oligocene (sequence C) in block 09-2/10

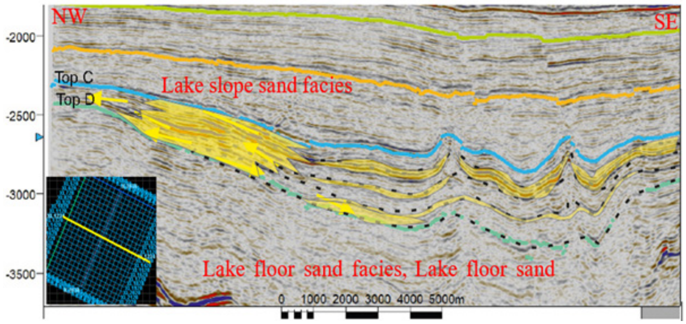


Fig. 16. Reconstruction of lake slope sand facies and lake floor sand facies

The facies C is characterized by a turbidite sedimentary, which is formed at the bottom of the lake.

The seismic facies distribution of the C sequence is shown in figure 10. Seismic facies A, distributed mainly in the western edge of the area (yellow-orange covers about 15% of the area) is characterized by discontinuous reflections. Seismic facies B have strong, continuous reflectivity (light green covers about 15% of the area) distributed in the middle of the block. Seismic facies C, which shows medium amplitude and poor continuity of reflectors, occupies most of the central part of the block (80% of the area – blue color).

4.3. The results of lithology, paleontology combined with well logging analysis

According to the results of the petrographic stratigraphy of wells A1, A2, B1, and B2, sand and clay sequences are shown. Petrographic results of thin rock slices at wells A1, A2, and B1 show arkose and sub-arkose sandstone (Figure 11), poor selectivity, and poor roundness. The sediments were formed in alluvial and pro-deltaic environments. The results of palaeontological analysis of sequence C at wells A1, A2 and B1 are mainly chalky spores and freshwater spores such as Bosedinia, showing that the sequence was formed in the fluvial and freshwater lacustrine environment [9]. The mainly block, funnel shape of the GR curve is typical for the delta environment (Figure 12).

At wells C1, C2, and C3, the sequence C includes sand layers interspersed with clay layers. Sandstone is arkose with good roundness and good sorting. The blocky and funnel shapes on GR logging curves (Figure 13) indicate the marginal lacustrine environment. The seismic expression of this sequence is characterized by medium seismic amplitude and moderate to poor continuity of reflectors, associated with marginal lacustrine sediments.

At well D, the GR log has high values and tends to be fining upward. The lithology is mainly shale layers formed under low-energy conditions can to related to the lacustrine environment. When analysis result of well G (Northwest) and well E (Northeast) also shows the lacustrine environment. The well logging analysis result of well F (Northern) indicates the marginal lacustrine environment [11] (Figure 14).

4.4. Sedimentary environment reconstruction

The Oligocene period was in the period of rifting, creating space for sediment accumulation [6,7]. Stratigraphic results of the Cuu Long Basin have shown that Oligocene sediments were formed during a period of low water level, related to river and lake environments [8,11]. The paleontological research results also clearly show a freshwater lacustrine environment [9]. Therefore, the late Oligocene sedimentary environment of block 09.2/10 can be the same. a sedimentary environment map of the Upper Oligocene was established based on the combination of the seismic facies with well data, lithology, and paleontology. On the figure 15, the center of the lake is deviated to the East, and the direction of sediment transport is mainly from the West. Delta/marginal lacustrine environments are present in most of the wells around block 09.2/10; the marginal lacustrine environment in wells A1, A2, B1, B2, C2, C3, while lacustrine environment in wells C1, D.

From the sedimentary formation model of sequence C, it is possible to reconstruct the distribution of sedimentary facies of the study area as follows:

Prograding wedge sediment has been transported towards the basin center and accumulated from the edge of the lake shelf to the slopes of the lake and can spread far into deeper water (Figure 16). Prograding wedge sediment is characterized by combinations of coarse-grain sand and grit facies with poor to moderate sorting.

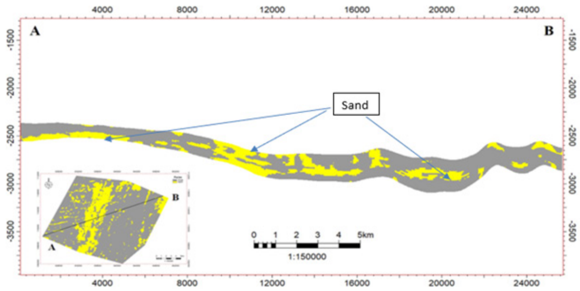


Fig. 16. Reconstruction of lake slope sand facies and lake floor sand facies

Lake floor fan sediment was formed when the lake water level was lowered, sediment was quickly transported by underground flows to the lake bottom. When dividing the facies by seismic reflection features, the distribution of sand layers has also been shown and the distribution is quite appropriate with the seismic facies model (Figure 17).

5. Conclusions

The study has clarified sedimentary facies and depositional paleoenvironment of block 09.2/10 cuu long basin in the east sea during the upper Oligocene based on the integrating of seismic facies, welllog, petrographic, and paleontology.

The results of the interpretation of seismic data indicate three facies A, B and C. The facies A are characterized by chaotic reflections, poor continuity, and low amplitudes associated with delta. The facies B is characterized by continuous seismic reflection, strong reflection amplitude, low frequency, overlapping pattern related to shelf slopes. The facies C is characterized by a weak to moderate amplitude, parallel wavy, which is related to the deep lake.

The Upper Oligocene environment was formed mainly in the lacustrine environment. The sedimentary facies include the lakeside and deep lake. The lakeside and bottom sands sequence may be potential oil and gas reservoirs.

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