14 Journal of Mining and Earth Sciences Vol. 62, Issue 6 (2021) 14 - 22

Journal of Mining and Earth Sciences

Website: http://jmes.humg.edu.vn

Application of seismic attribute analysis in Lower Miocene reservoir characterization, northeast Bach Ho field, Vietnam

Hoa Minh Nguyen *, Anh Ngoc Le, Muoi Duy Nguyen, Ngan Thi Bui

Hanoi University of Mining and Geology, Hanoi, Vietnam

ARTICLE INFO

Article history:
Received 15th June 2021
Revised 18th Sept. 2021
Accepted 19th Oct. 2021

Keywords:
Artificial neural network,
Bach Ho field,
Cuu Long basin,
Reservoir,
Seismic attribute.

ABSTRACT

The Cuu Long basin is an Early Tertiary rift basin of southern Vietnam, and the most potential basin in the country with high productive for oil and gas. Special interest in the Lower Miocene reservoir in the Cuu Long basin is caused by the gradual depletion of unique oil-bearing in the fractured basement and the possibility of transferring production wells to overlying deposits in the terrigenous rocks of the sedimentary cover and entering new deposits into development. In recent years, seismic attributes analysis has emerged as an effective tool to predict ancient riverbeds where sand bodies may exist in nonstructural traps. Understanding the distribution of these sand bodies will be of great significance in the orientation of oil and gas exploration activities. The paper applied seismic attribute analysis method combined with artificial neural network (ANN) and well data to predict the distribution of sandstones reservoirs of Lower Miocene sediments in the Northeastern Bach Ho oil field. Seismic attributes selected as input for ANN training including Relative Acoustic Impedance, Root Mean Square, Sweetness. The attributes provide the most obvious opportunity to display geological features with varying seismic amplitude characteristics as well as predict lithofacies, petrology and the distribution of sand bodies. The research results have identified the potential reservoirs in the Northeastern area of Bach Ho field, which are deposited in the fluvial, marginal lacustrine and deltaic environments.

1. Introduction

Cuu Long Basin is an Early Tertiary rift basin of southern Vietnam. It is the most potential basin in the country with high productivity for oil and gas. Since the 1970s, many oil and gas fields have been discovered and operating since 1986. The primary interest focused on pre-Cenozoic fractured basement highs and sandstone reservoirs in Oligocene and Miocene.

*Corresponding author
E - mail: nguyenminhhoa@humg.edu.vn
DOI: 10.46326/JMES.2021.62(6).03

The particular interest in the Lower Miocene reservoir in the Cuu Long Basin came from the gradual depletion of unique oil-bearing in the fractured basement, the possibility of transferring production wells to overlying deposits in the terrigenous rocks of the sedimentary cover and the development of new deposits.

Currently, the exploration phase is not only carried out in less studied areas. Great attention is paid to non-structural, lithological traps with a thorough analysis of drilled wells' materials to increase field operations' efficiency.

Recently, the strong development of modern technology applied in seismic data processing and interpretation helps seismic attributes analysis become an effective tool for solving geological tasks, such as determining direct hydrocarbon indicators, evaluating reservoir properties and predicting ancient riverbeds where sand bodies may exist in non-structural traps. In addition, the use of multiple seismic attributes helps in vividly identifying and facies zones (Suarez et al., 2008).

In this article, the seismic attribute analysis combined with well data was applied to predict the distribution of sandstone reservoirs of Lower Miocene sediments in the Northeastern Bach Ho oil field.

2. Geological setting

The study area is located in the Northeastern Bach Ho oil field in block 09 - 1 of Cuu Long basin in Vietnam's continental shelf, 120 km southeast of the city of Vung Tau (Figure 1). This field is the first and most significant oil field produced industrially in Vietnam since 1986.

The geological section of the Bach Ho field is represented by the pay zones: Cenozoic fractured basement composed of magmatic crystalline rocks. The basement consists of crystallized magmatic granitoid, basal - andesite and poocfia diaba of Jura - Cretaceous age. The oil pay zones in the fractured basement are considered unconventional with an extremely high degree of heterogeneity, anisotropy and permeability. Sedimentary cover, which overlaps the basement with stratigraphic and angular unconformity, is represented by terrigenous deposits of Lower Oligocene, Upper Oligocene and Lower Miocene. Regarding tectonic characteristics, the northeastern area of Bach Ho field is an uplift zone formed by the compression phase in the Upper Oligocene stage. Due to the influence of the tectonic setting of the Cuu Long Basin, the study area is considered a tertiary structural unit with a small scale, located in a narrow sub-though.

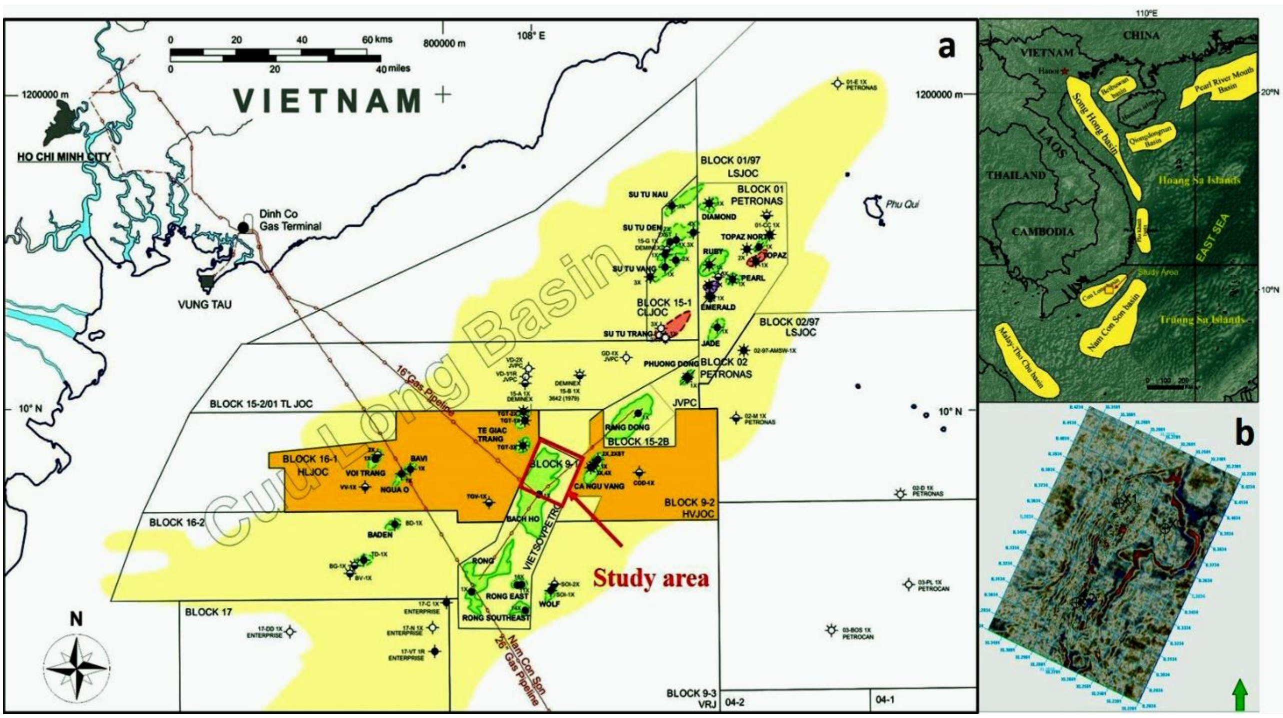

Figure 1. Location map of study area (a) with a base map showing well sites realative to the seismic survey inlines and crosslines (b).

This article focuses on Lower Miocene sediments bounded between two seismic horizons SH7 and SH5 (Figure 2). Generally, the SH5 and SH7 surfaces structure are relatively similar, composing a small structure with low amplitude. The minor faults indicate the period of stable development of the structure. The SH7 - SH5 is the main reservoir 23 - 27, consisting mainly of grey sand and silt.

Lower Miocene reservoirs developed in the entire field, mainly in the north and central regions. This reservoir varies from 11.6÷57.6 m in thickness with an average of 30.4 m in the northern part. Lower Miocene is of good quality (porosity ranging from 15.3÷22.9 %, permeability = 0.1 - 2000 mD) (Nguyen, 2011).

In general, the depositional environment of Bach Ho field is consistent with the regional stratigraphic framework of the Cuu Long basin. The depositional environment in Lower Miocene was fluvial, coastal plain and shallow lacustrine/marine conditions (Giao et al., 2015).

3. Data and Methodology

3.1. Database

The seismic data used for this study is a 600 km^2 PSDM 3D seismic cube (Figure 1) and three wells with sufficient data for study (Figure 4). In general, seismic data is of high resolution, good quality, ensuring the seismic interpretation and seismic attribute analysis. Two horizons SH5 and SH7 were extracted from these data to define the top and base of the reservoir with 10x10 inline/crossline. This study used Artificial Neural

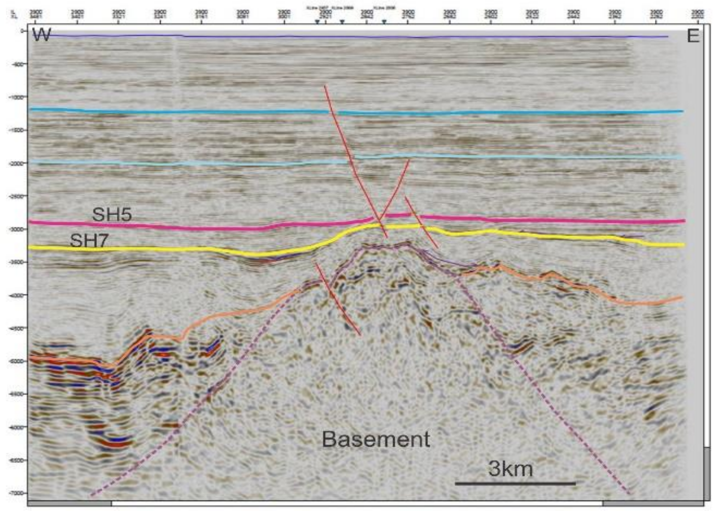

Figure 2. Seismic cross - section through the field shows the main horizons and the studied object in the Lower Miocene (SH5 - SH7).

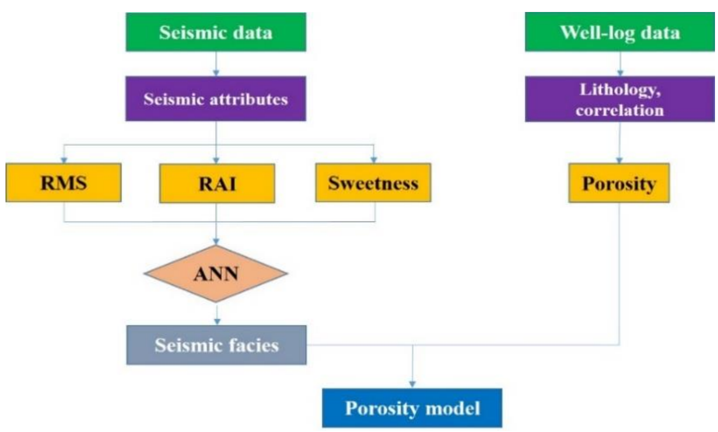

Figure 3. The workflow for seismic facies classification using Artificial Neural Network method and prediction of porosity model.

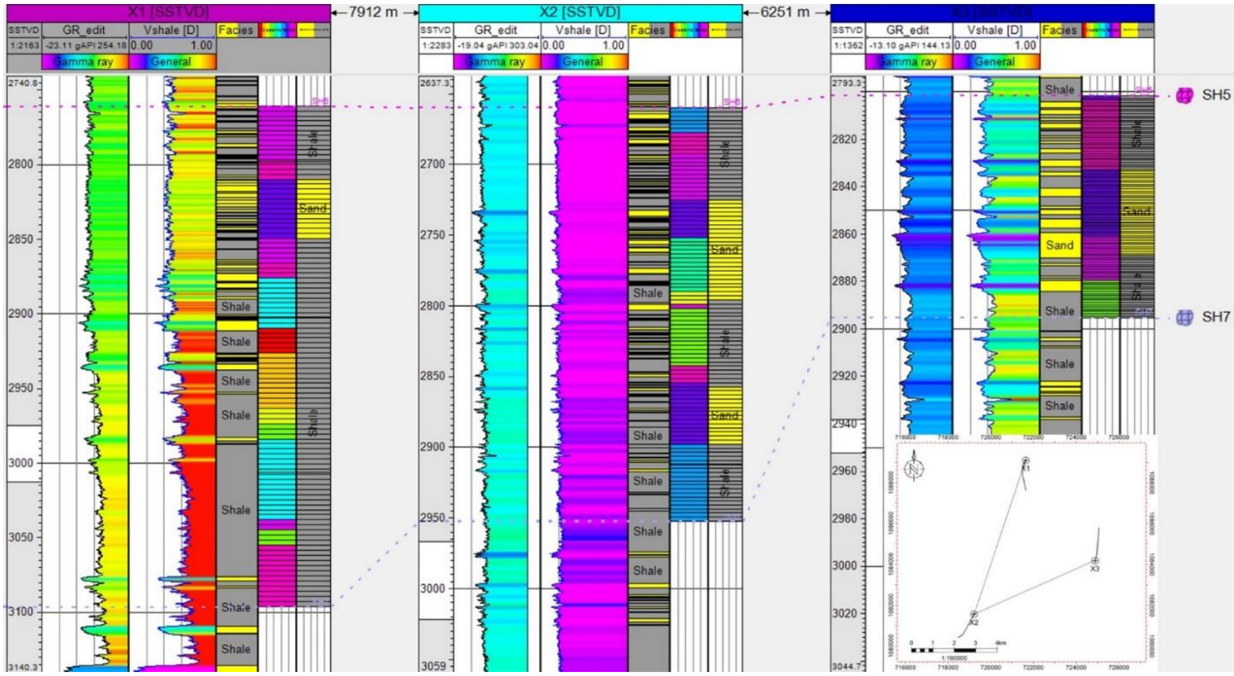

Figure 4. Well correlation and lithofacies classification from well logs.

Network (ANN) to predict the porosity model combining seismic attributes and well log data (Figure 3).

3.2. Methodology

3.2.1. 3D Seismic attribute extraction

In recent years, the seismic method has been strongly developed. It increases efficiency when studying the geological structure and defines parameters, such as porosity, thickness, saturation, etc. Seismic interpretation determines the horizons, faults based on reflective characteristics on the seismic sections. Several new seismic methods have been developed to meet the growing demand for oil and gas exploration and production. One of the most widely used methods for improving the efficiency of seismic interpretation is seismic attribute analysis. More than 50 distinct seismic attributes are calculated from seismic data and applied to interpret the geologic structure, stratigraphy and rock/pore fluid properties (Chopra and Kurt, 2005). Seismic attributes can be used to infer formation physical properties, e.g., porosity, permeability and changing bed thickness (Taner, 2001).

The amplitude attribute is used as the principal parameter to determine the physical properties of the rock-fluid composite, as the strong amplitudes (bright spots) have a reasonable correlation with lithology, pore fluid properties and edges of hydrocarbon-water interfaces (Tahir et al., 2016). The change in amplitude is the basis for distinguishing differences in the petrographic composition of facies, clay-sand ratio. Amplitude anomalies are signs related to oil and gas in the reservoir.

Root - mean - square (RMS) amplitude is a computed seismic attribute measuring reflectivity within a time window. This attribute is used to map hydrocarbon indicators within a zone. It is defined as the square root of the sum of the squared amplitudes divided by the sample size of data within the time window desired. The RMS amplitude is calculated according to (Nguyen and Le, 2012):

$$RMS = \sqrt{\frac{1}{N}.\sum a_i^2} \qquad (1)$$

Where: N - the number of samples in the calculation window; a_i - i^{th} amplitude value

Sweetness (instantaneous amplitude, which is divided by the square root of Instantaneous Frequency) is defined as the trace envelope a(t) divided by the square root of the average frequency fa(t) (Radovich and Oliveros, 1998).

This seismic attribute is used to highlight thickness clean reservoir (sands and sandstones) and/or hydrocarbon-filled reservoir because sand bodies generate stronger and broader reflections than surrounding shales. The sweetness attribute becomes less useful in environments where sands and shales are highly interbedded or the contrast in acoustic impedance between sands and shales is low (Hart, 2008).

The Relative Acoustic Impedance (RAI) is a simplified inversion. This attribute is widely used to indicate sequence boundaries, unconformity surfaces and discontinuities. It may also be related to porosity within the formations and fluid content inside a hydrocarbon reservoir.

3.2.2. Seismic facies classification

Artificial Neural Network (ANN), first introduced in 1943, was a computational model based on brain-inspired systems. ANN is becoming a more powerful tool that can perform classification, feature extraction, diagnosis, function approximation and optimization. Scientists and engineers have widely used ANN to predict data from other information data. The neural network techniques are applied for well log and seismic facies classification and characterization of reservoir properties.

Seismic facies analysis plays a crucial role in deriving reservoir properties from seismic attributes (Brown, 2011). Understanding different attributes that can be used as tools in interpretation is helpful to understand the classification of other attributes. The more seismic features available, the more confusion geoscientists may have in selecting the appropriate ones. Seismic facies classification algorithms can be divided into two major categories: supervised and unsupervised learning techniques.

- Supervised classification methods involve data labeling, i.e., manual facies interpretation, which is inevitably affected by the differences in the interpreters' knowledge base and experience level.

- Unsupervised facies classification algorithms are a data-driven way to determine the clusters present in the data, unbiased by the interpreter. Traditional unsupervised seismic facies classification methods include principal component analysis (PCA), K - means clustering and the Self-Organizing Map (SOM).

In summary, seismic attributes can give an indirect indicator in geological interpretation. Thus, the geological analysis of seismic attributes must be combined with other data such as geological features, depositional environment, petrographic analysis, etc., can obtain the most reliable results. The workflow of studying and evaluating the distribution of sand bodies is shown in Figure 3:

- Detailed analysis of seismic attributes could image the geometry and spatial distribution of sand bodies in horizons to select the optimum seismic attribute set.

- Seismic facies classification using an Unsupervised neural network with the selected seismic attribute set.

- Porosity model building using Sequential Gaussian Simulation (SGS) to integrate seismic facies with porosity calculated from well data in the region.

4. Results and discussion

4.1. Well correlation

Well log data were available from 3 wells X1, X2, X3 located in the study area. The well data analysis shows that the overlying strata consist mainly of shale interbedded with sandstones. In well X3, thicker sand layers dominated in the lower part and thin sand layers dominated in the higher one. The GR curve is bell-shaped, reflecting the lacustrine environment. In wells X1 and X2, sandstones and shales alternate more evenly. The GR shape is cylindrical, reflecting a point-bar environment (Figure 4).

4.2. Seismic attributes analysis

The selection of attributes can reflect the changes in amplitude to identify the sand bodies and their distribution. The combination of seismic attributes, including RMS, RAI and Sweetness, provides the most obvious opportunity to display geological features with varying seismic amplitude characteristics and predict lithofacies, petrology and the distribution of sand bodies.

Integrating seismic attributes, including RMS, RAI, Sweetness and well log at Bach Ho field, shows that sand beds are well correlated with the positive peaks of seismic traces. With the oil and gas findings in the study area, such as the center part of Bach Ho field, the positive peaks represent thick layers of sands and high amplitude anomalies are consistent with the structures. Therefore, we used the seismic amplitude attributes to identify hydrocarbon potential in the Northeastern Bach Ho oil field reservoirs.

The results of seismic attributes calculation RMS, Sweetness and RAI are shown in Figure 5. It can be seen that there are a lot of high amplitude regions in the northern part of the Bach Ho field. The amplitude anomalies spread over most of the area and distribution concentrated near the central uplifting area of Bach Ho field (circled in black) in Figure 5. The high amplitude anomaly in the Northwest is located near the Tho Trang field so that it can be closely related to the oil sand bodies of this field. Besides, high amplitude anomalous areas may be potential sand bodies in the Northeast. Combined with the RAI analysis (Figure 5c), seismic facies model and well logs have precisely identified anomalous areas.

4.3. Application of ANN

Each seismic attribute has its function and represents a particular feature or signal. Therefore, we need to use a combination of seismic attributes by integrating many attributes simultaneously by using ANN to evaluate the overall distribution of a particular geological object. This method allows classifying seismic facies according to the characteristics of sedimentary sets. In this article, seismic facies classification by the Unsupervised method is based on a clustering algorithm. This method was applied based on the correlation between seismic attributes without the control of wells.

Recognizing the reservoir characteristics, Unsupervised Neural Network was used to subdivide three attributes into several facies in this study. The three input attributes were selected, including RMS, RAI and Sweetness. These attributes are most obviously reflect the distribution of sand bodies. Ten classes of facies have been tested using this method to improve the results. And the result is shown in Figure 6.

Based on the histogram of ten seismic facies, the authors decided to reduce the number of facies to 2 types: sand (class I - reservoir) and shale (class II - non - reservoir) to be able to integrate with two rock types from log data. The facies model has been smoothed to reduce the noise’s influence in the 3D seismic data,.

The facies model (Figure 7) shows that the sand bodies are mainly concentrated around the central uplifting area of Bach Ho field. The sand bodies were deposited in the fluvial and deltaic environments. According to the research result on the Lower Miocene sediment environment of Bach Ho field, it is shown that fluvial and shallow lacustrine conditions are mainly (Giao et al., 2015; Nguyen, 2011).

The main source of sediment supply comes from the central uplift zone of Bach Ho field.

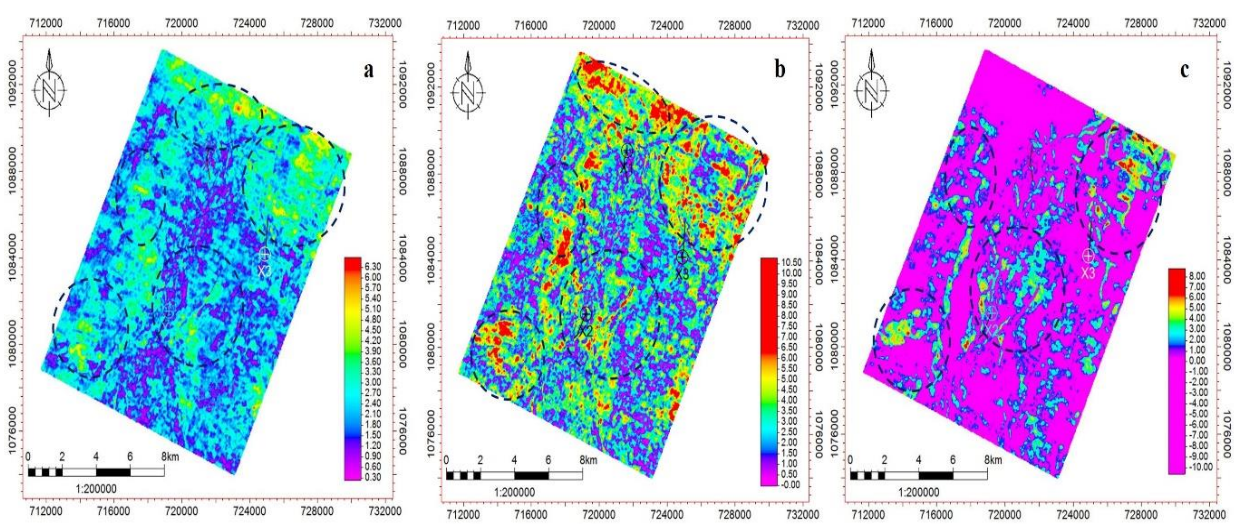

Figure 5. Potential areas (black) on the attribute maps of SH5: a) RMS; b) Sweetness; c) RAI.

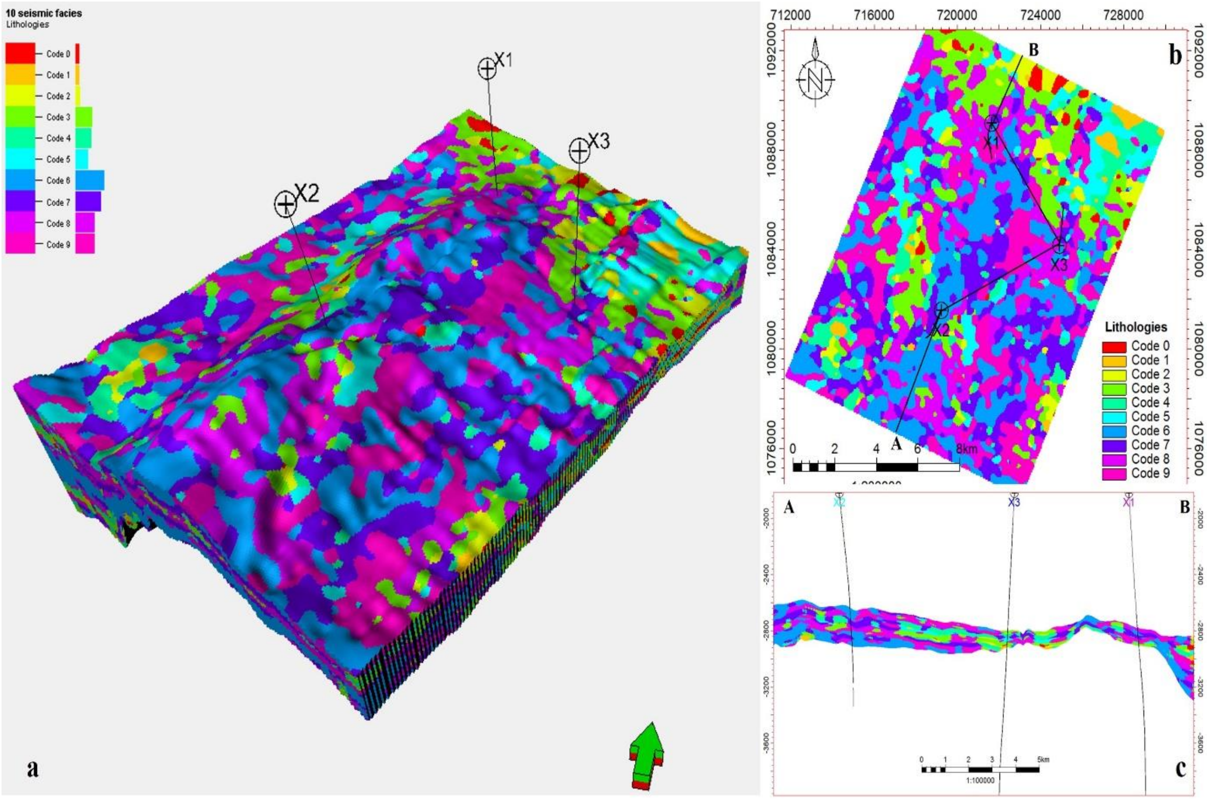

Figure 6. Ten seismic facies classification using the ANN method is illustrated in the 3D model (a); Facies map of SH5 (b) and Cross - section A - B (c).

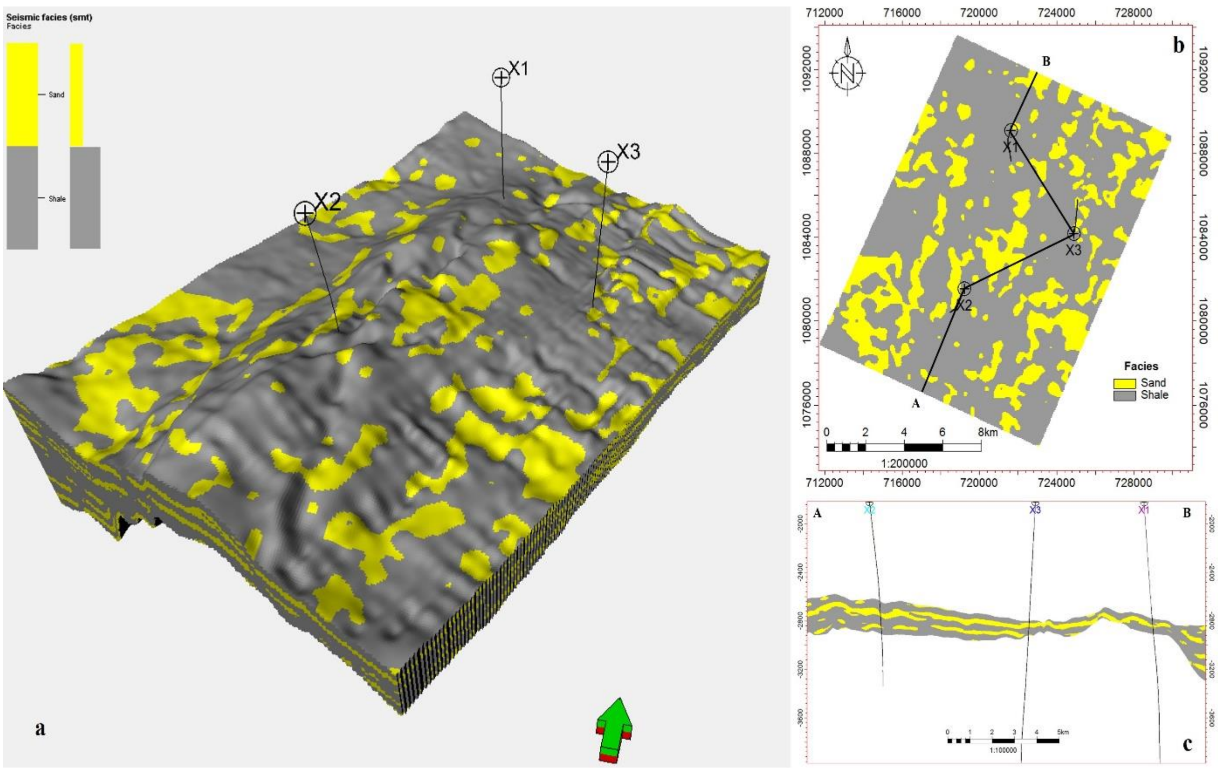

Figure 7. Two seismic facies classification in the 3D model (a); Facies map of SH5 (a); Cross - section A - B showing the distribution of reservoir.

The results of analyzing seismic attributes, facies model and depositional environment showed quite consistent and high reliability.

On that basis, it is possible to predict and identify potential reservoirs in the study area. Four potential reservoirs located around the central uplifting zone of Bach Ho are in Figure 8. The average porosity ranges from 20÷30%. Thus, potential Northeast objects are sand bodies deposited in the fluvial, marginal lacustrine and deltaic environments.

5. Conclusion

This paper presents an integrated well log and seismic attribute analysis study to distribute sandstone reservoirs of Lower Miocene sediments in the Northeastern Bach Ho oil field.

The results showed that the seismic attribute analysis could extract the complete geological information from the seismic data that is otherwise hidden in the data and has been used to identify potential reservoirs of Lower Miocene in the study area. Furthermore, the seismic amplitude attributes effectively study the characteristics of reservoir rocks. RMS amplitude combined with RAI, Sweetness attributes were helpful for detecting the amplitude anomalies and allowing more accurate identification of the potential hydrocarbon reservoir areas.

There are two potential reservoirs in the Northeastern area of Bach Ho field, which are deposited in the fluvial, marginal lacustrine and deltaic environments.

Author contributions

Hoa Minh Nguyen analyzed seismic attributes, ANN and wrote the article. Anh Ngoc Le analyzed geological setting and finalized the article. Muoi Duy Nguyen and Ngan Thi Bui prepared the methodology and database.

References

Chopra, S. and Kurt, J., (2005), 75th Anniversary Seismic Attributes - A historical perspective. *Geophysics* 70(5).

Giao, P. H., B. D. Trung and D. Q. Do. (2015). Porosity Partitioning of a Fractured Granite Basement (FGB) Reservoir in the Cuu Long Basin, Offshore Southern Vietnam. *15th Asian Regional Conference on Soil Mechanicsand Geotechnical Engineering, ARC 2015: New Innovations and Sustainability*, 621 - 624.

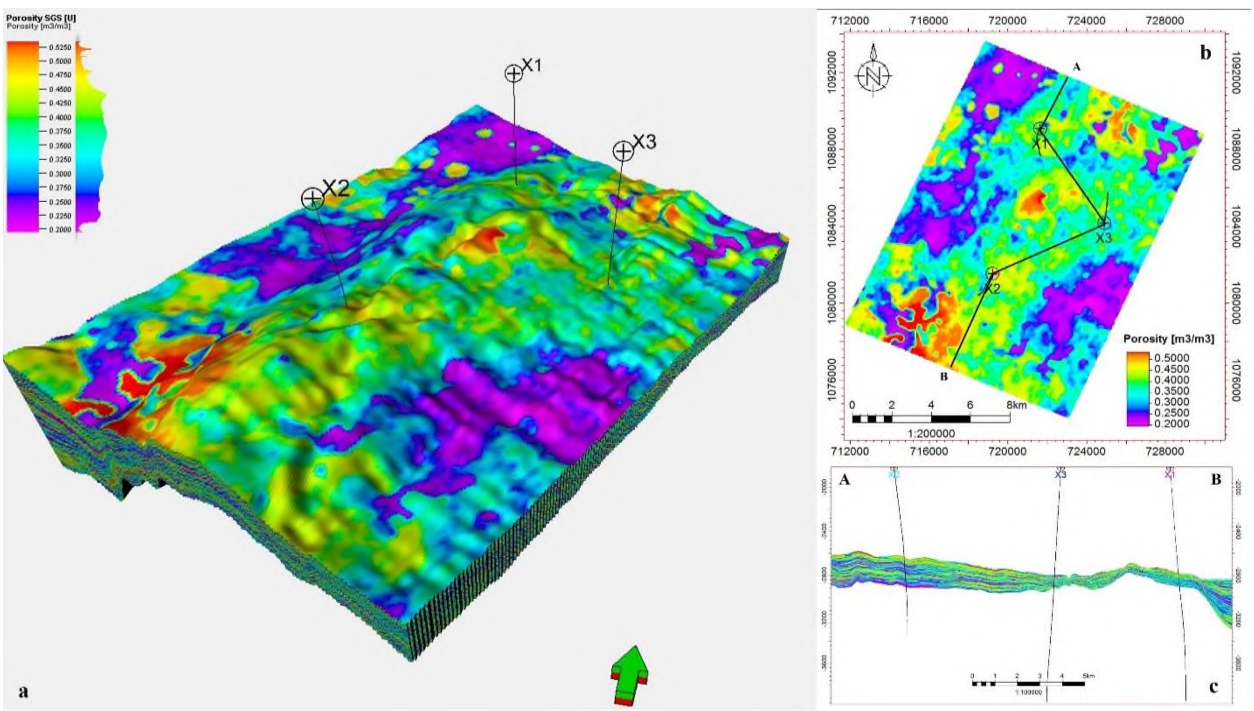

Figure 8. Reservoir porosity prediction in the study area. 3D *porosity model (a); Porosity map of SH5 (b); Cross - section A - B showing the distribution of porosity.*

Hart, B. (2008). Channel detection in 3 - D seismic data using sweetness. *AAPG Bull* 92. 733 - 742.

Nguyen, D. C., Mai, T. T., Tran, V. X., and Tran, N. H. (2019). Oligocene combination/stratigraphic traps and their reservoir quality in Cuu Long basin, offshore Vietnam. *PetroVietnam Journal, 6,* 30 - 40.

Nguyen, T. M. H., & Le, H. A. (2012). Seismic attributes analysis for Miocene reservoir characterization in block 103. *Journal of Mining and Earth Sciences, 37,* 6 - 11.

Nguyen X. T. (2011). *Reservoir modeling on the basis of seismic attributes and wireline logs analyses in Miocene formation of White Tiger oilfield (Cuu Long basin)*. Summary of Ph.D thesis. Hanoi Univeristy of Mining and Geology, Hanoi, Vietnam.

Radovich, B. J., and Oliveros, R. B. (1998). 3 - D sequence interpretation of seismic instantaneous attributes from the Gorgon field. *The Leading Edge,* 17, 1286 - 1293

Suarez Y., Marfurt K. J., Falk M. (2008). Seismic attribute - assisted interpretation of channel geometries and infill lithology: A case study of Anadarko Basin Red Fork channels, in: *78th Annual International Meeting, Society of Exploration Geophysicists*, 963 - 967.

Tahir A., Wang Y., Perveiz K., Liu X., Fang, Y., Cheng L. (2016). An application of seismic attributes analysis for mapping of goas bearing sand zones in the Sawan gas field, Pakistan. *Acta Geodaetica et Geophysica, 51,* 723 - 744.

Taner, M. T. (2001). Seismic attributes. *CSEG Recorder, 26*(7), 49 - 56.