Interpretation of mud diapirs using 2D seismic attributes and Unsupervised Neural Network: A case study of the Song Hong Basin

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ABSTRACT

Structures associated with mud diapirs have been recognized as being of great significance in hydrocarbon exploration and production. However, its formation mechanism and behaviour of shale have been less understood than salt until the last few decades, as mud diapirs attracted more attention from hydrocarbon exploration and production industry. Our studies demonstrate that the occurrence of mud diapirs in the Song Hong Basin associated with major petroleum fields within the basin, which have a significant impact on all the aspects of petroleum systems. detail interpretation of the 2D muntichannel seismic data in the central part of the Song Hong Basin allowed us to identify 4 diapir structures. These mud diapir confined to several lithology units, which have been resulted from a typical tectonic and geological period, reflecting critical overpressuring events. The discovery and identification of the occurrence of mud diapirs implied a great potential for prediction of structural traps in the central part of the Red River Basin.

Key words: Mud diapir; Song Hong Basin; Petroleum system; K-mean; SOM.

1. Introduction

Mud volcanism and diapirism have been recorded to be present in many places within the solid Earth. They have mainly been produced in compressional tectonic setting (Kopf 2002). A mud diapir is an intrusive structure characterized by a slowly upward migrating mass of clay-rich sediment and fluid discharge (Kopf 2002), whereas a mud volcano usually occurs above the diapir, as a result of fluid migration directly along the body of the mud diapir or through faults (fractures) connected to the mud diapirs (Kopf 2002, Milkov 2005). Therefore, mud volcanoes represent the last manifestation of diapirism (Kopf, 2002). Thus, all mud volcanoes are diapirs but not vice versa (Soto, Fernández-Ibáñez et al. 2012).

Mud diapirs have been linked to both extensional and compressional stress regimes. The diapirsm is triggered by overpressure in sedimentary layers due to the rapid sedimentation and gas generation (Milkov 2000, Dimitrov 2002, Talukder, Comas et al. 2003); Tectonic processes are considered to be the main driving forces for the development of the mud diapirism (Milkov 2000, Talukder, Bialas et al. 2007).

The Song Hong Basin is the one of largest Tertiary sedimentary basins situated in continental margin of the East Sea. Its formation is often considered to be linked with the timing and motion of the Ailao Shan-Red River Strike-slip Fault Zone and transtensional break-up of the pre-Cenozoic basement along the East Sea during the Cenozoic. (Rangin et al., 1995; Sun et al., 2004; Clift and Sun, 2006; Hoang et al. 2009; Zhu et al., 2009). Previous studies based on 2D and 3D muntichannel seismic data have documented the occurrence of many submarine mud volcanoes, gas seeps and mud diapirs within the Song Hong Basin (Fig. 1). Although these mud diapirs are of importance for formation of structural traps, its formation timing and mechanism are still opened to uncertainty.

In this study, the authors will focus on characterization of mud diapir-like structures by detail seismic facies analysis and re-interpretation of 2D seismic lines cutting across the central Song Hong Basin. We will further establish the geodynamic conditions in order to explain how the mud diapirs have been produced in this area.

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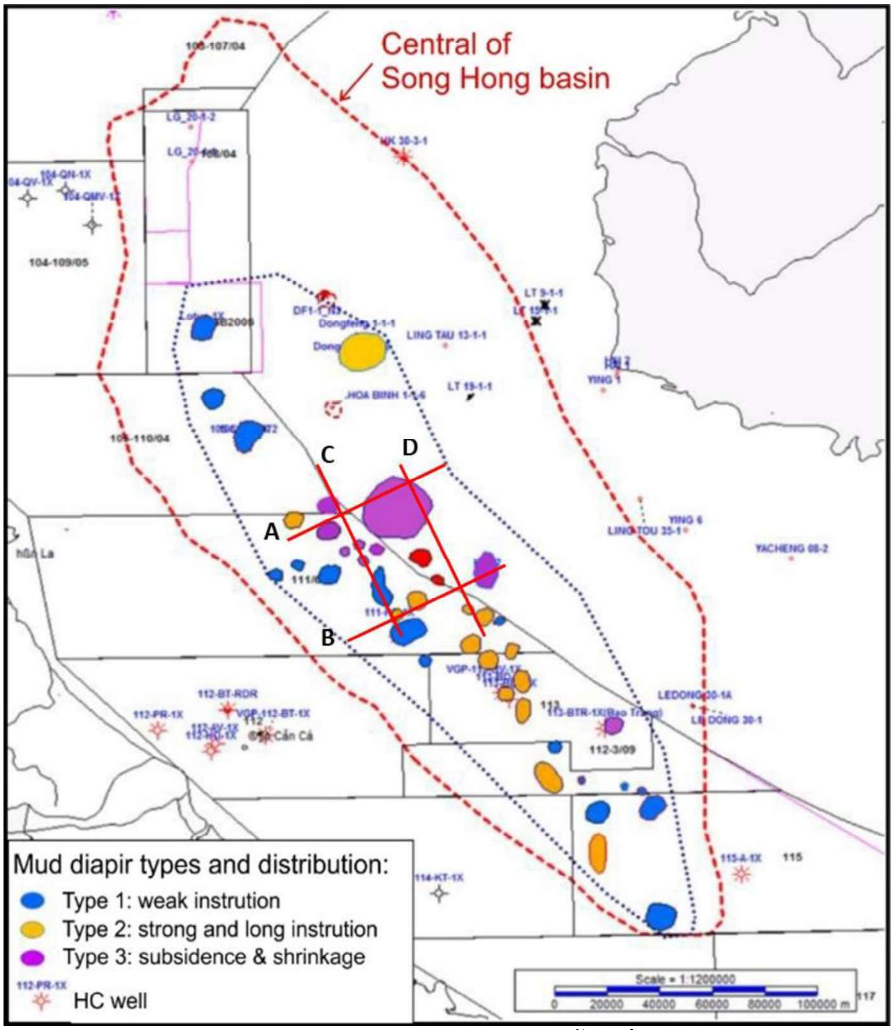

Figure 1. Mud diapir distribution in Song Hong basin (Nguyễn Tiến Thịnh 2017) and location of seismic line B used in this paper.

2. Methodolgy

2.1. Seismic facies and attribute analysis

Seismic attributes can be conveniently defined as the quantities that are measured, computed or implied from the seismic data. From the time of their introduction in the early 1970s, seismic attributes have gone along the way and they became an aid for geoscientists for reservoir characterization and also as a tool for quality control (Chopra and Marfurt 2007).

Seismic facies analysis is an useful tool for reservoir characterization. A seismic facies unit can be defined as a sedimentary unit which is different from adjacent units in its seismic characteristics. Parameters that should be taken into consideration in the seismic facies analysis are as follows: reflection amplitude, dominant reflection frequency, reflection polarity, interval velocity, reflection continuity, reflection configuration, abundance of reflections, geometry of seismic facies unit, and relationship with other units (Roksandić, 2006). Interpretation of seismic facies data may be either direct or indirect. The purpose of the direct interpretation is to find out geological causes responsible for the seismic signature of a seismic facies unit. So, the direct interpretation may be aimed at predicting lithology, fluid content, porosity, relative age, overpressure shales, type of stratification,… Generally, frequency attributes relate to bed thickness, wave scattering, and absorption. Time attributes relate to structure and amplitude attributes relate to stratigraphy.

2.2. Seismic facies Classification

Understanding different attributes that can be used as tools in interpretation, it is useful to understand the classification of different attributes at this stage. The more seismic attributes available, the more confusion geoscientists may have in selecting the appropriate ones. Improved documentation and a greater understanding of the underlying rock physics that give rise to an anomaly, the role that seismic processing plays in enhancing or destroying attribute anomalies, and the value of seismic attributes in the absence of good well control are areas where assistance is needed (Russell et al. 1997). Guidance should be available to the interpreter to help with the choice of the seismic attributes that will provide the greatest insight into the current problem under investigation. The one way to classify seismic attributes is based on their characteristics and hence geometrical and physical. Seismic facies analysis techniques combine classification algorithms and seismic attributes to generate a map that describes main reservoir heterogeneities. However, most of the current classification algorithms only view the seismic attributes as isolated data regardless of their spatial locations, and the resulting map is generally sensitive to noise.

The geometry of the diapir bodies also corresponding to the seismic facies unit and its geological setting will be interpreted by unsupervised method of classifying seismic facies using K-mean clustering and Self Organizing Maps (SOM) methods.

- *Self-Organizing Mapping:* Neural Network is a type of Artificial Neural Network that is trained using unsupervised learning to produce a low-dimensional (typically 2D), discretized representation of the input space of the training samples, called a map. This is therefore a method to reduce dimensionality. Self-organizing maps differ from other artificial neural networks in that they apply competitive learning and use a neighbourhood function to preserve the topological properties of the input space (Kohonen, 1982). Applying this method we can generate a seismic facies map or volume from single or multiple seismic attributes.
- *K-means clustering:* is a type of unsupervised learning, originally used in signal processing, and popular for cluster analysis in data mining. k-means clustering aims to partition n observations into k clusters, in which each observation belongs to the cluster with the nearest mean, and serves as a prototype of the cluster. Data points are clustered based on feature similarity. This method can help us for clustering electrofacies and seismic facies volumes in a reservoir properties analysis and modeling workflow.

3. Results and Discussions

In this case study, we tested one high quality seismic sections, which have been subjected to auto detecting geobodies of diapirs. We used both of K-means and SOM methods for seismic facies classification. The seismic section will be testing, exploring architectures from 3 to 6 clusters corresponding to seismic facies.

After testing with several 2D seismic attributes, we decided to use 4 seismic attributes that demonstrate good correspondence to geometry of the diapir such as Instantaneous Frequency, Envelop, RMS, Chaos and Amplitude (raw data) input to K-mean and SOM for seismic facies classification (Fig.2).

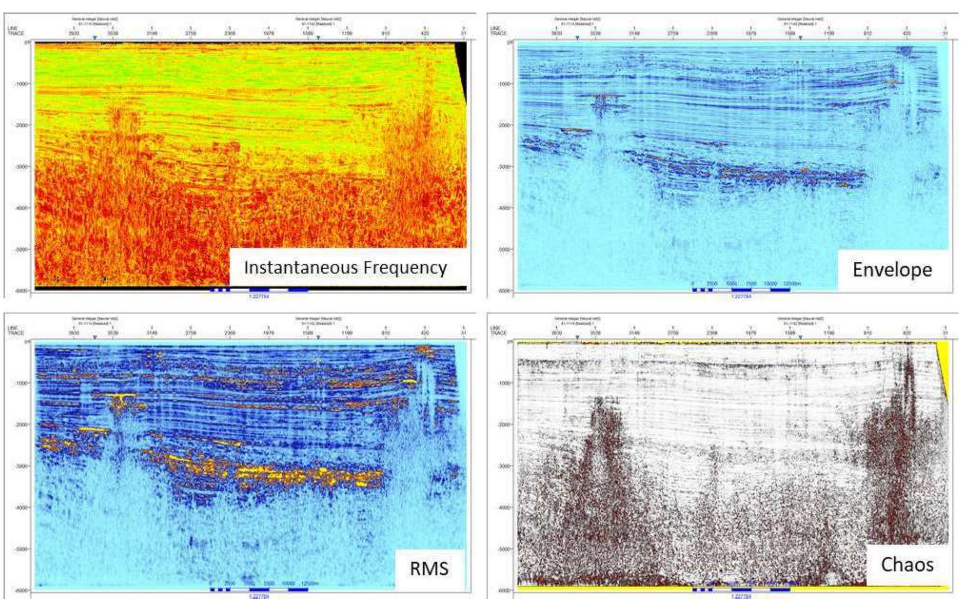

Figure 2. The four attribuites engerated from 2D seismic section

Recognizing the geobodies of diapirs, in this study both K-mean and SOM methods were used to subdivide 4 attributes of 2D seismic data into several facies. In order to improve the results, 3 to 6 classes of facies have been tested for each method, the results are presented in the Fig. 3 for K-mean and Fig. 4 for SOM method.

Oncer comparing the results of K-mean and SOM classification, we realized that the clusters outcome are not so much difference but the 6 Facies_SOM look like more accurate and hence good correspondence to geometry of the diapir (Fig.4). Fig. 5 shows the final result of the mud diapir geobodies in the study area.

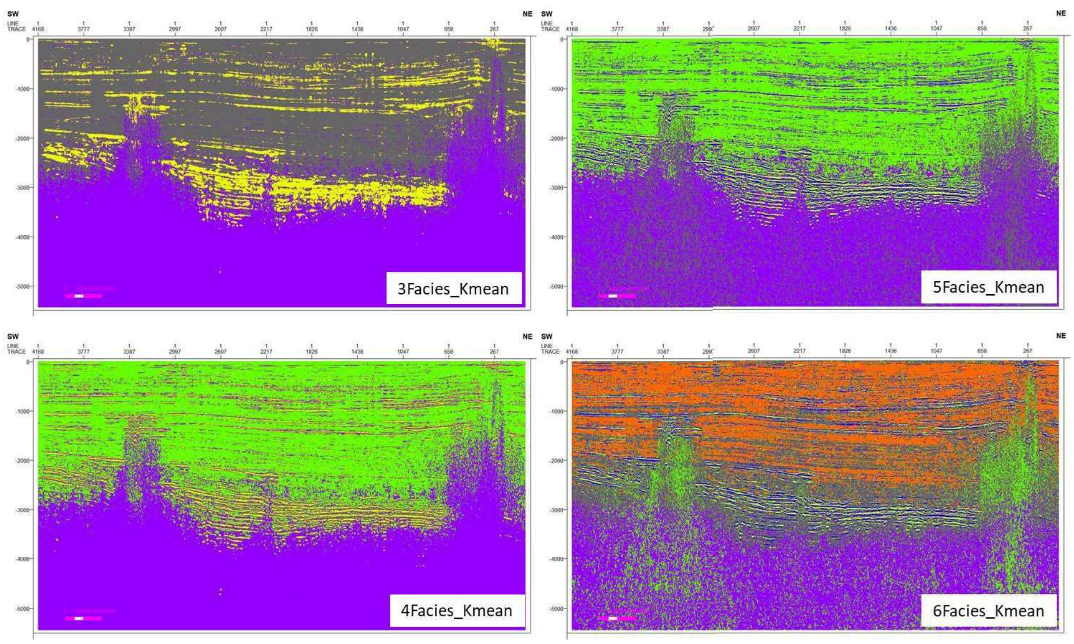

Figure 3. The results of seismic facies classification using K-mean method

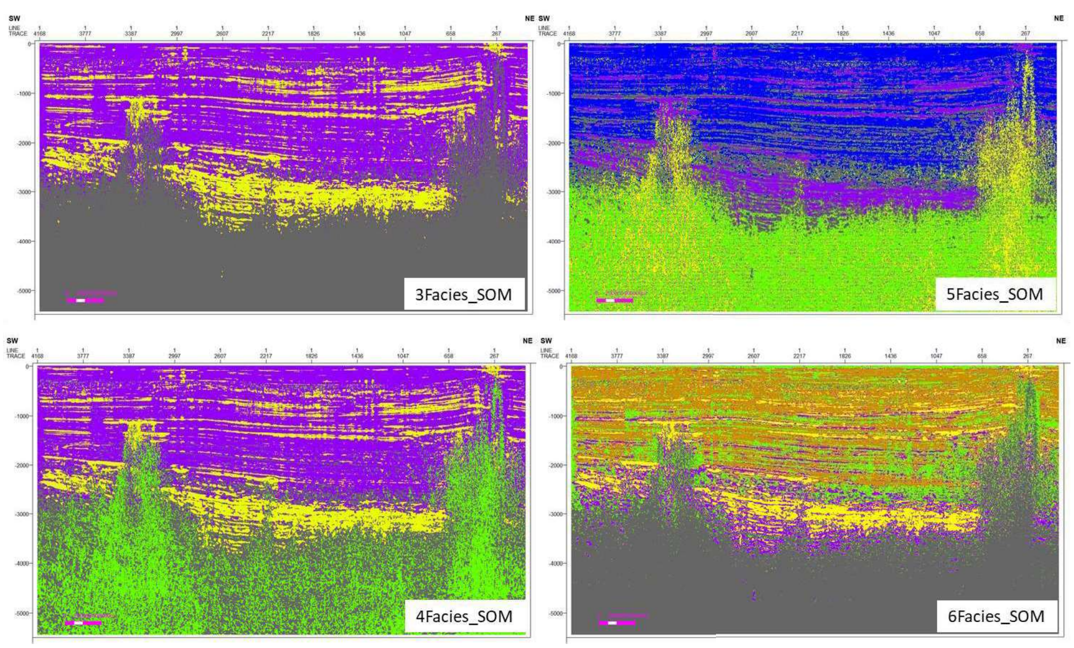

Figure 4. The results of seismic facies classification using SOM method

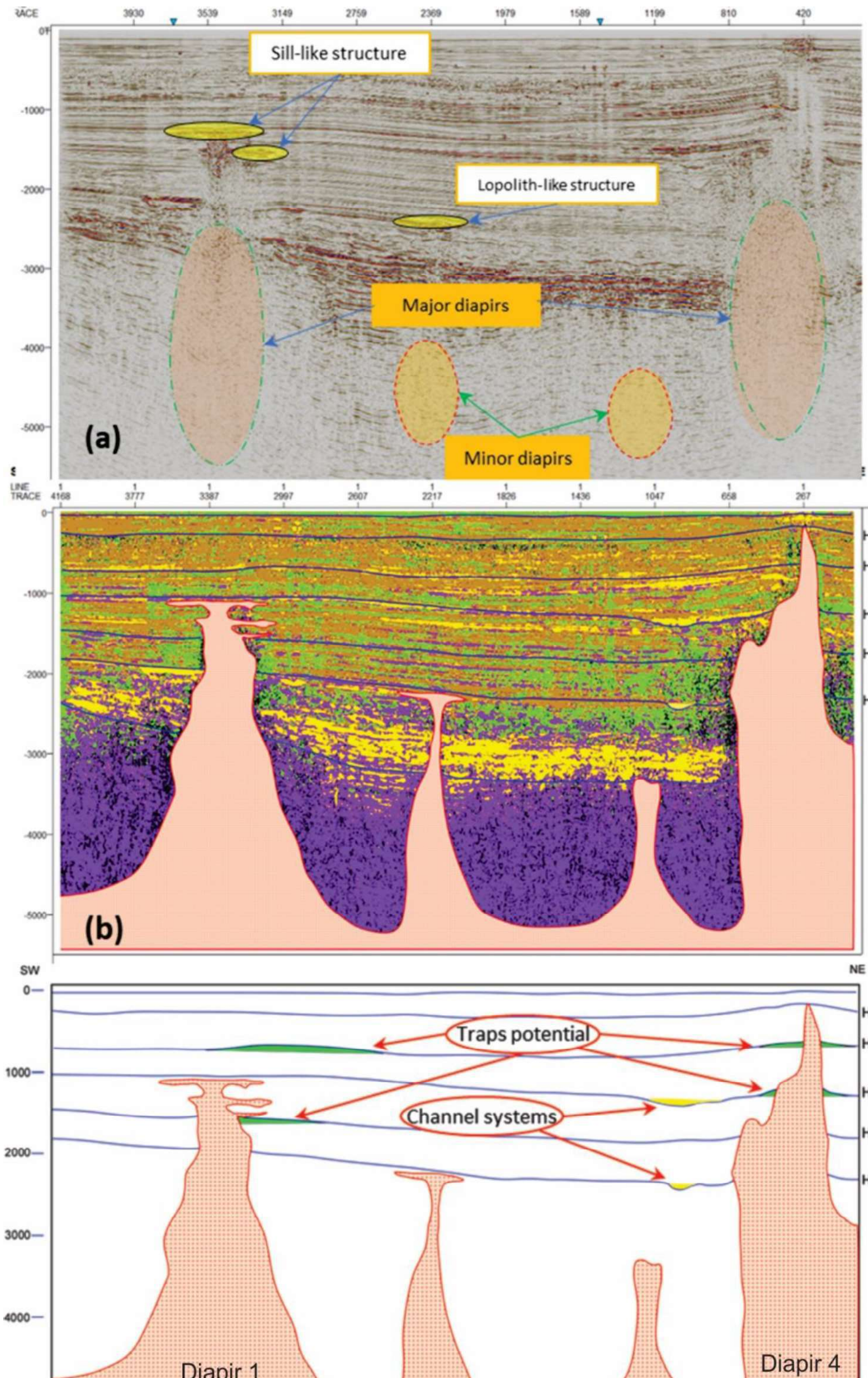

Figure 5. The diapir geobodies using SOM method
a) Raw Amplitude section shows not clearly facies and features of geologial setting
b) The diapir geobodies interpretaion base on the 6 facies classification using SOM method
c) The geological section shows some traps protential in the study area

Figure 5 shows 4 mud diapirs, which are characterized by chaotic seismic reflections, terminated at different stratigrphic level, making sediment layers on both side of the diapirs folded. The morphology relationships between diapirs and host strata indicate that while some diapirs (diapir 2 & 3) became inactive and are sealed by the H5 reflector, others continued their upward migration vertically, piercing the upper sequences. The sedimentary sequence were folded towards the diapir 4, probably due to the development of collapse structures within the interval of 1 - 2s. As diapirs migrate upward, the overlying sedimentary layers have been folded and/or uplifted. This deformation has triggered a shift of the depocenter from one place to another through time. As the result, the pathway and direction of sediment transport may have been redirected. Especially, some sandy layers (often considered good reservoir rock) have likely been folded and/or uplifted to form local anticlininal structures, which can become potential structural traps in many cases.

4. Conclusions

Mud diapir occurence in the study area has been confirmed its existance in the central of the Song Hong Basin. However the image of the diapirs have not been clearly clarified. Using the K-mean and SOM method are useful proxies in order to enhance the boundary of the geobodies, giving quite similar results but the SOM method is likely more accurate and depict the geobodies better. There four diapirs have been clearly imaged on seismic section. While some diapirs stopped rising in the H1 and H3 horizon and developed pluming structures in their tops, others stop in the H5 horizons. Association with this mud diapir is formation of potential structural traps. This interpretation allowed us to identify at least 4 potential structural traps. However, this interpretation should be confirmed by further and more detail seismic data interpretaion, especially using 3D seismic data for mapping thes structures more accurately.

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TÓM TẮT

Minh giải cấu trúc diapir bùn dựa vào thuộc tính địa chấn 2D và hệ mạng Nơ ron không giám sát: áp dụng cho bể Sông Hồng

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Cấu trúc diapir bùn đã được xác định có vai trò quan trọng trong tìm kiếm thăm dò và khai thác dầu khí. Tuy nhiên, cơ chế hình thành và các đặc trưng của diapir bùn vẫn chưa được nghiên cứu nhiều trong suốt những thập kỷ qua cho đến khi chúng được phát hiện ra có mối liên quan đến tìm kiếm thăm dò và khai thác dầu khí. Trong nghiên cứu này, chủ yếu đề cập đến sự tồn tại của diapir tại khu vực bể trầm tích Sông Hồng và mối liên quan đến hệ thống dầu khí. Chi tiết minh giải địa chấn 2D tại trung tâm bể Sông Hồng đã xác định được sự tồn tại của 4 cấu trúc diapir bùn. Những diapir này xâm nhập và kết thúc tại một vài địa tầng, là kết quả của các thời kỳ kiến tạo và địa chất, phản ảnh từng giai đoạn tới hạn dị thường áp suất cao. Phát hiện và xác định được sự tồn tại của diapir bùn chỉ ra cơ hội lớn cho dự báo phân bố các bẫy cấu tạo tại khu vực trung tâm bể Sông Hồng.

Từ khóa: Diapir bùn; Bể Sông Hồng; Hệ thống dầu khí; K-mean; SOM.