BUILDING POROSITY MODEL OF FRACTURED BASEMENT RESERVOIR BASED ON INTEGRATED SEISMIC AND WELL DATA IN HAI SU DEN FIELD, CUU LONG BASIN

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Summary

The Pre-Tertiary fractured basement is an important hydrocarbon-bearing reservoir in Vietnam. Due to their very small matrix porosity, basement rocks become reservoirs only when they are strongly fractured, consequently it is a big challenge to construct the porosity model for the basement. Based on the good seismic imaging of the Hai Su Den basement, different seismic attributes have proved to be effective tools in basement fracture characterisation, and the integration of 3D seismic attributes, well data and other geological information by using Artificial Neural Network (ANN) and Co-Kriging techniques has been demonstrated as a good way to construct porosity model for the Hai Su Den fractured basement reservoir. The accuracy of the model has been verified by well results.

Key words: *Fractured basement, Pre-Tertiary, porosity, permeability, Hai Su Den field.*

1. Introduction

Pre-Tertiary fractured basement (referred to below as “fractured basement”) is an important type of hydrocarbon-bearing reservoirs offshore Vietnam. In the last decade, thanks to advanced seismic technology, seismic imaging of fracture zones associated with faults within the basement has significantly improved. Seismic attributes can, therefore, be widely applied to identify and outline good fracture zones inside the basement as well as to predict some of the main characteristics of existing fracture systems, such as dip and azimuth [2, 4].

Currently, the application of seismic attributes and well data for fractured basement studies in Vietnam could be classified in two groups. Based on detailed analysis of different seismic attributes the authors of the first group [1 - 4] have proved the possibility of using seismic attributes in the identification and outlining of good fracture zones inside the basement as well as in the prediction of fracture systems’ characters. The authors of the second group [5] have tried to build geological model of the fractured basement based on integrated seismic attributes and well data using ANN and Co-Kriging technique without detailed analysis of the applied seismic attributes.

This paper demonstrates the good results of combining the ideas of both author groups in the construction of a porosity model for the Hai Su Den fractured basement reservoir. The workflow of porosity model building for the Hai Su Den basement is consistent with two steps. In the first step, meaningfull seismic attributes have been selected based on a detailed analysis of the possibility for basement fracture imaging and characterisation. The second step builds a porosity model by integrating the ANN and Co-Kriging technique. The final model has a good correlation with blind test well results and a high degree of reliability.

2. Hai Su Den field overview and study method

2.1. Hai Su Den field overview

The Hai Su Den oil field is located in Block 15-2/01 of Cuu Long basin, offshore the South of Vietnam (Fig.1). The Hai Su Den structure is an anticlinal drape over a basement high, which is elongated along the NE-SW direction. At the Early Miocene, Oligocene and basement levels the structure is intersected by a series of E-W to NW-SE and NE-SW faults (Figs.2 & 3).

Previous studies in the area suggested that the granitoid basement in Block 15-02/01 is considered to be Cretaceous Deo Ca suite granitoid. It is possibly constituted of the Cretaceous-Paleogene mafic, intermediate and felsic dykes (Deo Ca, Cu Mong, Phan Rang suites). The basement could be strongly hydrothermal altered. Secondary minerals were formed and filled fractures and/or partly replaced primary minerals. The most common alterations are sericitisation, calcitisation of plagioclase, kaolinisation of potassium feldspar, chloritisation of

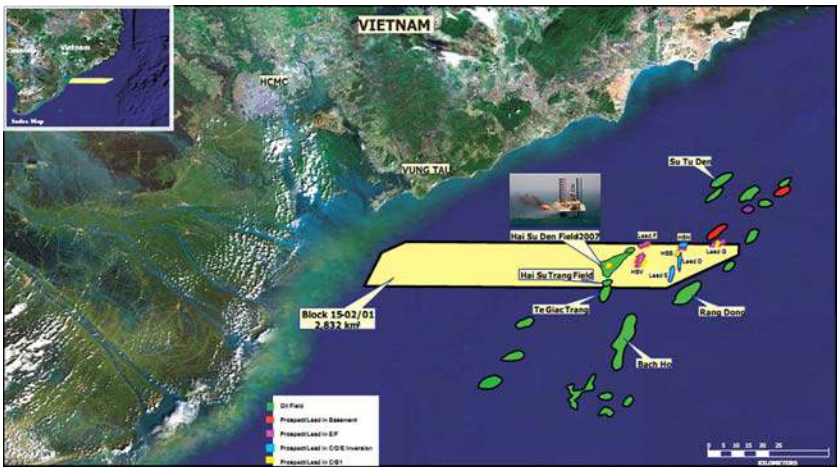

Fig.1. Hai Su Den oil field location map

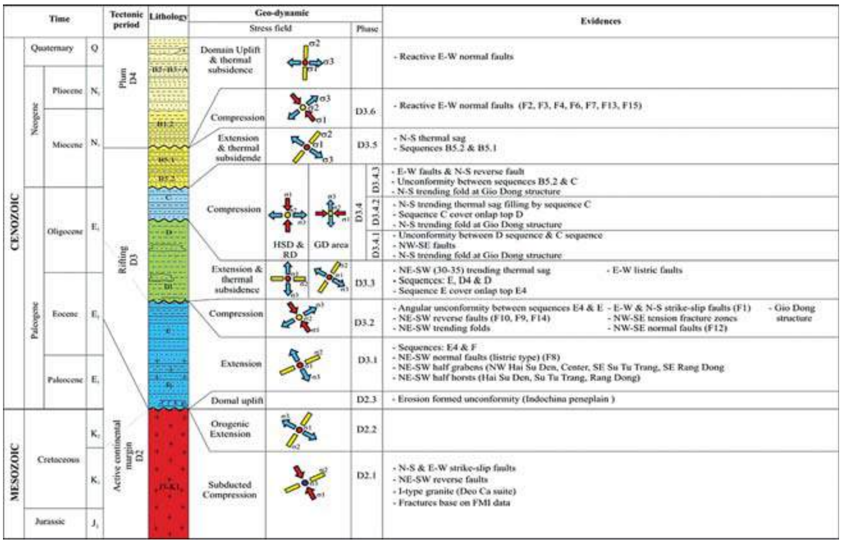

Fig.2. Stratigraphy and main deformation phases in Block 15-02/01, Cuu Long basin

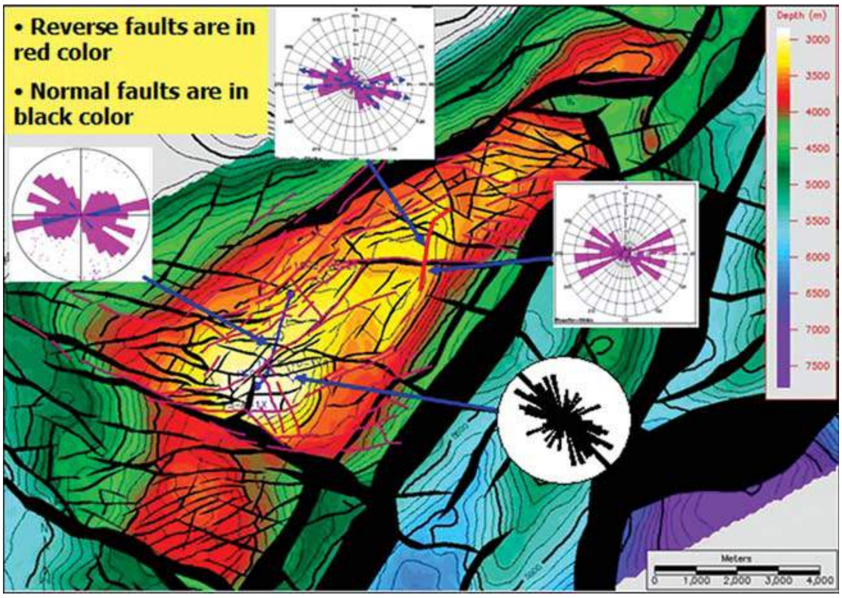

Fig.3. Depth structural map of Hai Su Den basement top with results of FMI interpretation. The azimuths of fractures interpreted by FMI data are consistent with fault direction interpreted by seismic data

biotite and hornblende. There are some veins of zeolite observed on core [8].

Seven wells have been drilled into the Hai Su Den basement, which are HSD-1X, HSD-2X/ST, HSD-3X, HSD-4X, HSD-5XP, VD-1X and VD-2X. HSD-1X drilled in Block B in September 2007 has a maximum flow rate of more than 20,000 bop while VD-1X, which was drilled before in the same basement block and is only about 600 metres away from HSD-1X surface location, was dry. These results show very complicated reservoir characters of the Hai Su Den fractured basement.

Source rock consists of mainly shales of the Oligocene D sequence with high TOC and HI values, which are considered good to excellent oil-prone source rocks. The lacustrine shales of Early Oligocene E sequence are also considered as having good source rock potential.

Trap: The fractured basement reservoir is known to be formed in the Hai Su Den prospect from existing well control. Multiple trending faults are present within the neighbourhood of the structure. This fault pattern suggests the presence of a complex of shear and extensional fractures.

Seal: Thick shales of the D Sequence are main seals for the clastic reservoirs of the E Sequence and/or basement reservoirs. Intra-formational shales, interbedded within sandstones in the E, C and BI sequences may also be potential seals, or have partially sealing capacity for the immediately underlying sandstone reservoirs.

Reservoir: The fractured/weathered granite basement is the primary reservoir objective in the Cuu Long basin, from which hydrocarbon has been produced from fractured zones within the pre-Tertiary basement. The secondary reservoir objectives are the reservoirs within the Oligocene fluvio-deltaic sandstones and the Lower Miocene sandstones, from which oil has been discovered.

In the Hai Su Den basement, three fault systems with E-W, NE-SW and NW-SE directions are strongly developed and fractures associated with these fault systems interpreted by FMI data are consistent with the interpreted faults in their characters (Fig.3). Within the Hai Su Den basement, the role of the E-W fault system was also highlighted by the previous studies [2] as the main faults related with oil flow zones inside the basement.

2.2. Study method

Several methods have been applied to build the porosity model for fractured basement in Cuu Long basin including Halo model/Advanced Halo model, DFN (Discrete Fracture Network) and ANN [5]. The Halo model has been widely applied in Vietnam, which much depends on the fault interpretation and assumes that the porosity remains unchanged along the interpreted fault planes. In the Hai Su Den basement, the Halo model method has been used at the beginning, but the results were too optimistic, therefore the advanced Halo model method has been tested. The difference between the Halo model and advanced Halo model methods is mainly related to applying seismic attributes to take into account the discontinuity of reservoir quality along the interpreted fault planes. Besides, DFN is also a method which can create the connectivity between faults and fracture systems from the geological information of an area. This method requires several information of a fracture system including orientation, aperture, intensity, location, mineralogy, hydraulic and mechanical properties [9]. However, DFN has the same disadvantage as the Halo model since it does not reflect the heterogeneity of fracture systems. In order to promote the role of seismic attributes in porosity model building process, ANN has been applied [5]. This method is able to combine seismic and

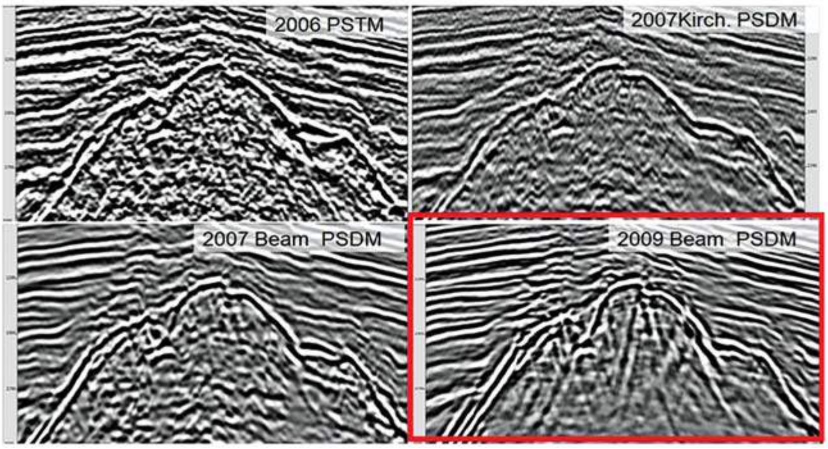

Fig.4. *Comparison of different seismic data in Hai Su Den basement [4]*

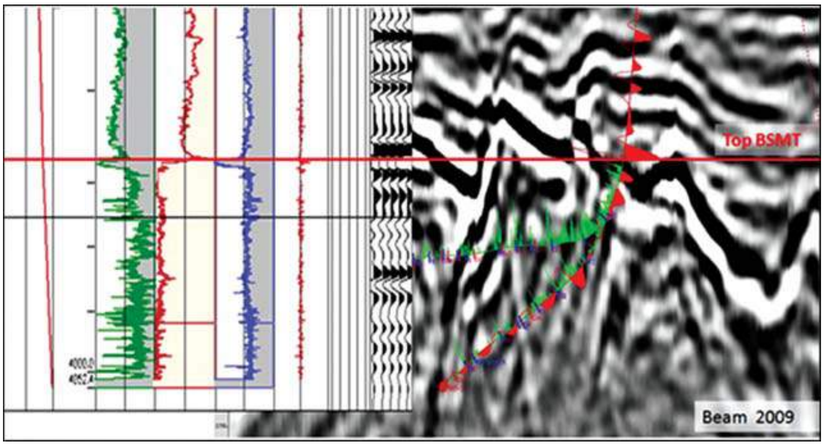

Fig.5. *Good tie of dipping reflection events inside the Hai Su Den basement with synthetic seismogram (red filled curve) and fracture porosity (Green curve) derived from well log data by using BASROCK software*

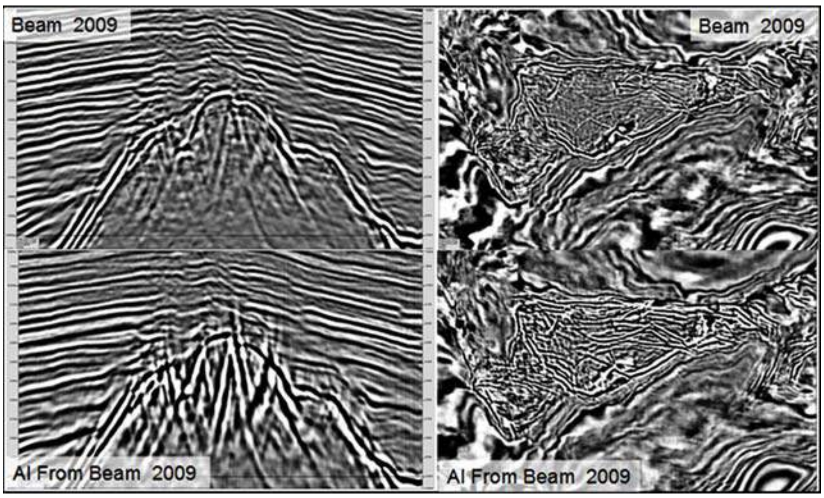

Fig.6. *Relative acoustic impedance (RAI) gives much better images inside basement elements than the original seismic data*

well data to produce a porosity model which reflects the vertical and horizontal porosity variation trends. The main weakness of the current method applying ANN in Cuu Long basin is the lack of a detailed analysis of the applied seismic attributes in imaging and characterisation of fracture systems.

The quality of 3D seismic data of the Hai Su Den basement is good and could clearly image fracture associated faults. Fig.4 shows a comparison between 4 seismic data versions of the Hai Su Den area (2006 PSTM, 2007 Kirchoff PSDM, 2007 Beam PSDM and 2009 Beam PSDM), which were the result of applying different processing sequences. It is clear that the 2009 Beam PSDM data has better quality while it could clearly image dipping elements inside the basement. Beam migration can enhance the signal to noise ratio, especially enhance steeply dipping events, handle multi-arrival ray paths and preserve steep dipping reflection, hence providing a clear image of the basement [1]. By using synthetic seismograms, it's clearly to see that the dipping reflections inside the basement have good tie with fracture zones generated from logging data. The synthetic seismogram in Fig.5 shows good consistency between seismic and well data.

To avoid the above mentioned weakness of current application of the ANN method, under the condition that good seismic imaging of fracture systems was achieved in the Hai Su Den fractured basement, an integration of ANN and Co-Kriging techniques was used for porosity model building for Hai Su Den fractured basement reservoir with the following workflow:

- Detailed analysis of seismic attributes, which could image and characterise fracture systems inside the basement to select meaningful fracture porosity and the optimum seismic attribute set.

- Porosity model building using ANN with the selected seismic attribute set and fracture porosity estimated by BASROCK software.

- Porosity model building using Co-Kriging to integrate seismic attributes, fracture porosity and other well data and fracture characters collected in the region.

3. Possibility of using seismic attributes to build porosity model of the fractured basement reservoir in Hai Su Den field

Recently, many seismic attributes have been successfully applied to image and characterise the fracture systems inside the basement. Among them, the following seismic attributes have been highlighted in different publications from the previous studies [1 - 4, 7]: *Relative acoustic impedance (RAI), Variance (Coherency), Curvatures,*

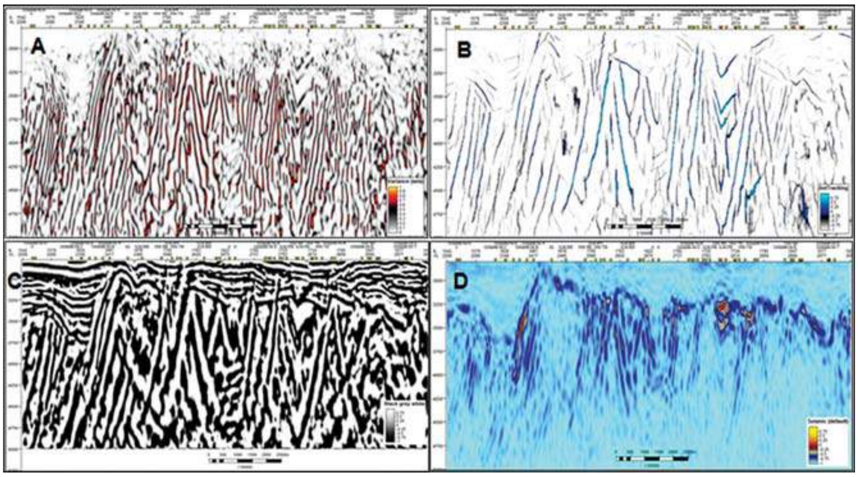

Fig.7. *Vertical section of different seismic attributes showing different quality in imaging of fracture zones inside the Hai Su Den basement. A: Variance; B: Ant-Tracking; C: Cosine of Phase; D: Envelope*

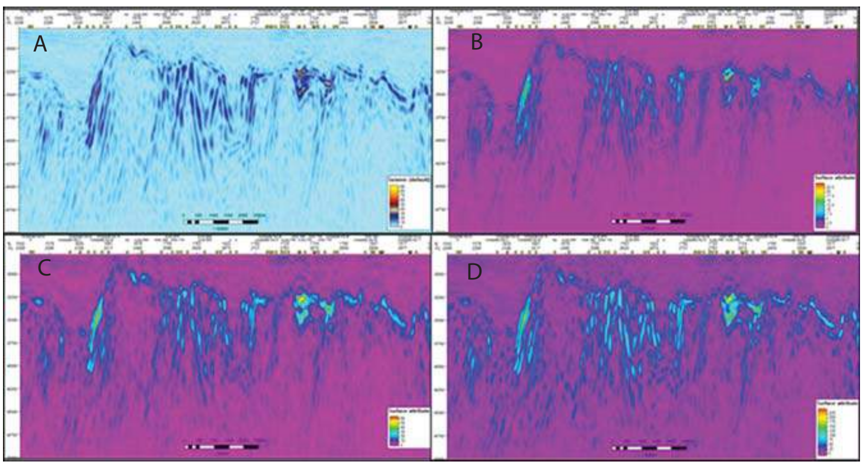

Fig.8. *Vertical section of different seismic attributes showing different quality in imaging of fracture zones inside the Hai Su Den basement. A: RMS Amplitude; B: Gradient magnitude; C: Sweetness; D: Reflection intensity*

RMS amplitude, Envelope, Ant-tracking, Cosine of phase, Gradient magnitude, Sweetness and reflection intensity.

Based on our study results, the relative acoustic impedance is the most important attribute. At first, the seismic inversion process normally increases the signal to noise ratio, consequently it improves dipping reflection events inside the basement. Fig.6 shows this advantage in the Hai Su Den basement. Secondly, RAI is a layer property, which is different from the surface property of the original seismic data, it, therefore, directly reflects the fracture zones inside the basement, which are characterised by lower density and lower seismic velocity (Lower RAI) compared to the fresh basement. For the Hai Su Den basement the RAI was selected as the input data instead of the original seismic data to assess other seismic attributes.

To select the meaningful fracture porosity and optimum seismic attribute sets, the seismic attribute analysis is performed in two steps:

- Qualitative analysis to select the meaningful fracture porosity: The qualitative analysis is based on visual inspection of seismic attributes in imaging of fracture systems and qualitative correlation between seismic attributes and fracture porosity.

- Quantitative analysis to select optimum seismic attribute set: The quantitative analysis calculates and ranks correlation coefficients between seismic attributes and well fracture porosity. The optimum seismic attribute set is selected by the highest correlation coefficient among different combination of the seismic attributes.

3.1. Qualitative analysis of seismic attributes

3.1.1. Variance and curvature

These attributes are well known in fault and fracture imaging for sediment section and top of the basement [1, 3, 7], but for inside the basement these attributes become too noisy to image the fracture systems. Fig.7 presents the vertical section of the variance attribute for inside the Hai Su Den basement. It is clear that the attribute anomalies exist everywhere and many of them are vertical dipping events; they are, therefore, probably related to noise. These attributes were not selected for further quantitative analysis.

3.1.2. Ant-Tracking

Ant-tracking is a well known attribute for fault mapping and fracture system characterisation for both sediment and inside-basement sections [3]. Based on this attribute we can successfully predict azimuth, dip angle, density and intersection between different fracture systems (Fig.7B). But it is difficult to identify and outline high fractured zones inside the basement using this attribute. In principle the Ant-tracking will gain the weak

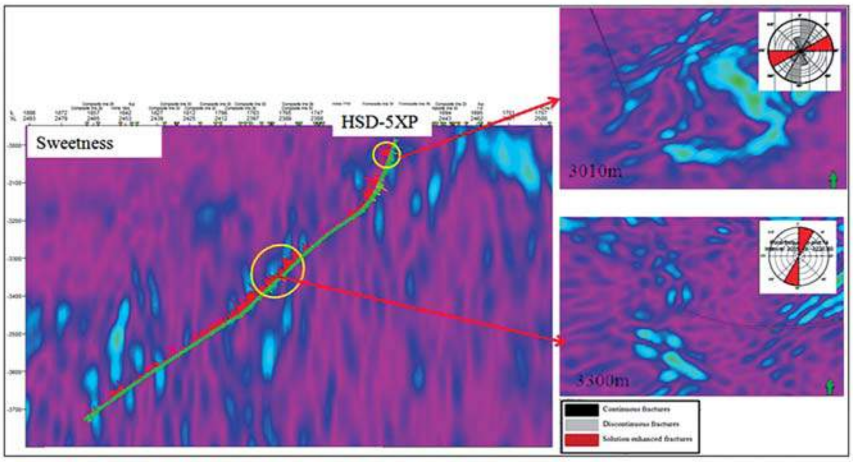

Fig.9. *Comparison between sweetness and HSD-5XP well fracture porosity (red curve) on both section and depth slices*

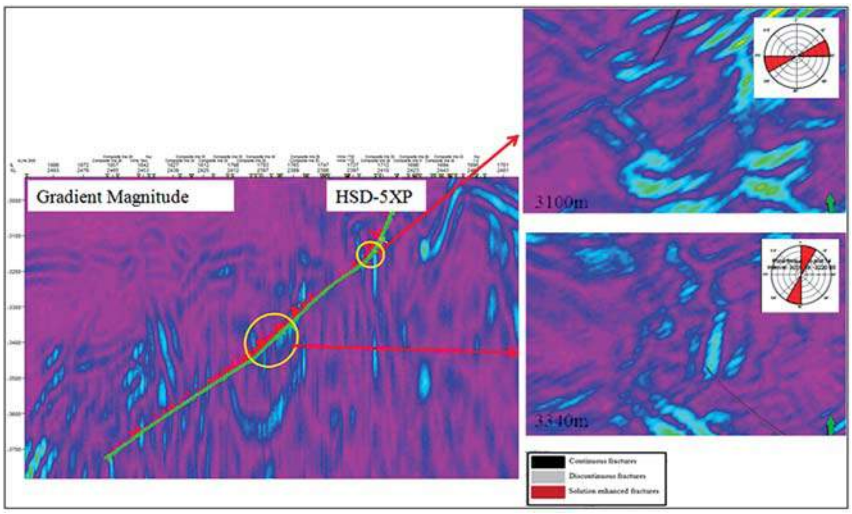

Fig.10. *Comparison between gradient magnitude and HSD-5XP well fracture porosity (red curve) on both section and depth slices*

seismic events, therefore it does not preserve the true amplitude and reduce discontinuity along fault plane, which is an unexpected effect in fracture porosity model building. In Fig.7B we can see good fault imaging, but the anomaly intensity is similar everywhere in the section and it is hard to be correlated with variation of fracture porosity with depth.

3.1.3. Cosine of phase

Similar to the Ant-Tracking attribute, Cosine of instantaneous phase could be applied for inside fault imaging and fracture systems characterisation (Fig.7C), but it is hard to be correlated with fracture porosity.

3.1.4. Envelope

Envelope or instantaneous amplitude is the complex seismic trace, which is related to the intensity of AI contrast between fractured and fresh basement and thickness of the fracture zones, it could, therefore, not only image good fracture zones inside the basement but also be used for fracture system characterisation. Fig.7D presents the section of the Envelope attribute for the Hai Su Den basement. In this figure we can see that strong Envelope anomalies exist in different areas and reduce with depths. The strong envelope anomaly zones are also consistent with location of good oil flow basement wells. This attribute was definitely selected for quantitative analysis.

3.1.5. RMS Amplitude

RMS Amplitude computes Root Mean Squares on instantaneous trace samples over a specified window. Similar to the Envelope attribute it could be used for both identification and outline of good fracture zones inside the basement as well as fracture system characterisation. Fig.8A presents RMS amplitude section in the Hai Su Den Basement.

3.1.6. Gradient magnitude

The magnitude of the instantaneous gradient computed in three-dimensions of the sample neighbourhood. This attribute can highlight the lineament of faults and indicate zones of high-fractured density, thus enhance the signature of fractured zones inside the basement (Fig.8B).

3.1.7. Sweetness

The sweetness attribute is calculated using the following formula: "Sweetness = Env/sqrt (Inst. Freq)", it reflects both the contrast between the fractured and fresh basement and the fracture zones thickness itself. Within a fractured zone, the frequency is also reduced due to attenuation of energy. Fig.8C is the sweetness section for the Hai Su Den basement.

3.1.8. Reflection Intensity

Reflection intensity is the average amplitude over a specified window multiplied with the sample interval. Visually, reflection intensity can help to highlight the lineament of faults and indicate zones of high fracture density (Fig.8D).

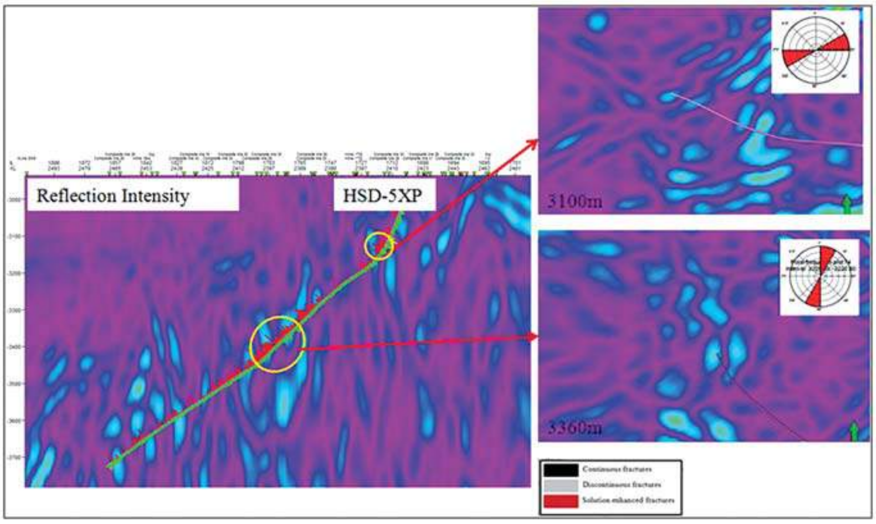

Fig.11. *Comparison between reflection intensity and HSD-5XP well fracture porosity (red curve) on both section and depth slices*

3.2. Quantitative analysis of the selected seismic attributes

The latest six seismic attributes and RAI were chosen for quantitative analysis to select the optimum seismic attributes for further porosity model building using ANN.

Based on the quantitative analysis, the three following seismic attributes were selected as the optimum fracture porosity attributes.

3.2.1. Sweetness

Fig.9 shows a comparison between the sweetness attribute and well fracture porosity in both vertical section and different depth slices. It is clear to see that the seismic attribute (blue colour) is consistent with the well data not only in location of good fracture zones, but also with dip and azimuth of the fracture systems.

3.2.2. Gradient magnitude

Gradient magnitude attribute has a good tie with the well fracture porosity in location of good fracture zones and in dip and azimuth of different fracture systems (Fig.10).

3.2.3. Reflection Intensity

Similar to the Sweetness and Gradient magnitude attributes, Reflection Intensity also has a very good tie with the well data (Fig.11).

4. Porosity model building using ANN and Co-Kriging technique

4.1. ANN

ANN is applied to integrate the selected seismic attributes with well fracture porosity to predict the distribution of porosity within basement.

ANN is a tool for automatically finding the relationship between multiple known parameters and a single unknown parameter. The behaviour of a neural network is defined by the way its individual computing elements are connected and by the strength of those connections, or weights. The weights are automatically adjusted by training the network according to a specified learning rule until it properly performs a desired task.

Supervised ANN is an algorithm that takes multiple inputs and returns one or several outputs. These inputs may match with log values, seismic attributes, surface values or properties from the same cell. Each input is multiplied by a weight; the result is summed and passed through a nonlinear function to produce an output [5].

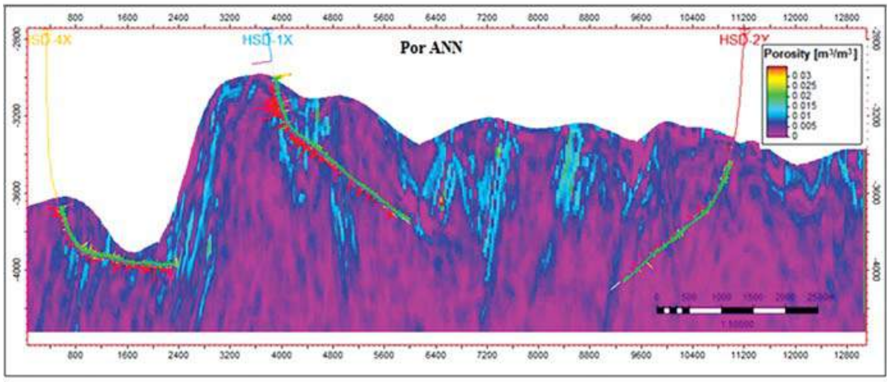

Fig.12. *Vertical section of porosity model using ANN. The red curves are well fracture porosity*

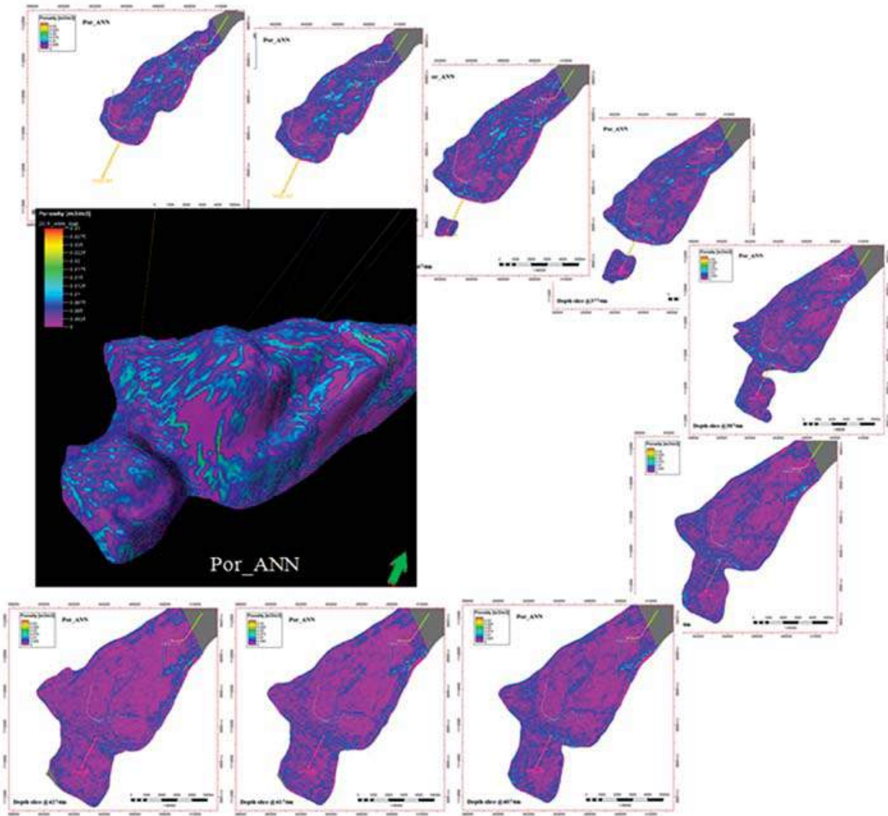

Fig.13. *Porosity model and depth slices using ANN of Hai Su Den fractured basement*

The set of 03 selected seismic attributes (*Reflection Intensity, Gradient Magnitude, and* Sweetness) was run in supervised mode using ANN and well fracture porosity was used as training data. We can observe that this optimum seismic attribute set has a good correlation coefficient (as 0.76) with well porosity, therefore the result of predicted porosity by ANN is highly reliable. Figs.12 and 13 show a very good consistence of well fracture porosity with the fracture porosity predicted by using ANN.

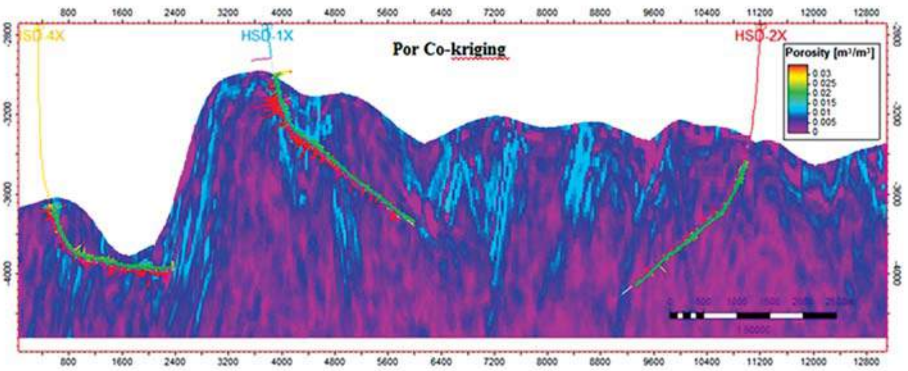

Fig.14. Vertical section of porosity model using Co-Kriging technique of Hai Su Den fractured basement

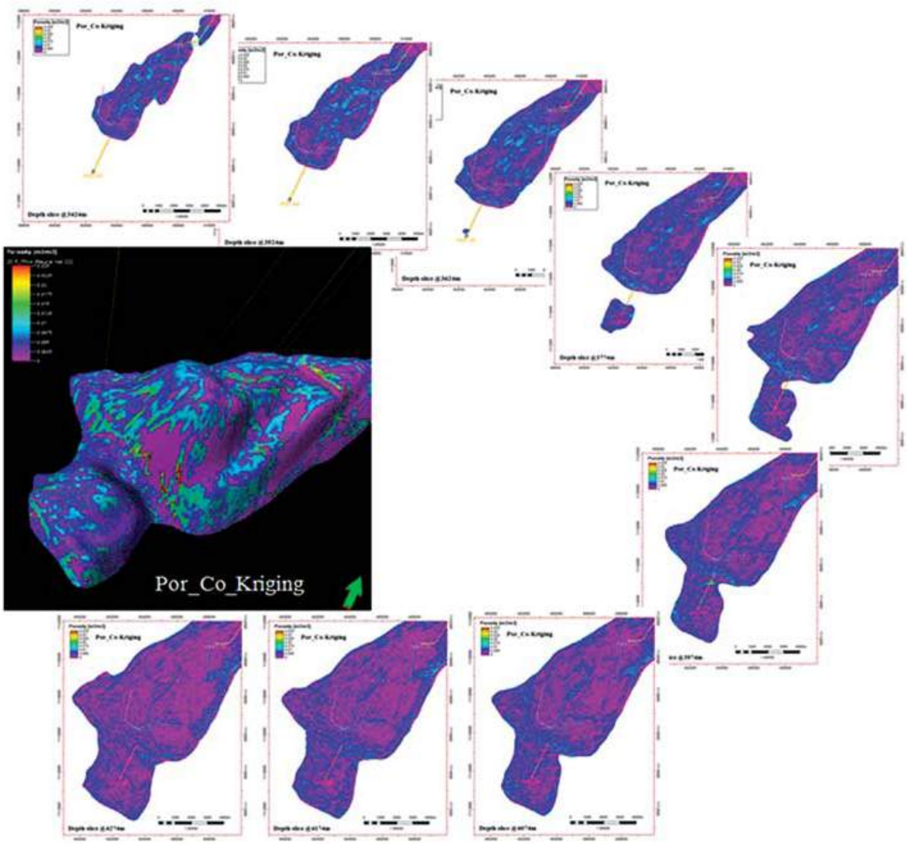

Fig.15. Porosity model and depth slices using Co-Kriging technique of Hai Su Den fractured basement

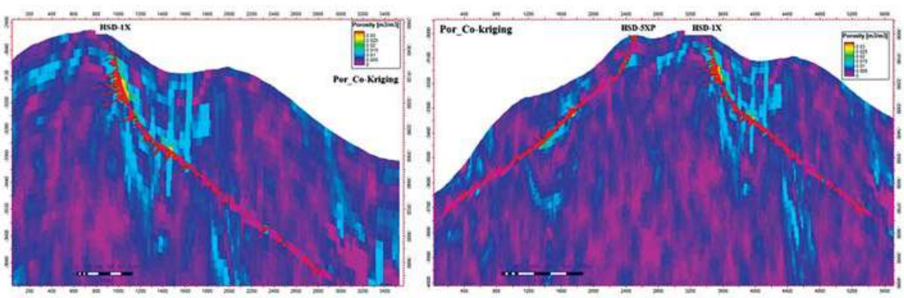

Fig.16. Comparison between secondary porosity modelling using Co-Kriging technique and well's porosity on section

4.2. Co-Kriging technique

Based on the result of predicted fracture porosity model using ANN, Co-Kriging steps have been taken to correct the trend and extent of fractures in the model by well parameters, fracture parameters and tectonic elements of the study area. In this process, the model was used as a secondary variable, while porosity data of wells was used as a primary variable. In addition, a distribution of fractures in the secondary porosity model was also governed by geo-tectonic parameters such as dip, azimuth, major and minor values of fault systems or fractured zones [5].

Co-Kriging is a method that is used for simulation of oil-field by interpolating algorithms, which based on the analysis of error changes with distances. Co-Kriging solution is used to integrate the primary variable with secondary variables by calculating correlation coefficients and the experimental variogram statistics function. Figs.14 and 15 present a very good correlation between well fracture porosity (red curves) and the fracture porosity model of the Hai Su Den basement, which was built by integrating ANN and Co-Kriging techniques.

In order to assess the reliability of the porosity model, a series of correlations were carried out. The distribution and the relationship between well fracture porosity and porosity received from ANN and Co-Kriging show a very high degree of correlation (Fig.16).

5. Conclusions

The quality of Hai Su Den 3D 2009 Beam PSDM seismic data is good for the basement; as a result many seismic attributes could have positive results in qualitative and quantitative analysis for identification and outlining of good fracture zones inside the basement and for characterisation of the fracture systems.

The seismic attribute set which can optimise fracture porosity has been selected, consisting of the three following attributes: *Reflection Intensity, Gradient Magnitude, Sweetness*.

In the case of good seismic data as in the Hai Su Den field, integration of ANN and Co-Kriging techniques was proved as a good method to build fracture porosity model for the fractured basement reservoir.

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