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Combining low frequency spectral decomposition and post-stack seismic inversion to identify Middle Miocene gas bearing sands at Hai Thach field

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Summary

Located in the Nam Con Son basin, offshore Vietnam, Middle Miocene gas bearing turbidite sands at Hai Thach field are very difficult to identify on conventional seismic data due to their complex architectures and geometries [1]. The purpose of this study is mapping this reservoir in terms of its geometry and distribution by applying an integration of rock physics analysis, seismic attributes and post-stack seismic inversion. In the study areas, the P-impedance of sand is the same values with shale and the presence of gas in sand causes a decrease of acoustic impedance, which can be used to differentiate gas saturated sandstone from water saturated sandstone and shale. Seismic attributes applied based on the rock physics analysis result can also be used to define gas sand distributions. Low-frequency amplitude anomalies from 17 - 19Hz, obtained from spectral decomposition, have a high gas content where penetrated by wells, whereas low gas saturation zones in the wells do not correlate with the observed high amplitudes. Moreover, the gas sand distribution was successfully identified in the extracted P-impedance slice along horizon from an inverted P-impedance volume. Thus, the combination of low frequency spectral decomposition and seismic inversion may be used to successfully map gas distribution. Proposed workflow for mapping sand and gas sand can be used for future drilling programmes.

Key words: Gas sand, P-impedance, post-stack seismic inversion, low frequency spectral decomposition.

1. Introduction

Hai Thach field is located in Blocks 05-2 and 05-3, Nam Con Son basin, offshore Vietnam (Figure 1). The major types of reservoirs identified in the Nam Con Son basin are pre-Cenozoic weathered fractured basement, Oligocene and Miocene clastics, and Miocene carbonates [2]. This paper focuses on the Middle Miocene turbidite sandstones which are complicated due to their complex architecture and geometry. The HT-3P and HT-2X wells at Hai Thach field encountered reservoir with vertical thickness of 45m and 32m, respectively. Results from core description indicate that those intervals are turbidites deposited in deep water with mainly clean sandstone and minor interbedded siltstone and mud stone. Intense post depositional faulting further complicated the reservoir distribution. Since using conventional seismic data to predict reservoir distribution is not reliable enough, a combination of spectral decomposition and post-stack seismic inversion was utilised to investigate this reservoir in term of lithology and hydrocarbon distribution.

2. Methodologies

- Rock physics analysis

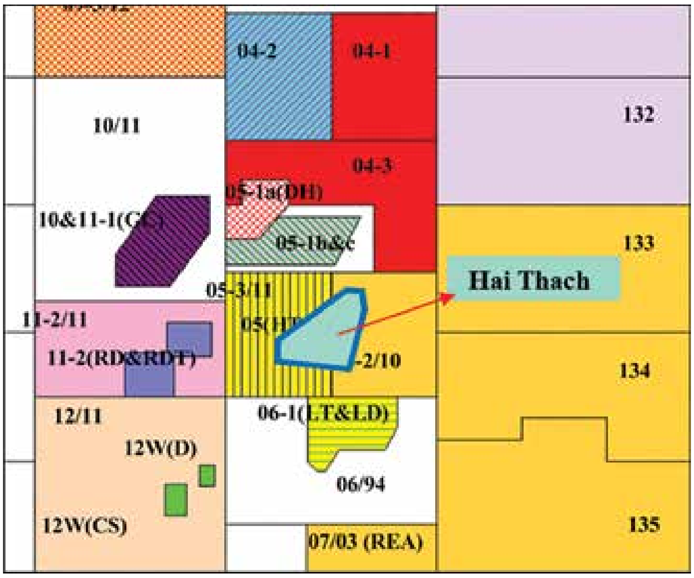

***Figure 1.** Location of the study area in offshore Vietnam.*

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Rock physics analysis aims to determine the rock properties based on logging curves. From these properties, gas bearing and water bearing sands, and bounding shale can be discriminated. Cross plots of acoustic impedance (product of density and compressional velocity) versus gamma ray (GR), clay volume (VCL) and water saturation (SW) are useful technique to differentiate in terms of lithology and fluids [3, 4].

- Spectral decomposition

Spectral decomposition is a mathematical tool for transforming seismic data from the time domain to frequency domain. In the low-frequency range, the abnormal amplitude associated with the presence of hydrocarbon, validated by well data, provides useful information for reservoir characterisation [5].

- Seismic post-stack inversion

Seismic inversion is a technique that has been used to transform seismic data into acoustic impedance, which is useful for predicting lithology and fluid distribution [6].

3. Results and interpretations

3.1. Rock physics analysis

The rock physics was analysed at wells

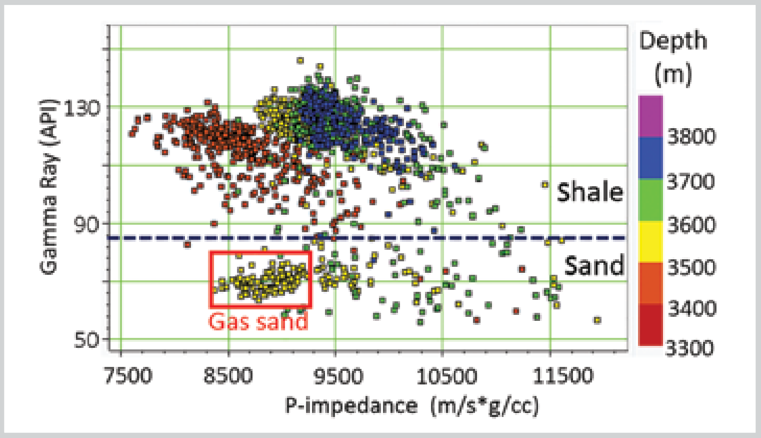


Figure 2. *Cross plot of P-impedance and GR coloured by depth for well HT-3P showing the acoustic impedance overlapping when analysed in large depth intervals.*

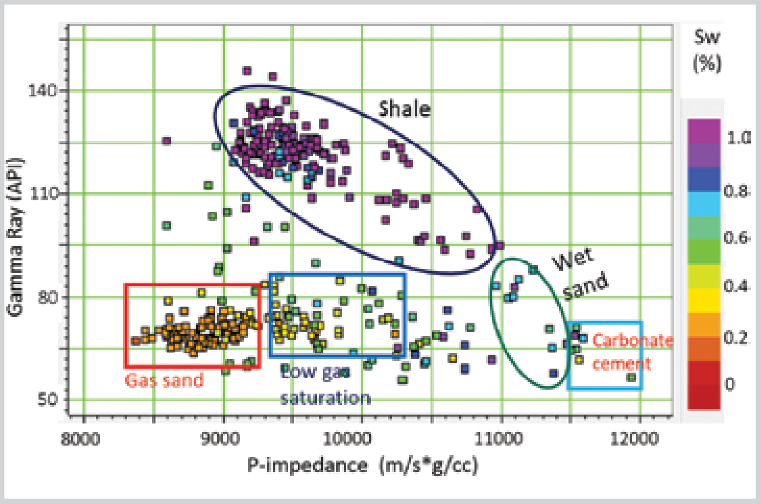


Figure 3. *Cross plot of P-impedance and GR coloured by water saturation from a narrower depth interval of 3,550 - 3,650m in well HT-3P.*

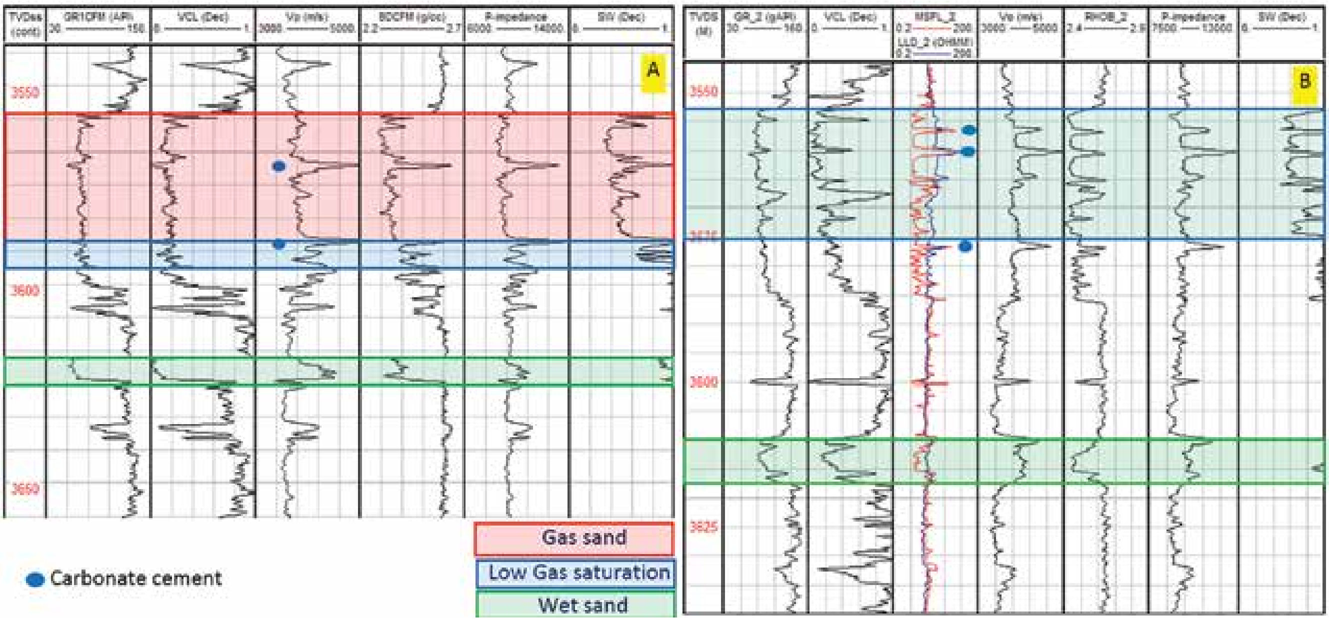


Figure 4. *Well log data comprising gamma ray (GR), clay volume (VCL), P-wave (Vp), density, computed acoustic impedance and water saturation for depth interval 3,550 - 3,650m at well HT-3P (a) and well HT-2X (b).*

HT-2X and HT-3P. The gas sand has been defined by using a clay volume; water saturation cut-off is about 40% and 60% respectively. The cross plot of the GR and P-impedance (computed from density and P-wave logs) from the zone of interest (3,300 - 3,800m) shows that the P-impedance of gas sand cannot be separated with shale in terms of 500 thickness of sediment (Figure 2). In another test analysis of narrower interval which consists of reservoirs from 3,550 - 3,650m, a clear difference of P-impedance can be observed among gas sands, wet sands and shale (Figure 3). This shows that the presence of gas caused reduction of P-impedance in sand reservoir;

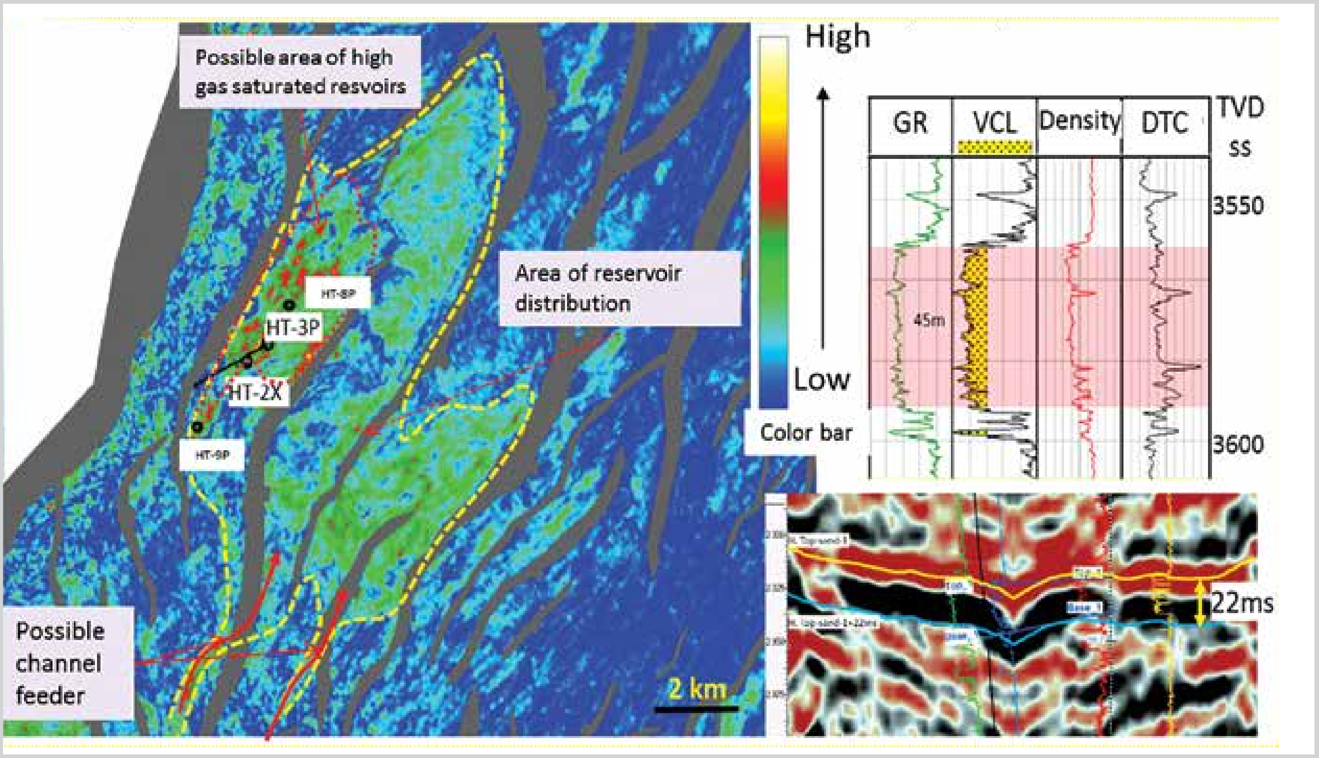


Figure 5. *The RMS amplitude map of Horizon top-sand. The well logs show the RMS window range (red zone) covered in well HT-3P and the seismic section along well bores.*

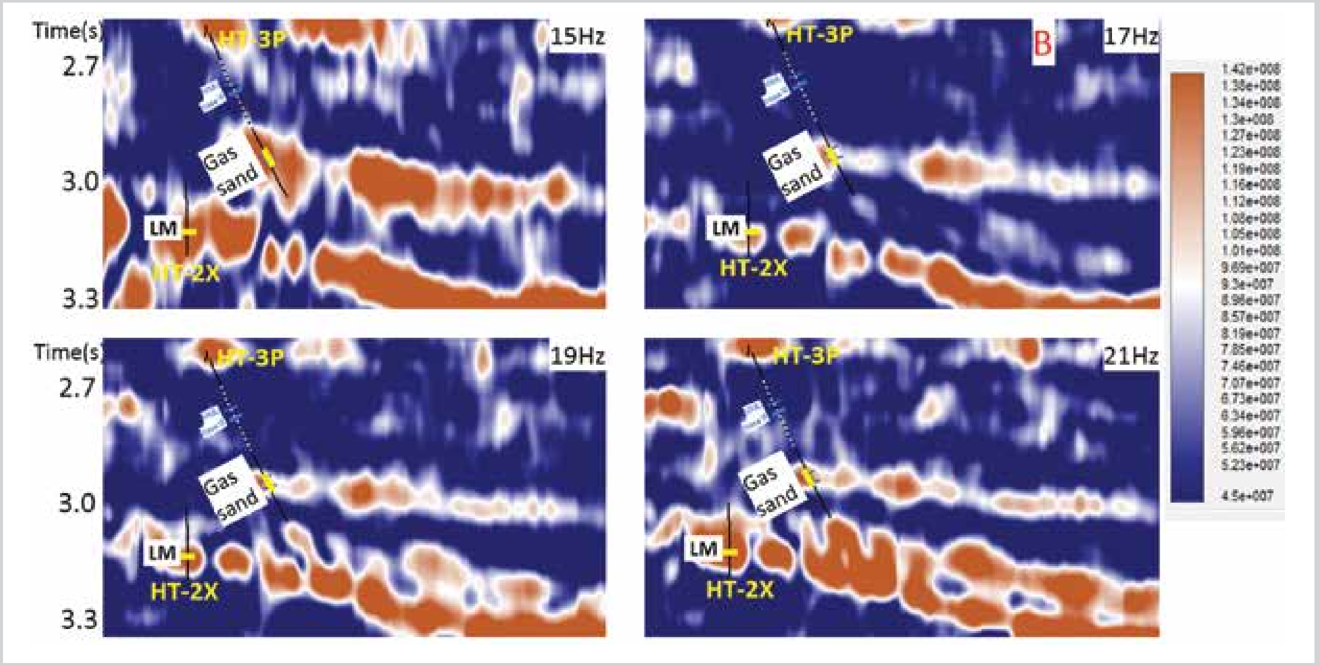


Figure 6. *Spectral decomposition section with different frequency range.*

therefore, using P-impedance in this interval is useful to determine high saturated gas sand [3].

A petrographic report for well HT-2X proved the existence of carbonate cement in core plugs at depths of 2,598m, 3,593m, and 3,605m, which is characterised by low GR, high density and high Vp (velocity) and density (Figure 4).

3.2. Sand body prediction

Delineating sand body distribution is the first step to investigate this reservoir. An extraction of amplitude from conventional seismic data was applied using RMS (root mean square calculation). The RMS amplitude attribute covers a 22ms window determined from interpreted top of the sand predicted by tracking high amplitude events. This window is estimated good enough to ensure it can cover all of the turbidite sandstone bodies, the thickest of which was penetrated at HT-3P with a thickness of about 45m (Figure 5). The results of amplitude extraction maps show the predicted distribution of sand body (yellow polygon). Sediment supply from SW-NE, and the extension of sand body to the west and east sides is possibly controlled by syndepostional faults.

3.3. Spectral decomposition

For further investigation of the reservoir in terms of its bearing gas capability, low frequency spectral decomposition attributes have been applied to observe the gas response within reservoir [5, 7]. By screening frequency amplitude to seek the best match with existing gas at wells (Figure 6), it is shown that the most suitable frequency is estimated at around 17 - 19Hz. Hence, high amplitude extraction from 17 - 19Hz spectral decomposition can be useful for identification of gas areas. An extraction amplitude map derived from 19Hz spectral cube shown in Figure 7 shows a high gas saturated in HT-3P, and low gas saturated in HT-2X amplitude response.

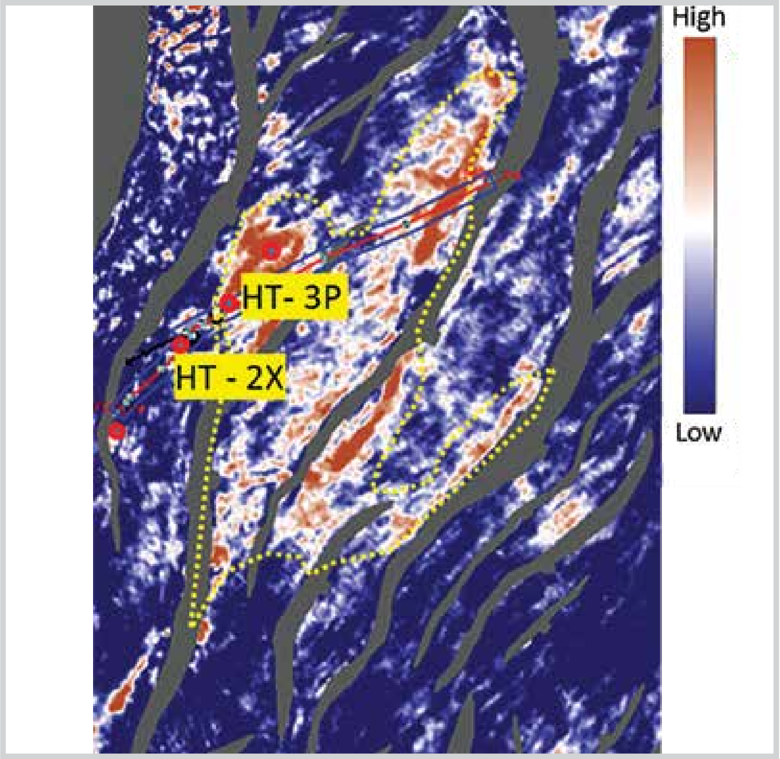
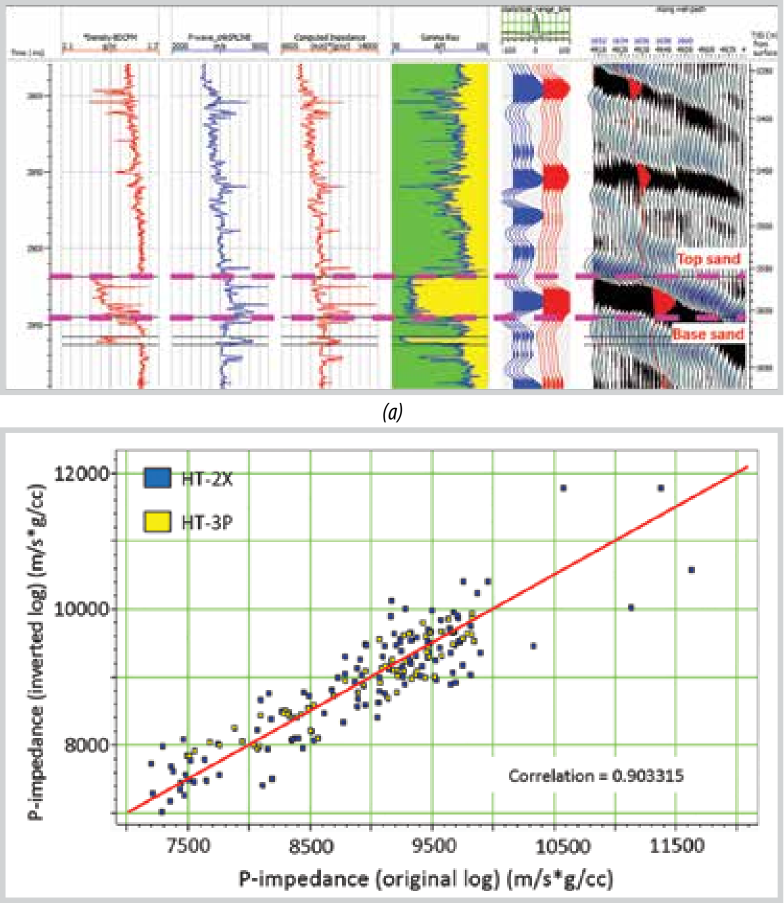


Figure 7. *RMS amplitude extraction of 19Hz spectral decomposition cube at the top of sandstone.*



(a)

(b)

Figure 8. *Synthetic seismogram for well HT-3P(a). The linear relationship showing a good correlation in P-impedance of original logs and inverted results at two well locations (b).*

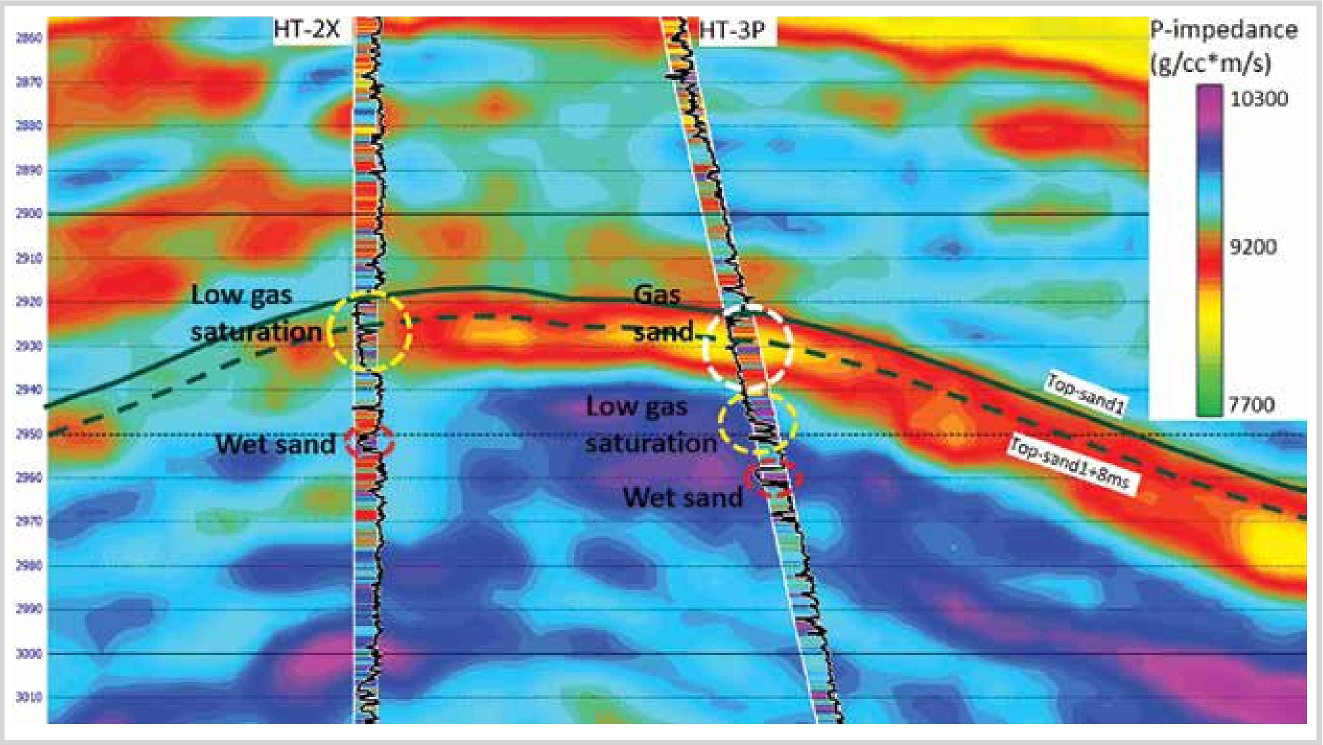


Figure 9. *P-impedance generated using model-based inversion at well HT-3P and well HT-2X. The log curve displayed in cross-section is the GR.*

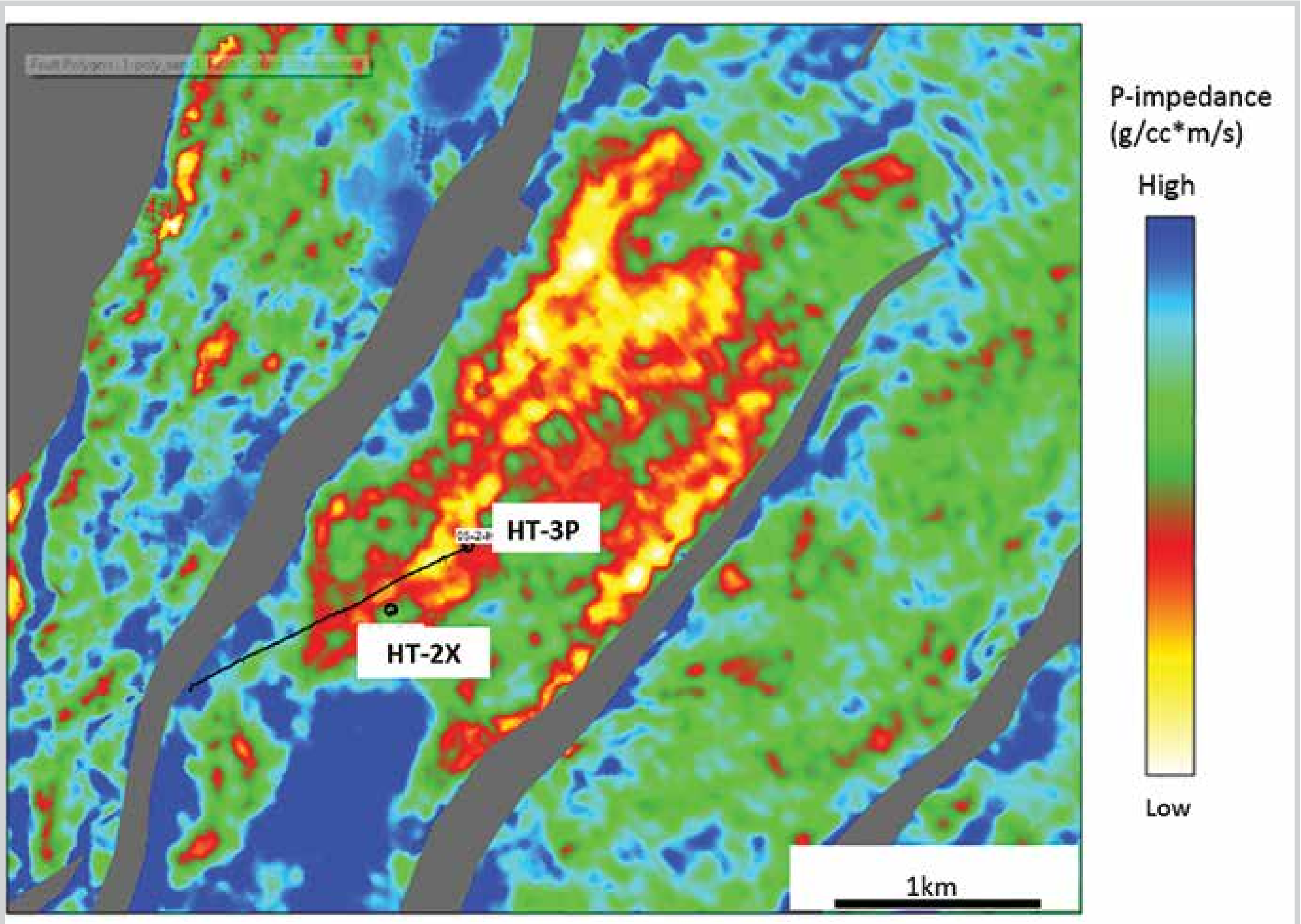


Figure 10. *Horizon slice of inverted P-impedance volume extracted at phantom horizon top-sand 1 + 8ms. Low P-impedance only represents at high gas saturation well HT-3P.*

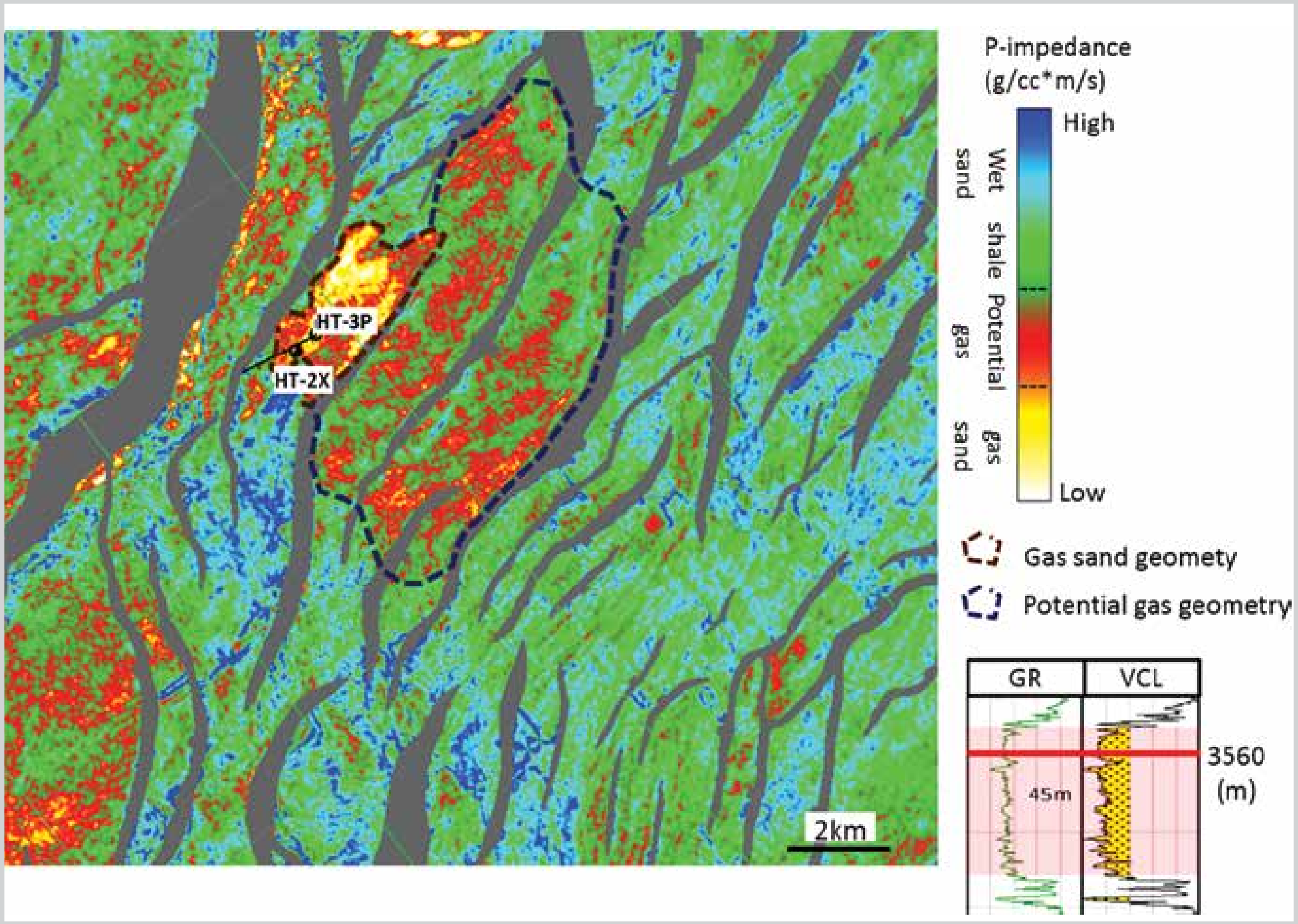


Figure 11. Horizon slice of inverted P-impedance volume extracted at phantom horizon top-sand 1 + 8ms. Low P-impedance indicates gas sand.

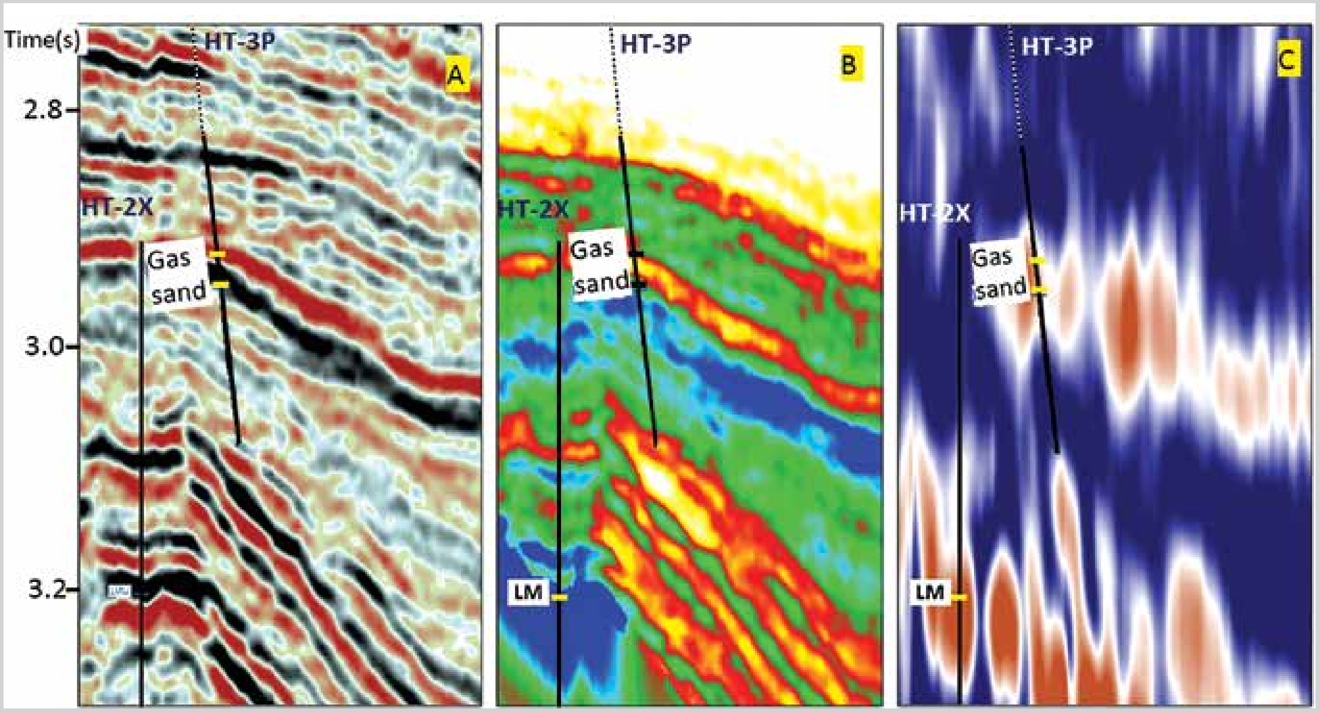


Figure 12. Comparison of full stack seismic data (a) with inverted acoustic impedance section (b) and low frequency (19Hz) spectral decomposition. (c) The gas sand interval was defined at well HT-3P.

3.4. Seismic post-stack inversion

Synthetic seismogram was generated to link the well data and seismic data (Figure 8a). The decrease of acoustic impedance computed on well from sonic and density at the top of reservoir sand corresponds to trough on seismic section. Based on the results of post-stack inversion analysis, it is shown that inverted P-impedance and the well-log calculated P-impedance have a good correlation coefficient, more than 90% (Figure 8b) within the zone of interest from horizon Middle Miocene to horizon Lower Miocene, which covers the reservoir sand interval. Thus, the inverted P-impedance can be reliable for gas sand distribution prediction [8, 9].

At well HT-3P, the lower part of the reservoir (2,920 - 2,930ms) shows a high P-impedance; this interval has low gas saturation as defined from the wells (Figure 9). However, the thickness of wet sand body of two wells (from 2,950 - 2,960ms approximately 8m in thickness) is too thin for inverted P-impedance to work, thus it cannot be recognised on inverted cube due to the resolution of original seismic. Therefore, the inverted P-impedance cube is possibly helpful with sufficient reservoir thickness.

To predict gas sand distribution, extracted P-impedance along horizon with 8ms shifted down top-sand 1 was applied (Figure 9). This extracted low P-impedance surface from inversion volume can provide the possible lateral distribution of gas sands. The low value of the inverted P-impedance along this horizon represents the gas sand distribution of well HT-3P, whereas the low gas saturation well HT-2X location shows high P-impedance (Figure 10). The predicted gas-saturated area is bounded by fault blocks and distributed around the drilled wells (Figure 11).

3.5. Combination of RMS, spectral decomposition low frequency attributes and seismic post stack inversion.

RMS amplitude attribute may be useful as a quick tool to observe the distribution of sands in the area. RMS map shows bright amplitudes for sands. However, RMS computation depends on a window length that may not be appropriate for the variable thickness of sands or sand/shale interbedded layers.

Starting from the preliminary distribution of sand defined by RMS attribute in the study area, a spectral decomposition (limited to frequency of 19Hz) and a seismic post-stack inversion were applied to further detect gas sand distribution. The position of highly saturated gas sand may be differentiated from low saturated gas sand by observing the high amplitude indication on the low frequency spectral decomposition section. In fact, a high amplitude from the 19Hz spectral decomposition can be observed at the location of well HT-3P, which has high gas saturated sands and similarly, a low amplitude at the location of well HT-2X which has low gas saturation.

Furthermore, in order to investigate the gas sand body, the method of seismic post-stack inversion can provide additional information which does not show up on the low frequency spectral decomposition volume. From the post-stack inversion results, the boundary between higher and lower P-impedance in the inverted volume matched with the formation top and base of gas sand layer at well HT-3P. Thus, the thickness of gas sand layer may be predicted by the thickness of low P-impedance layer observed in inverted section.

Thus, the combination of RMS, spectral decomposition low frequency attributes and seismic post-stack inversion for gas sand prediction can reduce the uncertainty and provide valuable additions to reservoir characterisation in Hai Thach area. Lastly, further information about geology, lithology and drilling is beneficial to make the best possible prediction on gas sand quality and distribution.

4. Conclusions

At Hai Thach field, sands have the same acoustic impedance with interbedded shale. The presence of gas is the main cause for the reduction of the acoustic impedance of sand within the depth interval of 3,500 - 3,600m. Therefore, using inverted volume is effective for gas sand identification.

The RMS attribute is useful to predict sand distribution. High gas saturation zones were delineated by amplitude anomalies of spectral decomposition low-frequency from 17 - 19Hz.

Acoustic impedance extracted from inverted volumes can predict gas sand distribution. The acoustic impedance section can be used for defining the boundary of the gas sand zones effectively.

The combination of acoustic impedance and low-frequency amplitude analysis is critical for reservoir characterisation in Hai Thach area. However, the combination still has some uncertainty, especially within areas of low gas saturation sand and highly saturated thin gas sands.

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