Identifying shallow gas zones by using seismic attributes, offshore Vietnam

Anh Thi Van Ngo*

Department of Geology, Faculty of Science, Chulalongkorn University, Bangkok, 10330, Thailand
*Corresponding author email: vananhngo90@gmail.com

Abstract

The overall aim of this study is to predict shallow gas hazards by using a series of seismic attributes. Shallow gas zones are a major concern in offshore drilling because of their potential to quickly cause kicks or blowouts. Combining of seismic data analysis and well log analysis is applied to identify the location and distribution of shallow gas layers in the study area. The research provides an opportunity to observe seismic data before and after a large influx of gas due to a blowout well. The study is unique because data without gas effects can be compared to data affected by gas after a blow-out. The study area is located in Nam Con Son Basin, offshore Vietnam. Direct hydrocarbon indicators (DHI) are the measurements by which presence and absence of a hydrocarbon accumulation can be predicted. The changes of reflectors between 2D seismic data (pre-blowout well) and 3D seismic data (post-blowout well) are analyzed by using seismic attributes. The characteristics of shallow gas can be defined such as high amplitudes, push-down effects and low frequency shadows. This study also concentrated on shallow gas layers in terms of the best combination of seismic amplitude attributes and frequency attributes. A series of attributes were run by looking for the identification of shallow gas hazards from Pliocene to Recent in the whole study area.

Keywords: Nam Con Son Basin, shallow gas, blow-out well, seismic attributes.

1. Introduction

The study area is located in Nam Con Son Basin, offshore Vietnam. The majority of the basin is situated in a shallow water and is approximately 300km from the Vietnamese continent. The area is covered by vintage 2D seismic data acquired in 1989, 1993 and 3D survey broadband data over all fields that were acquired in 2014 (Figure 1). There are three wells that are used in this research.

Identifying shallow gas by using seismic attributes is important in petroleum exploration and production. The identification and avoidance of shallow gas is a principal objective in well planning and site survey procedures. Shallow gas is characterized by amplitude anomalies, push-down effects and low frequencies. There has been no detailed study on both evolution of sedimentation and shallow hazards during the post rifting phase in the study area. The study is unique because data without gas effects can be compared to data affected by gas after a blow-out. The research has been done by using seismic attributes to map potential shallow gas zones in shallow part of seismic data (0-1.5 second). This study focuses on the following objectives:

- To run seismic attributes on both 2D and 3D seismic data to show the changes of shallow gas effects near the blow-out well.
- To identify the best combination of attributes to uniquely define shallow gas zones.
- To define shallow gas zones in the entire study area of 1100 sq. km. using the optimum combination of attributes determined from the detailed attribute study at the blow-out well location.

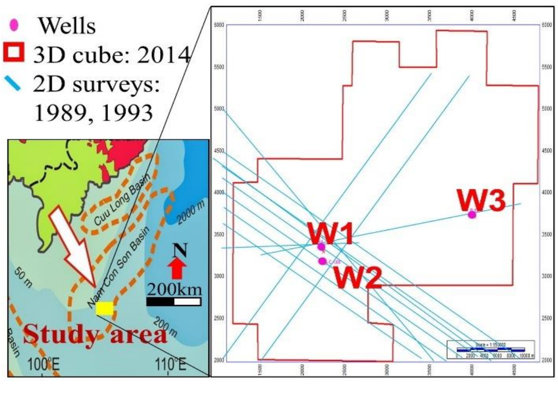

Figure 1: The database and location are shown in an image that involves eleven 2D lines, one 3D cube with 1100 sq. km. and three wells in NCS Basin, offshore Vietnam.

2. Methodology

The methodology involved analysis on both seismic data (2D seismic consisting of 1989, 1993 surveys, 3D post-stack seismic volume) and three exploration wells with checkshot data, final well reports, biostratigraphy reports and main log curves. No synthetics were generated in the study interval. The thesis focuses on shallow interval; hence, the analysis of shallow gas is mainly based on the seismic data.

2.1 Well log analysis

Gamma ray log was used to calculate V_{shale} using appropriate clean sand and clean shale baselines. Combining with results of final well reports and biostratigraphy reports, it can help to predict the depositional environments in the study area. The lithological characteristics were tied in more detail with the changes in seismic facies for each horizontal and seismic interval.

2.2 Seismic analysis

The essential next stages were to analyze seismic data: (1) based on well log analysis, characters of reflections, six key horizons are interpreted, (2) to run several seismic attributes including root mean square (RMS), sweetness, instantaneous frequency (IF), spectral decomposition (SD) attributes on both 2D and 3D seismic data which show the shallow gas effects near the blow-out well W1 and (3) using the most optimum combination of seismic attributes to uniquely define shallow gas layers, then a prediction of the location and distribution of shallow gas in the entire study area.

3. Background

3.1 Blow-out well

Well W1 was spudded by the semi-submersible drilling rig and reached a total depth of 1613m DDBRT on April 1993. After penetrating 4m of the Nam Con Son Formation carbonates, a gas kick occurred during drilling. Gas break out occurred at the sea floor 2 km away from the rig location and another gas break out at the well position. The blow-out resulted in gas with high pressure moving through weak sedimentary layers (Figure 2). After 12 days, the well was abandoned following gas break out at surface off the starboard side of the rig. Because of the blow-out, two craters with a 200m diameter are observed in the water bottom.

3.2 Shallow gas

Gas present in sediments down to 1000 m is referred to as shallow gas (Davis, 1992). Shallow gas in sedimentary basins can have biogenic and/or thermogenic origin. There are several factors for identifying shallow gas: (1) Shallow gas is a potential geohazard for drilling operations, (2) Shallow gas can be used in hydrocarbon exploration as an indicator that there is a working petroleum system present, (3) Shallow gas may be produced and (4) Shallow gas reduces the seismic velocity of the sediment significantly (Haavik & Landro, 2014).

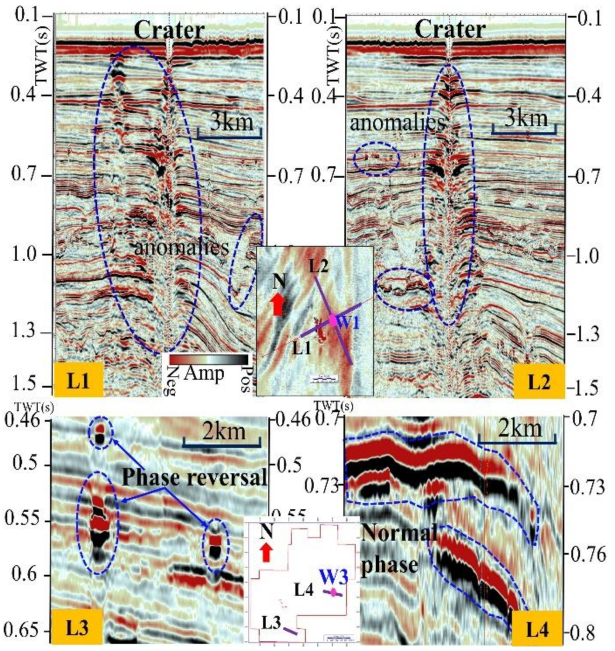

Figure 2: Seismic sections describe the blow-out well W1 and its effects on seismic data (arbitrary line L1 and L2). High amplitudes with phase anomalies are shown in the lower images (arbitrary line L3 and L4).

Shallow gas in the Quaternary sediments has been identified within seismic and also encountered in wells drilled in this area. The shallow gas can be recognized in seismic data based on several criteria: (1) acoustic turbidity: the smearing of reflector images caused by scattering energy; (2) high amplitude reflection:

the presence of gas results in anomalously high amplitude from the top of gas due to a negative change in acoustic impedance and (3) acoustic blanking: the area where the reflections are absent from the seismic image due to wave scattering and amplitude attenuation.

3.3 Seismic data

2D and 3D surveys have different acquisition and processing parameters, therefore, amplitudes have been balanced between 2D and 3D surveys in this thesis. The purpose of this feature is to make it easier to compare and interpret surveys when they differ significantly in amplitude. The bin-size in 3D data set is 12.5 m x 25 m and the temporal sampling is 2 ms while it is 4 ms in 2D seismic data. Hence, sampling was rescaled to 2 ms in 2D lines. The data sets are processed to zero phase wavelet and the dominant frequency is about 10-58 Hz.

Attributes include reflector amplitude, reflector phase, flat spots, ringing/ masking of underlying sediments, velocity sag and signal attenuation. DHIs are the measurements by which presence and absence of a hydrocarbon accumulation can be predicted. Seismic single attributes and multi-attributes are combined for the classification and identification of shallow gas zones in the study area.

- RMS attribute: shows hydrocarbon indications because it points out bright spots (high amplitudes), geomorphologic features and are also useful maps to enhance depositional environment.
- Sweetness attribute: is used to identify bright spots associated with thicker reflection spacing.
- IF attribute: is useful in indicating reservoir rock properties such as hydrocarbon, fracture zones detection, and change in thickness and lateral changes in lithology.
- SD attribute: identifies where the highest amplitudes are present at different frequencies and is useful for imaging of thin-bed sand layers.

3.4 Geobodies

A geobody is a distinct feature in seismic data that has geological or geophysical significance. Bright spots, channels, diapirs, and gas chimneys are commonly extracted as geobodies. Geobodies are mainly defined by strong amplitudes or by low frequencies and low impedance. Some features are better defined by two or more attributes than by a single attribute. In this case, geobody extraction is improved by employing multi-attributes. These geobodies show the location and distribution of shallow gas layers. The spatial distribution of color change is due to the change in the seismic response of different geobodies.

4. Results and interpretation

4.1 Well log interpretation

Well analysis was used to incorporate the lithology of each unit with the changes in seismic facies. The detailed biostratigraphy information collected from the well report was used in the general depositional environment interpretation. Histogram of GR curve shows the distribution of values for the selected well logs or for a selected individual property. Interpretation of sand to shale lithology is based on GR log. Normally, a simple way to separate lithofacies such as sandstone, siltstone and claystone layers was using shale volume. If $V_{shale} \leq 0.3$, lithofacies is sandstone and if $V_{shale} \geq 0.3$, they are siltstone and claystone layers (Figure 3).

To combine well information with seismic reflections, five main horizons are interpreted. Biostratigraphy reports are referred to confirm the interpretation. Nannofossils and foraminifera date the interval as Early Pliocene to early Late Pliocene. The top of horizon S3 is a sequence boundary at the base Pleistocene relative sea-level low stand. At the well W3, lithology, interpreted based on wireline log, is sand dominant with a small amount of interbedded shale. The depositional environment of this interval target is Late Pliocene deep marine clastics passing upward into Quaternary shelf clastics (VPI-labs, 1994).

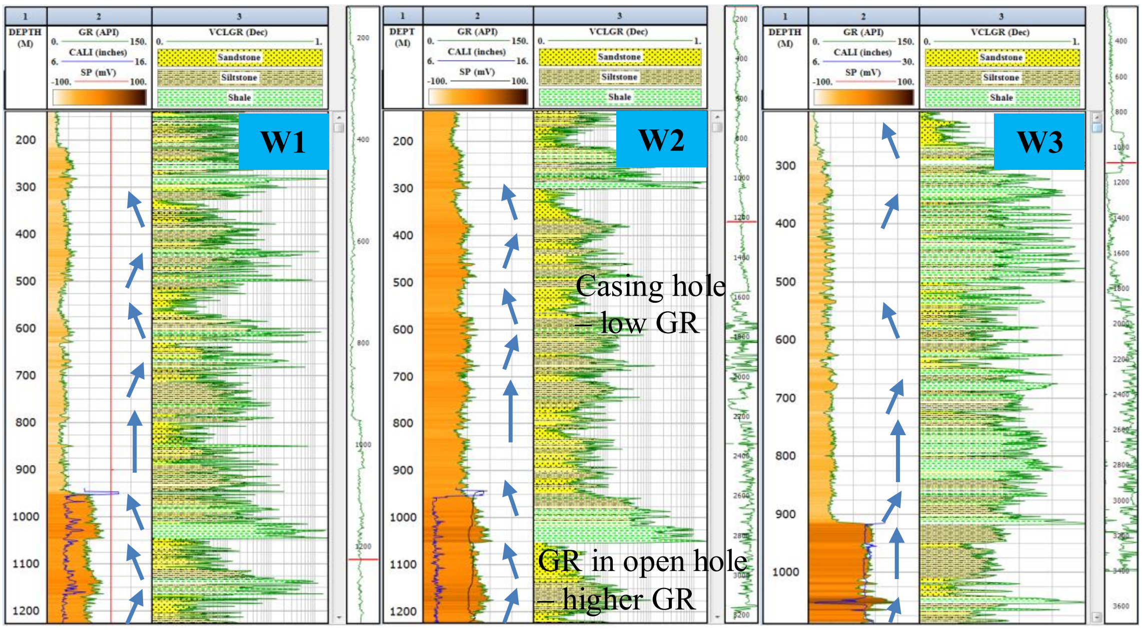

Figure 3: The calculation Vshale of three wells from Gamma ray curve show the proportion of sand to shale at each depth. The fining upward and coarsening upward changes within each interval are depending on the changes of depositional environment. GR is reduced due to logging through casing points.

4.2 Seismic interpretation

Stage 1: Horizon picking – mapping

Following the methodology mentioned above, the 2D and 3D seismic were interpreted to define the seismic facies. Based on the variation of features of seismic reflections and well log analysis, five intervals bounded by six horizons were identified. These horizons were named from S1 to S5 and Seabed horizons (Figure 4). The seismic facies units were identified and picked with a 50 by 50 grid. Because of the high quality seismic data within the shallow interest interval, these interpretations are enough to generate maps and analyze seismic attributes A total of ten normal faults are encountered in all intervals within the 3D area. The interpreted faults generally strike ENE-WSW and dip towards NNE and SSW.

Structure surfaces in depth domain were generated using a gridding algorithm in Kingdom suite 8.8 software. Three T-D charts are used to identify the velocity function in general (Figure 5). These maps are very important to identify and characterize the structure of each horizon (Figure 6), which is key to indicate potential locations of gas zones as well as predict geological features.

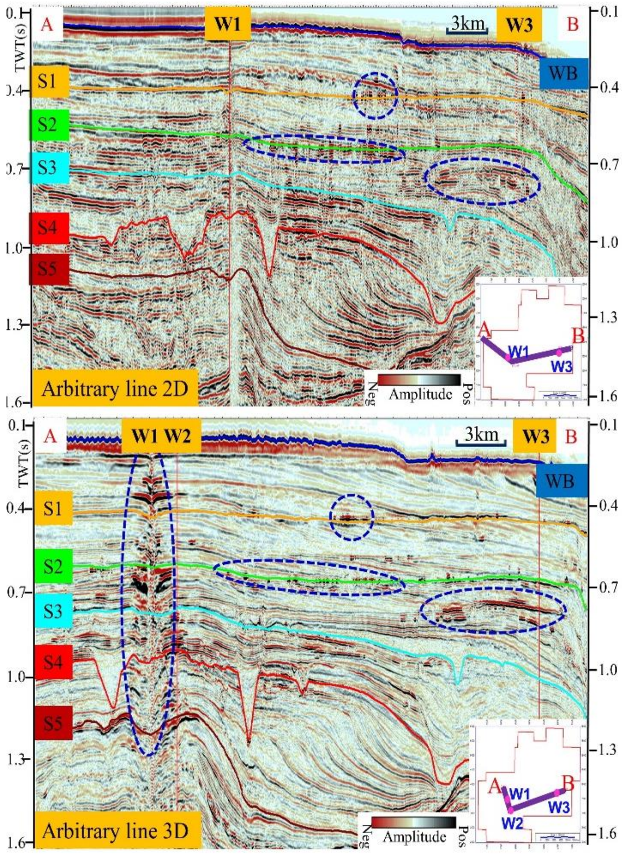

Figure 4: The correlation seismic through three wells by using arbitrary lines in the study area both in 2D and 3D data. Amplitude anomalies and reverse phases are illustrated in blue ovals that are associated with shallow gas layers. Some anomalies are due to the well blow-out and others are not relate to well blow-out.

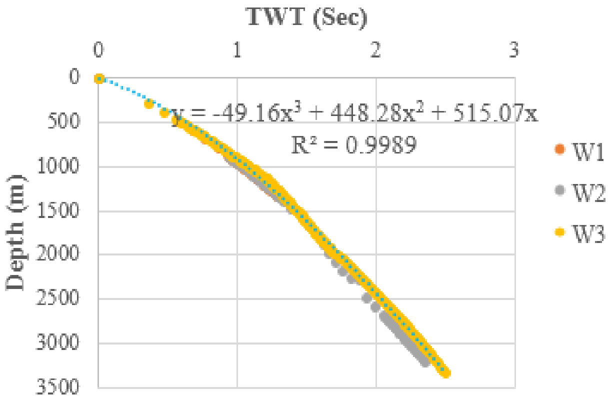

Figure 5: T-D curve is used to generate structure maps in depth domain

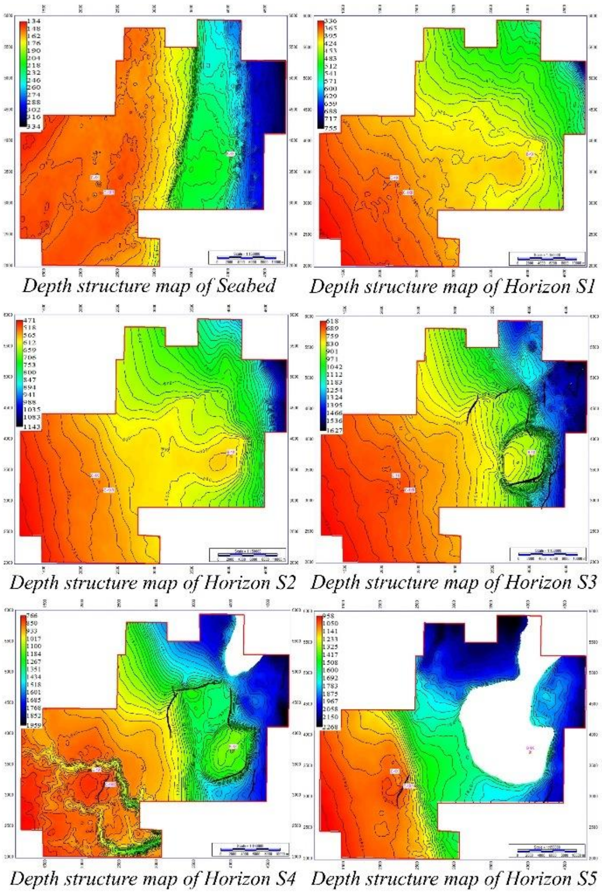

Figure 6: Depth structure maps with contours of six horizons are generated with the basinward trending from WSW to ENE of the study area. There are several normal faults with SW-NE direction and channel complex systems. The high structures (yellow to red color) are situated in the western of the study.

Stage 2: Seismic attributes analysis

a. The characteristics of the blow-out well

The history of the blow-out indicated that gas columns moved from the main reservoir formation to weaker formations at the south-southwest direction from the rig resulting in gas break out at the sea floor 2km from the rig. The characteristics of the blow-out well are reviewed in both seismic vertical section with seismic attributes.

Significant TWT push-down effects occurs from seabed to the top of Nam Con Son Formation which can be observed on the 3D seismic data in the vicinity of well W1. This effect and high amplitudes appear to be caused by the presence of gas in the shallow section and by the craters in the sea bed. Gas comes up with the sediments from below to emerge onto the sea floor resulting in the changes in dip of sediments at the water bottom. This can be seen in curvature dip direction and dip variance that were extracted from the sea bed horizon. Figure 7 shows the location of these gas columns which bring sediments from the lower formations to come up and be deposited as a ring around the sides of holes

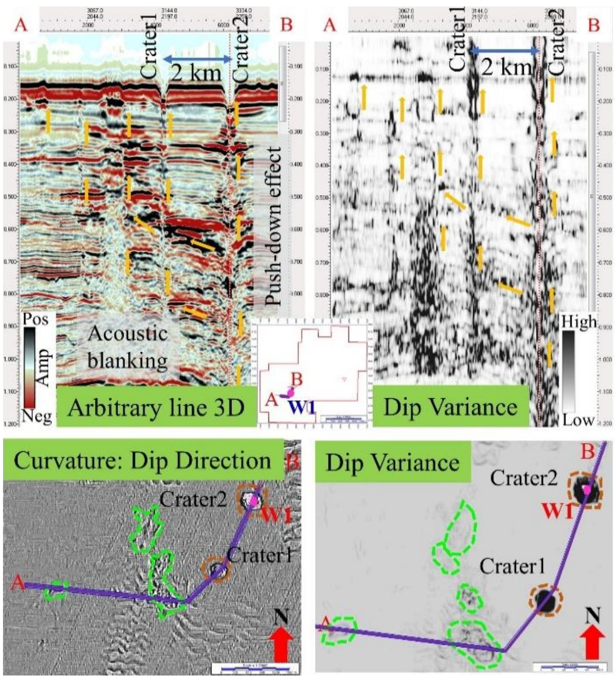

Figure 7: The seismic vertical section and attribute maps illustrate the position and the characteristics of the blowout well W1. Gas columns come up and through the weaker formations to break out at the sea floor (gold arrow) with sediments emerging out to sides of craters. The crater 1 occurred first at 2 km south - southeast of the rig, after that crater 2 appeared due to blowing out around the drive pipe and the formations collapse as the sea floor opens up.

b. The comparison of seismic attributes on 2D seismic data (pre-blowout) and 3D seismic data (post blowout) to show the changes of gas effects near the blow-out well W1.

There are some bright spots on 2D seismic sections that can be seen in both sweetness and RMS attributes (high values). Because 2D surveys were acquired before drilling the well W1, gas from the blowout well W1 does not affect the 2D seismic data. These characteristics show the appearance of natural gas in shallow part of the seismic volume. Although The 2D seismic attributes has limitations, the attributes analysis suggests that bright spots exist in the shallower part that might be a potential shallow gas reserve.

Gas anomalies can be seen clearly along the blowout well and in some shallow sand layers in the arbitrary line from 3D data. The appearance of anomalously strong amplitudes is explained as weak sand formations where gas from main reservoir came up based on the blowout well information (Figure 8). Seismic section on 3D arbitrary line shows the presence of gas from both blow-out well and natural gas. The high value of RMS amplitude commonly is related to high porosity lithologies, such as porous sands which are potential traps for gas accumulation.

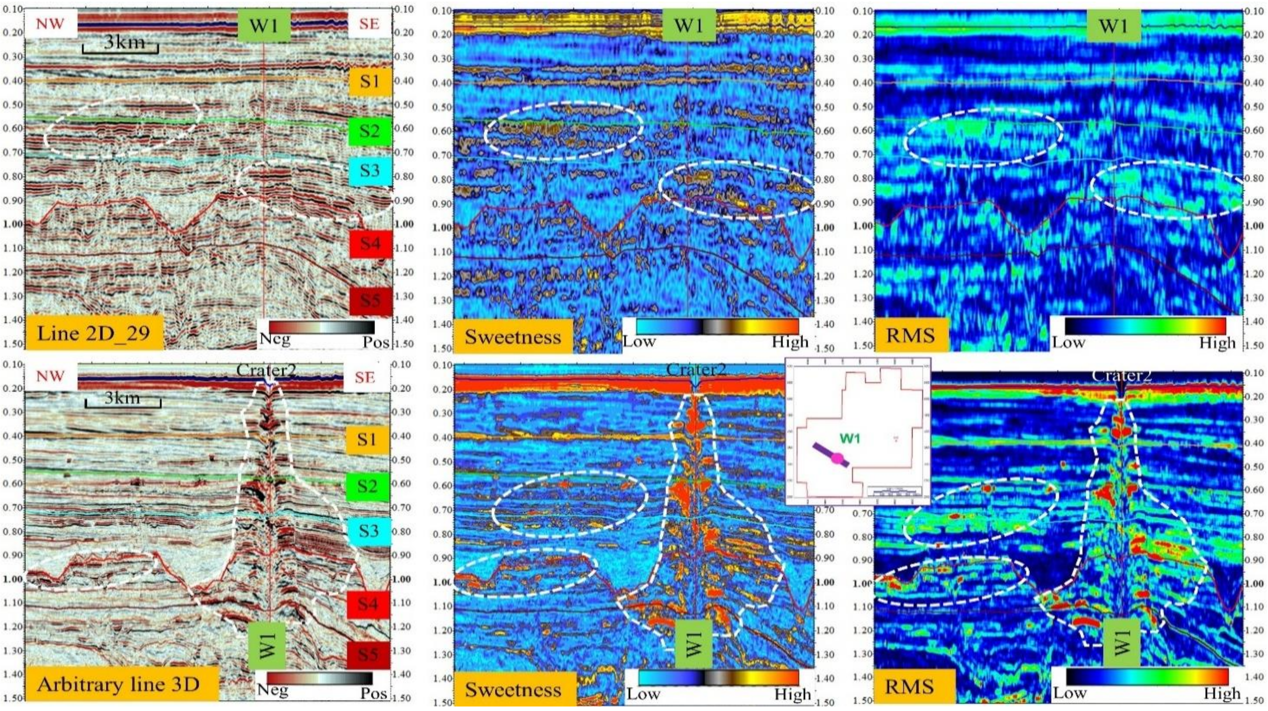

Figure 8: The seismic sections of line 2D_29, an arbitrary line on 3D cube and their attributes (RMS and sweetness). The white ovals show high values on both seismic attributes that correlated with the appearance of gas.

The instantaneous frequency can also be useful in mapping a gas accumulation. In seismic section in 3D data, gas accumulations cause attenuation of seismic wave and often exhibit low frequency anomalies below the accumulation where high frequencies have been attenuated (Taner, 2001). The shallow gas zones are distinguished by its low frequencies. In 2D seismic data, it is difficult to separate the location of natural gas layers with other lithologies. The range of dominant frequency of 2D seismic vertical section is 05-45 Hz while in 3D seismic data it is 05-75 Hz, as shown in Figure 9. In the shallow interval (100-250 ms), the reflections are flat and continuous. Lithologies are difficult to separate in seismic section because of the same low values of instantaneous frequency range.

Based on all of the characters above, shallow gas zones can be detected by bright spots, anomalously strong amplitudes, reverse phase and low frequency on seismic data.

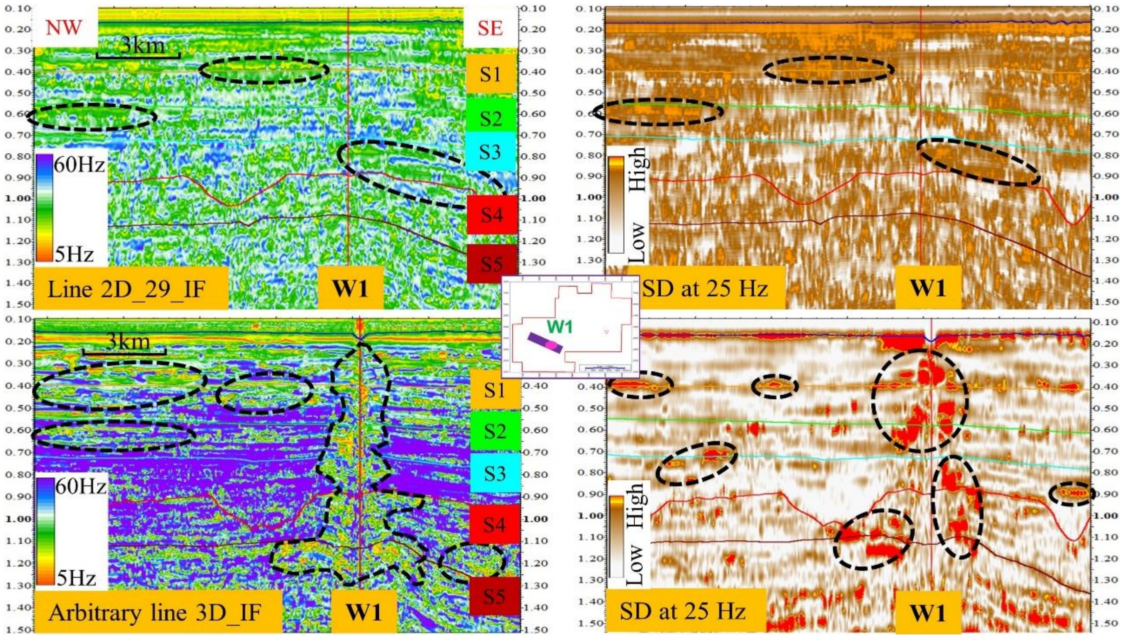

Figure 9: Instantaneous frequency and spectral decomposition are calculated on line 2D_29 and on 3D cube displayed on an arbitrary line coincident with the 2D line. In comparison, the right images at 25 Hz can separate gas. 2D seismic attributes has its limitation and lower resolution. The black ovals are associated with gas anomalies.

c. Multi-attributes

Seismic attributes also provide some qualitative information of the geometry and the physical parameter of the subsurface. Single attributes do not add much insight beyond that taken from the original seismic data. An attribute combination can be a more reliable direct hydrocarbon indicator than either attribute alone.

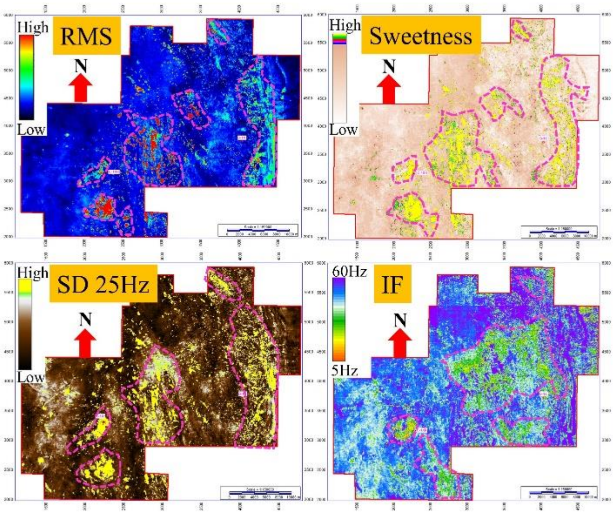

Figure 10: Amplitude and frequency attributes are generated to Horizon S2. There is a different distribution of anomalies at each attribute, hence, these attributes should be combined to identify the exact the location of shallow gas.

Another way to add more dimensions to display attributes is co-rendering by decreasing the opacity of one attribute and merging it on the other attribute. Instead of overlaying maps, we can improve the result by modulating the lightness of the amplitude image according to the frequency of the reflectors. The result is one image, instead of two. Multi-attribute analyses are beneficial when single attributes are indistinct or when the interpreters want to understand more about the geologic significance and improve seismic interpretations. The high values of RMS and low frequency of instantaneous frequency attributes are mixed to show the location of gas in Figure 11.

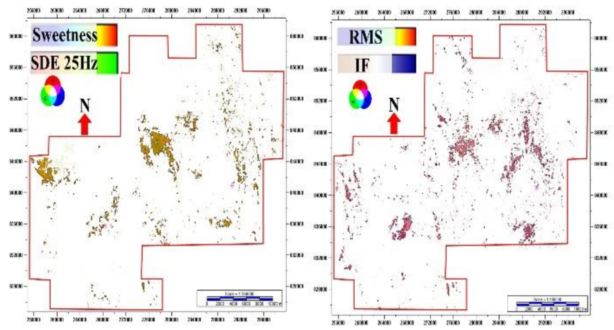

Figure 11: The combination of attributes is extracted to Horizon S2. This image illustrates the distribution of gas sand with characteristics such as high amplitudes and low frequencies.

Stage 3: The best combination of seismic attributes to define the location and distribution of shallow gas in the study area.

a. Shallow gas assessment

Shallow gas assessment was dependent on the number of seismic attributes observed and the magnitude or severity of these attributes. Not all amplitude anomalies are due to the presence of gas. Organic materials, localized lithological changes and tuning effects associated with closely spaced reflectors may create amplitude anomalies. Hence, amplitude anomalies and frequency are associated together as is used in the sweetness attribute. The following table presents the summary of the anomalous reflectors identified within the study area.

Anomaly Group	Interval in Depth in well W1	Characteristics	Probability of being gas related
1	0 – 330 m	High amplitude, phase reversal, gas spout on the sea floor	Moderate
2	330 – 545 m	High amplitude, phase reversal, push-down effect, significant frequency loss of the underlying reflectors	Moderate
3	545 – 630 m	High amplitude, normal-reverse phase, push-down effect, associated with faults	High
4	630 – 790 m	High amplitude, normal reversal, push-down effect, significant frequency loss of the underlying reflectors	Low
5	790 – 1050 m	High amplitude, normal phase, associated with fault, masking of the underlying reflectors	Moderate

Table 1: Summary of anomalies within the study area.

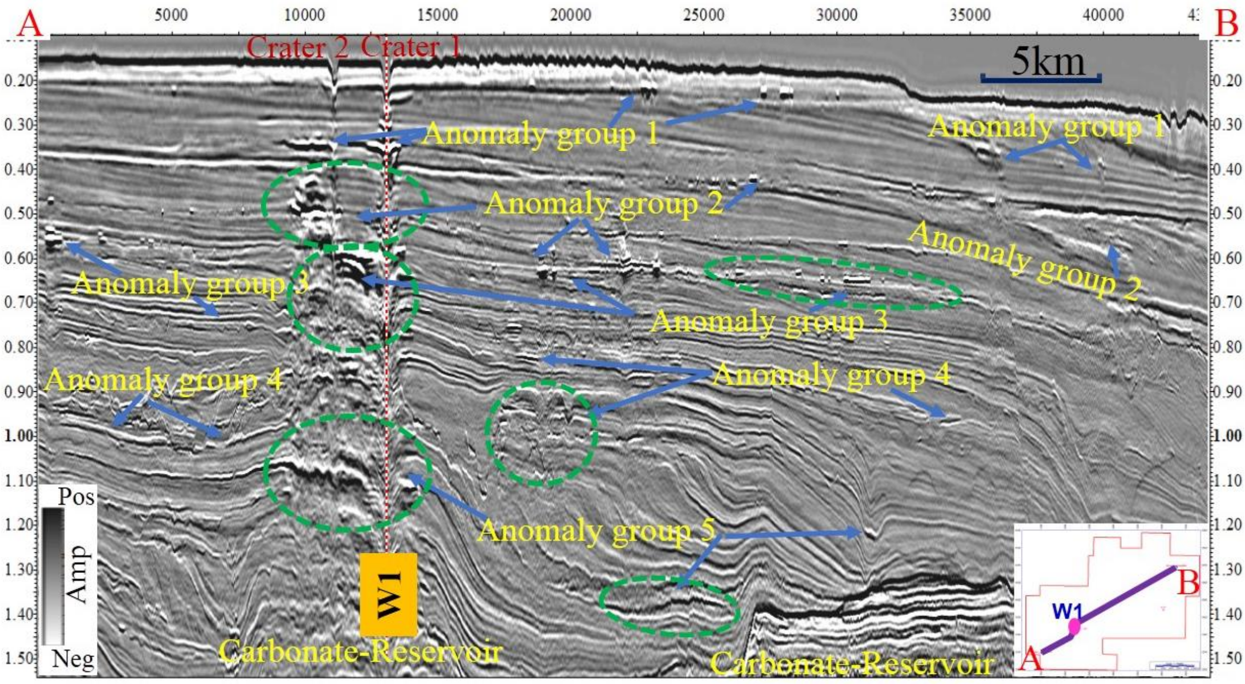

Figure 12: Seismic section illustrates several anomaly groups in the interval target, which are classified by the characteristics of seismic likely bright spots, changes in phases, blow-out well effect.

b. Geobodies

Geobody extraction is built in this study to understand about geological and shallow gas zones. Geobodies are almost always defined by strong amplitudes or by low frequency and low impedance. In this case, geobody extraction is improved by employing multi-attributes.

One way to accomplish this identifies the geobody as the intersection of the select attribute ranges. Alternatively, the geobody values are identified as an anomaly on a crossplot of two attributes. RMS and instantaneous attributes are combined to extract geobodies with the characteristics such as high amplitudes and low frequency. The high values of RMS attribute (yellow-red color) and low frequency of instantaneous frequency (blue color) are mixed to show the location of gas (pink color), which is shown in Figure 13.

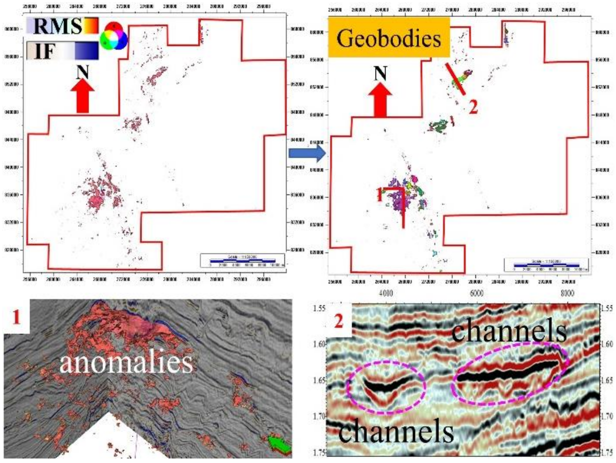

Figure 13: Geobodies are generated from the best combination of seismic attributes, which shows the position of shallow gas on Horizon S5. Arbitrary lines 1 and 2 illustrates the characters of seismic such as high amplitudes, frequency anomalies that are associated with the existence of gas. These geobodies are small and do not connect together except a geobody near well W1 and W2.

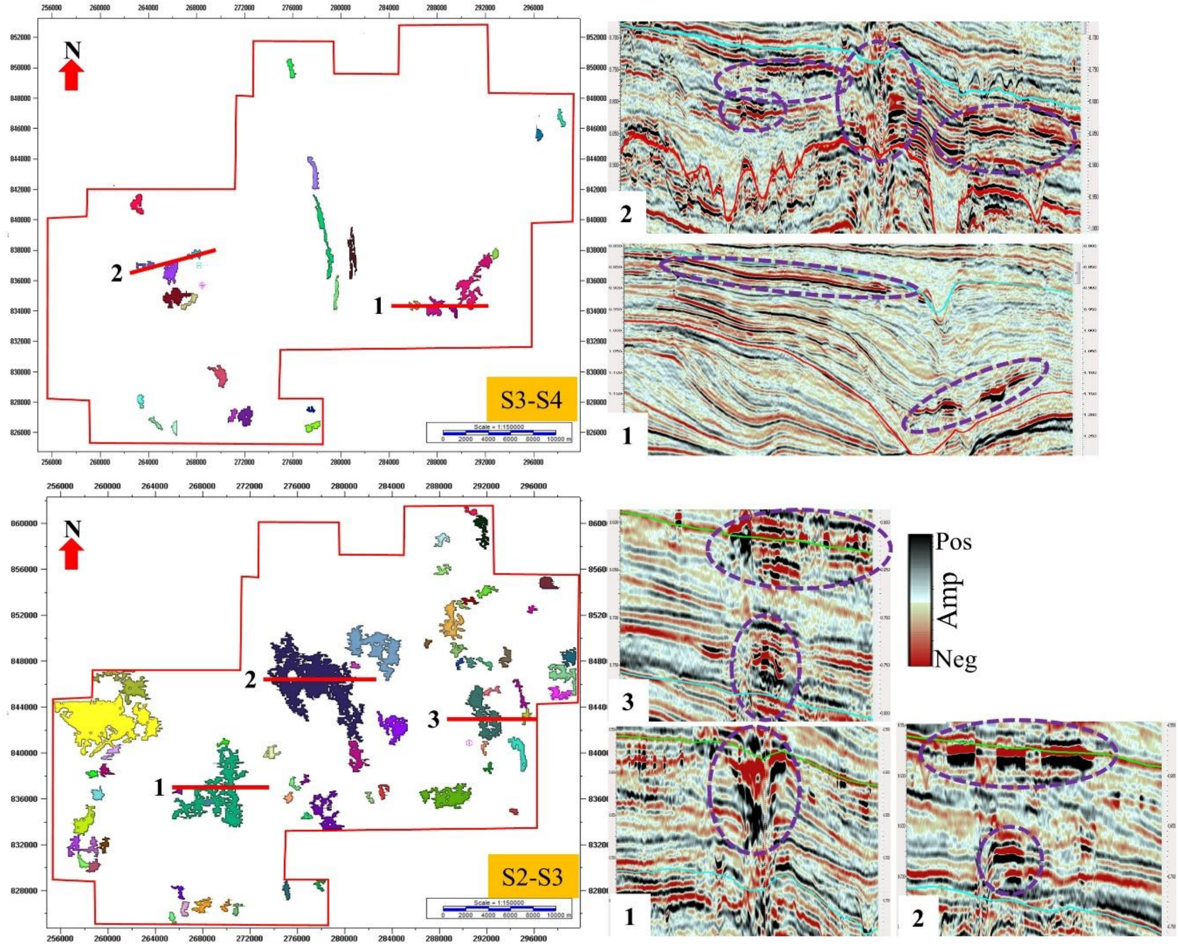

Figure 14: The examples of true amplitudes at vertical sections and geobodies that are extracted from two horizons interval. RMS and instantaneous frequency attributes are combined to extract geobodies. High amplitudes, push-down effects near blow-out well, phase reversal are interpreted as the presence of gas layers.

5. DISCUSSION

a. The characteristics of shallow gas

In 2D seismic data, shallow gas zones are difficult to see. There are some bright spots but the distribution is small. The reason might be acquisition and processing that do not highlight the gas sands. The 2D seismic attributes has limitations and all bright spots do not indicate gas accumulation. In the 3D seismic cube that was acquired in 2014, the amplitude anomalies, reverse phase, low frequency can be identified easily. Based on them, the shallow gas zones can be defined. The shallow gas represents potential hazard and information on their distribution is crucial when designing and constructing sea bed installations or during drilling for deeper hydrocarbons.

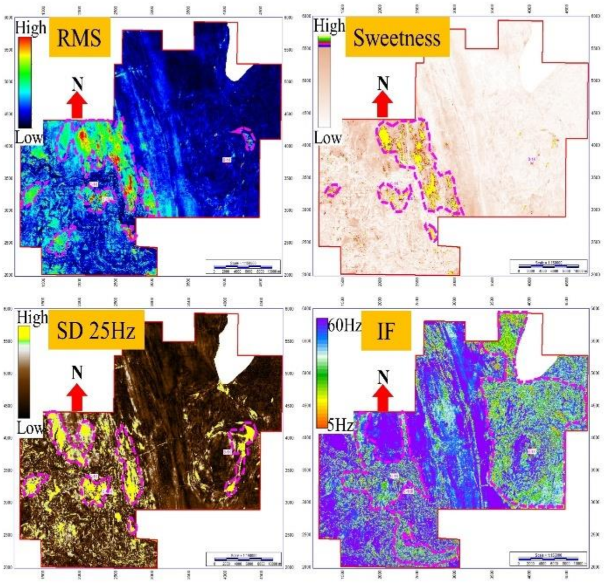

Figure 15: Seismic attributes are extracted to Horizon S4 in the whole study area. Channels are reported to be filled with low amplitudes and point bars are associated with high amplitudes (high value of RMS, sweetness attributes) and low frequencies (instantaneous frequency and spectral decomposition attributes). All of anomalies are shown in purple outlines.

b. Original of shallow gas.

There are both naturally occurring gas and gas from the blowout well present in the shallow gas layers. In the study interval (Pliocene to Recent) sediments represent a post rift succession and rifting has no influence on the sedimentation. These zones are major recipient of gas leakage from below and serve as an extra buffer against leakage to the surface. These faults are significant to the area in shallow parts which develop around the reservoir carbonate. There are some amplitude anomalies and reverse phase zones in individual formations (Figure 16) which are not affected by tectonic setting and are far away the blow-out well.

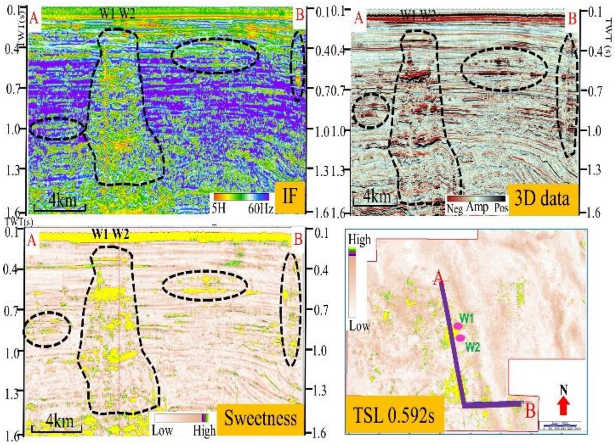

Figure 16: Gas come up by leaking from below-the top carbonate. The well W2 shows the presence of shallow gas zone in 1050-1135 MBRT with 1.21sg pressure in geological completion report. It confirms the gas leaking from carbonate formation to sandstone above or gas from the blowout well moved to shallow sand formations. In time slice 0.592 second, the anomalies are displayed by high value with green and yellow color.

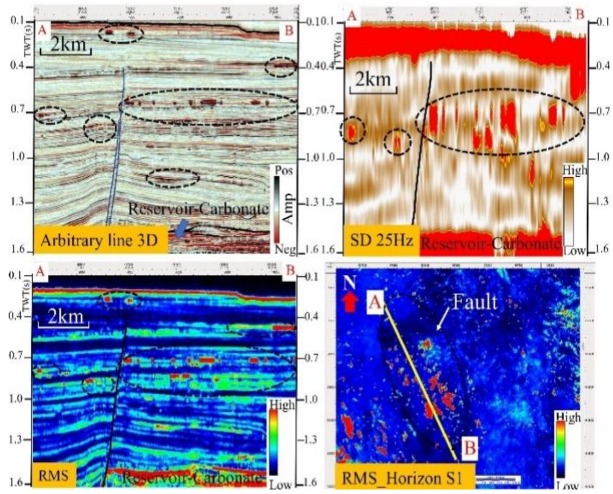

Figure 17: Gas come up by leaking from below top carbonate - reservoir and natural gas. The presence of gas is characterized by high amplitudes and phase reversal in seismic section. The faults likely are good pathways for gas which migrates from main reservoir to shallow areas. High values of RMS and spectral decomposition attributes are associated with gas zones.

c. The best combination of seismic attributes to identify the location and distribution of shallow gas zones in whole study area.

Different attributes were effective within different levels of the study interval. For general amplitude mapping, applying RMS amplitude successfully resolved sand body geometries. The sweetness attribute was used to identify bright spots associated with thicker reflection spacing. A thick gas sand usually causes a strong reflection, so true low-frequency shadows could be expected beneath a bright spot and can be identified by applying instantaneous frequency or spectral decomposition attributes.

The attributes mixture is a more reliable direct hydrocarbon indicator than either attribute alone. Therefore, the image quality can be further improved. Using a blending of seismic attributes, depth structural map and vertical sections, several observations can be explained. The shallow gas can be recognized in seismic data based on several criteria such as: push-down effect that demonstrated the delay in travel time throughout the slower zone, high amplitude with negative phase reflection at the top of shallow gas layers and acoustic blanking from wave scattering and amplitude attenuation.

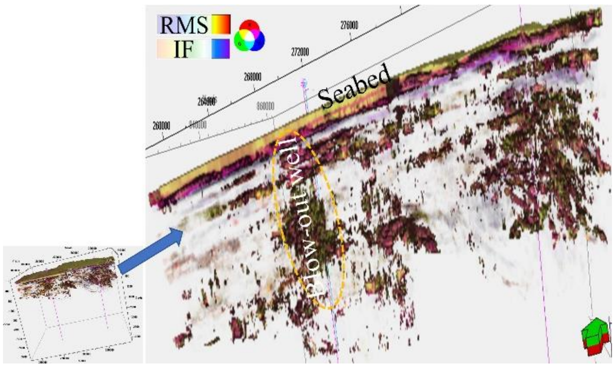

Figure 18: The best combination of attributes illustrates the presence of shallow gas zones. High values of RMS attribute are combined with low values of instantaneous frequency attribute are shown as the features of gas. The shallow gas in gold oval (near the blow-out well) makes sure that this mixture is a good choice for identifying shallow gas.

All geobodies in the entire study interval are generated which is shown in Figure 19. The location and geometry of shallow gas zones can be defined relatively. These geobodies are associated with strong amplitudes, low frequencies and phase anomalies.

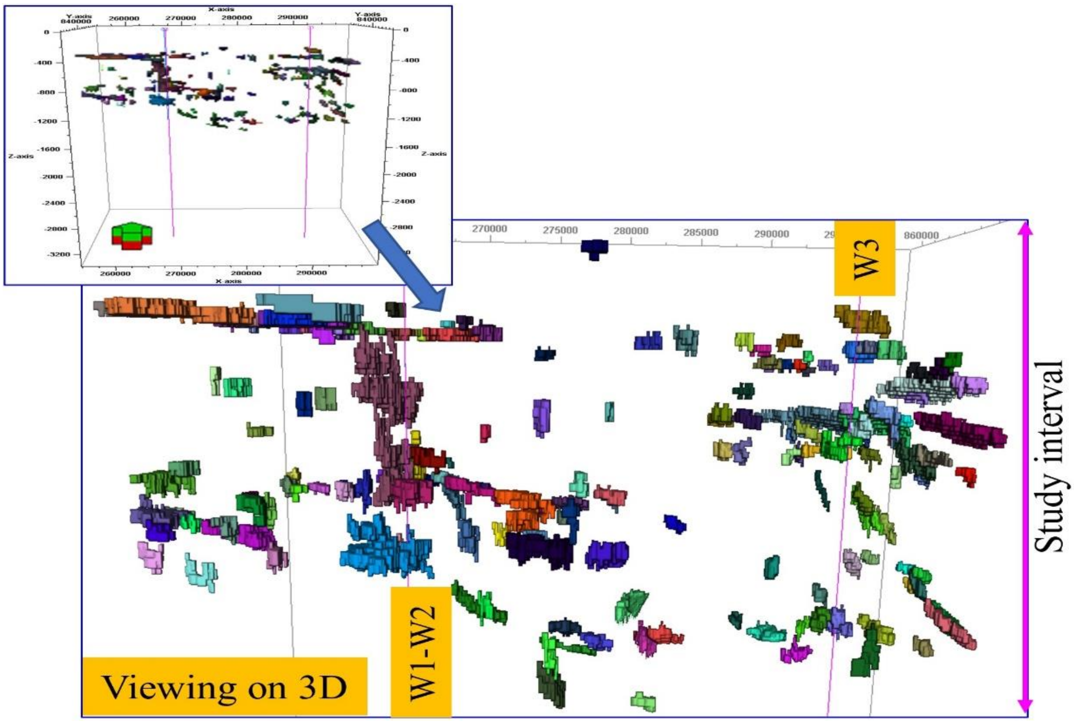

Figure 19: The most optimum combination of RMS and instantaneous frequency attributes illustrates the shallow gas zones which generated geobodies in the study interval (0-1.5 second). The distribution and location of gas bodies are displayed on 3D windows.

6. CONCLUSIONS

The main findings are summarized as:

- The study is unique because data on 2D seismic without gas effects can be compared to data on 3D seismic with known gas effects after a well blow-out. The features of gas zones could be detected such as amplitude anomalies, phase reversal and low frequency shadow.
- The characteristics of shallow gas layers are not clearly observed and distinguished either in seismic amplitude slices or in single seismic attributes. The position and division of shallow gas areas can be predicted by using a mixture of seismic attributes. Seismic amplitude attributes combine with seismic frequency attributes are useful and more confident than single attribute to identify the presence of shallow gas.
- Both naturally occurring gas and gas from the blowout well are presented in the shallow gas layers. Several normal faults are observed within the intermediate geological zones. These faults become good pathways for gas leaking from below section to trap into shallow sand layers.
- Finally, this identification of shallow gas zones should be a principal objective in well planning and site survey procedures. It could also be used to identify new unconventional gas reserves resource that can be explored and exploited. The results of this study will be an excellent reference for understanding about the characteristics of shallow gas layers by using seismic attributes.

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