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Geohazard investigation on gas cloud distribution at 'B' field (channel influence)

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Abstract: Sedimentary rock deposition occur in very fast rates in offshore basin and might cause shallow subsurface geohazards that will incur high risk and increase cost of drilling operations. In general, offshore geohazards consist of a variety of geological features that contribute potential risks to the labour force, offshore amenities including the environment and surrounding areas due to the consequences of long or short period of geological processes. Therefore, further study need to be done properly in terms of geohazards classification that is significant to the offshore oil and gas developments in the Malay Basin (Bujang Field, refer Figure 1); such as shallow gas, gas hydrate, shallow water flow, slumping, landslides, faulting, pockmarks and liquefaction. To mitigate the point of costly drilling and safety risks, several techniques are needed during data gathering to visualize, interpret and identify the potential shallow drilling hazards. Besides, to a geoscientist, data integration and modelling techniques can be used to analyse the structural and physical circumstances of shallow subsurface. At the same time, gas models and geohazards map can be established based on seabed hazard analysis from seismic data to plan secure wells. Several seismic attributes such as instantaneous phase, instantaneous frequency, remove bias and envelope (reflection strength) had been used for channel detection. For gas cloud identification, seismic attributes such as remove bias, instantaneous phase, Chaos and RMS (Root Mean Square) amplitude are used. Besides that, spectral decomposition technique are used to display channel systems and other stratigraphic features in the field. Generally, this paper will explain about the meaning of geohazards in the oil and gas industry, the types of geohazards, general geohazards analysis, and will focuss on the identification of gas cloud through channel structure by applying several seismic attributes on specific parameters. All of this will be related to geohazards perspective and consequently, precautions can be undertaken systematically.

Keywords: Geohazards, gas cloud, shallow gas, gas hydrate, shallow water flow

INTRODUCTION

For areas that are likely to experience offshore geohazards, this will pose high risks to the labor force, offshore amenity and the environment as well as the surrounding areas of the oil and gas facilities. As an advanced precaution, detailed study needs to be done in terms of gas cloud distribution which is significant to the seismic exploration.

Generally, a gas cloud is an overburden region of low-concentration gas, escaping and migrating upwards from a gas accumulation. It represents the area that have poor seismic data quality corresponding with low velocity and with velocity sags (push down) underneath the gas cloud overburden (Ghazali, 2011). Due to the above matter, this paper is focussed on identifying gas cloud through channel structure by applying several seismic attributes with specific parameters. Volume attributes such as seismic-instantaneous attributes, remove bias, envelope, chaos and RMS amplitude will be applied at particular horizons.

Based on a specified interest zone, a surface and thickness map will be produced to further analyze the pattern of gas cloud distribution. A geohazard map and gas model will be produced finally to prevent or reduce the impact of gas cloud geohazards.

DEFINITION OF GEOHAZARDS IN OIL AND GAS PROSPECT

A geohazard can be defined as a geological state that may lead to widespread damage or risks. Geohazards are geological and environmental conditions and involve long-term or short-term geological processes. It can be relatively small features, but can also attain huge dimensions and affect the local and regional socio-economy to a large extent (Wikipedia, 2019). From the oil and gas prospect, geohazards means a geological process that causes damage to the oil and gas industry, in terms of labor force, the amenity and the environment either onshore or offshore and it also involves a certain period that significantly affect the oil and gas

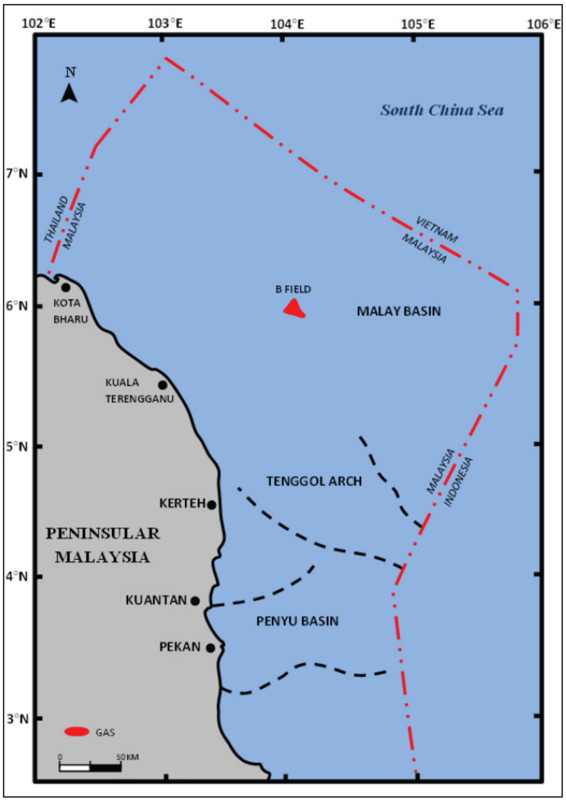

Figure 1: The location of 'B' field in Malay Basin offshore, Peninsular Malaysia.

production. For this paper, geohazards specifically refers to offshore geohazards which impact the oil and gas industry.

Kvalstad (2007) described geohazards from an offshore oil and gas perspective as a local and/or regional site and soil conditions having a potential of developing into failure events causing loss of life or damage to health, environment or field installations. There are many types of geohazards related to offshore oil and gas developments, such as mud diapirs and volcanoes, fault ruptures, shallow gas, seabed gas hydrates, debris flow run out, unstable slopes, landslides, pockmarks, liquefaction, turbidity current and rock outcrops and Methane-Derived Authigenic Carbonate (MDAC). The geohazards can occur in the form of a combination of the various types of geohazards and cause huge damage and complicated problems to be solved. Each geohazard type has a different solution to the problem, due to different period of occurrences in the geological processes. Other influencer such as the area of incident will also affect the geohazard due to the different condition of temperature and pressure that significantly contribute to geological processes.

CLASSIFICATION OF GEOHAZARDS IN OIL AND GAS INDUSTRY

Gas hydrates (bottom simulating reflector, BSR)

Gas hydrates becomes a common phenomenon in deeper waters and is expected to be present in half of the world's future gas reserves. Most of these reserves occur in the coast of the USA, Canada, Japan, Korea and India. These countries have taken an advance step by having national programs to further study geohazards occurrences.

Seismic detection of gas hydrate and/or free gas can be based on the presence of enhanced reflections (high amplitudes), BSRs and paleo-BSRS, or zones of reduced reflectance (Andreassen *et al.*, 1995; Ecker *et al.*, 1998; Holbrook *et al.*, 2002; Wood *et al.*, 2008; Hilman *et al.*, 2017). It was claimed that one unit of hydrate contains 170 units of free gas. From the mineralogy perspective, these hydrates are solidified gas and the lattice of the crystals is hydrogen molecules with methane as the compound component trapped. An excellent environment for hydrates to form is when the temperature is low and pressure is high, typically below 100 m of water in deeper waters. Hydrates can form a threat and becomes a potential drilling hazard. Sudden temperature increase due to circulating drilling fluids and dis-balance of pressure regimes can cause hydrates to have a high tendency to rupture, causing the free gas below to escape. This situation can lead to catastrophic blowouts, fissures and cracks in the sediment above.

Gas hydrates is often called a bottom simulating reflector (BSR) because it often takes the shape of the sea bottom and crosscut the sediments. The hydrates are seismically characterized by high acoustic impedance, higher density, high Poisson's ratio and higher interval velocities. It is much easier to detect geophysically compared to shallow water flow (SWF).

Shallow water flow (SWF)

Shallow water flow is a phenomenon that frequently happens in deeper waters of the Gulf of Mexico, typically about 400 m to 600 m below the mudline. The exact reason for its occurrence is still under research. But generally it is related to the rapid rate of sedimentation in the late Pleistocene period where sand under high pressure got confined and had no chance of de-watering. The proximity of the depocenter to the Mississippi delta river mouth can be the possible explanation. The sand are under compacted and highly unconsolidated in deeper waters (Purnomo & Ghosh, 2018). The porosity is approaching "critical porosity" and because of the low permeability shale/clay factor, a perfect seal was provided.

The sand is under high pressure and dis-equilibrium with the bounding shales. If the structure of this sand is sloping or tilted with a large lateral extent, it will provide perfect conditions for water in substantial quantity to flow towards the well head (Purnomo & Ghosh, 2018). For this phenomenon, a knowledge of the internal pore pressure is of critical importance in drilling safe wells. An advanced research and development in logging will greatly help to understand this phenomenon.

Slumping, landslide, faulting

Sediment is unconsolidated in deeper waters and have chaotic forms due to rapid sedimentation. This fact may cause instability or incompetent sediments with weak rock matrix. Seismically, they form a chaotic sequence of reflection often with changing waveforms in seismic data.

These sediments can transform into a landslide and cause the SWF phenomena. A high quality seismic is needed to perfectly image them. A drop piston coring in geotechnical studies to depths up to 50 m is required to study their shear and mechanical strength. Advance developments in geophysical technology including AVO/inversion and visualization of 3D models helps to identify the fluid exclusion pockmarks, slumping, gorges and faulting for precise placements of the wells and platforms. Sea floor instability is a function of sediment strength, localized slope and seepage forces slumping because instability can be due to any of the two phenomena which are downslope erosional flow (externally driven) and flow processes like overpressures coupled with surface slope (Iinternally driven).

Shallow gas

The most common geohazards occurring in the Malaysian waters are gas seepage and fluid expulsion. They are coined as shallow gas as they are found close to the sea bottom. Except for biogenic gas, the shallow gas pockets often have deep seated roots and can also give light towards hydrocarbon occurrences and possible migration paths. This anomaly cause serious problems in drilling safe wells and is a constant threat during the laying of platforms and it also causes blowouts. They are also difficult to contain, often causing platforms to sink or to be evacuated. Fortunately, the gas pockets are easy to detect seismically as they have a strong amplitude response and positive AVO effects (Hato *et al*., 2004).

GEOHAZARD ANALYSIS

The most important data set required to carry out successful hazard analysis is the basic 3D seismic data that were acquired for prospect evaluation. Advanced technology in geophysical for data acquisition and processing has made it possible to get high resolution seismic data with good spatial and vertical resolutions. Given this high-quality data set, all forms of attribute studies can be performed of which some are listed in Table 1. For each type of geohazards, it has its own seismic rock property and various important methodologies to counter the hazard.

GEOHAZARDS ASSESSMENT PROCESS

Geohazards assessment is a prediction of geological processes that may present negative influence on a development and at the same time to understand the evolutionary history of the site through spatial and temporal context (Thomas *et al*., 2010). The assessment can reduce the uncertainty in every high-risk area by ensuring the geohazards with no potential for occurrence to be eliminated. Table 2 shows some geohazards assessment tools and their output. It is essential for a fit-for-purpose review and assessment to apply integration of all available data focusing on data acquisition program. Actual geohazards determination need multiple data acquisition, despite

Table 1: Geohazards analysis based on types of hazards, seismic rock property and methodology to counter the hazard.

Hazard	Seismic Rock Property	Methodology
Shallow Gas	Velocity / Absorption/ Poisson's Ratio	Amplitude, AVO, Wipeout, Time Sag
Gas Hydrate (BSR)	Velocity / Impedance	Reflectivity, Polarity, Interval Velocity and Inversion
Shallow Water Flow	Under compaction/Pore Pressure	Pore Pressure Prediction, Chaotic Reflection
Slumping, Landslide, Faulting	Discontinuity	Coherence Cubes, Time Slices 3D Visualization
Overpressure	Vertical Effective Stress	Velocity Inversion and Modelling

Table 2: Geohazards assessment tool with geohazards assessment output.

Geohazards Evaluation Appliance	Geohazards Evaluation Action
Geographic Information System (GIS)	Soil province/terrain unit mapping; Interrogation of spatial data; Provision of data for enhance marine slope stability analyses
Geochronological Analysis	Establishment of event frequency; Correlation with conditioning/triggering factors
Geohazards Core Logging	Facies-driven classification; Understanding of sedimentology; Identification of type and magnitude of events; Guide geochronological sub-sampling
Mineralogical Testing	Sediment provenance/behavior interpretation based on data given
Geotechnical Testing	Measures soil properties Identification the type of soil for engineering purposes
Swath bathymetry	Geomorphological mapping for site survey submarine mass movement/deposits environment
Ultra-High-Resolution CHIRP data acquired from Autonomous Underwater Vehicle (AUV)	Lateral and vertical extents of mass movement deposits in marine environment

obtaining standard geotechnical samples. There is a demand for long core samples for detailed geohazards core logging purposes.

The data integration process should be a repetitive process, recognizing requirements and locations for enhance data acquisition at each step of the assessment. The two-important aspects in this process are geohazards inventory and gas model that are updated throughout the assessment process.

MALAY BASIN FORMATION

The Malay Basin lies off the east coast of Peninsula Malaysia and is located in the southern part of the Gulf of Thailand, between Vietnam and Malaysia (Madon *et al*., 1999). The basin trends northwest-southeast and is approximately 500 km long and 200 km wide which gives a total area of 100,000 km² (Madon *et al*., 1999; Mansor *et al*., 2014). Mansor *et al*. (2014) mentioned that the Malay Basin is made up of two parts which is a southern part with NW-SE structural trend, and a northern part with northerly-trending structures. The central part of the basin area contains more than 13,000 m of Cenozoic strata. Malay Basin which is underlain by a continental crust and economic basement is composed of granite, diorite, limestone and metamorphosed sedimentary rocks which include quartzite, phyllite, argillite and arenite. Volcanic rocks is the other component underlaying the Malay Basin. Andesite, rhyolite and dacite were reported in Anding Utara area. They belong to volcanic arc series that is widespread in the Eastern Belt after the collision between Sibumasu and Indochina. Madon *et al*. (1999) mentioned that the basin is underlain by continental basement made up of igneous rocks from Cretaceous age and it is a combination of Mesozoic and Palaeozoic meta-sediments, carbonates and igneous rocks.

The Malay Basin is a pull apart basin formed in the Early Tertiary by reactivated NW-SE strike-slip zones (Madon *et al*., 1999; Mansor *et al*., 2014). It is filled with clastic sediments that were deposited in fluvial, lacustrine and marginal marine environments. The structural history of the Malay Basin is dominated by 3 major phases of tectonic activity - a) Early extensional phase during Oligocene time which resulted in the north-south tensional stress. b) Compressional phase during Early Miocene time to Pliocene which was due to compressional tectonics. c) Late extensional phase during Pliocene to Recent which was caused by deformation style that changed from compressional to a mild extensional. So generally, the B field formation underwent this three major phases which are very important to understand the geological structure and stratigraphic features on the field itself.

B FIELD

B field is located at offshore Terengganu about 200 km northeast of the Kemaman Supply Base. The field size is approximately 26 km in width by 25 km in length, which is equal to 650 km². The depths of water range from 65 m to 71 m. The age is from lower Miocene to recent. The hydrocarbon type consists of gas and oil, with gas being mostly dominant. The structure of B field is a circular dome anticline with east-west trending dissected by north-south oriented normal faults. Some of the area in the field represent poor imaging in crustal part where gas cloud is rampant which introduced high uncertainty in fault structures. Certain hazards had been identified at some particular wells, where possible shallow gas hazards are interpreted. Besides that, bubble gas is also observed at the surrounding areas, which might be from low saturated gas sandstones or shallow gas. The seabed morphology is undulating and is marked by individual clustered pockmarks. The undulating seabed and several localized seabed depressions of less than 2 m depth is associated with individual/clustered pockmarks. Some individual pockmarks are probably formed from defluidisation (water/gas) process of soft superficial sediments due to natural sediment compaction, while the pressure was introduced by massive water column. The seabed sediment comprises very soft sandy clay and is expected to provide ample anchor holding capacity. An accident happens when the well penetrates into relatively thin section of seabed sediment, causing rapidly increasing pore pressure in the well.

STRUCTURAL / GEOMORPHOLOGY

Geomorphological attributes - stratigraphic channel play

The main criterion is the mapping of the structure. Geomorphological analysis is an important aspect of stratigraphic plays such as unconformity, pinch-out, toplap and downlap. Geologic depositional-environment studies leading to seismic-facies analysis using seismic attributes are useful in reservoir modeling and delineation in locating sweet spots and reservoir efficiency and productivity (Ghosh *et al.*, 2014). In the Malay Basin, several channels have been identified, characterized and used for exploration and field development.

Figure 2 shows the combination of seismic-instantaneous attributes such as instantaneous phase, instantaneous frequency, remove bias and envelope (reflection strength). All of these attributes will be compared with the main seismic section to gain understanding and for interpretation of the channel structure at ‘B’ field. The channel for the ‘B’ field can be categorized as high sinuosity, possibly sand filled (in point bar) where the potential of locating hydrocarbon (HC) is high. But for this research which is more towards geohazards indication, the channel structure influence is more on the gas cloud distribution in the ‘B’ field.

Geohazards identification - gas cloud distribution

Figure 3 shows gas cloud characterization in 3D seismic obtained by using seismic attributes such as remove bias, instantaneous phase, chaos and RMS amplitude at Z

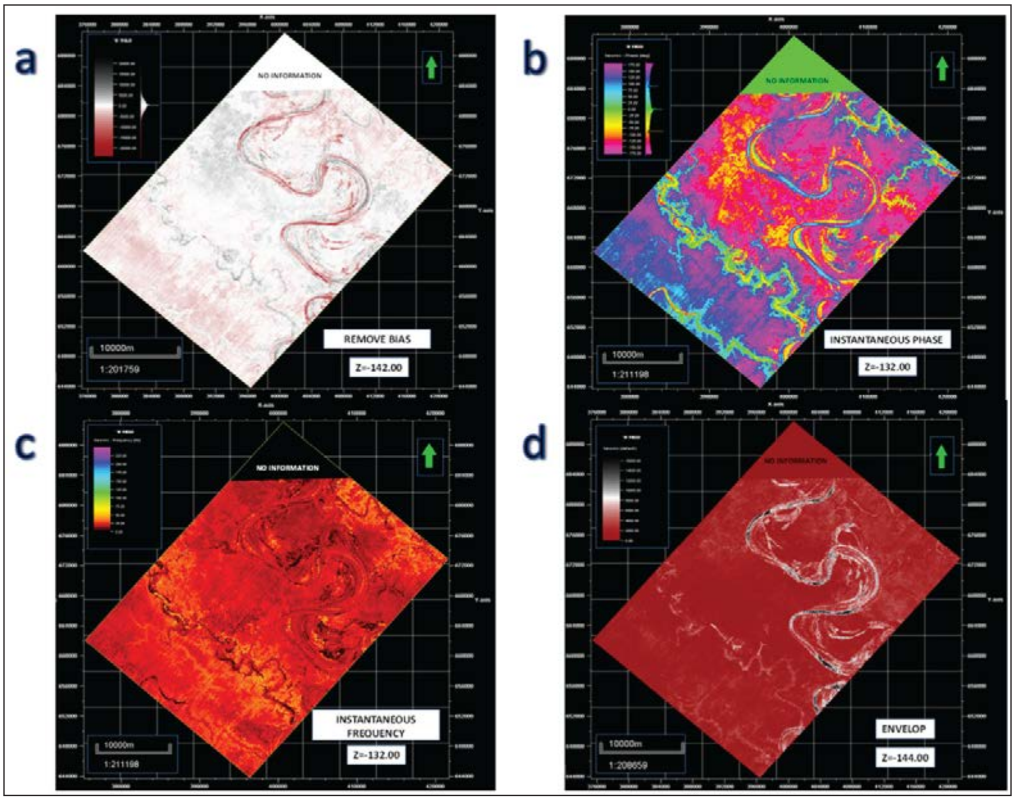

Figure 2: Channel characterization in 3D seismic obtained by using seismic-instantaneous attributes: (a) remove bias, (b) instantaneous-phase, (c) instantaneous-frequency, and (d) envelope.

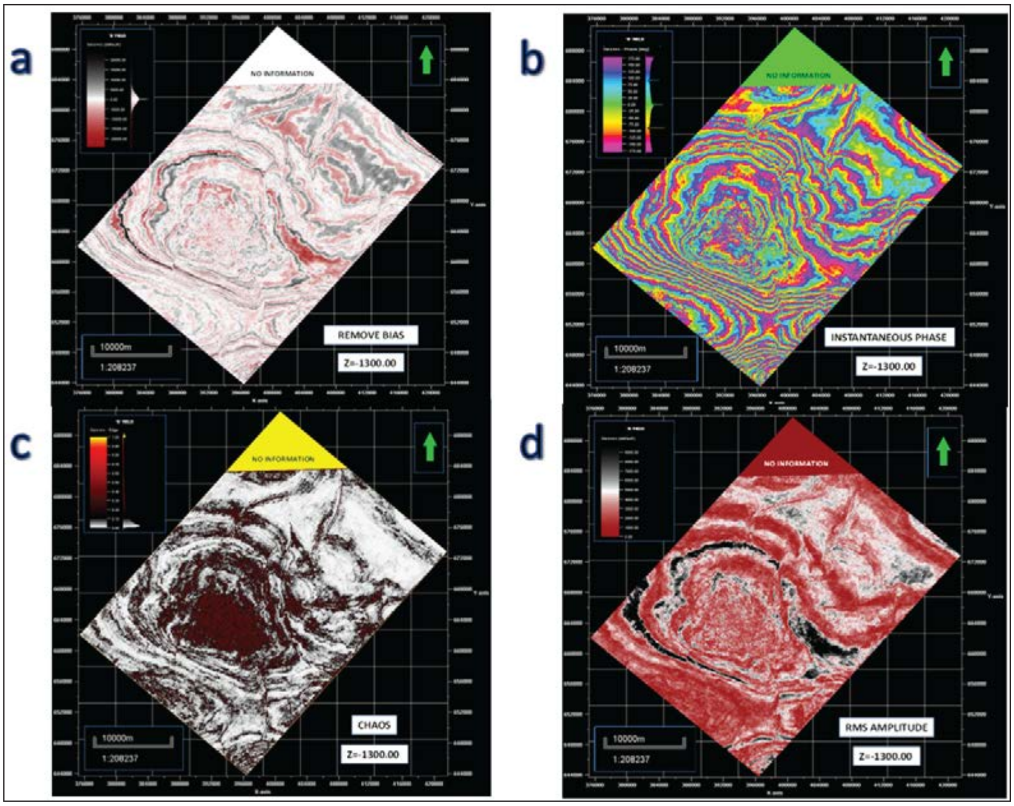

Figure 3: Gas cloud characterization in 3D seismic obtained by using seismic attributes: (a) remove bias, (b) instantaneous phase, (c) Chaos, and (d) RMS amplitude.

time slice. Based on these four attributes, the gas cloud distribution is briefly understood and it helps the interpreter to identify the reason behind its formation. It also shows some minor and major faults that might influence the gas cloud distribution. For a better understanding of the concept, Figure 4 shows the cross section INLINE and XLINE seismic section towards time-slices layer at Z = -1300. The white rectangle dash line shows the accumulated gas cloud in both seismic sections. Based on this distribution, it is clearly identified as gas cloud instead of shallow gas and gas chimney. Shallow gas usually occurs only at the top of the shallow surface. For gas chimney, the shape usually follows the chimney shape which is influenced by the concentrated fault and fracture of a particular area. Compared with a gas cloud, the fault and fracture is in a uniform formation, thus the gas moves upwards with an irregular distribution similar to a cloud shape. This differentiation between shallow gas, gas chimney and gas cloud is very crucial to be examined because generally it shows the same thing which is gas, but with different characteristics such as the cover area of gas, the shape of gas distribution and the presence of fault, fracture and other structural influence.

SPECTRAL DECOMPOSITION

Spectral decomposition is an advanced method for producing and analyzing seismic attribute maps in order to display channel systems and other stratigraphic features. In general understandings, spectral decomposition is a method that implements time-frequency analysis to generate maps based on different frequencies. It needs a detail analysis on interpreted horizons and selected data intervals. Spectral decomposition can be applied to the whole seismic volumes compare with the waveform classification (Chopra & Marfurt, 2007; Barnes, 2016).

Based on the volume spectral decomposition, it can be interpreted into two types of color blending which is red-green-blue (RGB) color and cyan-magenta-yellow (CMY) color. The idea of this research is to apply the color blending which give rise to further understanding on the effect of spectral decomposition towards gas cloud and other subsurface geobody imaging. Based on Figure 5, detailed analysis and interpretation works based on this application have sufficient performance in gas cloud geohazards prediction. Figure 5A shows low frequency value which indicates the gas cloud is concentrating on the fault and channel area. Figure 5B further proves the

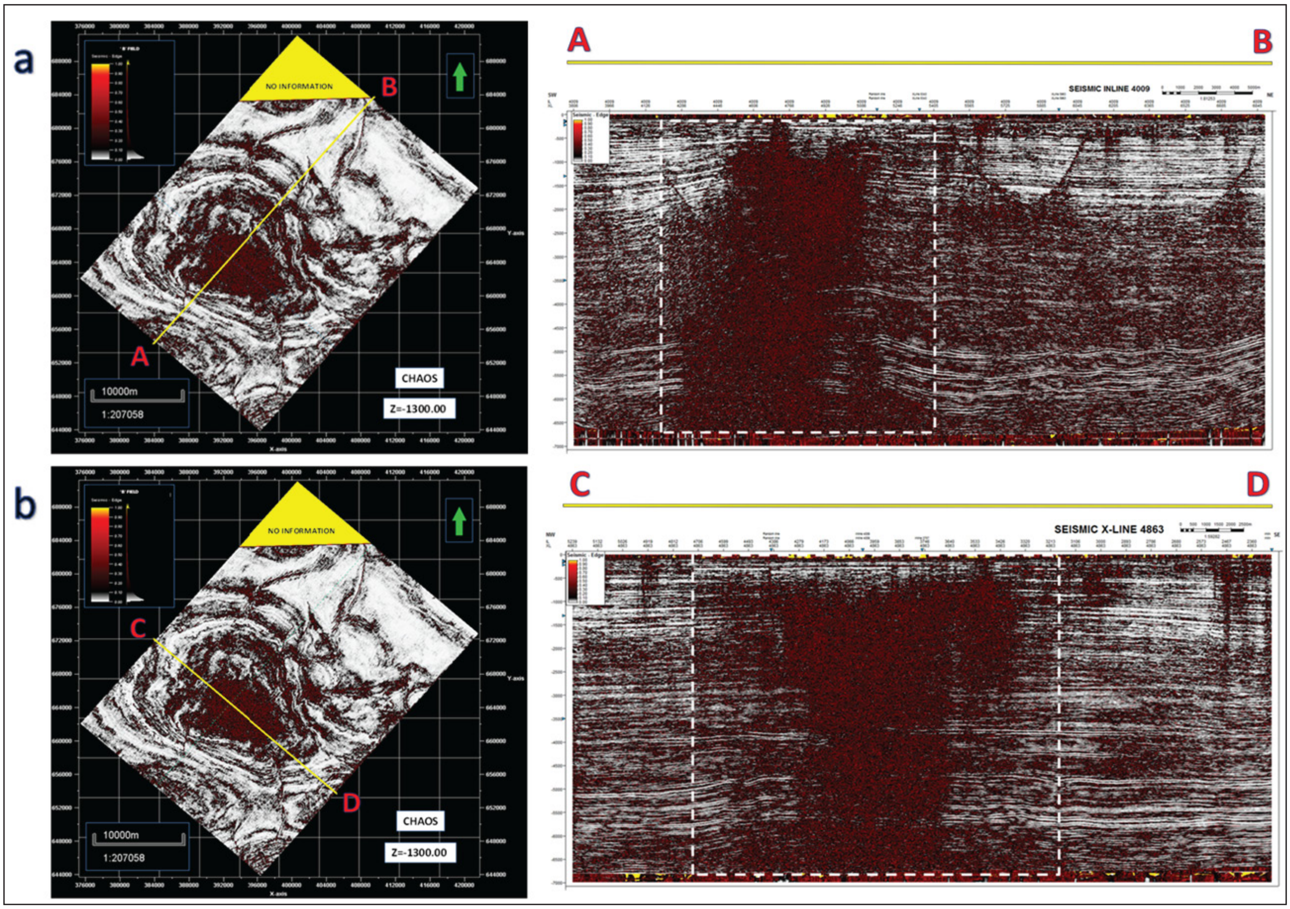

Figure 4: Cross section of time-slices layer (Z = -1300.00 with Chaos seismic attribute for gas cloud identification: (a) INLINE seismic section and (b) XLINE seismic section.

interpretation by showing the presence of gas cloud in this area when the horizon probe technique is applied. The yellow and orange color in the figure show the gas cloud distribution. Additional input in Figure 5C shows the surface map which gives strong anomaly on the gas cloud area. Cross section had been done to prove the gas identification in the interested gas (refer Figure 5D and Figure 5E). As an advance precaution, further study needs to be conducted properly on spectral decomposition in terms of gas cloud distribution which is significant to the seismic exploration.

GAS MODEL

In Figure 6, a gas model based on the combination of chaos and median filter attributes is presented. Chaos attribute which focus on edge detection (structural) enables

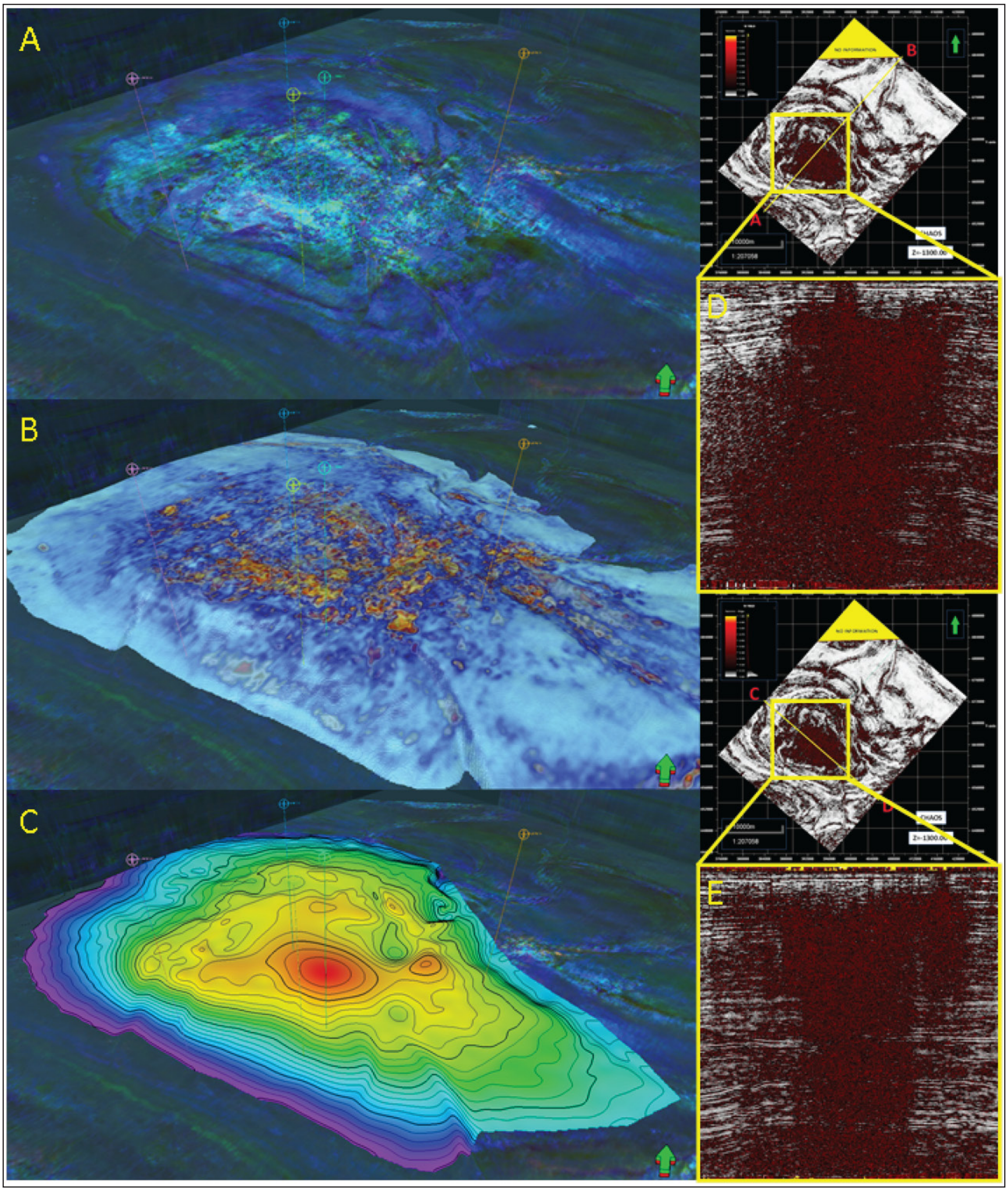

Figure 5: A - 3D seismic slices of spectral decomposition with low frequency value. B - Horizon probe on particular gas cloud distribution. C - Surface map at a particular gas cloud distribution. D - Cross section of time-slices layer with Chaos seismic attribute for gas identification (Inline seismic section). E - Cross section of time-slices layer with Chaos seismic attribute for gas identification (X line seismic section).

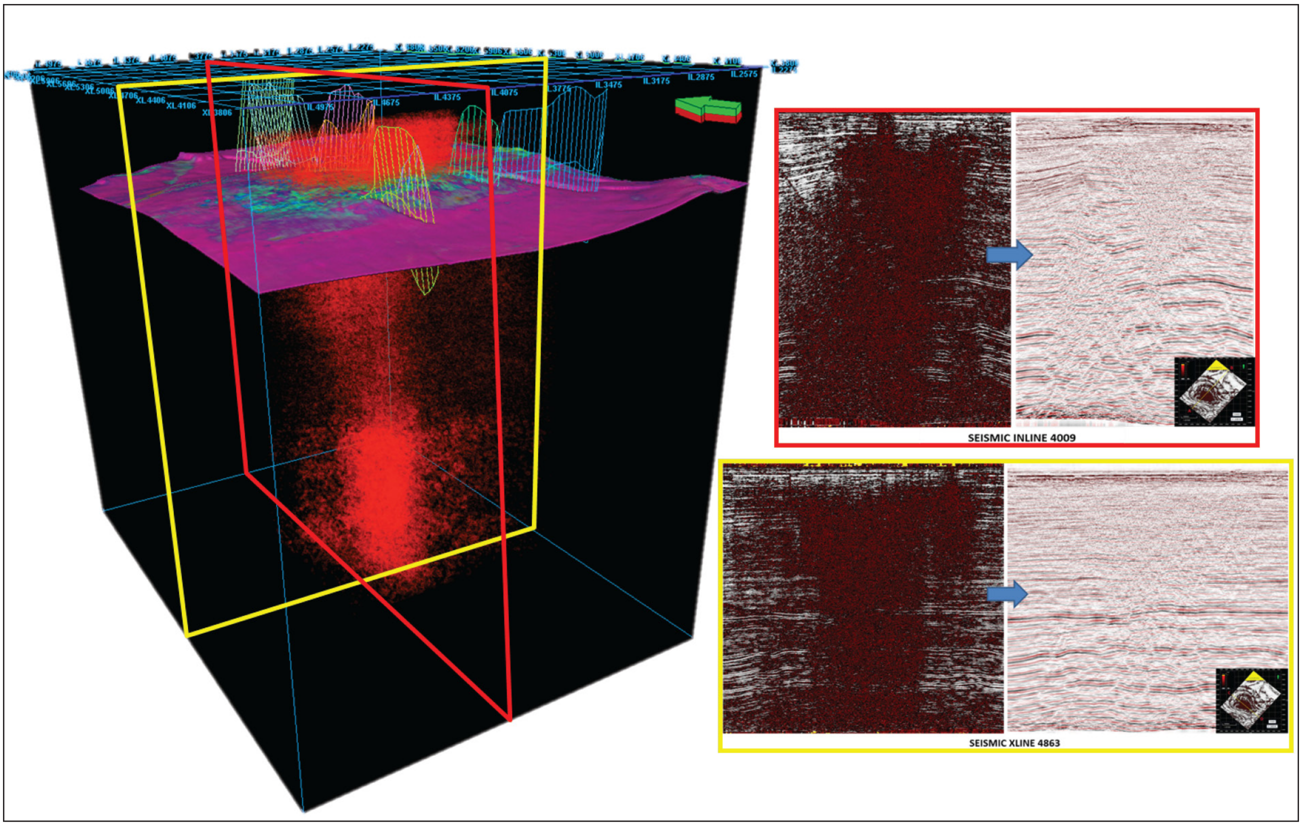

Figure 6: Gas cloud model based on a combination of certain attributes (some fault structures are also shown).

faults and fractures identification. It is also good for general stratigraphic identification such as channel infill, gas chimneys, sink holes and salt diaper. The median filter attribute acts as a frequency filter over time gates on seismic data which is focusing on the low frequency to detect the gas cloud. Besides that, it helps in noise reduction by muting unwanted frequencies, thus the outcome of the filtered seismic show clearer channels.

Therefore, by combining the two attributes and using certain parameters, a model can be developed which gives a brief explanation on how the gas is distributed from the bottom to the top of the field. Certain influence can be identified, such as faults which can be seen clearly. In spite of that, the formation of small fractures in the minor channel features also influences the distribution of the gas cloud itself. For future prediction, the gas cloud is expected to flow to major channel features which also have faults and fractures that can trigger gas cloud distribution.

DISCUSSIONS

Based on geohazards perspective in oil and gas projects, more researches are needed in term of gas cloud distribution. In the B Field, certain features had been identified which give strong indicator to gas cloud geohazards. During the early stage of developments, there was no presence or sign of bubble gas around the well. But after years of exploration, bubbles of gas start to appear around the well. This is an indicator of gas cloud geohazard or generally known as shallow gas. Shallow gas, gas cloud or gas chimney may counter the same geohazards but with different strength and problems. It can cause serious problems in drilling safe wells by causing blowouts, or it may be difficult to contain thus causing the platform to sink or has to be evacuated. The differentiation between shallow gas, gas chimney and gas cloud is very crucial because generally they show the same thing which is gas, but with different characteristics such as the cover area of gas, shape of gas distribution and presence of faults, fractures and other structural influences. Based on the chosen attributes (Refer Figures 3, 4, 5A, 5B and 6), the gas cloud distribution might be influence by minor and major faults in the field. The gas accumulated at the fault area. But for other factors which are related to channel influence (Refer Figure 2), the gas is shown to accumulate at the channel area. So based on this interpretation, the gas distribution can be influenced either by the movement of plates (fault factor) or because of the combination of small fractures which occured due to the weak structure of channel deposition (Channel factor). Further study need to be explored to differentiate between good gas and hazard gas which is related to economical and uneconomical gas.

CONCLUSIONS

The geohazards in offshore oil and gas development projects can cause potential impact in terms of increasing the intervention works which contribute to the side impact of project schedule and cost of project. This research aims to identify the gas cloud through channel structure by applying several seismic attributes on specific parameters Certain seismic attributes (volume attributes) such as seismic-instantaneous attributes, envelope, chaos and RMS amplitude are applied for further interpretation. After some interpretations had been conducted, a gas model was produced with detailed information to minimize the impact of gas cloud towards seismic exploration. Advanced precaution at the earlier stage can mitigate the effect on the project in terms of risk and cost. Both geophysical and geotechnical surveys need to be done properly to obtain high quality data with good resolution.

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