Structural Enhancement in Shallow Gas Cloud Region

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Abstract: This research will address the issue of poor structural interpretation below complex overburden and shallow anomaly that cause wave field distortion. The main objective of this research paper is to present the result of seismic interpretation over a seismic line extracted from a shallow gas filed located in Malay Basin. The readers will be briefly explained on the seismic data properties of shallow gas cloud, followed by methodology and techniques used in interpreting the data. Interpretation techniques used in this research work include the seismic data analysis based on the seismic attributes. The outcome from this work aims at recovering the hidden structure that cannot be seen in the data after processing and imaging sequences.

1. Introduction

The shallow gas clouds is defined as an overburden region [1], and was formed due to the gas leak from deeper reservoir [2], migrating upward through the fault and fracture system. This thin layered gas-filled sediments that formed a shallow cloud was accumulated within porous silt and sand-rich sediments after a biological process which produced thermogenic gasses that not related to hydrocarbon such as carbon dioxide, hydrogen sulphide, ethane and methane [3]. Either way, the presence of shallow gas accumulation along the sediment layers in near surface, is always associated as the clearest indicator of the existence of hydrocarbon reservoir underneath the particular field, as proven in offshore Malaysia, North Sea and Gulf of Mexico. It was further elaborated that the shallow gas cloud can be recognised in seismic data based on several criteria [4]:

i. Acoustic turbidity – The smear reflector images caused by scattering energy. Adjacent reflector position will appear as a pull-down effect; indicated the delay in travel time throughout the slower zone.

ii. High amplitude reflection – High amplitude with negative phase reflection normally visible at the top of shallow gas zone. The greater amplitude reflected back from this area due to greater impedance contrast of gas-charged sediments compare to surrounding sediments.

iii. Acoustic blanking – This is the area where the reflection absent from the seismic image (Figure 1). The main caused of this 'wipe-out' was originated from wave scattering and amplitude attenuation.

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In shallow gas cloud region, the acoustic blanking appears on the seismic data remains the main problem for seismic interpreters in order to locate the exact well location for drilling. This problem is attributed to non-uniform wave propagation from source to receiver location during the acquisition process. To enhance the structural image underneath the shallow gas cloud, kinematic (travel time delay) and dynamic (distortion of wave attributes) of the seismic data need to be corrected. The Diving Wave Tomography (DWT) technology [5] was used as one of the solution for reflector’s travel time delay (kinematic) as well as the application of Pre-stack Depth Migration (PreSDM) technique that was extensively used in processing procedure. On the other hand, a dynamic approach is required to solve the frequency and amplitude losses as well as phase distortion. In standard data processing procedure, the amplitude loss and phase distortion were compensated by using a Q-compensation technique as well as wavelet sharpening and de-convolution processes. For example, a two steps approaches was introduced as kinematic aspect of seismic data was solved by using reflector’s re-datuming concept while dynamic aspect of amplitude seismic data was solved through full waveform inversion (FWI) [6]. Each of the methods discussed will solve the travel time error and attenuation effect, although extensive computing power as well as sophisticated imaging algorithms will be needed.

2. Methodology

However, the resultant seismic section produced from these gas cloud region still requires the implementation of seismic attributes, for better structural enhancement, particularly within the ‘wipe-out’ zone. In definition, seismic attribute is a measure of seismic data that helps us to visually enhance interpretation interest which are sensitive to desired geological features that leads to identification of potential hydrocarbon reservoir by locating the true position of fault, fractures and well position through amplitude and geomorphological features characterization of the seismic section [7]. To date, many attributes have been extracted and developed for seismic interpretation purposes. To name some of them are volumetric curvature, instantaneous frequency, root mean square (RMS) amplitude, sweetness and many more. The most common attribute used for seismic interpretation is true amplitude attribute. The use of seismic attributes begins during 1980s and become more common in the 1990s.
Throughout this work, we incorporated several attributes to a seismic volume which suffered from poor illumination due to gas leakage. The main objective of attributes application is to enhance and improve our interpretation, especially when marking the faults, which is highly ambiguous using the present dataset. Three main seismic attributes (true amplitude, relative acoustic impedance and coherence-variance) were applied to the seismic volumes. These attributes are independently analysed in the next section along with the resultant seismic section and time slice produced after attribute implementation.

3. Results and Analysis

3.1 True Amplitude Attribute

The data true amplitude attribute was selected to display the original seismic trace. Seismic reflectivity can be displayed in variable density colour using seismic colour schemes available within the PETREL interpretation software (black-white or blue-red-white). Each of these colours represent positive (hard kicks) and negative (soft kicks). Horizons and structural interpretation were done based on true amplitude seismic at the beginning of the research, following the standard interpretation techniques by marking the horizons and faults visible on the seismic data.

From Figure 2a, interpretations of the horizons become more effortful at the deeper sections as amplitude of the reflectors dimmed and they experienced poor horizontal continuity. With the aim to improve the interpretation of the deeper reflectors beneath the shallow gas cloud area, relative acoustic impedance attribute has been applied to the seismic volume.

Figure 2: Comparison on a shallow gas cloud’s cross-section in (a) true amplitude image and (b) relative acoustic impedance image. The true amplitude data is the original data obtained from seismic data acquisition without any changes to its amplitude spectrum. The reflectors within the wipe-out zone (highlighted in orange rectangle) are more visible on relative acoustic impedance attribute. (Data permission from PETRONAS).
3.2 Relative Acoustic Impedance

Relative acoustic impedance is a running sum of regularly sampled amplitude values. It is calculated by integrating the seismic trace, passing the result through a high-pass Butterworth filter, with a hard-coded cut-off at (10*sample rate) Hz. In simpler word, acoustic impedance is a physical rock property given as the product of density and interval velocity [7]. Application of acoustic impedance in the industry is usually by doing inversion of the seismic to get the correct values of the acoustic impedance. As that is not the aim of this research and due to time constraint, seismic inversion of acoustic impedance is not applied on the data. Result from application of relative acoustic impedance on the seismic cube is already sufficient to achieve the target of correlating the reflectors located just beneath the gas cloud zone, as shown in Figure 2b.

3.3 Coherence-Variance Attribute

Coherence is a measurement of similarity between waveforms and traces. It operates on a spatial window based on the neighbouring traces. Highly coherent seismic waveforms indicate homogeneity in the lithology, while abrupt changes in the waveform can indicate displacement of faults or fractures in the sediments. Coherence attribute provides assistance to seismic interpreters by portraying subtle faults or improve interpretation below the limits of seismic resolution. The main purposes of applying coherence attribute on the seismic cube are to recognize and improve the interpretation particularly for detecting faults underneath the shallow gas zone. The application of coherence attribute is best viewed in time slice domain and horizon surface.

**Figure 3**: Comparison of time slices after application of coherence-variance attributes with: (a) application after structural smoothing and (b) application without structural smoothing (only dip and azimuth calculation). The implementation of structural smoothing to the seismic data before coherence attribute application increase the reflector visibility and continuity as seen in orange rectangle in (a). (Data permission from PETRONAS).
From several coherence calculations methods available, variance-based technique was used in this research. Variance method is the sum of the variance over a vertical analysis window of certain amount of samples (waveforms) and then normalize by the energy of all traces obtain from the seismic (Chopra and Marfurt [7]). A structural smoothing technique was applied prior to application of variance method. The purpose of applying structural smoothing on the input is to increase the continuity of the seismic reflectors using principal component of dip and azimuth to determine the local structure followed by structural smoothing, as demonstrated in Figure 3. Ignoring these procedures might introduce artefacts, hence misleading our interpretation.

Unlike in the area of higher resolution with better horizon continuity, the low amplitude distribution underneath the shallow gas cloud make it difficult to delineate fault system in this area. However, the implementation of coherence attributes on seismic section able to overcome this issue as demonstrated in Figure 4a. From the result, it clearly can be seen that a fault structure (indicate in red arrows) actually pass through the poor illumination zone (which is not visible in Figure 1 and Figure 2). This aligns with the theory that the gas accumulation was probably formed due to gas leakage from deeper reservoirs through the fault system. Therefore the fault line interpreted in Figure 4b can only be verified through the application of coherence-variance attribute method.

![Figure 4](image)

**Figure 4:** (a) Coherence attributes application after fault interpretation which the fault line clearly seen along the red arrows. (b) The same fault line then overlay into original (true amplitude) seismic section, give better insight of the fault within the wipe-out section. (Data permission from PETRONAS).
4. Conclusion

The application of seismic attributes in characterizing structure in poor illumination zone was shown throughout this work and it is proven as an effective tool for better fault and horizon detection for shallow gas cloud area. Without the implementation of seismic attributes to the seismic data, the fault detection process is extremely hard with no obvious fault line can be detected due to data ‘wipe-out’. In this work, seismic interpretation becomes more effective and meaningful when more than one attributes were used and integrated to each other. Therefore the quality of the seismic data is paramount for delineating and characterizing reservoir beneath the gas cloud. However, we have to emphasize that in the shallow anomaly exploration, the input seismic data should be acquired and processed optimally, for example by employing advanced solutions in seismic acquisition and seismic data processing and imaging, as this is more critical than post-migration processing such as structural interpretation through seismic attributes method.

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