Seismic Data Analysis to the Converted Wave Acquisition: A Case Study in Offshore Malaysia

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Abstract: Many fields in offshore Malaysia suffer from the presence of shallow gas cloud which is one of the major issues in the basin. Seismic images underneath the gas cloud often show poor resolution which makes the geophysical and geological interpretation difficult. This effect can be noticed from the amplitude dimming, loss of high-frequency energy, and phase distortion. In this work, the subsurface will be analyzed through the geophysical interpretation of the converted P-S data. This P-S converted dataset was obtained through ocean bottom cable (OBC) procedure which was conducted at a shallow gas affected field located in Malaysian Basin. The geophysical interpretation process begin by picking the clear faults system and horizons, followed by thorough post-stack seismic data processing procedure. Finally, the attributes analyses were implemented to the seismic section in order to image the unseen faults system. The interpreted seismic sections show significant improvement in the seismic images, particularly through median filter process. Moreover, the combination of structural smoothing and variance procedure had contributed to the correct faults location interpretation.

Keywords: converted wave, attribute analysis, Malaysia basin

1. Introduction

The potential hydrocarbon reservoir in Malaysia basin is always associated with the presence of shallow subsurface anomaly such as carbonate platform and shallow gas accumulation. While imaging techniques beneath carbonate body are well studies, a good quality seismic image underneath the shallow gas cloud remained a challenge in geophysics community. By definition, shallow gas cloud is an overburden region of low-concentration gas, escaping and migrating upward from a gas accumulation [1]. Generally it shows as a region of deteriorated seismic data quality associated with slow wave propagation velocity and reflection time sag beneath the gas zone. The P-wave reflected events in this region appear with lower amplitude and frequency content, which is due to wave energy’s anelastic and intrinsic loss. Such undesired effects lead to significant uncertainties in structural and stratigraphic mapping of reservoirs below the shallow gas area, and consequently the hydrocarbon resource assessment of the affected fields. This will affect the geologist and geophysicist’s ability in predicting and interpreting the structures and reservoir properties beneath shallow gas cloud (Figure 1).

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To overcome the poor data quality produced by P-wave seismic acquisition in shallow gas-affected areas, current industry practice uses the ocean bottom cable (OBC) technology that recorded reflected shear waves signals, which include larger signal frequency bandwidth that has no offset limitations. In addition, the converted shear waves generated from sea floor are unaffected by the presence of gas accumulation, which can give good reflections images that are not visible on compressional wave data. Therefore, by using converted shear waves obtained from OBC technology, the shallow gas cloud effects can be minimized. On the other hand, the downside of this technology is that it is only applicable to water-depth below 200m as well as the high cost of OBC vessel mobilization and demobilization. In this study, we evaluated the P-S converted waves obtained from Malaysia offshore in terms of geophysical approach such as faults and horizons picking, implementation of post-stack processes, and utilization of seismic attributes. At the end of this work, the outcomes generated from this work will provide some guidelines on optimum imaging of the structures at and beneath the shallow gas clouds.

2. Imaging Issues

The shallow gas cloud was formed due to the gas leakage through sediments. It is believed that faults or fractures are the main pathway for the gas migration towards shallower unconsolidated sediments [3]. There are three main indicators of shallow gas cloud; seismic acoustic turbidity, high amplitude reflection at the top of the gas zone and acoustic blanking at the bottom of the gas zone [4]. The strong reflected energy was recorded at the top of gas zone as the large acoustic impedance contrast was formed between the gas-filled with finely-layered porous silt-sand-rich, and the clay-sand-rich clastic sediments. Typically, a high portion of the reflected acoustic energy is reflected to the surface, leaving a smaller amount of transmitted energy through the gas zone. Therefore, this reflection response contains information on the properties of the shallow gas body. Due to heterogeneous nature of shallow gas-filled zone, it resulted in scattering, dispersion, internal multiples, wave mode conversion as well as anelastic losses. Due to strong acoustic impedance contrasts and the low velocity of the gas layers, the field shot gathers will show strong internal short-period multiples and non-hyperbolic moveout.
During the last few years, a number of 3D OBC surveys have been acquired all over the world as a countermeasure to conventional towed streamer technique. OBC technology is a hybrid marine and land seismic data acquisition operation where the system deploys a stationary array of multi-components receiver devices on the ocean floor while the marine vessel produce the seismic energy source (Figure 2). In conventional towed streamer, seismic data were processed and imaged only for the compressional wave (P-wave) reflections. This indicate that the P-wave propagates downward from the seismic source before being reflected and propagate upward to the receivers, also as P-wave. In the case of OBC data, converted shear wave data were recorded on the horizontal receiver components available from the multi-components receivers located on the sea floor. This converted shear wave was produced once the down-going P-wave partitioned its energy into reflected and refracted P and S-waves.

Due to poor seismic imaging and the fact that there are only a few available wells that had been penetrated beyond the gas accumulation zone, there is no in-depth knowledge as to the actual geology within and beyond the shallow gas cloud. However, the presence of shallow gas cloud leads to poor interpretation of the structures beneath this particular region. The shear wave imaging has several notable advantage compare to compressional wave imaging. As the wave propagate through the rock-gas matrix, shear wave is unaffected by the compressibility of the gas as compare to other wave types. In addition, the usage of S-wave imaging has contribute to:

a. Higher signal-to-noise ratio.
b. Broader signal bandwidth, which consequently improves data resolution.
c. Seismic data multiple elimination. This can be achieved by measure both pressure and particle motion, thus separate the up going wave from the down going wave.
d. Applicable for wide azimuth acquisition.
e. Quieter recording environment.

3. Results and Analysis

The converted shear wave, P-S data was analysed and compared to the conventional P-P seismic data in term of the seismic data quality. As expected, the P-S data shows a significant enhancement to the seismic images, as important reflectors clearly visible, while less acoustic turbidity has been recorded (Figure 3). The gas cloud effects which appear in the conventional data is no longer visible in the P-S data. However, the shallow gas zone could still be recognised in the P-S data.

Figure 3: The figures show the comparison between P-P wave imaging (a) and P-S wave imaging (b). Both imaging techniques still suffer from shallow gas cloud issue, as being highlighted by black ellipsoid.
3.1 Faults and Horizons Interpretation

The structural framework was implemented by picking assigned fault segments on inline sections of seismic with the trace appearing on the corresponding cross lines. These faults are represented on the seismic sections as a discontinuous reflection along a preferred orientation of reflectors or as distortion of amplitude around the fault zones. A total of two faults named as F1, F2, were identified (Figure 4). However, many difficulties have been encountered during picking the faults. Uncertainties during picking the correct position and extension of the faults were the main issues in this part. The shallow section of the seismic image still suffers from the acoustic turbidity, thus the extension of the faults cannot be distinguished.

Horizons picking are significant in order to get a clear picture on what have been observed from the shallow gas cloud effects. A total number of five horizons were interpreted from the data with time maps generated for each of the horizon. Some of the horizons were partially affected by the shallow gas cloud effect, while others were significantly affected specifically by the amplitude dimming. This in turn has led to some ambiguity while picking the horizons. The gas trapped in the shallow section attenuated the seismic signal in the area beneath it. Consequently, the image quality is deteriorated with lower resolution, amplitude and frequency, making the interpretations and horizons picking difficult.

3.2 Post Stack Processing

The primary objective of implementing the post-stack processing is to enhance the data quality through the gas cloud zone. Several processes were applied such as first derivative, frequency filter, median filter, original amplitude, time gain, and trace gradient. However, only two processes have provided a significant enhancement of the images; time gain and median filter, which able to reduce the effect of acoustic turbidity. The median filter is a non-linear digital filtering technique, often used to remove noise. The main idea of the median filter is to run through the signal entry by entry, replacing each entry with the median of neighboring entries. The pattern of neighbors is called the “window”, which slides, entry by entry, over the entire signal. As a result, the seismic images showed a significant reduction in the acoustic turbidity (Figure 5).
The median filtering technique is also one kind of smoothing technique, which is effective at removing noise in smooth patches or smooth regions of a signal. However, at the same time, the process adversely affects edges. The correction for the loss in amplitude of the signals is required in order to enhance the overall seismic images. In this case, the time gain procedure was applied, which involves multiplication of the signal by a number that increases with time. The outcome reveals that the amplitude and frequency losses are partially recovered in the areas where gas clouds present. The resulting image has improved resolution, horizons continuity, thus have improved the interpretations. The last step in post-stack processes was to apply time gain and median filter to the same seismic section in order to optimize the overall image (Figure 6). It is noticed that the true position of the fault can be clearly picked as pointed by the black lines. As a result, surface horizon maps were generated to correct our horizons interpretation.

3.3 Attributes Analysis

Seismic attributes form an integral part of qualitative interpretative tool that facilitates structural and stratigraphic features (e.g. channels, pinch out and meanders) as well as offer clues to lithology type and fluid content estimation with a potential benefit of detailed reservoir characterization. Seismic attributes such as instantaneous phase, envelope, structural smoothing, local structural azimuth, local structural dip, and variance were applied based on volume interpretation. The objective of implementing these attribute methods is to improve the faults’ interpretation. The first implemented attribute was the envelope which represents the instantaneous energy of the signal and is proportional in its magnitude to the reflection coefficient. It represents the acoustic impedance contrast, which is useful in highlighting gas accumulation (Figure 7), discontinuities, faults, tuning effect, and sequence boundaries. It is proportional to reflectivity and therefore useful for analyzing AVO anomalies. If there are two volumes that differ by constant phase shift only, their envelopes will be the same.
The next step in implementing seismic attributes is to enhance our faults interpretation. The extracted attributes were analyzed and it was observed that only variance, combined with structural smoothing, showed better response to faults than any other attribute in the gas cloud area. For this study, the variance attribute was calculated by allowing the software to perform structural smoothing attribute (Figure 8). Subsequently, the results from variance and structural smoothing attributes show that, F1 fault system did not terminate as previously interpreted. Therefore, the interpretation of faults has been improved, in which the true extension of the fault was observed as shown by the black brackets.

4. Conclusion

To sum up, the primary objective of this work is to analyze and enhance the seismic images beneath the shallow gas cloud areas for a field located in the Malay Basin. From the results, it show that post-stack processing methods able to improve the seismic images. This was clearly seen by the improvement in horizons visibility, as well as acoustic turbidity reduction. Meanwhile, seismic attributes also had given a better way to detect the true position of faults, by combining structural smoothing and variance. Lastly but not least, the results of geophysical analysis are very encouraging, however, further analysis is necessary to fully optimize the seismic images of this dataset.

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