Post-Stack Seismic Data Enhancement of Thrust-Belt Area, Sabah Basin

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Abstract: In this paper, an integrated post-stack seismic data processing and interpretation for a complex thrust-belt area was proposed. The sequence was suggested due to poor seismic data quality of the Sabah basin area that was obtained after a pre-stack data processing sequences. This basin consists of a complex geological setting such as thrust-belt with steep dip reflector which is the main features of the region. In this paper, we outlined several methods used in the seismic data processing and interpretation such as amplitude recovery and frequency filtering for enhancing seismic data quality, and relative acoustic impedance, structural smoothing and wavelet coherency were used for attribute analysis. The outcome from this research aims at illuminating the hidden structures such as proper beds termination and faults systems that was heavily affected by low signal-to-noise ratio.

Keywords: Post-stack Processing, Attribute Analysis, Thrust-Belt Region

1. Introduction

In simple geological structure, the final seismic image obtained is generally good, with identification of rock properties, hydrocarbon traps and fault systems are relatively straightforward. The seismic data acquisition deployed for this area can be considerably cheap, while the usage of a standard seismic data processing sequence is sufficient for producing good images. With the era of easy oil is over, more seismic exploration are focusing on complex structure, deep and limited accessibility area as well as marginal oil and gas fields, to arrest the decline in hydrocarbon production. However, there are many hydrocarbon-producing fields in offshore Malaysia suffered from poor seismic data quality due to the presence of near surface anomaly. For example, several fields located in the Malay Basin are located underneath the shallow gas cloud anomaly and need additional processing and imaging steps in order to enhance the quality of the dataset [1].

In the offshore Sabah area, where it is located at the northern part of Borneo (Figure 1), is generally known as a complex geological area, which also producing a poor seismic data quality. Geographically, the Sabah Basin is bounded by West Baram Line (west) and Balabac Strait Fault (east), while extends north westwards beyond continental shelf, into the Sabah Through. Based on the study in [2], the tectonic evolution of Sabah Basin has pass through three major deformations along NW-SE and N-S compression axes, involving changes in stratigraphy, structural geology, paleo-magnetic and its depositional history. This basin is predominantly Middle Miocene sedimentary basin that evolve since

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Late Cretaceous [3]. However the basement of the basin in deeper area is a relatively un-metamorphosed succession of turbidites, that belonging to the Oligocene-Lower Miocene West Crocker, Temburong and Kudat formations, which represent Crocker Fold-Thrust Belt.

The area of study is basically located in Central offshore Sabah, 150km from Kota Kinabalu, Sabah shoreline. It is situated adjacent to Inboard Belt to the west of the field of study, and consists of a tight, complex faulted asymmetric anticline structure along WNW-ESE trending with deep-seated thrust fault system. It was believe that these faults system as a result of strong basement induced wrench movements during the Late Miocene. The presence of steep dips along the fault planes caused the poor illumination of the seismic data. In addition, the prospects greater than 500m water depth are structurally complex, mostly due to toe-thrust plays with turbidite reservoirs. In previous years, several major discoveries have been made, with the fields such Gumusut-Kakap, Malikai, Ubah and Petai were discovered by Shell while Kikeh field was discovered by Murphy, which contributes approximately 15% of Malaysia’s domestic production [4].

2. Imaging Issues

Since the area of study is regarded as a highly complex geology in terms of structure and stratigraphy [5], the existing 2D seismic data which was acquired in 1970’s and 1980’s, unable to address the uncertainties surrounding the fault zones due to poor signal to noise ratio. Consequently, it will raise some difficulties in interpretation, proposing well location and hydrocarbon volumetric calculation and estimation in the later exploration stages. Generally the vintages data in this area have a good image quality over the flanks of the structure, but exhibit a considerably poor image quality at the steeply dipping reflectors where the faulted area are situated (Figure 2). This is because, the steeply dipping beds along with complex faulting caused a rapid lateral velocity variations over the whole subsurface structure in this area.
Although several re-processing seismic data had been carried out to improve the data quality, the presence of almost 30° to 70° steep dips at deeper depth caused the wave propagation path to be reflected away from the projected survey area. For example, if the dipping reflector is located some 1000m beneath the surface level, the reflected wave will be detected at the receiver located 2500m away from the source. However, if the dipping reflector is situated 2000m beneath the sea level, the reflected wave can only be detected at a distance around 6km away from the source location. Since the seismic data of this field was acquired by using streamer length ranging from 2400m to 3000m, the reflected signal from these dipping reflector was not properly processed and imaged.

Post-stack seismic processing and pre-stack seismic processing are two different methods. The seismic data processing for the former method can only be conducted if all the seismic data had been sorted and stacked according to Common Depth Point-Offset sequence. In pre-stack seismic processing, the data enhancement sequences are to be carried out before the sorting and stacking process. In order to enhance the quality of subsurface imaging in the post-stack sequences, several signal processing methods were tested, before a new post-stack seismic data enhancement sequence was developed. The sequence which consists of several steps resembles the pre-stack processes such amplitude gain using programmable gain control and frequency filtering, were incorporated to improve the resultant data for better interpretation, particularly in the complex faulting zones that is highly ambiguous to interpret using the vintage dataset. In addition, three seismic attributes methods were implemented (relative acoustic impedance, structural smoothing and coherence-variance), for better structural anomaly delineation. The proposed post-stack processing steps for this particular complex area are as follow:

1. Amplitude-time gain to boost up the low amplitude energy at the deeper section of seismic data.
2. Butterworth band pass filtering in order to remove the low frequency noise that affecting some major reflectors as well as to remove high frequency anomaly noise signal.
3. Incorporating relative acoustic impedance that yield important information about lateral changes in lithology and porosity.
4. Apply structural smoothing to preserve important discontinuities such as faults or channels.
5. Apply seismic coherence attributes based on variance method. The coherence attribute will give an easier tracking and interpretation of faults within a 2D window.

3. Results and Analysis
3.1 Amplitude Recovery and Frequency Filtering

In the original seismic data which was obtained after a pre-stack time migration process (Figure 2), the seismic data was displayed according to its true amplitude reflectivity using variable density colour scheme. This caused low signal energy detected at certain depth as it decays rapidly once the seismic wave penetrates the earth and reflected back to the receivers. Thus, if the seismic wave reflected from the deeper reflectors were displayed with the same amplitude scale as that from the shallow reflectors, peaks and troughs from deeper events would be invisible to the eye. Therefore a programmable gain recovery method is required to normalize all amplitudes within a trace by looking at a time windows over that trace and adjusting the amplitude of events within the window relative to a chosen standard. This will boosted up the seismic signal according to the depth of the signal, i.e. deeper section will experience a greater amplitude gain compared to shallower section. In Figure 3a, the seismic signal beneath the unconformity was gain up accordingly, and a ‘V’ shape dipping reflectors were spotted. However, as being highlighted in Figure 2, the area within the green box, still experiencing poor illumination even though several energy boosting procedure were applied. This probably due to the presence of shale diapir which cause amplitude attenuation to the seismic wave travelled pass through the area. To prevent any artefacts that may cause from unnecessary gain function, it was suggested to apply a moderate gain function that enable only important steep dips to be interpreted.
Figure 3: (a) The seismic section after amplitude recovery process has enable a steep dip reflectors to be imaged. However, some area still experiencing poor illumination (green box), probably due to shale diapir that caused loss of amplitude. (b) The seismic section after frequency filtering process which remove low frequency noises that masking the data (orange oval) as well as high frequency noises that produces artefacts on the data. (Data permission from PETRONAS).

The filtering procedure then was applied to the data in order to remove low frequency noises that has been masking the data as well as the high frequency anomaly that was created during pre-stack processing sequences. Basically, filtering in seismic data processing is a process of limiting the frequency content of the original signal. This process was carried out in order to differentiate the reflection signal of interest from the noises, multiples and artefacts, which lead to higher signal-to-noise ratio. Since the signal response recorded will be differ from field to field, each geophysicist must choose the correct frequency band required to highlights the area’s seismic target. Thus, the highly subjective decision is totally depend on several testing parameters, such as the cut-off frequency limit, filter slope and the types of filter, i.e. band-pass, low-pass, high-pass or notch filter, before choosing the parameters that works for that particular field. Throughout the process, we keep in mind that noise content may also vary with time and position along the line, thus multiple filtering processes of varying time / distance, is sometimes needed. In field located in Sabah basin with complex geological setting, a 10 Hz low frequency cut-off, and 70 Hz high frequency cut-off was implemented along with 18 dB/octave and 27 dB/octave of low and high filter slope respectively. The outcome from this filtering, shown in Figure 3b, indicates the low frequency noises were remove from the seismic data (orange oval), thus give a better quality seismic image.

3.2 Relative Acoustic Impedance and Structural Smoothing

In the next data enhancement sequence, a standard seismic attribute in relative acoustic impedance was applied to the field dataset. The acoustic impedance which was produced after inverting the post-stack seismic amplitude, is a physical property expressed as a multiplication of medium density and acoustic wave velocity [6]. The acoustic impedance contrast between adjacent mediums controls the angle and amplitude of acoustic reflection and refraction at the considered interface. This inverted impedance
section yielded some useful information about lateral changes in lithology and porosity. In Figure 4a, several seismic characteristic enhancement were seen, among them are reflectors which were correlated as a result of relative acoustic impedance implementation on the seismic section, particularly the angular unconformity reflectors (highlighted in orange box). In addition, several bright spots can be seen (in green circle), indicate a high reflectivity sediments compare to its surrounding, which also indicate that a potential hydrocarbon trap might existed in the area.

![Figure 4: (a) Seismic section after incorporating relative acoustic impedance attribute which enable a better correlation of reflectors, particularly the unconformity layer over the shale diaper (orange box). (b) Then the structural smoothing was applied to the seismic section in order to preserve important discontinuities such as faults or channels, before final attribute analysis, seismic coherence was incorporated. (Data permission from PETRONAS).](image)

Before the seismic coherence attribute was applied, a structural smoothing need to be applied to the whole seismic section. This method was chosen as it will reduce random noise while preserving structure without prior information of the structure orientation is needed. Principally, it measures the orientations of these beds and smooth the resistivity measurements along directions which lie along the measured orientations. Consequently, the boundaries between adjacent beds are preserved while noise streaks are removed. Hence, automatic detection techniques can be employed to identify beds or fractures and dip angles of the beds. The resultant structural smoothing for field data from Sabah basin (Figure 4b) shows a clearer reflections image, as more noises were removed, thus revealing a continuous horizon above the steep dip reflectors.

3.3 Seismic Coherence – Variance

Seismic coherence attribute is a measure of similarity between waveform or traces which is the response obtained from the seismic wavelet convolve with geology of the subsurface. A low coherency data indicate an abrupt changes in waveform which in turn represent faults and fractures system of the sediments and consequently will provide interpretation insights. Most of the time, coherence attribute was implemented on the seismic data with the target to enhance and impose a greater understanding of fault interpretation particularly in the complex geological area. From the result in Figure 5, it can be
seen that a fault structure (indicate in orange arrows) actually existed in the shallow sedimentary layers (which is not visible in Figure 2). This prove that the fault line can be clearly interpreted when a proper seismic data processes were applied before the application of any volumes and structural attribute methods.

4. Conclusion

Throughout this paper, we have demonstrate the benefit of post-stack seismic data processing implementation towards improving vintage seismic data. It is also proven as an effective methodology before any seismic attributes analysis on structural characterization was conducted. Without the implementation of noise and artefacts removal processes to the seismic data, the interpretation and fault detection process in the complex geological setting is extremely difficult as no obvious fault line can be recognized. Therefore the outcomes from this integrated processing and attribute analysis will provide a better data quality compared to separate data analysis and implementation. However, it is also suggested that a new 3D seismic data should be acquired to significantly improve the seismic data quality.

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