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Improving Vintage Seismic Data Quality through Implementation of Advance Processing Techniques

Improving Vintage Seismic Data Quality through Implementation of Advance Processing Techniques

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Abstract: It is essential in petroleum exploration to have high resolution subsurface images, both vertically and horizontally, in uncovering new geological and geophysical aspects of our subsurface. The lack of success may have been from the poor imaging quality which led to inaccurate analysis and interpretation. In this work, we re-processed the existing seismic dataset with an emphasis on two objectives. Firstly, to produce a better 3D seismic data quality with full retention of relative amplitudes and significantly reduce seismic and structural uncertainty. Secondly, to facilitate further prospect delineation through enhanced data resolution, fault definitions and events continuity, particularly in syn-rift section and basement cover contacts and in turn, better understand the geology of the subsurface especially in regard to the distribution of the fluvial and channel sands. By adding recent, state-of-the-art broadband processing techniques such as source and receiver de-ghosting, high density velocity analysis and shallow water de-multiple, the final results produced a better overall reflection detail and frequency in specific target zones, particularly in the deeper section.

Keywords: deghosting, shallow water demultiple, high density velocity analysis

1. Introduction

Seismic imaging, sometimes called "reflection seismology" is a primary exploration method that estimates the seismic characteristics of the Earth's subsurface. The technology measures reflected acoustic energy waves, and is used mostly for coal, oil and gas and geothermal exploration. Seismic images provide geophysicists and geologists a method of mapping the subsurface structure of rock formations. This data tells geophysicists and geologists where rock properties change, thus helping find oil and gas deposits. When geological objectives are not achieved in the processed data, the exploration team were encouraged to re-process the data rather than re-acquiring a new seismic data because of time and cost constraint, where new processing work saves a lot of time and is cost-effective. In addition, the technological advances and improved methods of data processing were made over time when the data was first processed compared to current processing algorithms.

The field of study is located in Penyu Basin, offshore Peninsular Malaysia (Figure 1a). The reprocessing of the seismic data is aimed at obtaining a more concise geological image using modern imaging technologies of data processing to overcome limitations of the previous processing which were conducted in 2004 and 2009. The Kirchhoff Pre-Stack Time Migration (PSTM) workflow is applied

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alongside enhanced 3D processing technologies to attain improved results. Previously in 1991 and 2011, Texaco Exploration Penyu Inc. and Lundin Petroleum had discovered hydrocarbon reserves in Penyu Basin, but eventually discover that the basin to be marginal and no commercial discoveries were ever made. It is said that the poor coverage and imaging quality especially at the basement faults and across the syn-rift half-grabens had contributed to the lack of success [1] (Figure 1b).

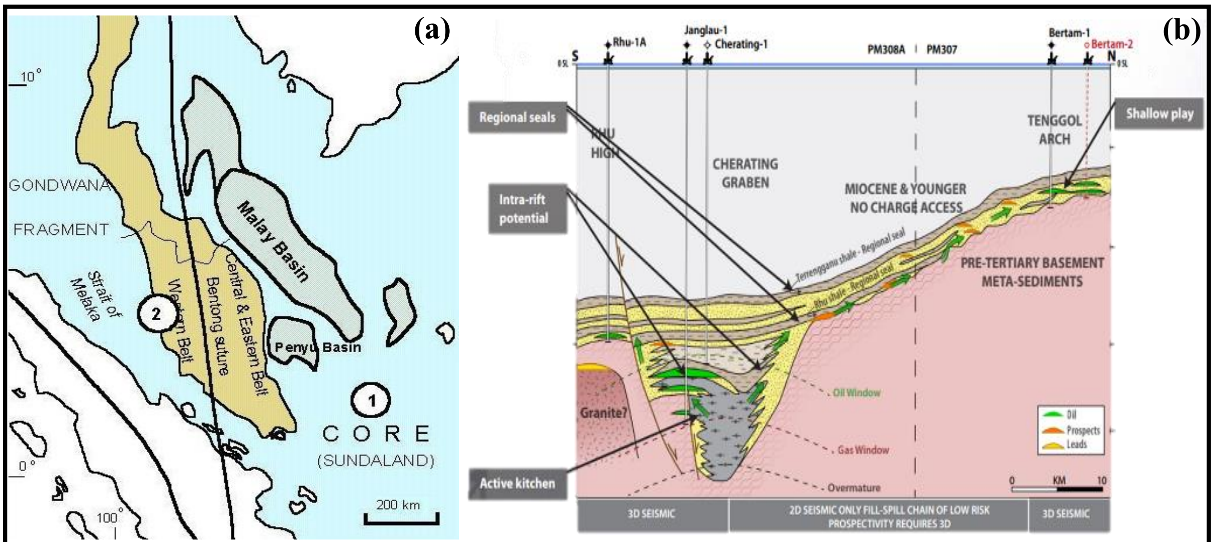

Figure 1: Survey location map and schematic cross-section of Rhu play concept [2].

This paper will mainly focus on application of an enhanced Pre-Stack Time Migration (PSTM) processing workflow to improve on the previous imaging of the seismic data located within the Penyu Basin. Through re-processing the available seismic data, we aim to obtain a better quality seismic section with full retention of relative amplitudes and significantly reduce seismic, structural and stratigraphic uncertainty. In addition, it is hope that re-processing will help to facilitate new prospect discovery through enhanced data resolution, fault definitions and events continuity, particularly in syn-rift section and basement cover contacts. The improved dataset will be subsequently used for future exploration wells placement, and enable AVO and inversion techniques to be applied in a more quantitative manner. In this region, our zone of interest is range in between 1.0 to 4.0 seconds of two way time.

2. Advance Processing Techniques

a. De-multiple

Multiples is a type of energy which has more than one reflection in its travel path. It may disguise, hide or falsely assumed to be primaries which cause data analysis and processing images will be more difficult than normal. The primary wavelet may be affected and distortion in quality of imaging and obstructs primary reflections. A wide range of techniques have been derived and applied to solve for multiple attenuation. Overall, these techniques differ based on the type of multiples – long period or short period. Predictive deconvolution (τ-p deconvolution), surface related multiple elimination (SRME)[3], and shallow water de-multiple (SWD) focuses on short period multiples [4], where high resolution linear & parabolic radon de-multiple [5] is for long period multiples. De-multiples techniques mentioned before are generally time consuming, expensive, while accurately removing the multiples masking the important events.

b. De-ghosting

In marine seismic, there is always the unavoidable ghost effect from the result of reflections of waves off the sea surface. The energy from a marine source emanates in all directions, such as downwards into the earth, while upward travelling energy is also reflected downwards by the free surface causing a secondary signal. These ghost reflections can either be source ghost, receiver ghost or both, where all three of reflections meet the sea surface before being recorded at the geophone. They pose a threat because of the constructive or destructive interference on primary reflections and in some cases mistaken as primaries.

The process of source and receiver de-ghosting upgrades the conventional data to the appearance of a broadband data. This broadens the bandwidth and improve visibility of impedance contrasts for enhanced imaging. classified There are two possible approaches to de-ghosting in processing; a statistical approach based on the classical minimum phase deconvolution algorithm, and a deterministic approach which entails computation of the analytic inverse of the ghost operator [6]. While statistical deconvolution has remained the workhorse in wavelet processing of land data, it has been eschewed in modern marine processing flows in favour of deterministic techniques.

c. Kirchhoff Migration

Kirchhoff migration is the most flexible migration algorithm and can be implemented in 2D and 3D, pre- and post-stack and as a time or depth migration. The principal parameters for Kirchhoff migration are trace spacing, summation aperture and dip limit [7]. These can all be tested on test sections before production migration is carried out. Some implementations also request frequency limits. It consists of searching the input data in x-t space for energy that would have resulted if a diffracting secondary source were located at a particular point. It is summation along the hyperbolic trajectory that is governed by the velocity function.

3. Re-processing Results

a. Receiver and Source De-ghosting

In conventional processing, receiver de-ghosting is usually applied before any de-multiple processing. The aim is to remove receiver and source side of ghost event (including ghost caused by event and multiples) and to produce data with broader bandwidth and higher resolution using a pre-migration receiver de-ghosting algorithm. Receiver and source de-ghosting was performed in common shot domain to derive the ghost filter using a bootstrap approach. A few iterations were executed using the bootstrap approach and the original data to refine the initial ghost filter to account for time shift, noise and receiver depth uncertainty. Finally the inverse of the resulting ghost filter was applied on the original shot gather to obtain a ghost-free output.

After zero phasing, the ghost reflections are distributed across each wavelet whereby it can be seen on both side lobes of the primary reflection and overlapping the primary reflections itself. Thus after application, the amplitudes are reduced in the side lobes and the primary signature. From the stack sections, the data appears to be much cleaner (Figure 2a and Figure 2b) and notches reduced significantly in the amplitude spectrum. Furthermore, the bandwidth of the processed data is broadened while significant improvement obtained in low frequency section.

b. Shallow Water Demultiple (SWD)

Shallow Water Demultiple (SWD) is used to attenuate the water bottom multiple in shallow water areas where the water bottom reflector is not recorded or is unclear due to interference from the direct arrival. SWD was tested with a low frequency limit applied to the SWD multiple model prior to the adaptive subtraction process to preserve the low frequency content in the data. SWD involves 3 steps; 1) Predict water bottom wavelet: In the shallow water area, the water bottom wavelet is not recorded due to the fact that the near offset is much bigger than water depth, even though the water bottom wavelet can be reconstructed from water bottom related multiple; 2) Construct water-bottom related multiple models by similar method as SRME; 3) Subtract water-bottom related multiple by adaptive subtraction. One quick way to evaluate the effectiveness of SWD is by examining the first bounce water bottom multiple removal after application of SWD (Figure 3). In addition, the resultant amplitude spectrum saw a reduction of multiple notches at low frequency while preserving low frequency data content. In order to generate a better multiple model at the upper part of the data, the hybrid SWD method is used. The non-hybrid SWD model usually degrades in upper part. This mainly caused by limited angle of estimated operator. The hybrid SWD using model base approach for upper part gives a better model than SWD.

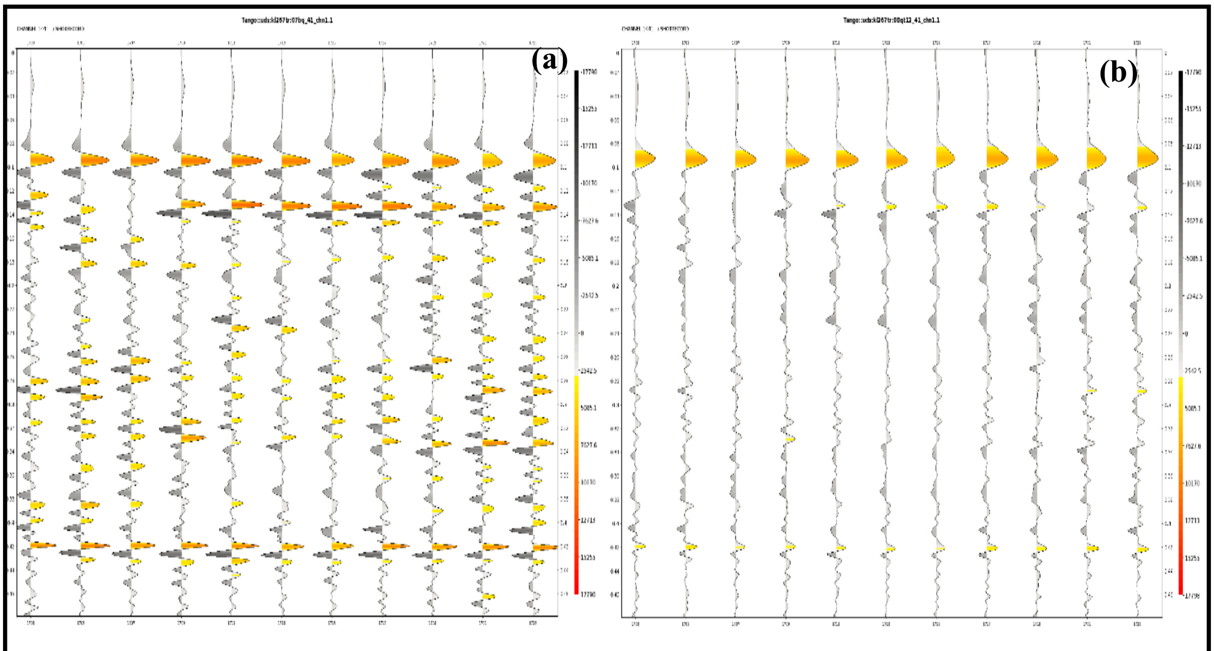

Figure 2: Near trace gather in wiggle display before (a) and after (b) receiver and source de-ghosting.

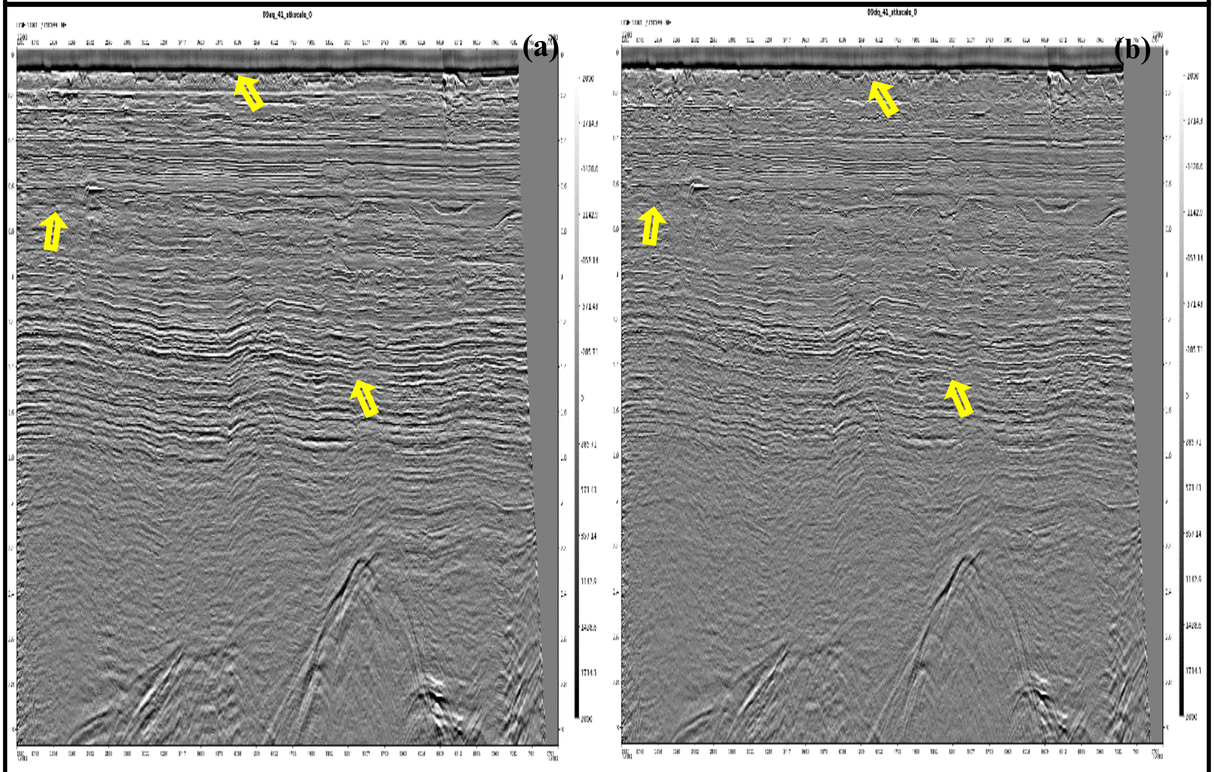

Figure 3: Stack before (a) and after (b) shallow water de-multiple process.

c. High Density Velocity Analysis

After PSTM, the smoothed PSTM velocity field was removed and a high density velocity analysis was conducted using amplitude oriented kinematics program. The program is a robust and continuous velocity analysis program which uses the concept of fully flatten gathers that combine with AVO intercept and gradient will be in phase (Figure 4).

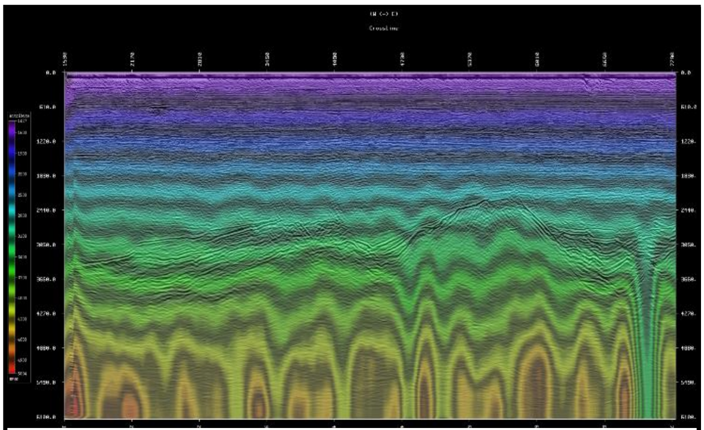

Figure 4: High density velocity field overlaid on stack.

4. Comparison with Vintage Data

Figure 5 represent the selected seismic section from the survey processed from two separate years. The target area we are interested in, is improving at the deeper section (around 750 m – 3km in depth or 1 sec to 4 second in time). The basement area has more structural complexity (e.g. syn-rift half grabens, post-rift structure) as well as it is heavily faulted, which makes it challenging to image accurately. However, there are several improvements after modifying and applying a few added steps to the vintage PSTM workflow.

Firstly, with SWD, source and receiver de-ghosting incorporated into the sequence, the vintage data which was initially severely contaminated with multiples, now appears to be much more geologically accurate. With a significant reduction of surface multiples and ghost reflections, we can be almost certain that the events present are only primary reflections. Thus this allows more confident interpretation. The effective noise and multiples attenuation also allowed for good quality velocity analyses and the subsequent migration.

There is also notable improvement in event continuity and impedance contrast in the re-processed data. The enhancement is credited to the use of high density velocity analysis, and new post-stack processing techniques. The events are more defined and less disrupted across the strata, making it appear cleaner. This in turn highlights the faults, fractures and any sort of discontinuity particularly in the basement region. Overall, the comparison between 2009 vintage data and new re-process image is obvious. It proves that with advanced tools and methods in seismic data processing, a superior imaging result can be acquired.

5. Conclusions

The re-processing work conducted has generally achieved the objectives, delivering a good quality pre-stack time migration dataset, as shown in Figure 5. In previous exploration based on the vintage seismic dataset, the hydrocarbon potential of the basin is considered marginal with no commercial discoveries due to the poor coverage and imaging quality especially at the basement faults and across the syn-rift half-grabens. However, the results discussed above have significantly eliminate structural and stratigraphic uncertainty while retaining the signal to noise ratio of the data. The enhanced resolution, fault definitions and events continuity allow more confident mapping and interpretation to be conducted for further prospect delineation. Essentially the revised processing PSTM work flow has proven that with state-of-the-art tools and methods, appropriate parameterization, innovate approach and careful quality control, we can obtain a geologically accurate results. Therefore, reprocessing seismic data is still a more cost-effective approach to achieve better-quality results.

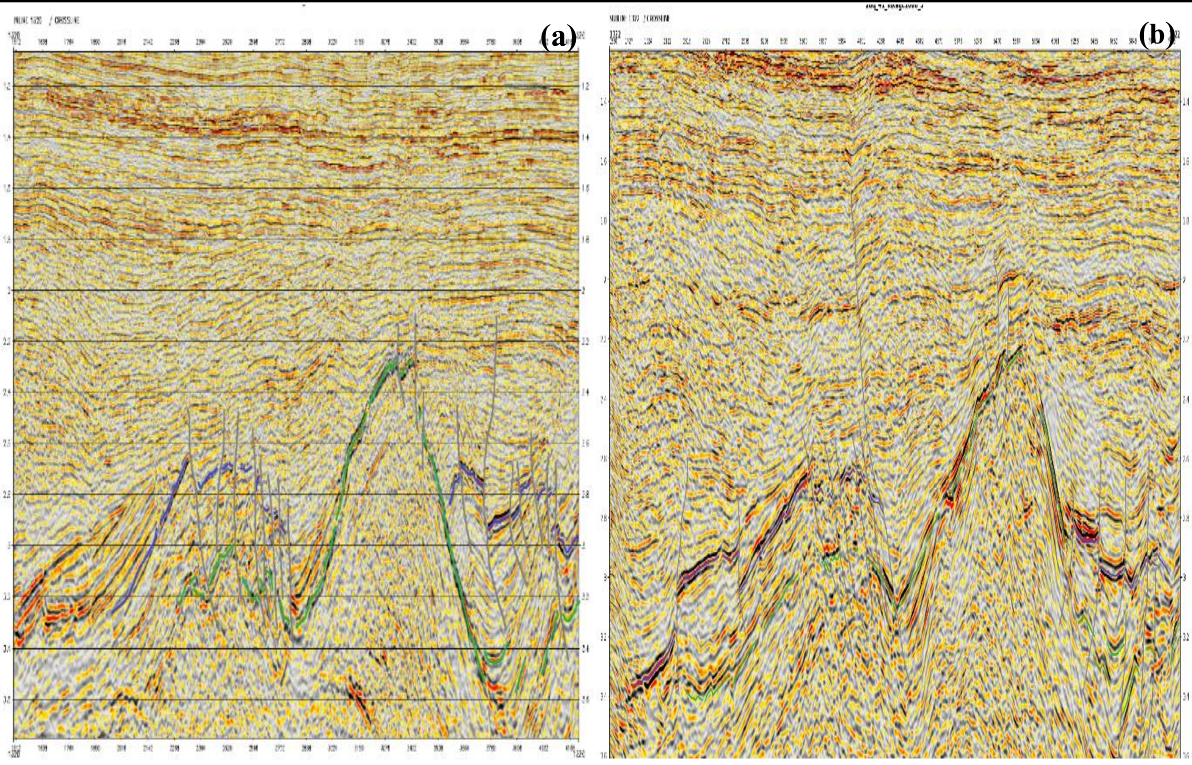

Figure 5: (a) 2009 vintage seismic section and (b) new re-process seismic section.

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