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Improved Imaging Inside Fractured Basement Using Broadband Technology, Offshore Vietnam

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SUMMARY

The oil-bearing fractured granite basement rocks are a very important and complicated hydrocarbon reservoir offshore Vietnam. In this paper, we present a case study demonstrating improvements to the fracture imaging in the Cuu Long Basin offshore Vietnam through broadband technology, which not only provides great uplift in the low frequency penetration but also makes it possible to incorporate TTI/HTI anisotropy inside the granite basement. We will review the issues with conventional data and present the new approach, the result and its importance as to the interpretation for drilling.

Introduction

The oil-bearing fractured granite basement rocks form a very important and complicated hydrocarbon reservoir in Cuu Long Basin offshore Vietnam. Ever since the first discovery of White Tiger field in 1987, oil has continued to be discovered and produced in the fractured granite basement which now accounts for 80% of Vietnam’s total annual production (Tran et al., 2008). Reservoir quality in the basement is directly linked to the fracture development, which can be highly variable in any given oil field. The fracture imaging quality and accurate position are essential to the successful identification of fracture zones within basement reservoirs and the interpretation of individual fracture/damage zones for input into the geological model. However, the lack of good low frequency signal in the conventional flat tow survey acquisition often prevents clear and accurate fault/fracture imaging inside the basement, creating difficulties for seismic interpretation.

Variable-depth streamer acquisition, as one of the widely-used marine broadband solutions, has shown great advantages in providing high resolution seismic imaging and better low frequency penetration than conventional data from examples around the world (Lin et al., 2011). Normally the maximum streamer depth is deployed around 50m to give better low frequency signal and pick up less ambient noise; however, for the most part in Cuu Long Basin, the average water depth is around 40m with some areas even shallower than 30m. The shallow water environment and heavy fishing activity put a strong challenge to the deployment of variable-depth streamers in this region. In this paper, we will review the acquisition and processing of the first marine broadband survey in Cuu Long basin, and present the uplift in the fracture basement imaging and its impact on drilling.

Broadband acquisition

This survey is located at Block 15/01 in Cuu Long Basin, offshore Vietnam, where the water depth ranges from 27m to 50m. With the main objectives of the survey being to improve the top basement delineation and the intra-basement fracture imaging for fault network mapping, it is of utmost importance to improve the signal penetration inside the basement, especially the low frequency. Therefore, it is preferred to tow the streamer as deep as possible. Figure 1(a) shows the cable profile used in this survey: Four 6km-long solid streamers were deployed with 75m cable separation. Cable depth increased from 5m to 25m around 3000m and then remained at 25m till the maximum cable length. This profile design maximizes notch diversity in the shallow target and provide sufficient low frequency penetration in the deep basement targets. Typically, 5m is an acceptable safety distance between the streamer and the sea bed with high resolution bathymetric data. The streamer is raised during acquisition to cover areas of the prospect where the water depth becomes too shallow for the proposed profile. Streamer depth control and lateral steering are achieved by the intergrated acoustic range measurement and streamer control system.

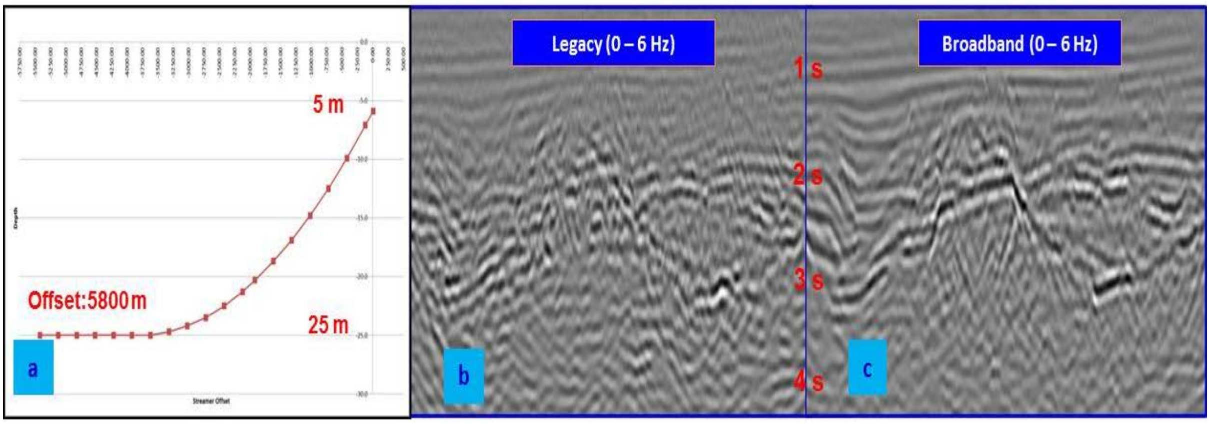

Figure 1: *(a) Broadband cable profile; (b) Legacy PSDM stack (b); (c) Broadband PoSTM stack*

A fast track post stack time migration (PoSTM) volume was quickly generated after the acquistion, with Tau-P deconvolution for multiple attenaution and post stack joint deconvolution for ghost attenuation to assess the data quality. Compared with the legacy PSDM stack from the 2004 survey (receiver depth 7m), the new broadband data have much better low frequency signal and thus provide more continuous top basement and clear fracture imaging although the processing flow is far from optimum (Figure 1 (b) & (c)).

Pre-migration deghosting and demultiple

One of the main concerns from the fast track post stack time migration volume is the residual multiple inside the basement, either in the form of residual surface multiples or inter-bed multiples. Before we can apply a comprehensive demultiple flow, it is necessary to remove the ghost influence which changes from channel to channel. Ghost wavefield elimination (GWE) using a bootstrap algorithm (Wang et al, 2013) is applied to remove the receiver ghost. This is a data driven approach to iteratively derive the pseudo-3D ghost-delay times in the Tau-P domain. These ghost delay times are then used to estimate the ghost-free data through a least-squares inversion. GWE can also re-datum the ghost-free data to the water surface during the inversion. Figure 2 (a) shows a middle channel before deghosting, (b) resulting upgoing wavefield (ghost-free data) and (c) the downgoing wavefield (ghost) all re-datumed to the sea surface. After GWE, we can see that the upgoing wavefield and downgoing wavefield are almost identical after re-datuming and the receiver ghost notches have been removed from both amplitude spectra. Both primaries and multiples are deghosted which means that we can apply the advanced demultiple technologies developed for conventional data on this broadband dataset.

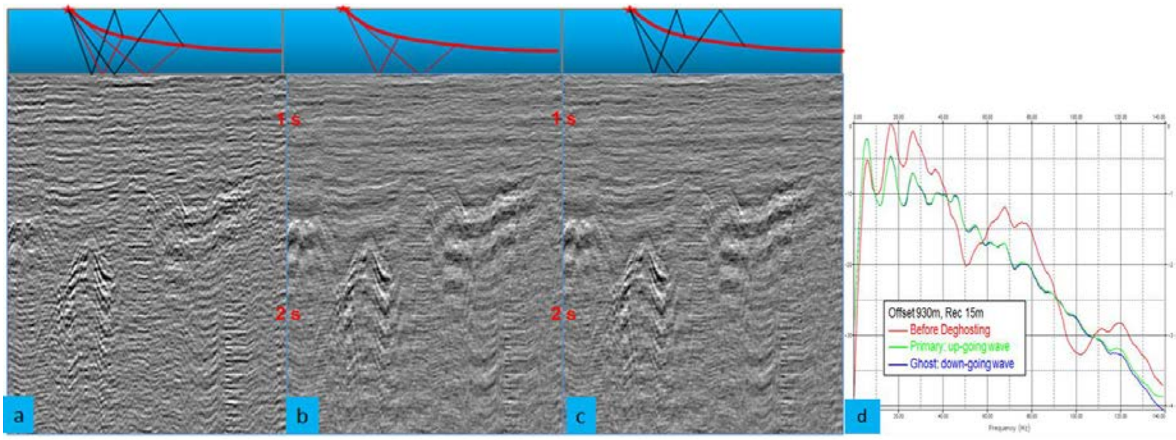

Figure 2: *(a) Mid channel before deghosting; (b) Mid channel of upgoing wavefield; (c) Mid channel of downgoing wavefield; (d)Spectrum before and after deghosting*

Next, a comprehensive demultiple flow was applied to tackle both the surface related multiples and interbed multiples:

- Shallow water demultiple (SWD)
- 3D surface related multiple attenuation (SRME)
- Inter-bed demultiple (ISS)
- Tau-P deconvolution
- High resolution Radon demultiple

A two-step surface related multiple attenuation approach (Yang and Hung 2013) was applied by targeting the short-period and long-period multiples separately using a multichannel prediction filter and 3D SRME respectively. For inter-bed multiples, the inverse scattering series (ISS) method is a data-driven approach that can predict all internal multiples of a given order without any subsurface information (Hung 2012). By applying ISS, the high frequency inter-bed multiples were effectively removed, hence improving the event continuity. The majority of the multiples are removed from the data as shown in Figure 3, the notches from the multiples are removed from the spectrum and the the amplitude spectrum curve is much smoother.

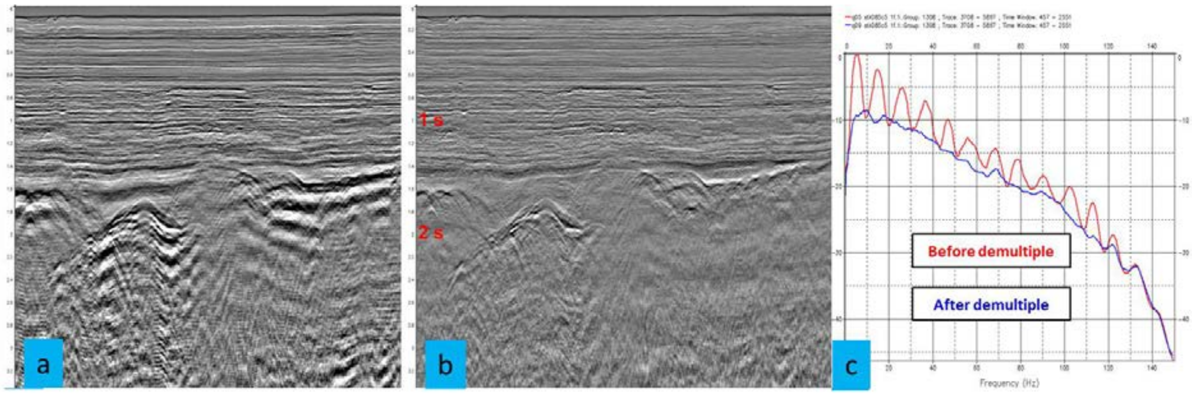

Figure 3: *(a) Stack before demultiple;(b) Stack after demultiple;(c) Spectrum before/after demultiple*

Velocity model building inside basement

In the case of the basement being highly fractured, sound waves travel faster along the vertical direction (or along the main fracture direction) than along the horizontal direction perpendicular to fractures. TTI anisotropy should be introduced to solve the conflict between imaging velocity and well velocity inside the basement, which is generally much faster (>5000m/s) than the imaging velocity from velocity sweeping. Zhou et al. (2011) proposed a double sweeping method to derive the epsilon (ratio between vertical velocity and horizontal velocity minus one) and theta fields (slow velocity azimuth angle) for TTI in the basement. However, the effectiveness of this method is limited for the legacy dataset: hardly any coherent fracture events can be picked up during the velocity sweeping process. Figure 4 shows the impact of the velocity field by comparing the PSDM Kirchhoff stacks with the legacy VTI velocity and the new TTI velocity field. Although both migrations use the same broadband input, the new TTI velocity field gives much clearer/more coherent fracture imaging. The additional low frequency signal from Broadband data plays an important part in the fractured basement imaging: better S/N ratio intra basement and thus better velocity estimation inside the basement.

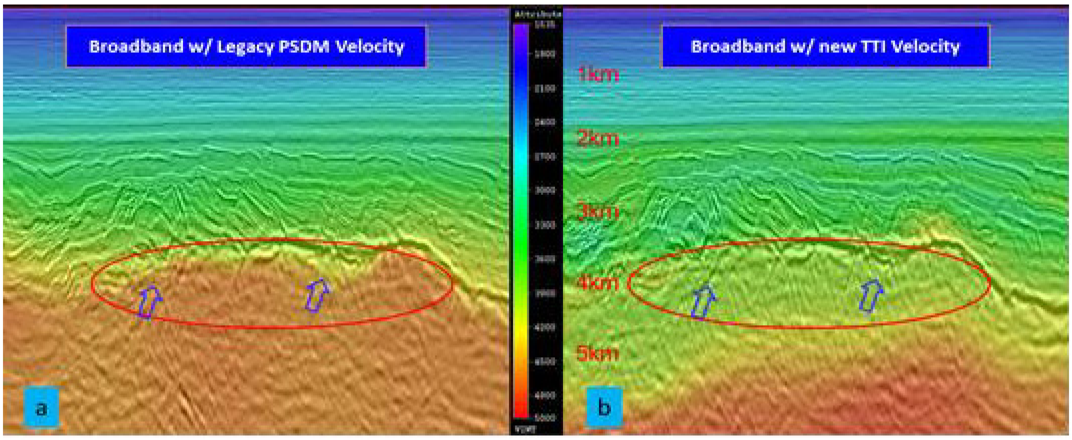

Figure 4: *PSDM Kirchhoff stacks: (a) with the legacy VTI velocity ;(b)with the new TTI velocity field*

Final results and impact on interpretation

Controlled Beam Migration was used in the final migration to further reduce migration artifacts, to enhance signal-to-noise ratio and to preserve the relative amplitude. Compared with the legacy CBM result, the new broadband CBM image provides a step change in the imaging quality: broad bandwidth in the clastic section with high resolution, reduced side lobes, rich texture, sharp fault imaging and most importantly much clearer/improved fracture imaging inside basement. Based on the new result, a severely fractured zone has been identified which also explains a great mud loss during previous drilling crossing that area. Two new horizontal wells have been designed based on the new data to intercept the key open fractures in this field.

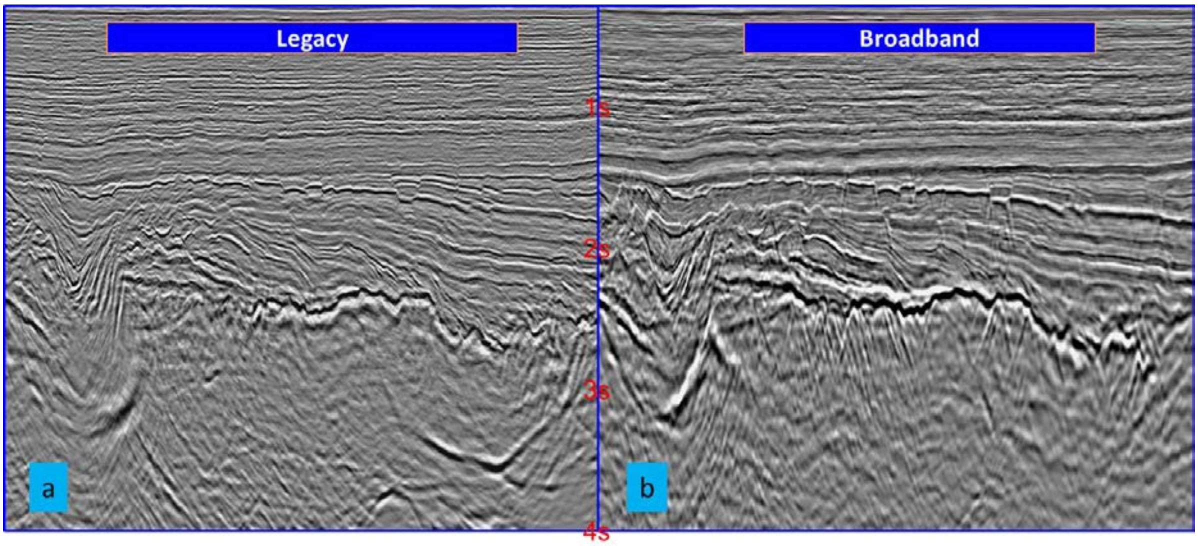

Figure 5: *CBM stack stretched to time: (a) legacy conventional; (b) Broadband*

Conclusion

This case study demonstrates the flexibility and value of variable-depth streamer technology in shallow water environment. It also provides an effective and efficient solution for the fractured granite basement imaging offshore Vietnam.

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