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Depth Velocity Model Building beyond Reflection Tomography, a case study, offshore Vietnam

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SUMMARY

In the Southeast Asia offshore exploration, shallow reefs and channels, widely spread volcanic rocks and basement fracture system are some of the major challenges in seismic imaging. Geo-mechanical modeling, reflectivity inversion and TTI/HTI modeling in basement are introduced in this area. Together with the conventional reflection tomography, they generate high resolution velocity model for PSDM thus provide much needed imaging uplift.

Key words: geo-mechanical modelling, reflectivity inversion, TTI/HTI

INTRODUCTION

In the oil rich Cuu Long Basin, Offshore Vietnam, shallow reefs and channels, widely spread volcanic rocks and basement fracture system are some of the major challenges in seismic imaging. However, conventional reflection tomography has hard time to provide accurate and high resolution model to solve these challenges and other model building techniques are needed to introduce those velocity anomalies. First, reflection tomography has limited resolution at shallow (50-400m) because of limited number of offsets. So geo-mechanical modeling is used to put fast and slow velocity of reefs and channels. Second, the intrusive and extrusive volcanic rocks are too thin (around 50m-100m) to be resolved by tomography. Reflectivity inversion is used to derive the high resolution velocity of the volcanic rocks. Third, TTI/HTI anisotropy is used to simulate the situation, that image velocity is always much slower than well sonic velocity inside basement, and improve the image.

Overall, geo-mechanical modeling, reflectivity inversion and TTI/HTI modeling in basement, together with the conventional reflection tomography, generate high resolution velocity model for PSDM thus provide much needed imaging uplift.

Geo-mechanical modeling

The geo-mechanical modeling (Sergey, 2008) was used to model the velocity at reefs and channels. Velocity models for the shallow sediments affected by variable water depth or shallow reefs and channels can be more effectively restored using geo-mechanical approach. Geo-mechanical modeling calculates anomalous geo-stress from reefs and channels and transforms it into interval velocity variations.

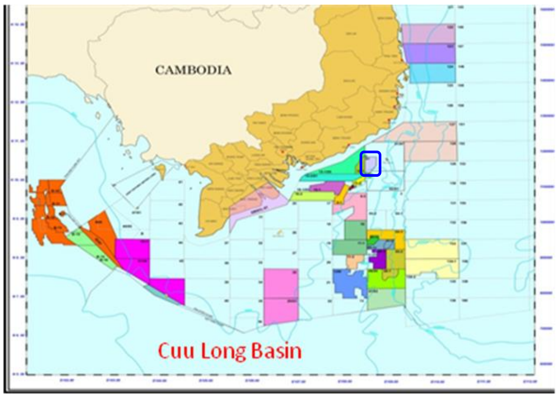

Figure 1. Cuu Long Basin, Offshore Vietnam and the area of case study (Blue)

Reefs and channels were treated slightly differently:

- For reefs, top of reefs was picked; faster velocity perturbation was introduced by geo-mechanical modeling. Then the wrongly positioned deeper fast velocity was smoothed out.
- For channels, bottom of channels was picked; slow velocity was inserted in channels. Then additional slow velocity below channels was introduced by geo-mechanical modeling.

In Fig 3a, the initial smoothed velocity is displayed with stack section. The water depth is about 40m but the water bottom wavelet is not well recorded due to limited near offsets in seismic acquisition. The red line is the top of the reef. The pull-up events from 300-1000m below reef are not real structure, but the imprint of reef. There's a fast velocity layer from 600-800m in initial velocity. It's the fast velocity from reef but wrongly positioned in PSTM RMS velocity analysis, due to limited number of offsets above 300m. The yellow line in Fig 3a indicates the gathers range for comparison in Fig 3c and 3d.

In Fig 3b, the velocity inside reef follows the top of reef after geo-mechanical modeling, which is faster. The anomalous fast velocity layer between 600-800m is much reduced. The imprint of reef has been removed in the stack section.

In Fig 3c and 3d, gathers are displayed around the reef with 70 degree angle mute. It's clear that reflection tomography is hard to work due to limited number of offsets at shallow part. Gathers are much flatter after geo-mechanical modeling.

In Fig 4a and 4b, the velocity and stack are displayed around the channels. The velocity follows the bottom of channels and imprint of channels in the stack section have been removed after geo-mechanical modeling. In Fig 4c, the perturbation of geo-mechanical modeling is also displayed.

Reflectivity inversion

We used the reflectivity inversion method proposed by Shuo Ji (Shuo et al., 2010) to model the very thin intrusive/extrusive layers.

1D reflection equation can be simply written as:

$$R = \frac{\rho_2 V_2 - \rho_1 V_1}{\rho_2 V_2 + \rho_1 V_1}$$

Where R is the reflection coefficient, ρ is the density, and V is the velocity. For the intrusive/extrusive rocks, the reflection coefficient at the boundary is very big. This can be easily identified in the seismic section.

To model the velocity of these layers, we will start with a true-amplitude Kirchhoff PSDM volume.

- Convert seismic stack to acoustic impedance
- Filter out the smooth trend of acoustic impedance, keep the spikes only – which comes from intrusive/ extrusive layers
- Calibrate with well data using global scalar - this is necessary as we don't have exactly density information.
- Add the fast velocity layers to input velocity.

In Fig 5a, the velocity after reflectivity inversion is displayed. High resolution velocity model was built for intrusive and extrusive layers. In Fig 5b and 5c, two well velocity profiles are displayed. Red line is the final vertical velocity; blue line is the sonic P velocity. Final velocity profile with reflectivity inversion matches with well sonic velocity.

In Fig 6a and 6b, the stack and gathers are displayed. Gathers around the intrusive/extrusive layers are flatter and stack is also improved a bit.

TTI/HTI inside granite basement

We used the TTI/HTI modeling flow for granite basement introduced by Joe in 2010 (Joe et al., 2010). Reflection tomography doesn't work for basement fracture because of low S/N ratio and not enough coherent events. So CBM stack sweeping is used to estimate the best image velocity in basement. But the image velocity of granite basement fracture is always slower than the sonic velocity from well. In this case, one direction of horizontal velocity is slow for fracture image, and vertical velocity is as fast as the sonic velocity.

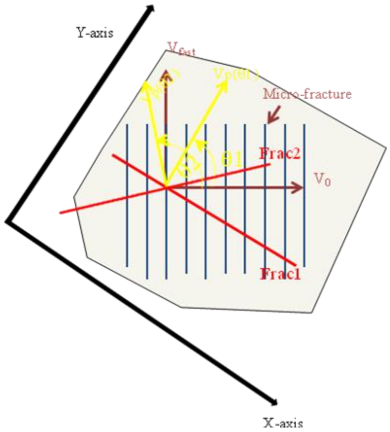

Fig 2. Example geometry of macro fractures in HTI basement

From Thomsen Equation:

$Vp(\theta 1)=V0(1+\delta \sin 2\theta 1 \cos 2\theta 1+\varepsilon \sin 4\theta 1)$
$Vp(\theta 2)=V0(1+\delta \sin 2\theta 2 \cos 2\theta 2+\varepsilon \sin 4\theta 2)$
…
$Vfast=Vv=V0(1+ \varepsilon)$

Where V0: Velocity along axis of symmetry
θ: Angle between direction of propagation(θfrac) and axis of symmetry (θsymm)
δ, ε: Thomsen's parameters, δ=ε for HTI case.
Vv: Vertical velocity

We start with reflection tomography to update the velocity above basement, then:

- Use CBM stack sweeping to estimate the best imaging velocity (isotropic velocity) inside the basement. The azimuth information of fracture is also register in the picking - Vp(θfrac).
- Estimate vertical velocity based on Well log
- Azimuth sweeping to find the best azimuth angle. For each picking location, the Vo/Delta/Epsilon will be updated based on the azimuth angle scanned.
- PSDM with final HTI velocity model.

In Fig 7, the depth slices in granite basement were displayed with different scanned azimuth, from 0 ~ 160 degrees, increment 20 degrees. The best image of fractures is between azimuth 80 and 100 degrees (defined in processing direction), which means slow velocity direction is NE-SW. From FMI, the dominant micro fracture direction is NW-SE, which will generate slower velocity in NE-SW. So the scanned azimuth matches with well log. Further, the macro fracture which can be seen in seismic has dominant direction NE-SW, it's almost perpendicular to the micro fracture direction in this area.

Result and impact on exploration

In Fig 8a and 8b, the previous Kirchhoff PSDM was compared with the new High Fidelity Beam, HFCBM result. In the new result, the imprint from shallow reef has been removed; clastic layer has higher S/N ratio above Top basement; Top basement is clearly defined; fracture inside basement is clear and sharp. This will optimize the deviated Wells drilling angle to maximize fractures penetration.

CONCLUSIONS

We have demonstrated the value of the technologies beyond reflection tomography in Offshore Vietnam. Together with conventional reflection tomography, they produce higher resolution velocity model for PSDM image.

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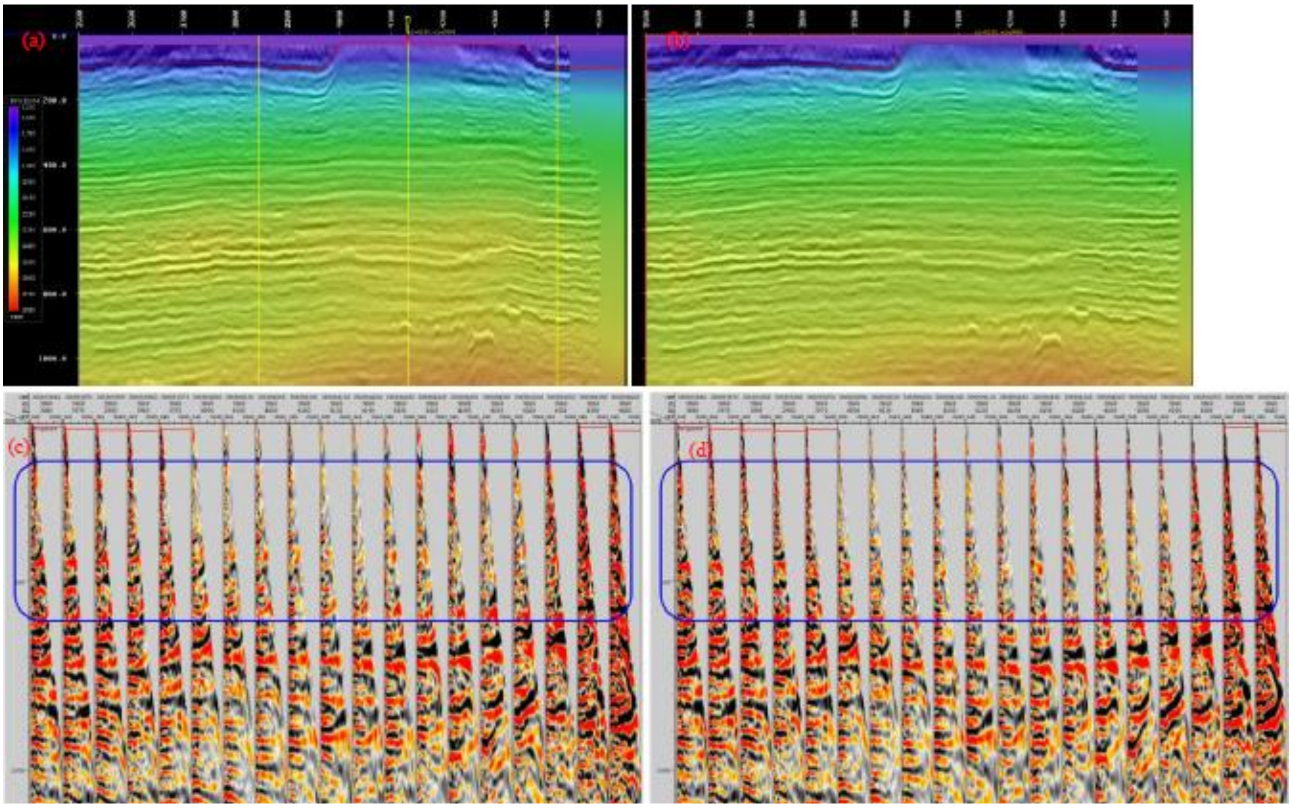

Fig 3: (a) initial velocity and stack around shallow reef (b) velocity and stack after geomechanical update (c)gathers around shallow reef (d) gathers after geomechanical update

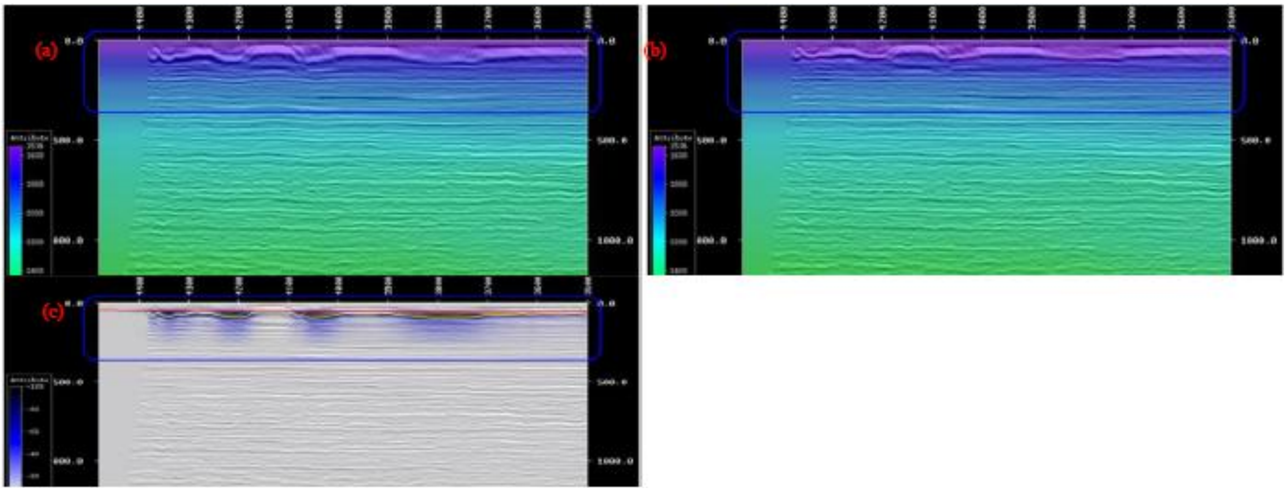

Fig 4: (a) velocity and stack around shallow channels (b) velocity and stack after geomechanical update (c)velocity difference of (b)-(a)

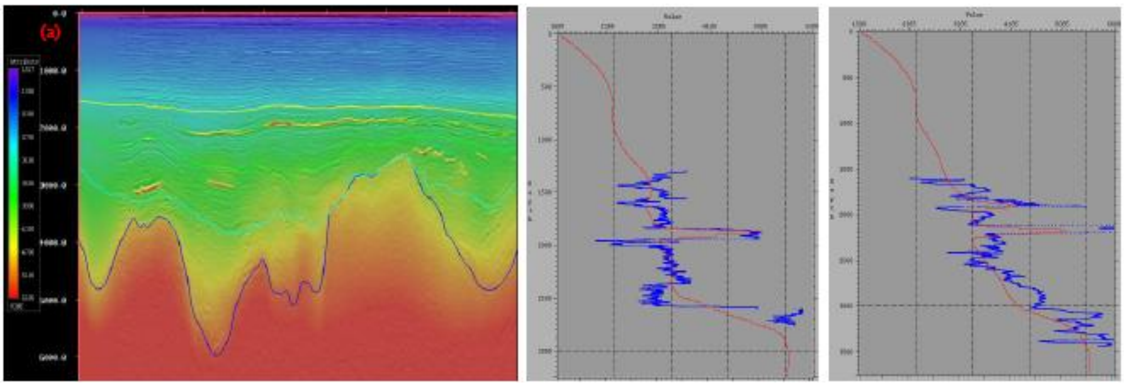

Fig 5: (a) Velocity after reflectivity inversion (b) and (C) 2 well profiles. Red – final vertical velocity, blue – sonic velocity

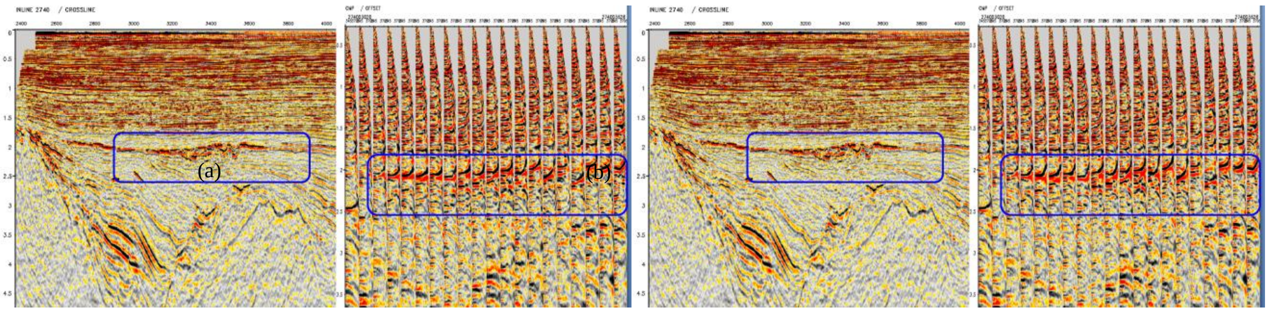

Fig 6: (a) stack and gathers around extrusive layers (b) stack and gathers after reflectivity inversion.

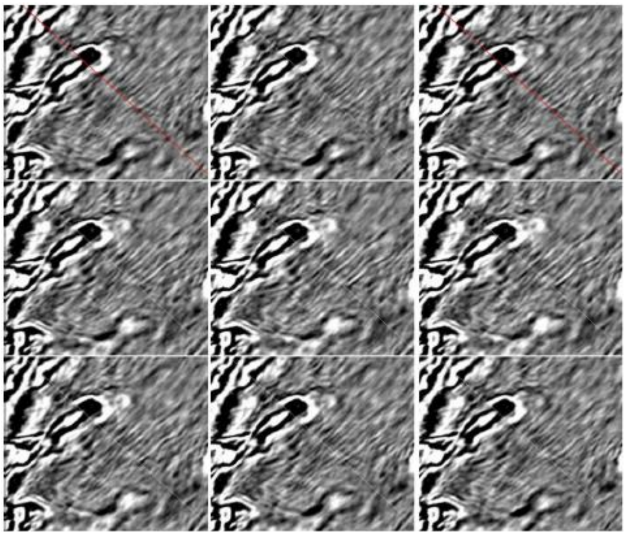

Fig 7 depth slice inside basement of different scanned azimuth, from 0-160 degrees, increment 20 degrees.

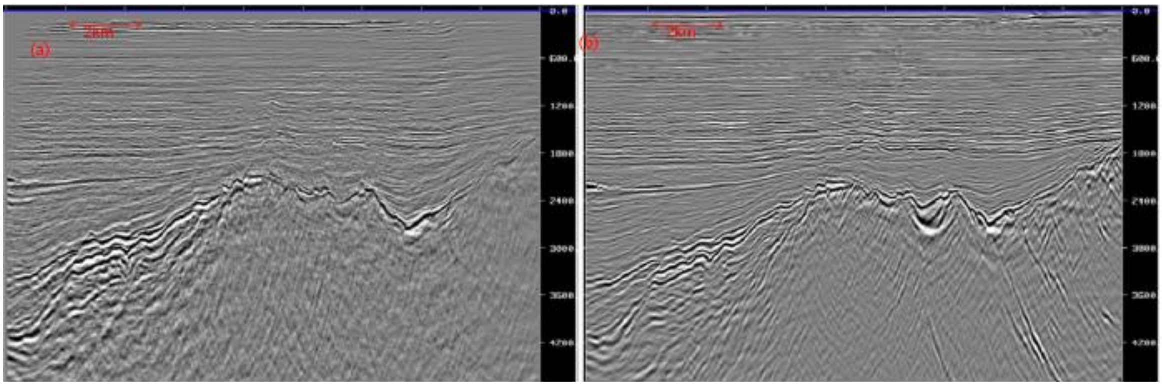

Fig 8 (a) Kirchhoff PSDM stack (b)HFCBM stack