Multi-azimuth PSDM processing in the presence of orthorhombic anisotropy -- a case history offshore North West Australia

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SUMMARY

In this paper we present a case history of multi-azimuth 3D PSDM processing. The datasets show strong HTI as well as VTI anisotropy. We show the processing workflow with emphasis on the construction of an imaging velocity model that correctly represents the orthorhombic anisotropy and short-wavelength velocity variations. The PSDM image is improved over earlier processings.

Key words: Orthorhombic anisotropy, Multi-azimuth, Tomography

INTRODUCTION

In this paper, we present a case history of 520 sq.km multi-azimuth (MAZ) 3D PSDM processing in an area at the northwest margin of the Timor Sea, offshore Australia. Seismic data over the area were acquired in the Onnia Survey, 1999 and the Pantheon Survey, 2005. The two surveys were acquired at an angle of 105 degrees from each other. Both datasets had been processed independently with limited success, before the current MAZ reprocessing. The geological cause of the unsatisfactory imaging includes severe faulting, which causes poor illumination beneath and shallow cementation zones (HRDZ) that cause distorted structures (pull-ups). In addition, the data exhibit strong HTI as well as VTI effects, which require the use of an orthorhombic velocity model and imaging tools. The theory and algorithm for orthorhombic PSDM imaging was developed by Xie et al. (2011). However, the challenge is the construction of an orthorhombic depth-velocity model.

The MAZ processing consisted of a few major stages:

- Preprocessing of each survey which includes denoise and demultiple.
- Regularize the two datasets to a common grid.
- Building a 3D orthorhombic velocity model.
- 3D orthorhombic PSDM.
- Post-migration processing that includes further noise removal, residual moveout corrections and stacking of each survey.
- Optimized stacking using individual stacks as input.

We will focus on the PSDM velocity model building in the following sections.

VELOCITY CONSTRUCTION AND UPDATE BY TOMOGRAPHY

The initial velocity model was constructed by smoothing the Pantheon 2007 PSDM processing velocity model. The velocity model update is performed in a series of nine iterations of 3D residual curvature based tomography. Each iteration consists of:

- 3D PSDM on a grid of CMP points: The Pantheon and Onnia datasets were migrated separately.
- Depth residual moveout picking. The Pantheon and Onnia datasets were picked separately to preserve velocity /anisotropy difference in moveout.
- Dual azimuth seismic tomography was performed to transform the measured residual moveout into a new and more accurate velocity model.

Although we anticipated the presence of azimuthal anisotropy, we still used isotropic velocity for the first iteration, to see if it was possible to reconcile the moveout of both datasets by a tomographically updated isotropic velocity model. After the initial iteration, we still observed significant and consistent differences in depth residual moveout between the Pantheon and Onnia datasets. It was not possible to ignore this effect and process the dual azimuth data with a single isotropic velocity model. The velocity model had to be upgraded to incorporate azimuthal anisotropy to account for the azimuthal dependent residual moveout. Iteration 2 and onwards used an orthorhombic velocity model.

ORTHORHOMBIC VELOCITY

The theory and algorithm for imaging in orthorhombic velocity media was developed by Tsvankin (1997) for weak anisotropy and Xie et al (2011) for stronger anisotropy. In its simplest form the velocity is described by 7 attribute fields. They are (see Figure 1):

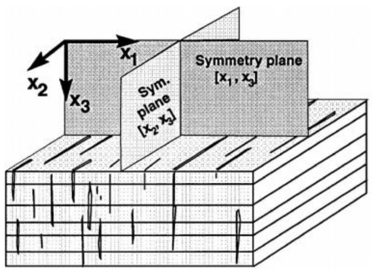

Figure 1. Definition of symmetry planes of orthorhombic velocity. From Tsvankin (1997).

- V_0, the vertical velocity.
- δ_1, delta in plane normal to axis x_1
- ε_1, epsilon in plane normal to axis x_1
- δ_2, delta in plane normal to axis x_2
- ε_2, epsilon in plane normal to axis x_2
- φ, orientation of axis x_1
- δ_3, delta in the plane normal to axis x_3

In each plane, the definition of delta and epsilon is the same as the Thomsen parameters. Together the seven attributes define the VTI and HTI behavior of the data. The orthorhombic anisotropy was introduced into the PSDM velocity model in two steps: firstly, we used dual-azimuth seismic data to estimate HTI component; then we compared seismic velocities with the well information and added the VTI component.

Azimuthal dependency of velocity can be represented by an ellipse. Independent measurement in three directions is required to uniquely define such a velocity field, i.e. the fast velocity, the slow velocity, and the direction of fast (or slow) velocity. However, we have only two datasets and have to make use of other information to help to define the velocity field. The first attribute to be defined is the orientation of the slow (or fast) velocity axis. After analyzing the data, we set the slow velocity in the direction of the Pantheon acquisition and the fast axis perpendicular to the Pantheon acquisition direction, as shown in Figure 2.

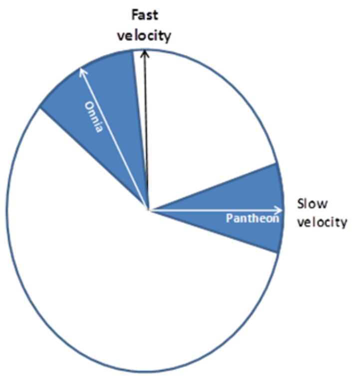

Figure 2. The slow velocity axis is parallel to Pantheon acquisition, and the Onnia acquisition is at 15 degree with the fast velocity axis. Due to multi streamer acquisition, the shot-receiver azimuths of data from each acquisition form a fan.

This leaves a 15-degree angle between the Onnia acquisition and the fast velocity axis. This decision is based on the following observations:

- In general, Onnia data exhibited faster velocities than Pantheon. The slow velocity direction should be closer to the acquisition direction of Pantheon than that of Onnia.
- Consistent azimuthal variations in residual moveout within individual sail-lines (acquisition footprint) are visible on Onnia residual moveout gamma volumes (Figure 3A), while it is not obvious on Pantheon data (Figure 3B). The footprint is more clearly seen in the difference volume between the gammas of Onnia and Pantheon (Figure 3C). In other words, for Onnia, data from the left and right streamers show significant moveout differences; while for Pantheon, the difference is small. This means that the slow velocity axis is parallel with the Pantheon acquisition direction. The 15-degree angle between the Onnia acquisition and the fast velocity axis explains the stronger acquisition footprint on Onnia residual moveout gamma volumes.

Having determined the orientation of slow velocity, we created a δ_3 volume for the HTI model (see Figure 5D). For the HTI model, we assumed that vertical velocity equals to the slow horizontal velocity, hence $\delta_1=\varepsilon_1=0$ and $\delta_2=\varepsilon_2=-\delta_3$. Figures 3D and 3E show the residual moveout gamma volume for Onnia and Pantheon respectively after two iterations of velocity update after changing the velocity to the HTI model, and Figure 3F shows their difference. The footprint in Onnia gamma volume is greatly reduced while Pantheon still shows no footprint.

The HTI model achieved a good and consistent image. The model was then calibrated with sonic logs, check shots and formation markers at the well locations to form a fully orthorhombic velocity. Delta and epsilon are updated in the well calibration stage accordingly.

INCORPORATING HYDROCARBON RELATED DIAGENETIC ZONE (HRDZ)

HRDZ is the cementation of shallow rocks by leaked hydrocarbon. It is quite common offshore northwest Australia. It usually gives rise to very high-velocity zones. Ignoring HRDZ in the velocity model will result in non-geological structures in the image, such as pull-ups. It can also cause a poor image beneath. HRDZ was observed in the data, and the extent was delineated by interpreters. After the extent of HRDZ was defined, localized tomography was performed to update the velocity in the HRDZ. Including identified HRDZ geometry into the tomographic model update allowed to resolve very strong and short-wavelength velocity anomalies.

RESULT AND DISCUSSION

Figure 4 shows comparison of common image gathers migrated using initial isotropic velocity and the final orthorhombic velocity. The Onnia and Pantheon gathers were joined back-to-back to form butterfly gathers. There were significant and consistent moveout differences between Onnia and Pantheon data when using isotropic velocity PSDM. The moveout difference was minimized by using orthorhombic velocity PSDM. This allows the two data-sets to be better focused, form structurally consistent images, and achieve constructive summation in optimized stacking.

Figure 5 shows comparison of Pantheon PSDM stacks from 2007 processing and 2011 processing. The adequate representation of high-velocity HRDZ improved the data quality beneath it and avoided pull-ups. The fault zone images in the 2011 processing is better focused with good terminations compared to the 2007 processing, and the improvement is clearly associated with the correct representation of orthorhombic anisotropy in data.

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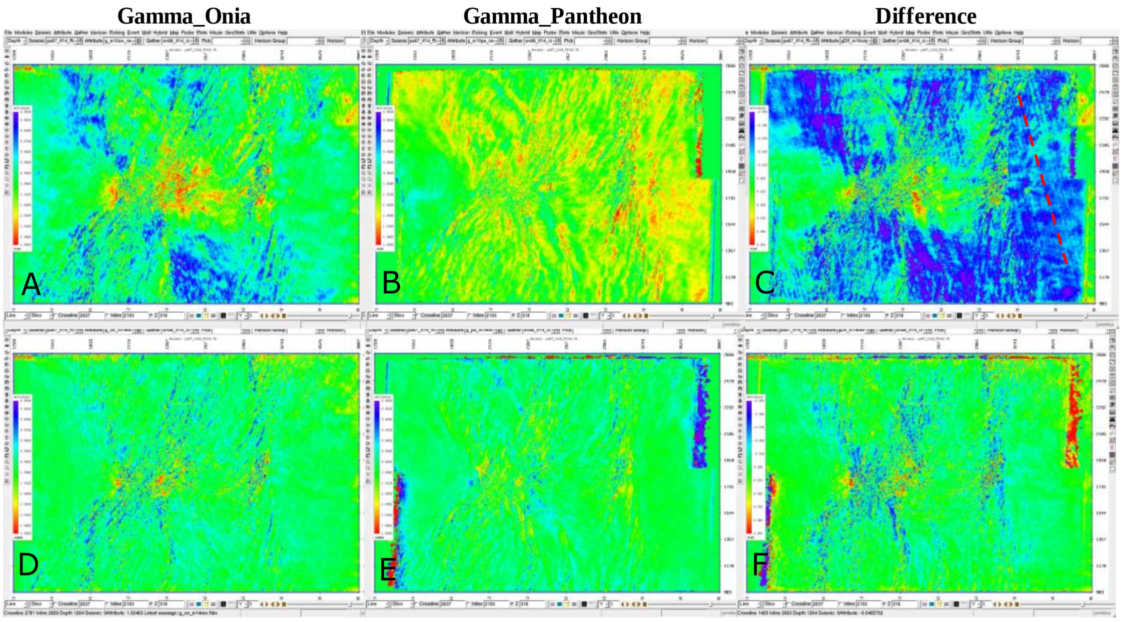

Figure 3. A & B: Depth slice of residual moveout gamma volume of Onnia and Pantheon data respectively, using isotropic velocity. C is the difference between A and B. Strong acquisition footprint in Onnia data is visible and is seen more clearly on the difference display. D, E & F: Same depth slices following velocity update after incorporating HTI anisotropy in the orthorhombic velocity model. Acquisition footprint in Onnia is greatly reduced, and the gamma difference between Onnia and Pantheon is overall closer to zero.

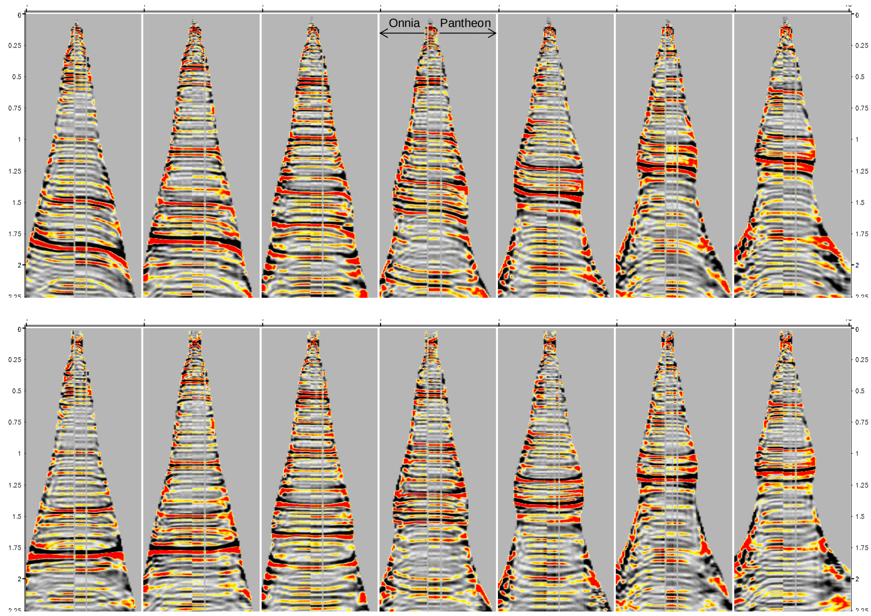

Figure 4. Above: butterfly gathers migrated using isotropic velocity. Below: corresponding butterfly gathers migrated using orthorhombic velocity model.

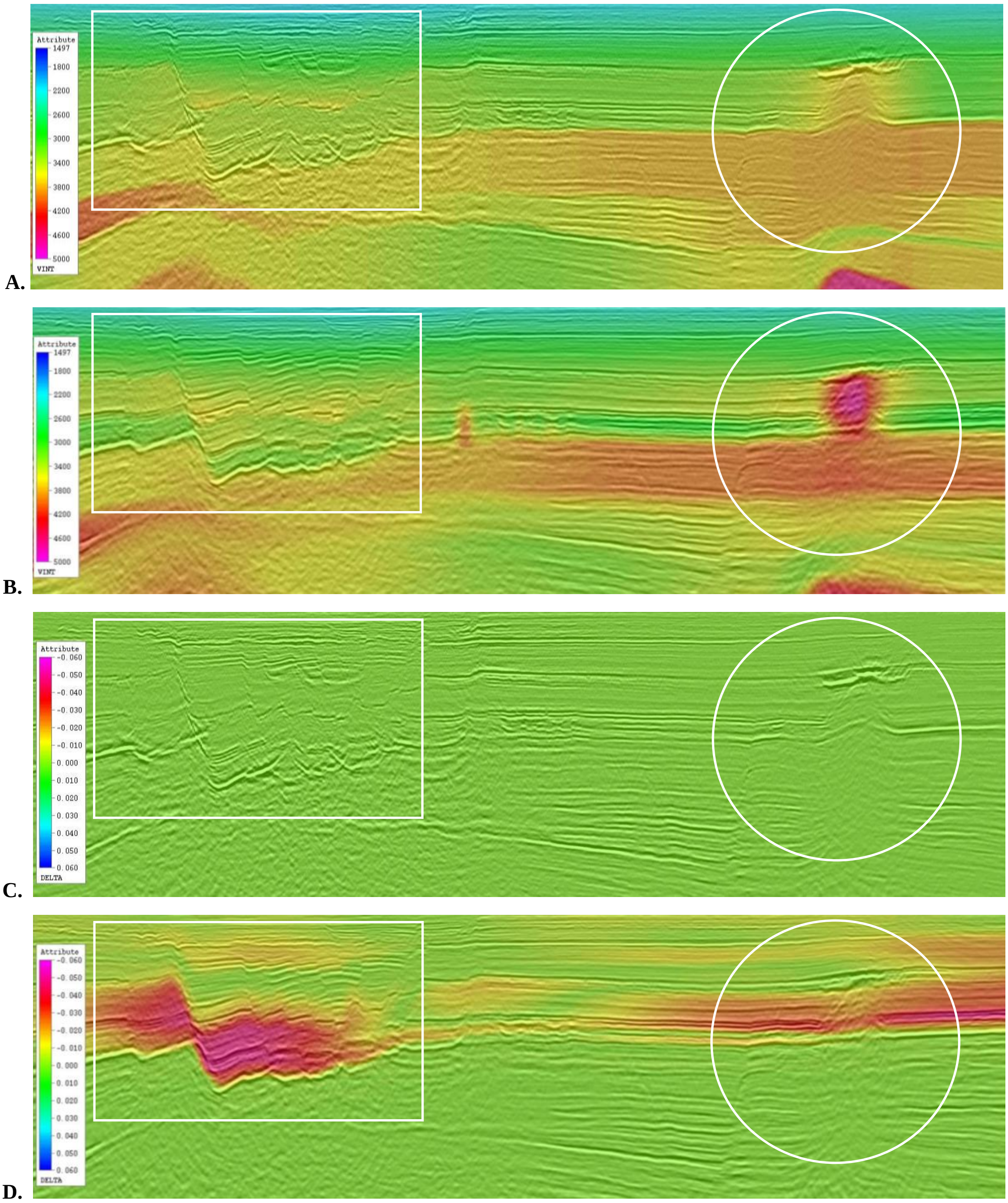

Figure 5. A. Pantheon 2007 PSDM stack overlaid with vertical velocity. B. Pantheon 2011 PSDM stack overlaid with vertical velocity. Comparing data in the circles, the 2011 velocity built in the high velocity anomaly due to the HRDZ. It is the reason for avoiding the pull-ups and improving data quality beneath the HRDZ. However the improved image of fault zone in the boxed zone cannot be explained by the difference in vertical velocity. C. Pantheon 2007 PSDM stack overlaid with difference of fast and slow velocities in percentage, which is 0. D. Pantheon 2011 PSDM stack overlaid with difference of fast and slow velocities in percentage. The improvement in the boxed zone is associated with correct representation of azimuthal anisotropy in the orthorhombic velocity model.