### Tu B3 04

# Adaptive Tomographic 3D MAZ PSDM Velocity Modeling with Tilted Orthorhombic Anisotropy. Example From NW Australian Shelf

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## Summary

We use real data examples from 4060 km2 3D Multi-Azimuth (MAZ) PSDM Fortuna project located in the North-West Australian shelf to present a workflow for 3D MAZ velocity modeling with tilted orthorhombic anisotropy. In this paper we focus on two aspects of depth-velocity model building that are extremely important for seismic data from the North-West Australian shelf: (1) high resolution adaptive seismic tomography to deal with strong velocity anomalies in complex geological settings and (2) practical workflow to build a tilted orthorhombic anisotropic PSDM velocity model in regions with complex velocity anomalies and strong horizontal and vertical anisotropy.

As seismic reflection tomography remains an important tool to build large scale depth-velocity models in seismic imaging, we discuss how an adaptive data driven approach to running tomography helps to provide accurate and robust velocity models in complex geological settings.

## Introduction

We present a workflow for 3D Multi-Azimuth (MAZ) PSDM anisotropic velocity model building (VMB) applied to Fortuna project located in Carnarvon Basin in the North-West Australian shelf. The project covers 4060 km$^2$ with geological settings and characteristics of the velocity model typical for this region. It uses two overlapping seismic surveys that were acquired with 73 degrees difference in acquisition directions (Fortuna in 2014 and Demeter in 2003). Figures 1 and 5 illustrate the final 3D PSDM anisotropic velocity model. The complex overburden includes high velocity carbonate layers and reefs embedded within lower velocity shale formations. This creates serious problems for seismic imaging of deeper target intervals and presents a real challenge for VMB. This area is also known for strong azimuthal velocity anisotropy, so successful wide- or multi-azimuth seismic imaging should be based on orthorhombic velocity modelling. Xie et al. (2011) presented the theory and algorithm for PSDM imaging with orthorhombic anisotropy based on Tsvankin (1997) set of parameters for orthorhombic media. Major practical steps of orthorhombic VMB were discussed by Birdus et al. (2012). In this paper we focus on two aspects of VMB that are extremely important for our geological settings: (1) high resolution adaptive seismic tomography that adjusts to complex geological conditions and strong velocity anomalies and (2) practical workflow to build a tilted orthorhombic anisotropic velocity model in regions with complex velocity anomalies and strong horizontal and vertical anisotropy.

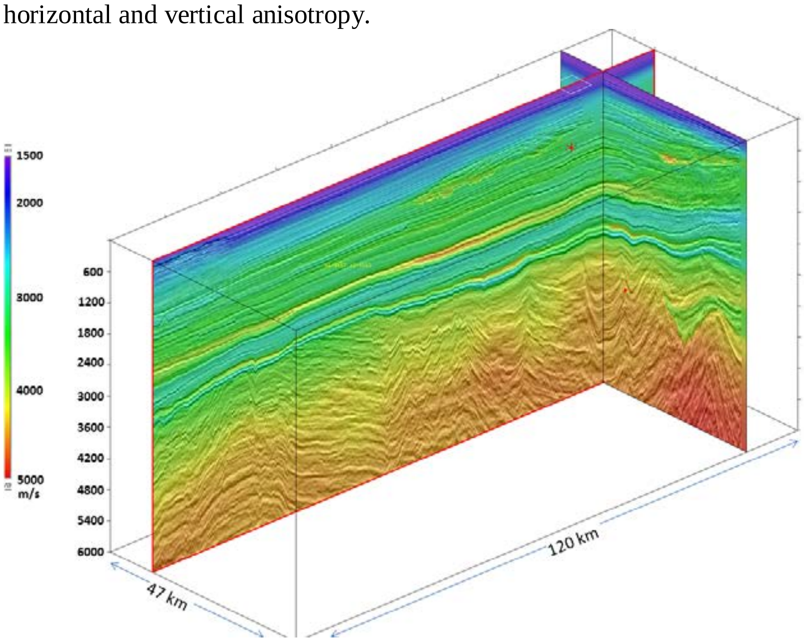

***Figure 1*** *Fortuna project - final PSDM velocity model overlaid on seismic image. All data courtesy Woodside Energy Ltd. and the participants of the Fortuna project.*

## Adaptive tomographic velocity model building

Seismic tomography remains an important velocity model building tool for seismic depth imaging (Lambaré et al., 2014), especially for large projects. When setting tomographic workflow and its parameters we take into account the fact that real seismic data is always contaminated by multiples and different types of noise and that some real events are too weak or distorted to be accurately picked. In real situations, it is not possible to automatically pick residual moveout (RMO) for all primary reflections (we pick only the strongest ones) and unfortunately, it is not possible to completely avoid picking some "wrong" events like multiples or noise. Even a small number of such wrong picks can cause a big negative impact on the velocity update. The main goal for setting parameters for automated RMO picking is to pick as many primary reflections and as little noise as possible. This process is very subjective and depends on seismic data quality, geology and experience of the processor. Also, seismic tomography can use certain user-defined criteria to exclude some wrong picks from the velocity inversion. We strive to set optimal parameters for automated RMO picking and subsequent 3D seismic tomography. We create and analyse illumination volumes (Figure 2) that show how many RMO related rays cross each subsurface cell. This illumination describes how accurately the ray-based seismic tomography updates velocities for different locations in the subsurface. As expected, the illumination is highly variable (Figure 2A). Unfortunately, every velocity anomaly that is strong enough to distort the seismic image on deeper intervals inevitably reduces our chances to pick reliable RMO and thus decreases the illumination of the anomalous area and lowers our ability to recover that velocity anomaly. Another noticeable effect is that convex geometry of some events on the seismic image (corresponding to structural highs) always leads to de-focusing of the image rays in the overburden and reduces the illumination. Some other effects can also impede the illumination. In a real situation all these effects exhibit themselves together and seriously hinder standard velocity modelling in areas with strong velocity variations and complex structures. Arrows on Figure 2A point to several zones of low illumination on our dataset.

We resolve this problem by applying an adaptive tomographic workflow. First, we analyse the illumination volume and identify problematic zones with impeded illumination (Figure 2A). Then we manually pick additional RMO within these problematic zones making sure that all these additional picks represent only real primary events. We add a relatively small number of the additional manual RMO picks but as we are confident in their quality we give them higher weights to be used in the tomographic velocity inversion. These additional picks radically improve the ray coverage of the complex zones (Figure 2B). This is a completely data driven (adaptive) technique as we use the initial illumination as a guide to add manual picks in locations where they are needed. After having addressed the poor illumination in the “bad” zones we can review and change the parameters for automatic RMO picking with focus on the “good” areas. Figure 2C illustrates the final illumination achieved by our adaptive tomographic workflow with significant improvement over the standard approach (Figure 2A). All parameters in the standard approach are based on a compromise between conditions in “good” and “bad” zones. The parameters in the adaptive workflow depend on a compromise between “good” and “improved bad” zones. A few days of additional work on manual RMO picking for the 4060 km$^2$ Fortuna project led to a high resolution velocity model (Figures 1 and 3) and saved us weeks of fruitless efforts to achieve similar results with the standard tomographic workflow.

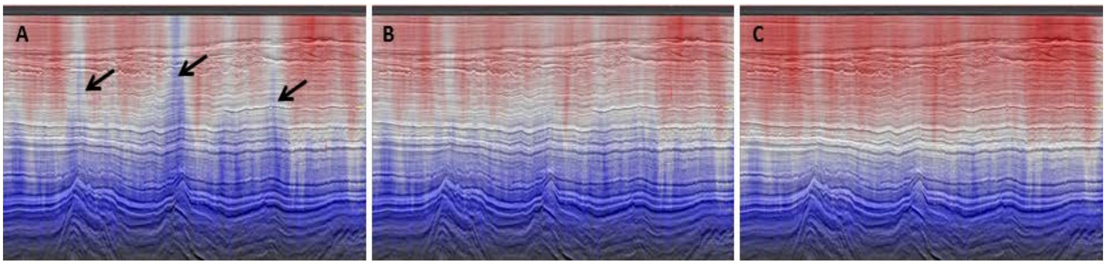

***Figure 2*** *Illumination of the subsurface by rays associated with RMO picks. Red and blue colours correspond to high and low illuminations respectively. (A) Standard approach, (B) with additional manual RMO picks and (C) adaptive workflow.*

## Tilted orthorhombic anisotropic velocity modelling workflow

(1) We started our VMB from a simple initial isotropic interval velocity model created from stacking velocities (Figure 3A). (2) The first two iterations of non-linear seismic tomography (Lambaré et al., 2014) focused on shallow intervals within a general top-down VMB strategy. Very soon we reached a situation where differences in RMO between the two seismic surveys included in the Fortuna MAZ project (73 degrees difference in the acquisition directions) became larger or comparable with the average RMO (Figure 4A).This was caused by horizontal azimuthal velocity anisotropy, which is well known in this area. We could not continue efficient use of MAZ tomography without taking it into account. So, (3) we focused the next two iterations on defining the azimuthal horizontal component of anisotropy (Figure 5D). Since only two azimuths are not enough to fully estimate the horizontal

anisotropy, we applied an additional analysis of RMO variations within individual sail-lines as described by Birdus et al. (2012) and set the constant azimuth of the fast horizontal velocity at 129 degrees along with the major regional stress direction and parallel to the Demeter acquisition direction. The azimuthal velocity anisotropy effectively removed the differences in RMO between the two surveys (Figure 4B).

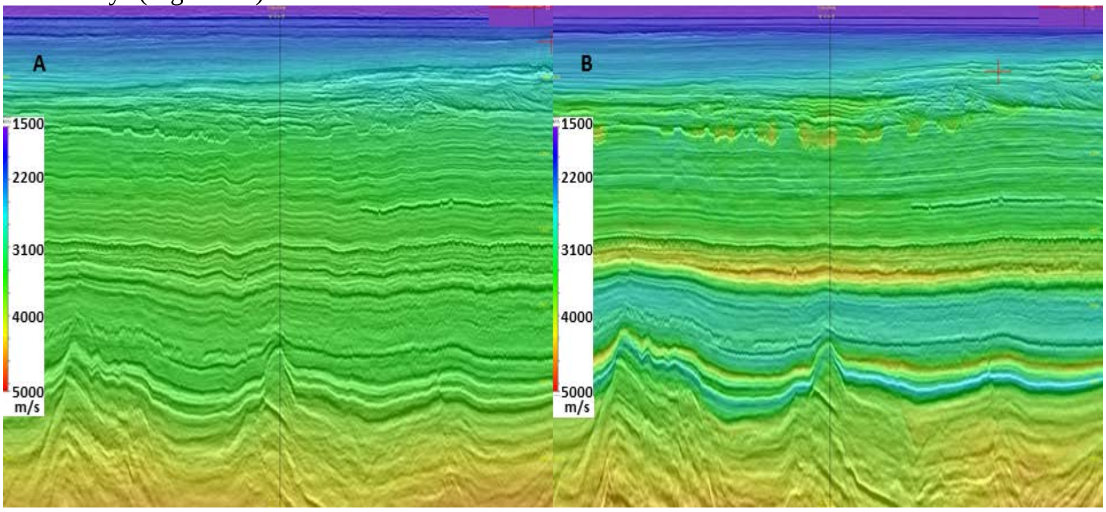

***Figure 3*** *(A) Initial velocity model and seismic image with visible distortions caused by unresolved velocity anomalies; (B) final velocity model and seismic image. The same line as shown on Figure 2.*

(4) We then continued with high resolution velocity updates, including the application of the adaptive tomographic workflow. (5) When the velocity model became mature enough with sufficiently determined main layers we used available well information (63 wells) to measure current depth misties and introduce the vertical elliptical component of the anisotropy (anisotropic parameter delta_1, Figure 5B). (6) Then we estimated the 4th order component of non-parabolic RMO to define the non-elliptical vertical component (anisotropic parameter eta_1, Figure 5E). (7) When all major events on the 3D seismic volume were correctly imaged and positioned, we measured and added a structural tilt to our model for layers with high values of delta_1 and eta_1 (Figures 5C, F). We did not introduce the tilt in shallow intervals with predominantly weak negative delta_1 and for the deepest part where our estimations of the anisotropy were less reliable due to a limited amount of well information and lower seismic data quality. (8) The final iterations of VMB were run with the full tilted orthorhombic velocity model with the main focus on the velocities in the deepest part of the section.

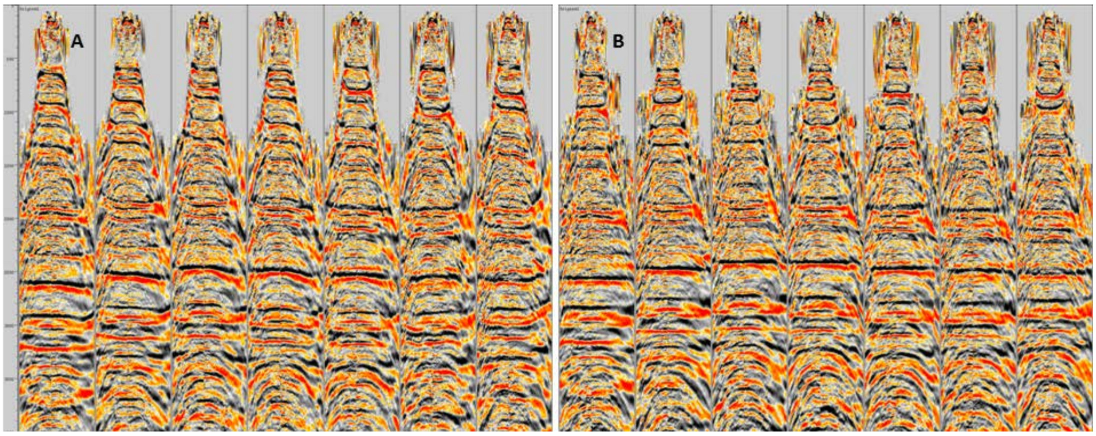

***Figure 4*** *Examples of PSDM butterfly gathers. Left parts – survey 1 (Demeter 2003), acquisition direction 129 degrees, max.offset 5125m; right parts – survey 2 (Fortuna 2014), acquisition direction 56 degrees, max.offset 7075m. (A) After two initial isotropic iterations, azimuthal differences in RMO can be seen; (B) after orthorhombic anisotropic VMB and PSDM, the azimuthal RMO removed.*

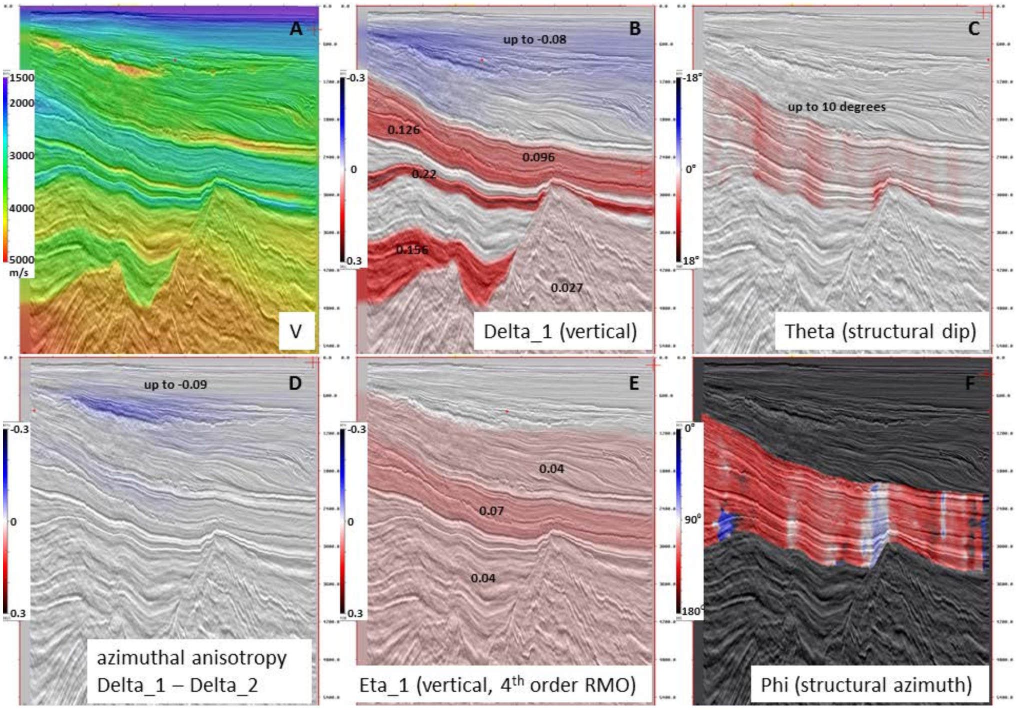

***Figure 5*** *Independent variable components of the final tilted orthorhombic velocity model.*

## Conclusions

We have presented a case study from the North-West Australian shelf involving a workflow to effectively build high resolution anisotropic velocity models in complex geological settings including strong velocity variations and azimuthal anisotropy. Within the standard top-down approach, the sequence is determined according to the magnitude of different effects and their importance for VMB. It is an iterative process with extensive use of well data, major horizons and a-priory geological information provided by interpreters with a deep knowledge of the area. We are currently extending our workflow to include the orthorhombic FWI and advanced techniques to increase resolution in the anisotropy. These should produce more detailed and accurate velocity models and seismic images.

## Acknowledgment

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## References

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