Making anisotropy in PSDM depth-velocity models conformal with geology and velocity. Case study from the NW Australian shelf.

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SUMMARY

We propose and successfully apply on a real 3D seismic dataset from the North-West Australian shelf a new technique that uses well information to correlate anisotropy with velocity for localized lithology driven anomalies. We assume that localized variations in both velocity and anisotropy are caused by changes in the lithology (shale vs carbonate vs sandstone etc). This should result in some correlation between anisotropy anomalies and velocity anomalies. We use well information to establish such a correlation. Our technique produces geology conformal PSDM anisotropic velocity models and reduces depth misties.

Key words: seismic anisotropy, imaging, depth misties.

INTRODUCTION

Having an accurate anisotropy model is very important for depth-velocity modeling especially for correct positioning of seismic reflectors in depth. Due to the intrinsic anisotropy uncertainty, the effective seismic velocity V_seis (seismic moveout) in VTI media depends on the true vertical velocity V_vert and anisotropic parameter δ (Thomsen 2002):

$$V\_seis = V\_vert * \sqrt{1+2\delta} \qquad (1)$$

The same effect is present in more sophisticated models for anisotropy (TTI, orthorhombic etc). If we use only seismic data we are not able to separate the two factors in the right hand side of equation (1), i.e., we cannot distinguish unambiguously arrival time variations due to velocity and anisotropy. This leads to uncertainties in depth/velocity estimations. This paper focuses on the elliptical component of anisotropy ($\delta = \varepsilon$), which is responsible for the depthing errors. We try to solve small and middle size anomalies when the major global trends are known.

UNCERTAINTIES AND DEPTH MISTIES IN ANISOTROPIC PSDM DEPTH-VELOCITY MODELING

We use seismic moveout, available well data and a-priori geological information to build the best possible imaging PSDM anisotropic depth-velocity model. We evaluate the quality of a model by the flatness of PSDM gathers, clarity of PSDM images and magnitude of well based depth misties. The problem with uncertainties is resolved by creating the simplest model that satisfies all input data. Traditionally we put all detected small scale anomalies into the imaging PSDM velocity volume and set the anisotropy values using some simplified smoothed models.

Depth misties for the well locations after PSDM depth-velocity modeling can be estimated by two methods: (a) we can compare seismic events on PSDM images in depth scale with corresponding geological well markers (examples on Figure 1C) or (b) we can compare check-shot based time-depth pairs with time-depth curves calculated for our PSDM velocity models (see examples on Figure 2C).

In general, two approaches can be used to reduce observed depth misties. The first is the standard "well calibration". We (1) locally compare/tie seismic velocities to the well data, (2) calculate vertical profiles of anisotropic parameter δ for the well locations that would remove the misties and preserve seismic moveout, (3) interpolate δ values between the wells and (4) create well calibrated vertical velocity and anisotropy volumes. This way, we can get zero (or significantly reduced) depth misties for the existing well locations and keep residual moveout unchanged. Such calibration has limited value as it is prone to "bull's eye" effect, often cannot be explained geologically, does not guarantee correct depthing for future well locations and can make subsequent well based uncertainty analysis meaningless.

The second approach is based on the idea that existing depth errors/misties are primarily caused by the intrinsic anisotropy uncertainty. They can be reduced if we solve this uncertainty by using additional information. Several researchers (Duranti 2010, Bachrach 2010) proposed similar models to tie anisotropy with velocity for shales as a function of the compaction load. These models describe global compaction driven trends that we observe in many parts of the world including the North-West Australian shelf: anisotropy increases in line with velocity within the shallow part of the model, reaches its maximum value at depth around 500-800m below the sea floor and can decrease at much deeper intervals (see examples on Figure 1B). Localized lateral velocity and anisotropy anomalies cannot be described by this "shale compaction" model because they are caused by changes in the lithology (shale vs carbonate vs sandstone etc) happening at the same depth. In this paper we propose and apply a technique that uses well information to find geology consistent anisotropy-velocity correlation for such localized lithology dependent anomalies and reduces depth misties in geology consistent manner.

REAL DATA EXAMPLE

We illustrate the proposed workflow on a 2300 sq km 3D marine dataset from the North-West Australian shelf. Figure 1 shows the initial isotropic interval velocity model created from Vrms and corresponding PSDM image. Depth misties were estimated by comparing 2 target horizons on PSDM volume (depth interval 2.5-3.0 km) with geological markers in 8 wells (blue dots on Figure 1C). All the misties were positive. This meant that the initial isotropic imaging velocities were too fast.

Blue lines of Figure 2A are vertical profiles of the initial velocity at well locations. Blue lines on Figure 2C are depth misties estimated by comparing available check-shot time-depth curves with time-depth values calculated for the initial velocity model at the well locations. At target level, these misties are similar to the misties based on geological markers (Figure 1C).

Standard 3D anisotropic tomographic depth-velocity modelling produced a model shown on Figure 3 (also see green lines on Figure 2). Velocity model (Figure 3A) now includes significant localized velocity variations mainly associated with layers of high velocity carbonates within relatively low velocity shale material. Anisotropy model (Figure 3B and green lines on Figure 2B) followed the generalized shales compaction trend. Anisotropy values were tied to the sea floor depth without any lateral variations except for a decrease at the major regional unconformity. Anisotropy values were calculated to minimize the depth misties and satisfy a-priori geological expectations.

As we can see on Figures 2C and 3C, the standard anisotropic velocity modelling removed the global trend in depth misties. Now all misties are centred around zero with the standard deviation decreased from 34.6m (the initial model) to 12.6m. Observed variations between minimal and maximal misties were reduced from 104m to 35m. These numbers give a quantitative measure how the standard depth-velocity modelling reduced the structural depth uncertainty.

We could easily further reduce existing well depth misties by applying cosmetic standard well calibration as it was described in the previous chapter. Instead we decided to create a geology conformal model for anisotropy and check if this approach can reduce the depth misties (uncertainty in our depth estimations) in a geologically meaningful and controllable way.

The current anisotropy model (Figure 3B) is too simple in comparison with the velocity field (Figure 3A). The anisotropy is simple and smoothed because we transformed localized variations in seismic data moveout entirely into localized velocity anomalies. This was the standard solution to the intrinsic anisotropy uncertainty problem.

Localized velocity variations correspond to changes in lithology. We can assume that the changes in lithology also create some variations in anisotropy and we just need to find a way to quantify such anisotropy anomalies. As the changes in both velocity and anisotropy are caused by the lithology we can assume that there should be a correlation between localized variations in velocity and localized variations in anisotropy: δ_var ~ V_var. If we use the simplest and robust linear correlation, we get the following equations to tie anisotropy with velocity: δ_var = S * V_var or

$$\delta(X,Y,Z) - \delta\_trend(X,Y,Z) = S * (V(X,Y,Z) - V\_trend(X,Y,Z)). \quad (2)$$

δ_trend and V_trend are smoothed functions similar to what we see on Figures 1A and 3B. S is the correlation ratio, which can be set as a constant for a certain interval. For any given value of S, we change anisotropy using the equation (2). At the same time we honour the seismic data and preserve the moveout (V_seis) by changing the vertical velocity accordingly to satisfy the equation (1). Updated vertical velocity automatically changes all well based depth misties. Working this way, we transform localized seismic moveout anomalies into localized anomalies in both vertical velocities and anisotropy, the value of S determines how much goes into the anisotropy. Our objective is to find an optimal value for S that minimizes the standard deviation of the misties. We use the standard deviation because this parameter describes the uncertainty of our depth estimations and this is what we want to reduce. Skipping some computational details we show our results on Figures 4 and 5.

The anisotropy (Figure 4B) is now conformal with velocity and geology, both anisotropy and vertical velocity values have been changed by few per cent (from green to red lines on Figure 2), seismic image was twisted gently in vertical direction by up to plus/minus 10m. All this significantly reduced the depth misties (the standard deviation from 12.6m to 5.8m and the variations between minimal and maximal values from 35m to 19m). We observed the positive correlation between localized velocity and anisotropy anomalies. In general, it is similar to correlation between the global velocity and anisotropy trends in the upper part of the model due to the shales compaction effects. This coincidence makes our anisotropy correction more stable.

The localized anisotropy anomalies are caused by several effects: real intrinsic anisotropy, quasi-anisotropy due to thin layering effects, possibly something else – everything that varies between different geological layers/bodies and affects seismic data moveout. We create an “imaging” PSDM anisotropy δ(X,Y,Z) model that is similar to the imaging PSDM velocities: it produces flat PSDM gathers, best focused image and minimal depth misties. If needed, after building a geologically conformal anisotropy model, the requirements of conformity can be relaxed to apply a standard well calibration sequence with the smaller remaining misties and smaller possible negative side effects.

Our correlation analysis requires a sufficient number of wells crossing geological objects with different velocity/anisotropy values. This condition was met on our project. Figure 5 shows 3D view of the final model with the well locations and horizontal slices at depth 1.8km (the level of the strongest lateral velocity/anisotropy variations). As we work for years within the same geological province, we gain experience after each project with wells and this experience (the velocity/anisotropy correlation coefficients) can be applied to new areas with limited or without any well information in the same way as we apply the general compaction driven trends.

CONCLUSIONS

Making anisotropy conformal with velocity and geology results in more accurate and realistic imaging PSDM anisotropic velocity models and reduces depth misties.

ACKNOWLEDGMENTS

We thank Hess Exploration Australia and CGG for permission to present these results.

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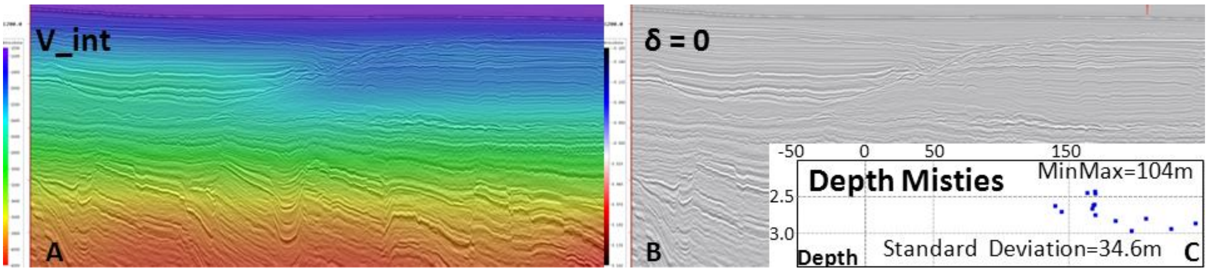

Figure 1. Initial isotropic velocity model.

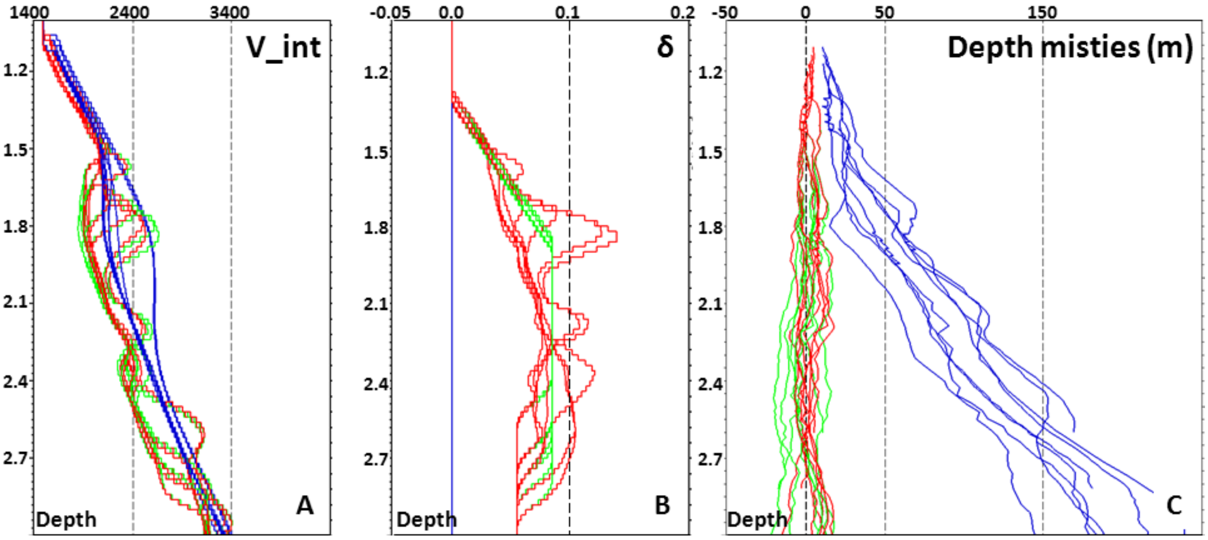

Figure 2. A-interval velocity profiles for 8 available well locations; B- anisotropic parameter δ; C-checkshot based depth misties. Blue – initial isotropic model, green – standard updated anisotropic model, red – updated model with geology/velocity conformal anisotropy.

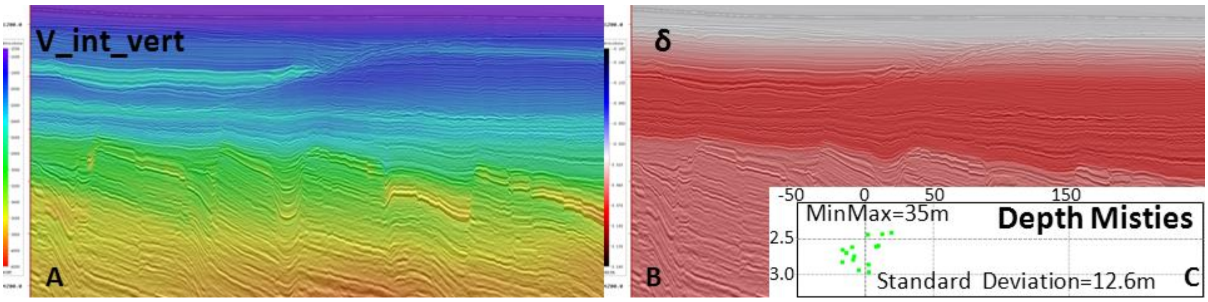

Figure 3. Model after standard anisotropic tomographic update.

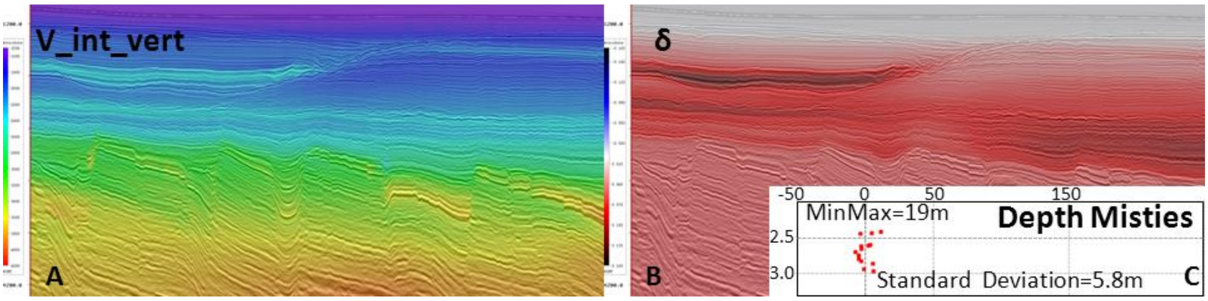

Figure 4. Final model with anisotropy conformal to geology and velocity.

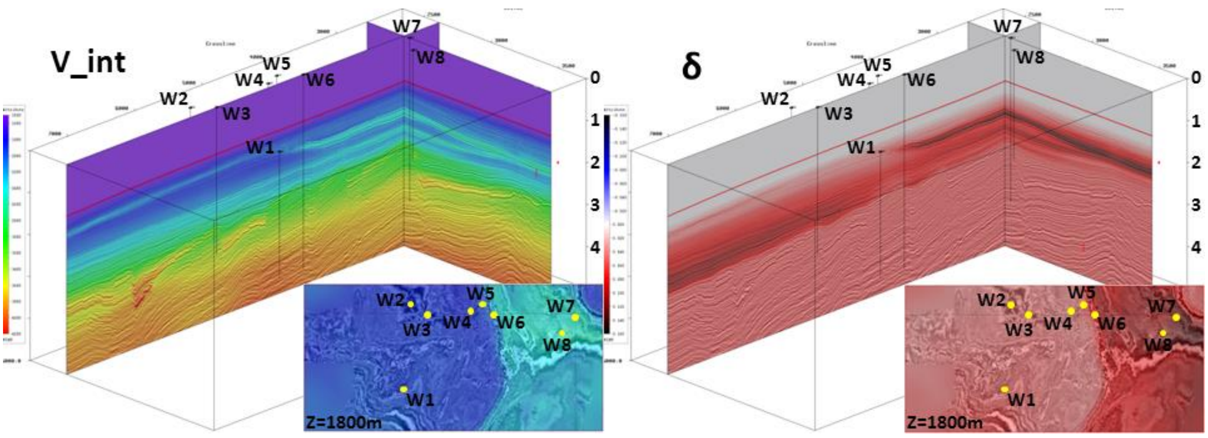

Figure 5. 3D view of the final model with the well locations.