Amsterdam '14

WS12-B03

Importance of Cross-disciplinary Constraints in Anisotropic Model Building and Updating

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SUMMARY

Over the last decade of building anisotropic earth models for depth imaging, we developed many methods and techniques that make them geologically plausible and maintain consistency with geomechanics and rock-physics.

In this paper, we demonstrate the importance of including of cross-disciplinary data in all stages of the anisotropic earth-model building workflow and discuss various methods and techniques for anisotropic parameter derivation and update. We illustrate them with successful examples from the Gulf of Mexico and offshore West Africa.

Introduction

Just 10 years ago, we considered only small-scale appraisal, development, and production studies as candidates for anisotropic imaging. Today, driven by increased demand for interpretable images in many areas with complex geology and/or targets at significant depth, anisotropic imaging is a standard for all imaging projects in majority of the world's geological provinces. This includes even exploration projects on ultra large scale.

Given that the most advanced migration algorithm cannot image the data correctly in the absence of model that well represents the earth's properties, anisotropic model building and updating remains the most important part of the imaging process. Creating such models however, continues to be challenging since seismic data does not contain all the information needed for deriving and constraining the parameters that describe anisotropic media.

In this paper, we demonstrate the importance of including of cross-disciplinary data in all stages of the anisotropic earth-model building workflows. We also discuss various methods and techniques for anisotropic parameter derivation while consulting such data. We illustrate with successful examples from the Gulf of Mexico (GoM) and offshore West Africa (WAF).

Methodology and examples

Anisotropic Model building and updating requires the use of additional information to find the most likely of the large set of anisotropic models that will fit a single surface-seismic data set. Incorporating cross-disciplinary data, information, and constraints in the steps of the anisotropic model building workflow (Zdraveva and Cogan 2011 and Zdraveva et al. 2012b) constrains the possible solutions. For example:

- We often derive anisotropic parameters using borehole measurements (Bakulin et al. 2010a, Bakulin et al. 2010b) and we can use these measurements as constraint in Common Image Point (CIP) Tomography (Woodward et al, 2008) ensuring that resulting images tie the wells.
- Rock physics modelling, enabled by temperature gradients from basin analysis and based on compacting shale model aids anisotropic parameter derivation and/or interpolation and extrapolation away from wells (Bacharach et al. 2011, Bachrach and Osypov 2013) and as constraints in Tomography (Li et al. 2011 and Yi et al, 2013).
- Future work in parameterization orthorhombic models will likely rely on understanding the potential for stress-induced anisotropy based on geomechanical finite element modelling.
- While image focusing, reduction of residual curvature, and ties to well data remain important for the evaluation of the model, we gain by evaluating the model's and image's geologic plausibility and their consistency with geomechanics and rock-physics.
- Extrapolation of anisotropic properties away from well locations benefits greatly from geologic information. (Zdraveva et al, 2010, Zdraveva et al, 2012)
- , We also use geologic information in various forms of constraints in tomography. (Bakulin et al, 2010c, Zdraveva et al. 2013)

Even in the simplest cases when we use regional parameters that enable the introduction of anisotropy in early stages of model building (Neal, 2007) we justify them with the compaction model. Latter we often complement with petrophysics and lithologic analysis from nearby or regional borehole data. When we add geologic and/or rock physics constraints in tomography, we then can conduct high quality anisotropic model building even in areas with limited well control.

Figure 1 compares two different options for propagating Thomsen's parameter δ after deriving it with the help of check-shot travel-times information and analysis of lithology sections of all wells in the area. The first (3a) shows a compaction trend simply hung from the water bottom surface. The second (3b) incorporated a merging of the compaction trend with a horizon interpretation so that isolated in that way carbonates could have differing anisotropic properties. Used in successful imaging in Kwanza basin, offshore Angola, both models delivered "fit for purpose" images.

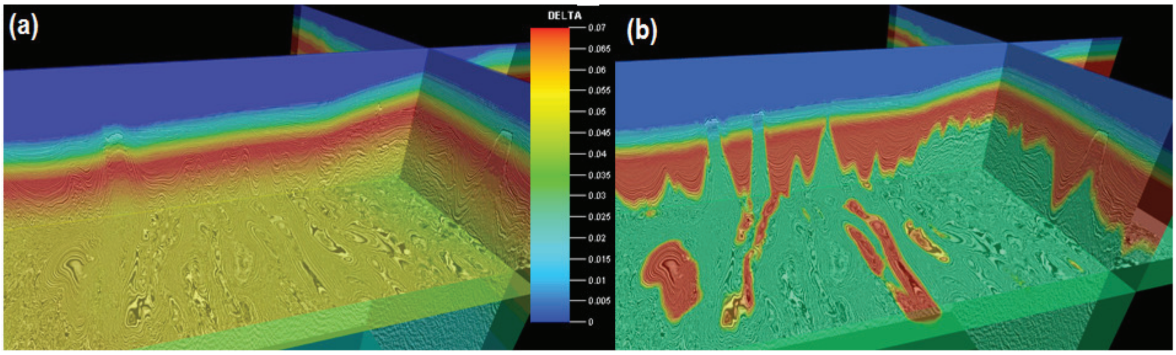

Figure 1 *3D delta field overlaid on seismic: (a) Regional compaction trend; (b) Geologically constrained compaction trend*

Figure 2 shows the results from Geomechanical modelling conducted over an area in Central Gulf of Mexico (GoM) where seismic data could not be explained with Transversely Isotropic (TI) model. Analysis of the stress and minimum stress direction (2b) clearly showed anomalies that coincide with zones of problematic residual curvature on seismic gathers in the TI model. In response, we built an orthorhombic model in an attempt to find a better representation for the earth.

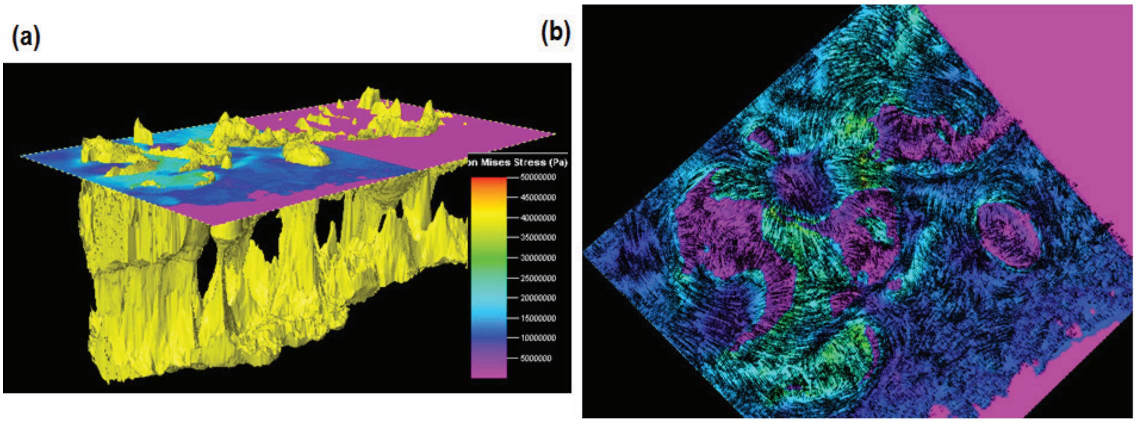

Figure 2 *Von Mises stress and minimum stress direction a) 3D view with salt bodies shown in yellow; (b) Map view at depth of approximately 10000 feet*

Figure 3 illustrates the improvements achievable by introducing geologic constraints in CIP Tomography (Zdraveva et al. 2013). The improved model, with much better delineated carbonate rafts above salt bodies, yields a much clearer and geologically more plausible image subsalt (3b) when compared against earlier model built without geologic constraints in tomography (3a).

Figure 4 compares the quality of the images, including the geometry of the base salt for an isotropic and Tilted TI (TTI) model built over area of more than 8000 sq km in offshore WAF. The TTI model significantly improves the flatness of the base of salt and better focuses some of the pre-salt events. This, together with the improved residual curvature statistics, indicates that the constraint with non-seismic information TTI imaging has the potential to dramatically improve the imaging of pre-salt targets in the Kwanza basin area. This occurred despite using short-offset seismic data in areas without significant well information. Cross-disciplinary information derived from other sources enabled us to achieve improvements in imaging across very large area of complex geology, yielding interpretable pre-salt targets for successful exploration drilling..

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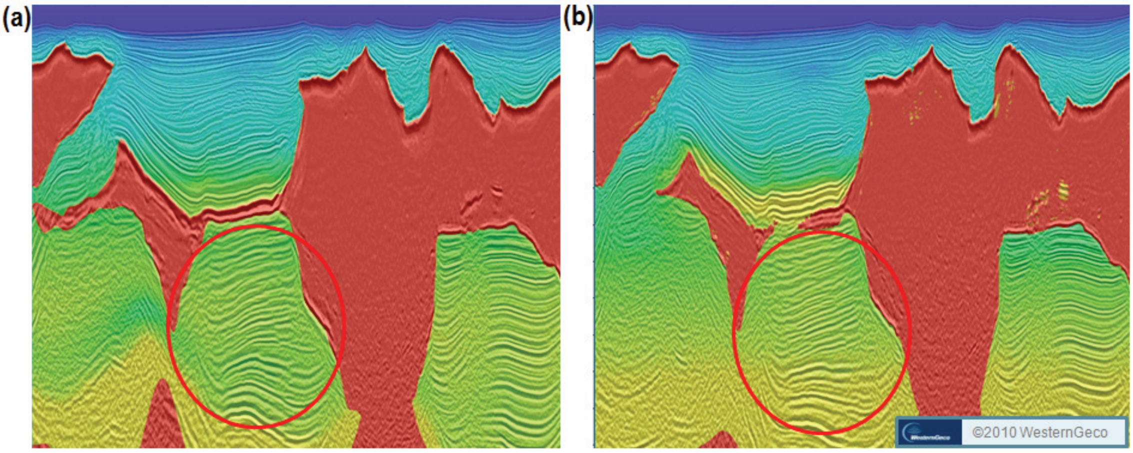

Figure 3 *Vp overlaid on seismic data: Updated without (a) and with (b) geologic constraints*

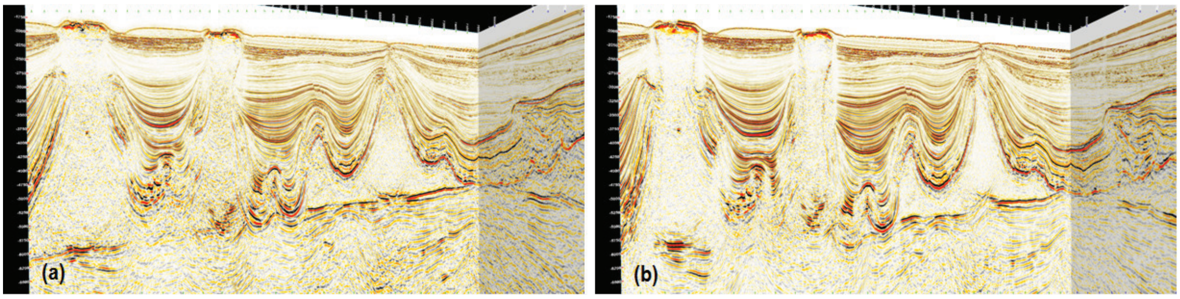

Figure 4 *Image produced with TTI (a) and isotropic (b) models*

Summary and conclusions

Over the last decade, we developed many methods and techniques that allow us to build geologically plausible and consistent with geomechanics and rock-physics anisotropic Earth models for depth imaging. Incorporation and extensive utilization of cross-disciplinary information remains essential.

Today, as we face the challenge to move even to lower classes of symmetry and start building orthorhombic models, the relative importance of incorporating cross-disciplinary information, together with adding multi-component surface and borehole seismic data, will undoubtedly increase.

Acknowledgements

We thank Sonangol and WesternGeco Multiclient Services for providing seismic data and many colleagues in WesternGeco for assistance with these case studies.

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