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Joint Inversion And Cross-Validation Of Bore-Hole And Surface Seismic Data For Reducing The Uncertainty Of Anisotropic Models

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Summary

Adding extra data and information in the process of anisotropic Earth model building (EMB) is very important to reduce the uncertainty of the results. Borehole seismic data, either zero-offset, walkaway or 3D vertical seismic profile (VSP) are very valuable but rarely available in large exploration areas. In recent years, with the wider spread of distributed acoustic sensing (DAS), 3D VSP surveys are becoming more common to help interpretation related to advanced development programs and production well placement. In some cases, they are even preferred as a foundation for 4D work and that sets even higher requirements for the accuracy of the Earth models.

In this work, we discuss and show how 3D VSP data can be used in two different stages of modern surface seismic anisotropic EMB workflows: model validation and model updating with joint tomography. We demonstrate the value of incorporating 3D VSP information using a real data example from the Green Canyon area of the Gulf of Mexico.

Introduction

Anisotropic depth imaging with transversely isotropic (TI) models is today's dominant industry practice. However, building such models is still a complex and challenging task, highly dependent on the quality and geometry of the available surface seismic data, and on the availability of additional data and information (Zdraveva et al., 2014). In anisotropic media, many Earth models will fit a single surface seismic data set and the only way to limit the ambiguity and reduce uncertainty of the resulting Earth model is the integration of borehole-seismic information such as check shots and vertical seismic profiles (VSPs) of various geometries.

Historically, 3D VSP surveys are conducted either to fill illumination gaps or to provide higher resolution at target (Reitz and Hartman, 2017). Today, with the introduction of distributed acoustic sensing (DAS), they are becoming more affordable and a common solution for 4D and monitoring (Zwartijes et al., 2017). Achieving all these objectives requires fairly accurate Earth model to be used in imaging of the 3D VSP data but, unfortunately, very often such data is processed and imaged separately and in complex media that may affect adversely the quality of the final images. Borehole seismic is often used in Earth model validation and for inversion of transit times to obtain anisotropic parameters (Li et al., 2015) but joint inversion with surface seismic data (Zdraveva et al., 2017) is not yet a common practice. We will illustrate the benefits of such joint inversion with an example from the Green Canyon area of the Gulf of Mexico.

Model validation with 3D VSP data

The model validation process is an integral part of earth model building (EMB) and updating workflows. It is the quality control and assurance step in which we verify that the earth model we have at any given stage of the workflow adequately explains the available data (both seismic and non-seismic). In cases with no well control, validation is carried out by evaluating the quality and general appearance of the resulting seismic images and the model property fields. The main criteria used are the model's ability to produce: (1) well-focused seismic images with minimum residual curvature on gathers; (2) geologically plausible images, and (3) model property fields that are free of artifacts and consistent with rock physics and geomechanics. In cases with well control, we add an additional criterion: (4) results consistent with well measurements. This consistency is most often quantified through traveltime misfit and well-markers mis-tie analysis. 3D VSP data provide additional options by allowing to study the 3D VSP images themselves and judge their quality, flatness of gathers (figure 1) and the match between bore-hole seismic and surface seismic images.

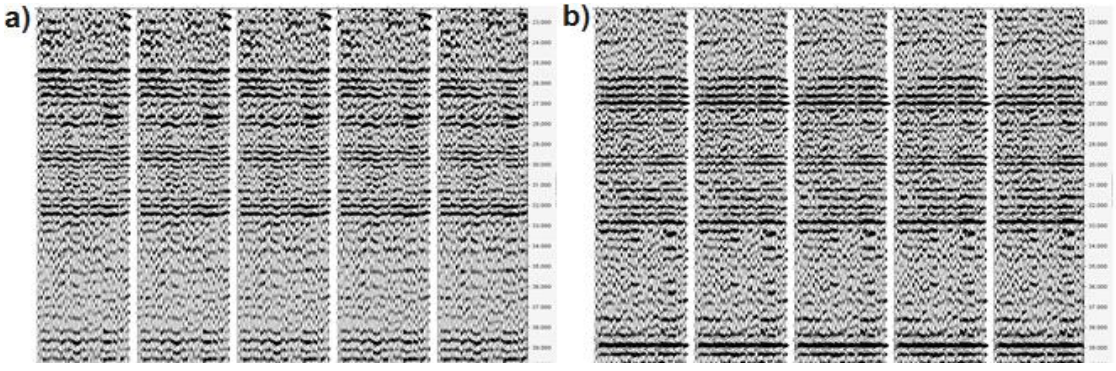

Figure 1 *A group of five neighbouring 3D VSP RTM receiver gathers: a) less accrate model built without any well information, and b) a better model that used bore-hole information in EMB process.*

Joint Tomographic inversion of 3D VSP and surface seismic data

VSP transit times can be used jointly with surface seismic data in tomography to constrain anisotropic parameters at and around well locations. Bakulin et al. (2010) used these types of updates for

anisotropic parameter derivation in a local sense. The same approach for simultaneous update of multiple anisotropic parameters can be used in a global joint tomography scheme to fine-tune a model that is already reasonably accurate (Zdraveva et al. 2017). To illustrate that, Figure 2a shows a 3D vertical seismic profile (VSP) transit-times misfit graph for a model that was built without the use of 3D VSP information. It produced reasonably flat gathers for all azimuths of full azimuth, long-offset seismic data, it yielded geologically plausible images, including 3D VSP image (figure 1b) and minimal misfit at three well locations with check-shots and zero-offset VSP but one could still see a presence of significant residual error indicating that the model is not fully consistent with the 3D VSP data. Figure 2b shows transit-times misfit graph for a model updated with joint tomographic inversion adding the 3D VSP transit times as a data constraint. This model is now consistent with the 3D VSP data and represents a better starting point for further interpretation and potential uncertainty analysis. The residual error left could be further reduced with more tomography iterations or it could be due to a genuine azimuthal variation that cannot be explained with TI assumption for the medium.

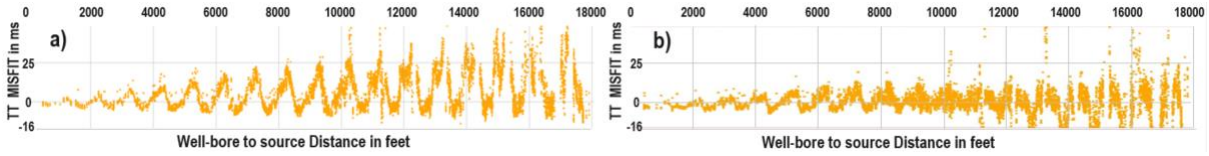

Figure 2 *3D VSP TT misfit for as a function of distance from the wellbore to the source location for Earth model: a) before joint tomography ans b) after one iteration of joint tomography with simultaneous parameters update using surface seismic data and 3D VSP transit times as constraints*

Discussion

Incorporating 3D VSP data in EMB workflows for surface seismic imaging can significantly improve the model accuracy and quality of the final surface and borehole seismic images. Models resulting from joint tomographic inversion of surface seismic and borehole seismic data (and their corresponding seismic images) are better candidates for well-placement or reservoir properties interpretation and represent much better starting point for any form of uncertainty analysis.

References

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