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Estimating Anisotropic Parameters Using Joint Tomographic Inversion - a Case Study from Offshore West Africa

T. Cao* (CGG), N. Vidal (CGG), D. Carotti (CGG), A. Kabbej (TOTAL) & M.L. Gaquere (TOTAL)

SUMMARY

Anisotropic parameter estimation is challenging for new exploration areas where there is no well data. In a 3000 km2 offshore survey from West Africa, we used surface seismic data in a non-linear tomographic inversion to simultaneously estimate migration interval velocity and anellipticity (η). Starting with an isotropic input model, joint tomography created a model of anellipticity. The anellipticity field computed without any well control was geologically plausible (structurally consistent) and the flatness of common image point gathers was significantly improved.

Introduction

Tilted transverse isotropic (TTI) model building has become a standard in seismic imaging in the oil and gas industry for areas where sediments exhibit significant dip. Thomsen's anisotropic parameter δ is usually estimated at well locations and then extended away from the wells. The other Thomsen's anisotropic parameter ε can be modeled by various methods: it can be extended away from the well locations with the guidance of one or several horizons; it can be calculated from an anellipticity η field derived from previous processing (Siliqi *et al.*, 2007; Fowler *et al.*, 2008; Nicoletis and Jousselin, 2011); it can also be optimized with migration scans or tomography (Woodward *et al.*, 2008; Zdraveva *et al.* 2011).

However, well data are not always available, especially for new explorations. Surface seismic data alone cannot constrain the inversion of all the parameters of transverse isotropy (Tsvankin and Thomsen, 1995; Jousselin and Biondi, 2007). In this case, other methods are needed to overcome or partially overcome this difficulty. Guillaume *et al.* (2001) demonstrated that the existence of reflectors with different dips reduces the ambiguity in the inversion for δ and ε. Panizzardi *et al.* (2010) proposed an approach of joint tomography to estimate Normal Move-Out (NMO) velocity and horizontal velocity. In an offshore exploration study in West Africa, we used non-linear tomography (Guillaume *et al.*, 2008) to jointly update the migration velocity V_{mig} and anellipticity η. More precisely, we used short-spread offset to estimate migration velocity and full-spread offset to estimate η. The Residual Move-Out (RMO) was measured on Pre-Stack Depth Migration (PSDM) gathers. Non-linear tomography allowed the efficient inversion of the picked RMO. While a large number of TTI model building workflows require an initial anisotropic model built from geological interpretation, our approach does not require this step of geological interpretation. A zero-valued ellipticity model was used as the initial input for tomography. This was one of the first projects where we used non-linear tomography to create an anisotropic model which was geologically consistent and minimized RMO.

An offshore exploration survey

This project is an exploration study of over 3000 km2 in an area with significant structure which requires a TTI model for imaging. There are no wells yet in the sector. Therefore, δ estimation cannot be guided by well data. The narrow azimuth 3D marine towed streamer data has a maximum offset of 8 km, which provides some information about anisotropy. According to neighboring studies, there should be a layer of significant anisotropy at about 1 km below the water bottom. We utilized joint tomography to solve for migration velocity and an anisotropic parameter, hypothesizing that the result would be consistent with geological expectation.

Method

Our approach was based on RMO picked on Common Image Gathers (CIGs) of an initial PSDM with an isotropic initial model. An automatic picking program was used to measure the residual moveout in the volume (*Figure 1a, 1b*). Then the picked RMO was used in a non-linear slope tomographic inversion (Guillaume *et al.*, 2008). As it was difficult to estimate the δ field, we aimed at a partial solution to the problem and estimated two parameters: migration velocity V_{mig} and anellipticity η. Considering V_{mig} is approximately equal to the normal moveout velocity, we have the following equations according to Alkhalifah and Tsvankin (1995):

$$V_{mig}=V_p(1+\delta)^{1/2},$$

$$\eta=(\varepsilon-\delta)/(1+2\delta). \tag{1}$$

The near-offset move out is mainly driven by V_{mig}, while η has a major impact on the far offset. This difference is taken into account in the joint tomographic inversion. Firstly, the RMO in short-spread offset was used to update V_{mig}. Then the full-spread offset was used to update V_{mig} and η (*Figure 1c*).

In the input model of joint tomography, δ was fixed at 0. Then V_p and ε were simultaneously estimated with tomographic inversion. When fixing δ=0, the equations (1) become:

$$V_{mig}=V_p$$
$$\eta=\varepsilon.$$

In this case, solving V_p and ε is equivalent to solving V_{mig} and η.

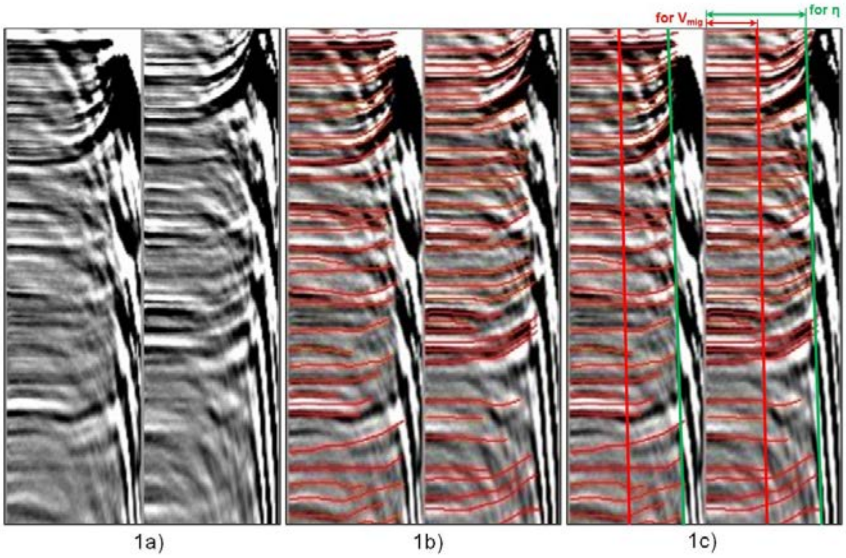

Figure 1 *1a) CIG migrated with an isotropic velocity model; 1b) Residual moveout picked on CIG; 1c) Selection of offsets for updating different parameters (red indicated short-spread limit for* V_{mig} *update, green indicates full-spread limit for* η*).*

Application

An isotropic velocity model was first built and updated with tomography. Since there was no well data in the area, a reliable δ model could not be derived and δ was set to zero. For the initial ε model, we tried a regional 1D ε function derived from CIG 1D analysis but the resulting CIG flatness was not satisfactory, probably because of the complexity of the geological structures. As a result, we used the updated isotropic model as input to the joint tomography. We focused on two criteria to evaluate the inversion result: 1) consistency with geological structure; 2) CIG flatness.

1) Geological consistency

The non-linear tomography managed to create a geologically consistent anisotropic parameter from an isotropic model. In the tomographic inversion, the structural smoothing constraint was minimized. So the picked RMO played a major role in finding the geological structures.

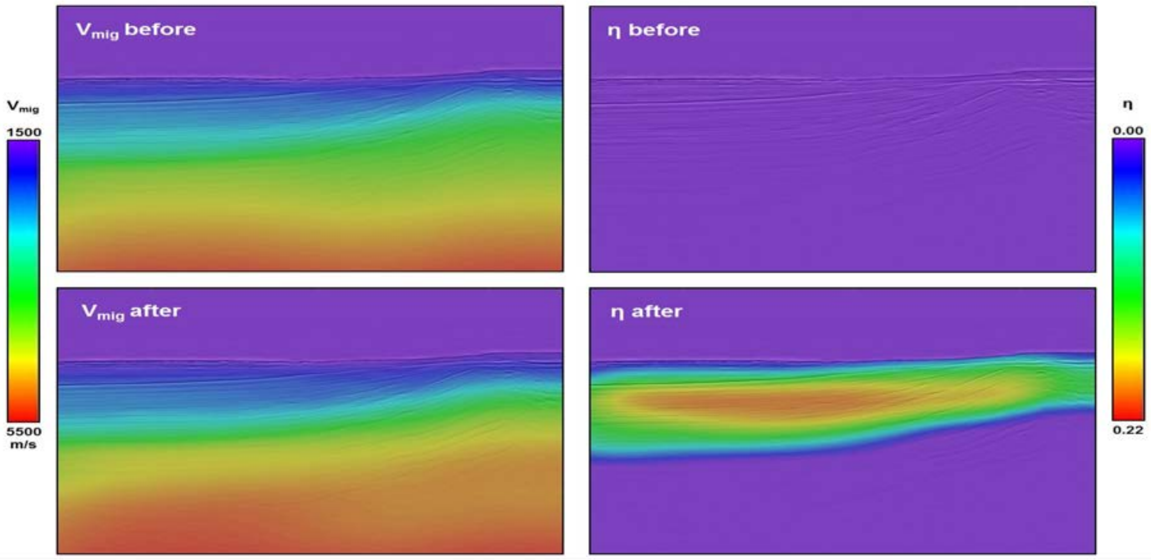

Figure 2 *Profile of anisotropic models overlaid on seismic, before and after joint tomography.*

Figure 2 compares the anisotropic models overlaid on seismic profile before and after joint inversion. The obtained η followed the geological structure and existed mainly in a layer near the water bottom, which corresponded to empirical evidence in the larger region. In addition, V_{mig} became more consistent to the geology in the deep part. Figure 3 displays the result of the joint tomography on three time slices. Both the velocity model and seismic data are stretched back to time. The different slices of η model overlaid on seismic show that the obtained anisotropic model is geologically consistent not only on one single profile, but also on the volume.

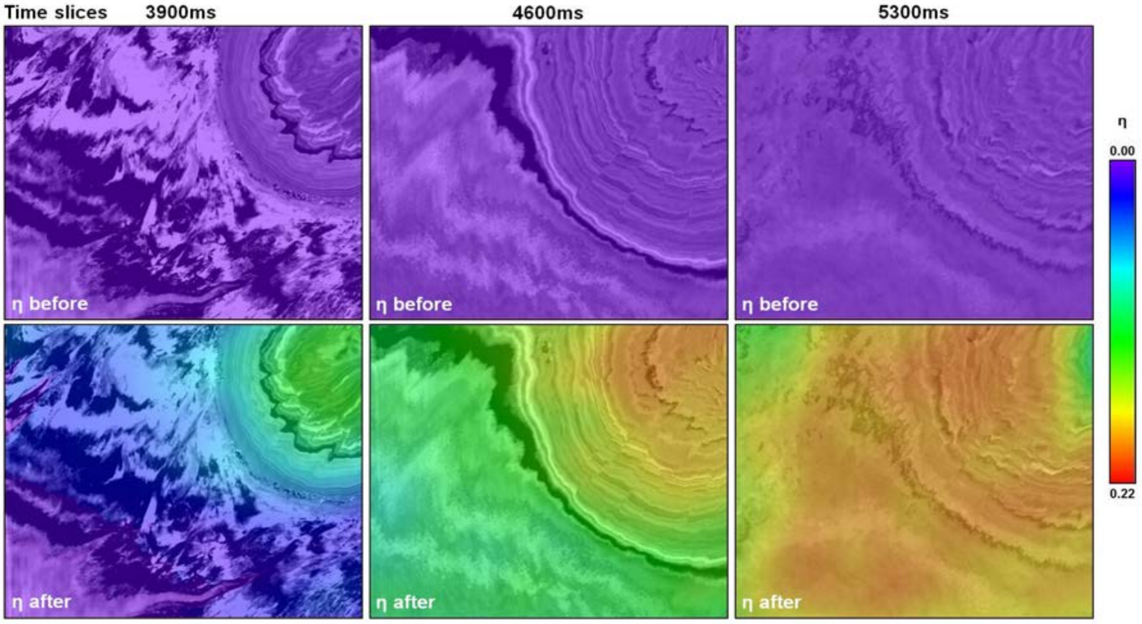

Figure 3 *Time slices of anellipticity models overlaid on seismic, before and after joint tomography. Three time slices are compared in three columns from left to right: 3900ms (just below the water bottom), 4600ms (in the middle of the layer of the layer of strong anisotropy) and 5300 (toward the bottom of the layer).*

2) CIG flatness

We made a comparative test of tomographic inversion where only V_{mig} was updated (isotropy assumed). Its result was compared to the joint tomographic inversion where V_{mig} and η were updated simultaneously. Figure 4 compares the CIGs of three models: starting model, model after V_{mig} inversion and model after joint inversion. The V_{mig} update can improve CIG flatness in the near offset, but the RMO in the far offset are not corrected. The joint inversion of V_{mig} and η improves both near offset and far offset gather flatness, which is important for subsequent work planned on AVO analysis for the survey area.

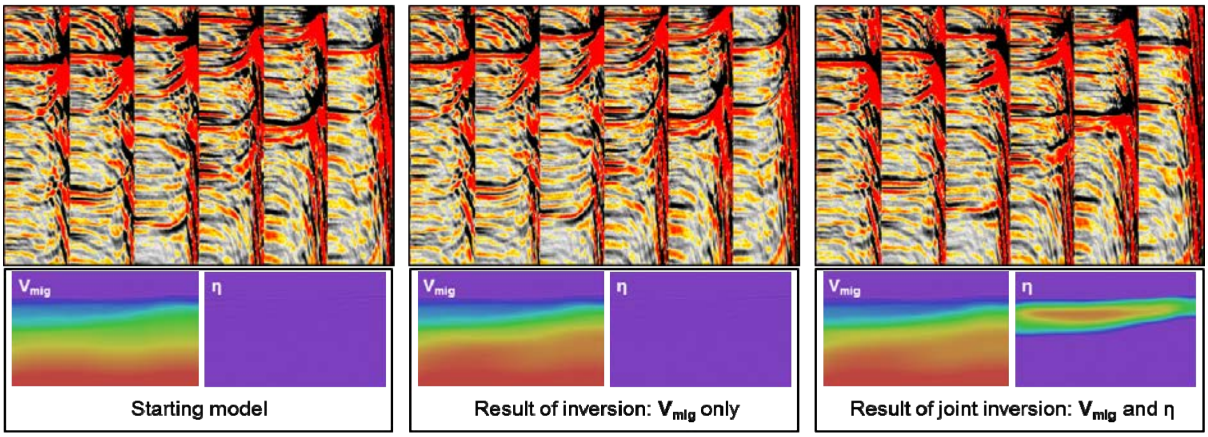

Figure 4 *CIGs of three velocity models, from left to right: starting model, result of single-parameter inversion and result of joint inversion. (The smaller images bellows display the corresponding velocity model. The starting model and the first inversion model are both isotropic.)*

The tests described above demonstrate that the joint tomographic inversion on this study, created a geologically consistent anisotropic model. Moreover, it improved the CIG flatness, especially in the far offset.

In this study we have inverted migration velocity and anellipticity. If well data become available in the future, a model of δ can be derived from well(s). Once the δ field is available, (V_p, δ, ε) can be calculated from (V_{mig}, η) with equations (1):

$$V_p=V_{mig} / (1+\delta)^{1/2}$$
$$\varepsilon =(1+2\delta)*\eta+ \delta$$

As V_{mig} and η remain the same, the gathers' flatness will be approximately the same.

Conclusions

The offshore exploration survey from West Africa did not have well data. But TTI model building was still required, because anisotropic effects were observed on common image point gathers. We used non-linear tomography to jointly update migration velocity and anellipticity η. The joint tomography resulted in flatter common image point gathers and in a velocity model with an anellipticity field following the geological structures.

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