Seismic anisotropy effects in 3D wavefield tomography

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Summary
We are presenting results how seismic anisotropy may affect waveform inversion images. Result from our Marmousi model extended to 3D as 2.5D morel show that not including appropriate anisotropy in the modelling algorithm can lead to mispositioning of anomalies in the images.

Introduction

Although waveform inversion is relatively old technique it has become increasingly interesting for the oil industry only recently when it was extended to 3D (Stekl et al 2007,Warner et al 2008, Sirgue et al 2008,Ben-Hadj-Ali et al 2008, Sirgue et al 2009, Plessix and Parkings 2009). Anisotropy is considered as important factor in seismic processing. We are presenting results of inverting 3D anisotropic data by 3D isotropic waveform inversion in order to show importance of at least forcing implied anisotropy model during waveform inversion even if the subsurface anisotropy is simple.

Using isotropic waveform inversion on anisotropic data may lead to wrong anomaly positioning in space both in depth and laterally but it can also introduce additional features in the results which may look quite geological in some cases so the data can be misinterpreted. We are showing examples what may happen.

Waveform inversion method

Seismic modelling we use can be formulated in either frequency or time domain. Frequency domain method uses iterative solver (Stekl at all 2007) while time domain code is based on time marching technique. Inversion is performed in the same domain as forward modelling based on standard Tarantola's formulation using steepest descent method.

Although forward modelling is done on anisotropic model we only invert the data to obtain velocity isotropic model at the moment although we are aiming to invert for a velocity using anisotropic code but to impose anisotropy model and not invert for anisotropy at the moment. In this paper we only show results with constant elliptical anisotropy obtained by inverting data in frequency domain.

Marmousi example

In order to present what happens if one does not account for anisotropy in waveform inversion we have extended Marmousi model to 2.5D (Figure 1a shows a 2D slice) and used a single line of sources and receivers to simulate 2D seismic acquisition. We are using 92 source positions 100m apart and fixed receiver array all located at the top of the model with 384 receivers spaced at 24m interval. Each source is recorded at all receiver position. All figures will show only a plane which contains both sources and receivers not out of plane results as there is no data coverage in third dimension.

We generated two anisotropic datasets which included elliptical anisotropy beneath the water layer at the top of the model one assuming 5 percent elliptical anisotropy and a second one assuming 10 percent elliptical anisotropy where we have higher vertical velocity then horizontal one by 5 and 10 percent respectively. The third data set contains isotropic data. Horizontal velocities in all 3 datasets are the same as are source and receiver locations. These datasets are inverted using frequency domain isotropic waveform inversion code in order to see the effects which anisotropy may introduce in the images which is consistent to applying isotropic inversion to a field dataset from the area where anisotropy levels are high. Results shown are generated using 10 iterations at each frequency. We used 4, 5, 6, 8, 10 and 12Hz data in inversion runs and inverted in slowness as inversion parameter.

Figure 1b shows inversion result for isotropic data set. One can note that it represents a low bandwidth image of the true model, although anomaly magnitudes are not completely correct because the gain in the image is quite large. When we supply isotropic inversion code with an anisotropic data like in Figure 2a results begins to look a bit different although quite realistic. There is an incline starting to appear in high velocity layer at 1700m depth on the left hand side of the model which is not present in the true model Figure 1a and the whole result gets shifted towards the top of the model. What is important to state is that the result still looks geological so it may be misinterpreted. When level of anisotropy is increased and we supply the data with 10 percent elliptical anisotropy to the isotropic code (see Figure 2b) a high velocity layer at 1700m depth on the left hand side of the model becomes almost split into two layers in the image. Some of high velocity anomalies now have quite different dips and are becoming bent in space more than in true model but the result still looks like it is geological and one may be tempted to try to interpret it although the image is not as clear as in isotropic result or the one with 5 percent elliptical anisotropy and gets quite noisy towards the bottom of the image. Most of the depths are far from correct. And there is much more noise in the result which may show that we are not able to fit the waveforms correctly but this will be the case with most of field data sets.

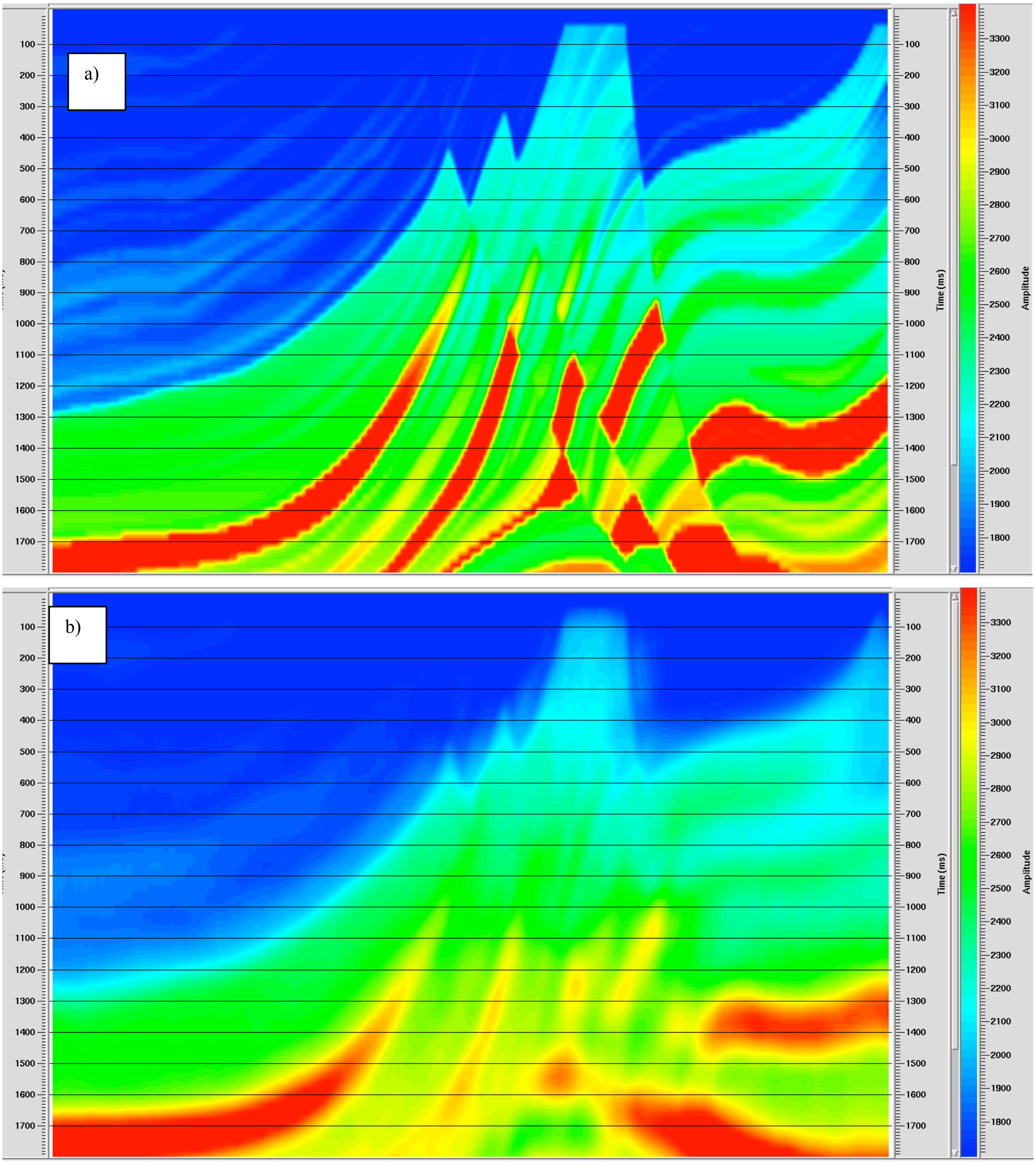

Figure 1 a) True model with a colour scale from 1700m/s to 3400m/s (colour scale is the same for other plots). b) Inversion result from isotropic data.

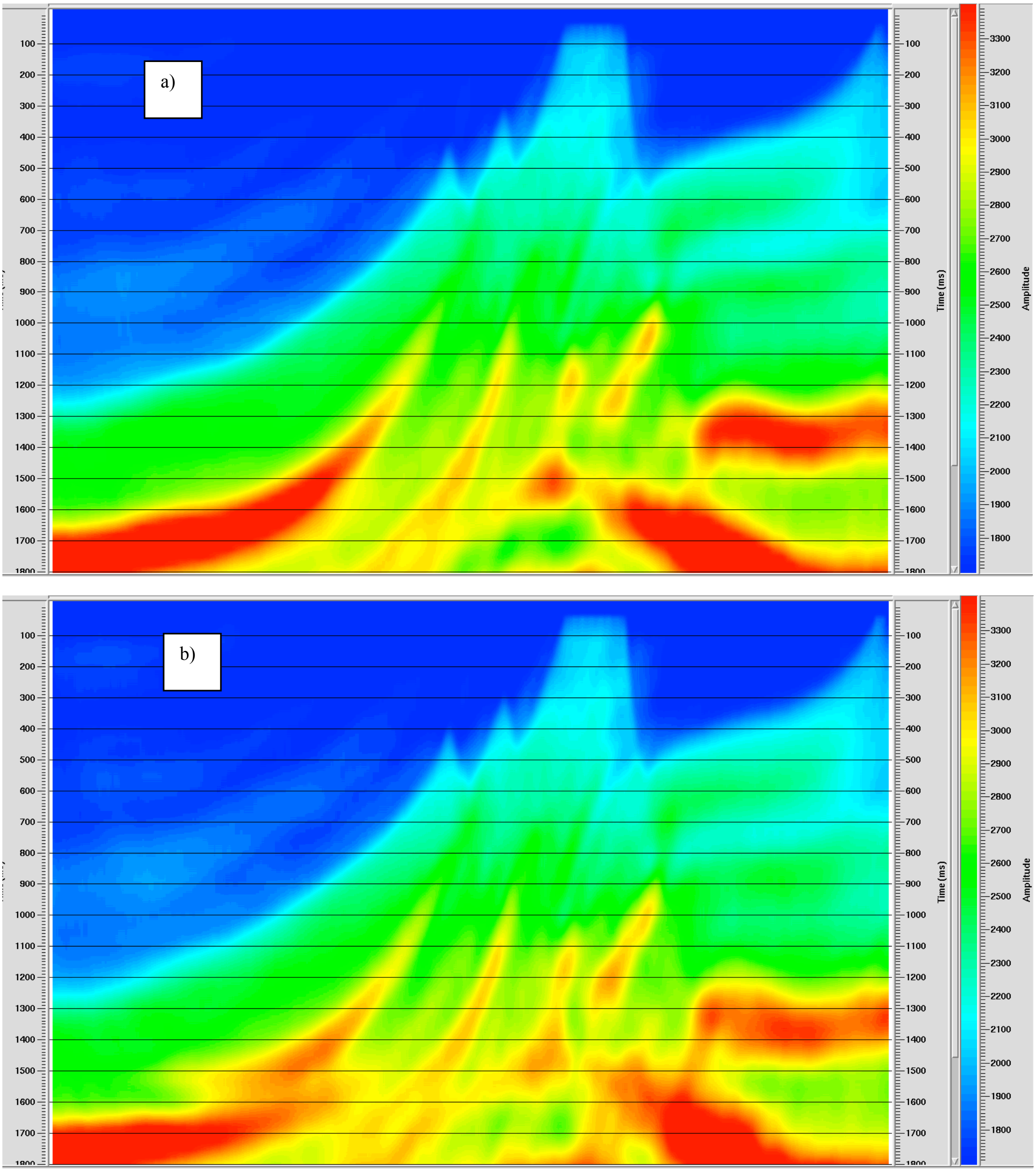

Figure 2 a) Isotropic inversion result using elliptically anisotropic data with Vp_v/Vp_h=1.05 beneath the water layer. Note the difference at high velocity layer at 1700m depth which now has an incline in it and change in anomalies depth. b) Isotropic inversion result using elliptically anisotropic data with Vp_v/Vp_h=1.10 beneath the water layer. The high velocity layer at 1700m depth has become to layers now. There is even more uplift of the whole model a noticeable change in dip and positioning of high velocity anomalies**.**

Conclusions

Using isotropic waveform inversion one has to be careful with interpreting, or evaluating results as anisotropy in the data may lead to wrong depth or positioning in anomalies, or introduction of additional features in the images. It may be a good idea to add known anisotropy model in the modelling or even better to try to invert for it but this will not be easy, due to poor coverage in the subsurface, to extract large number of parameters. One may need to reduce anisotropy parametrisation in space to a coarse grid in order to invert for anisotropy parameters in the field data in order to position anomalies correctly in space.

Acknowledgments

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