Resolution of Small Velocity Anomalies by Wide Azimuth Reflection Data Tomography

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Summary

Seismic velocity determination has suffered from insufficient coverage of the data acquisition. For this reason only smooth long wave length components of the velocity variation can be reliably recovered. A theoretical study has shown that multi azimuth data has the potential to significantly improve velocity determination.

In this study we examine the capability of multi azimuth acquisition in resolving small velocity anomalies by means of a 3D synthetic example. The model consists of a layered structure which contains two small velocity anomalies. The study compares the resolution when the migrated gathers contain no azimuthal information to the case when the gathers are binned both according to offset and azimuth. The results show that conventional gathers can only obtain a blurred image of the velocity anomalies, whereas with multi azimuth gathers the velocity anomalies appear distinctly.

Introduction

The determination of subsurface interval velocity and anisotropic parameters has been limited because of insufficient coverage of the seismic data. It has been demonstrated (Bickel, 1990, Kosloff et al., 2002) that with the range of offsets used in conventional narrow azimuth surveys, there are certain wavelengths of the velocity variations which cannot be resolved by velocity analysis. Thus velocity determination has mainly concentrated on determining the very long wavelengths of the subsurface velocity variation which can be reliably resolved. The resolution of small velocity anomalies thus remained unsolved. The determination of subsurface anisotropic parameters from the seismic data is more difficult even for the very long wavelength components of the variation.

An increase in the coverage of the seismic acquisition can significantly improve the velocity determination. One approach is to increase the offset range of the seismic surveys. However, for obtaining significant improvement in the velocity determination it would be necessary to use an offset to target depth ratio larger than three to one which is usually not practical. A second approach which is examined in this work is to use wide azimuth data and exploit the variation of seismic data moveout with the azimuth angle.

The resolution capability of multi azimuth surveys has been studied theoretically for the simple background model of a single horizontal layer with uniform velocity (Kosloff et al., 2002). Fig 1 and Fig 2 plot the resolutions as a function of the ratio of the velocity variation wavelength to the layer thickness for single azimuth acquisition and multi azimuth acquisition respectively. The example is of a single layer where the velocity varies only in the shooting (inline) direction. The maximum offset of the survey was one layer thickness. Fig 1 for the single azimuth acquisition shows that the resolution is good for the long wavelengths and the short wavelengths of the velocity variation. However, for wavelengths in the range of approximately 2.4 layer thicknesses there is very low resolution. Fig 2 shows the resolution for multi azimuth acquisition. The figure shows that with multi azimuth acquisition there is no longer a strong minimum in the resolution and thus all wavelength components can be resolved. On the basis of the single layer analysis we can expect in the general case a large improvement in velocity determination with the use of wide azimuth data.

In this study we examine the velocity resolution of multi azimuth tomography through a synthetic example of a model containing small velocity anomalies. In the following sections we explain the multi azimuth tomography approach and show its application to the synthetic example.

Multi Azimuth Tomography

The multi azimuth tomography uses depth migrated gathers from seismic data with different offsets and azimuths. For standard Kirchhoff migration the seismic data is binned in azimuth sectors according to the azimuths of the shot-receiver pairs. Kirchhoff migration is then carried out for each sector separately. The tomography calculates the contribution of the migrated gathers to the tomography for each sector and then sums the contributions. The ray tracing in the tomography is targeted to the different azimuths of the sectors.

For migrated gathers from common reflection angle migration the migrated data is separated according to the azimuth angle of the shot-receiver ray pairs at the reflecting points. The ray tracing is performed for each reflection opening angle and reflection azimuth.

Resolution of Small Velocity Anomalies

Seismic data over areas with small velocity anomalies can display non hyperbolic moveouts. For this reason, rather than use the hyperbolic moveout assumption, the depth moveout on the migrated gathers is picked automatically using the plane wave destructor.

Example

The synthetic data set was calculated for a model containing three layers which are horizontal except in two locations in the second layer where there are small anomalies in velocity and layer thickness with values of 10% and 15% respectively above the background (Fig 3a, b). For the tomography we used the reflections from the third layer for updating the velocities in the second layer. The maximum offset in this example was 3000 [m] which is equal to 85% of the depth of the third layer. The simulated seismic data was for four shot-receiver azimuths at the directions of 0, 45, 90, 135 degrees respectively. The background model for the tomography was a horizontally layered model without the velocity anomalies. The velocity updating was carried out with 3D grid tomography with an update grid size of 500m in the horizontal x and y directions, and 200m in the vertical direction.
Figure 4a shows the result, after one iteration of tomographic updating, where the input gathers were a stack of the migrated gathers from the four azimuths. Therefore no azimuthal information was utilized. As the figure shows, the tomography was able to detect part of the velocity anomalies, however the update values were only 35% of the correct ones and the image is blurry. Fig 4b shows the result of tomographic updating where at each reflection point four input gathers were used corresponding to the four shooting directions As the figure shows, the tomography was able to detect the velocity anomalies much better than when no azimuthal information was used. The update values were 85% of the correct values.

Conclusions

This study shows that 3D tomography on multi-azimuth data has the potential to significantly improve subsurface velocity determination for seismic reflection data. These results coincide with theoretical results which have demonstrated that with multi azimuth acquisition the uncertainty in velocity determination is highly reduced.
A similar research will be conducted on the determination of anisotropic parameters where improvements can also be anticipated.

Figure captions

Figure 1: Resolution as a function of wavelength for a single layer example with single azimuth data.

Figure 2: Resolution as a function of wavelength for a single layer example with data acquisition in four azimuths of 0, 45, 90 and 135 degrees.

Figure 3a: 3D view of velocity model of the synthetic example.

Figure 3b: Cross section of the velocity model of the synthetic example.

Figure 4a: Calculated velocity after one iteration of tomography without use of azimuthal information.

Figure 4b: Calculated velocity after one iteration of tomography with use of azimuthal information

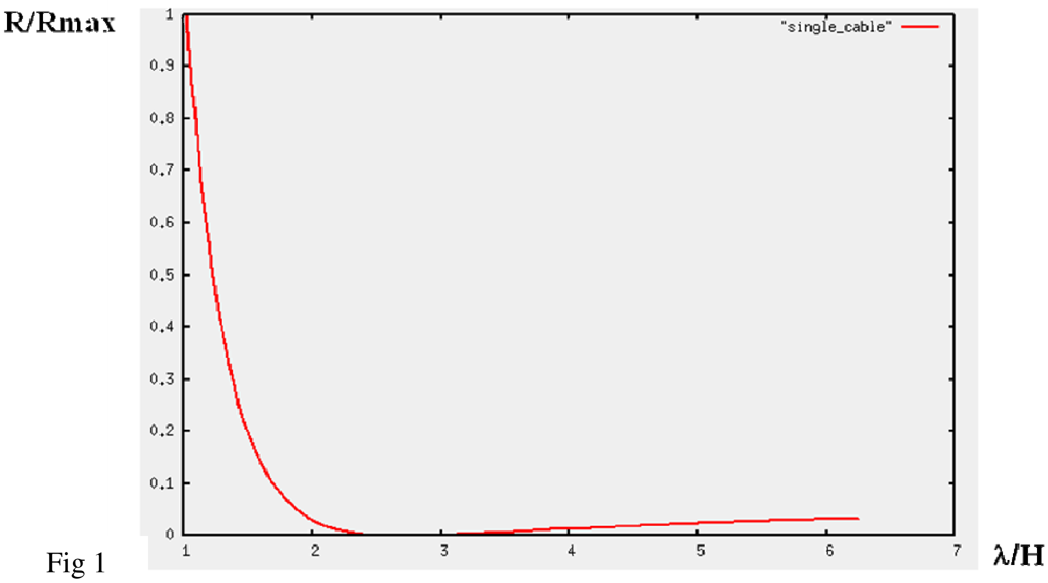

Fig 1

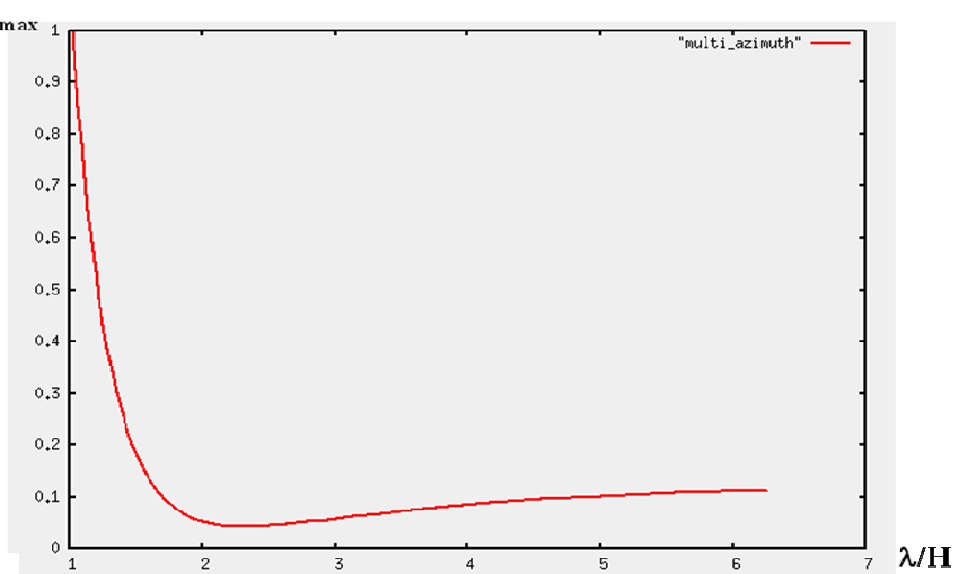

Fig 2

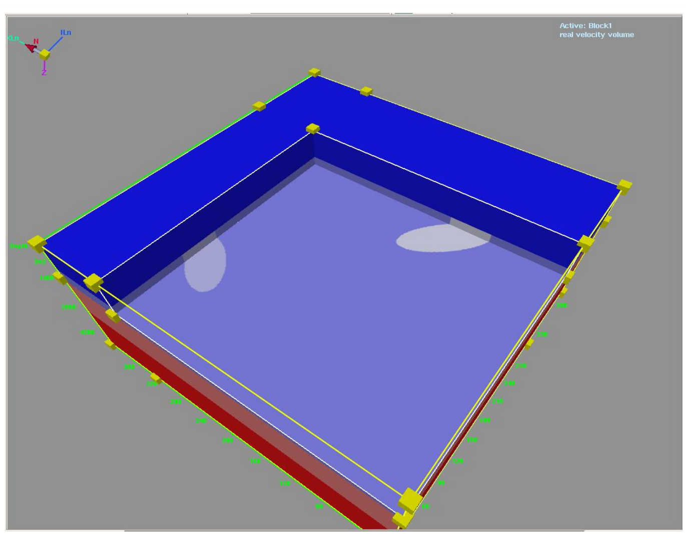

Fig 3a

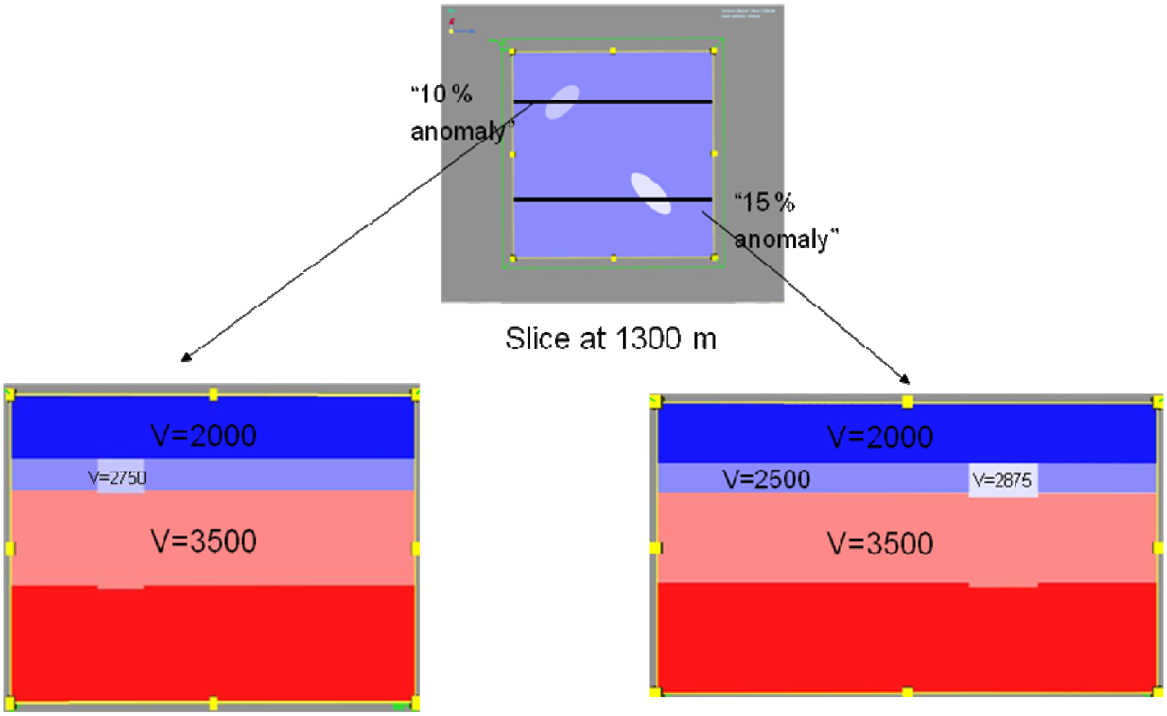

Fig 3b

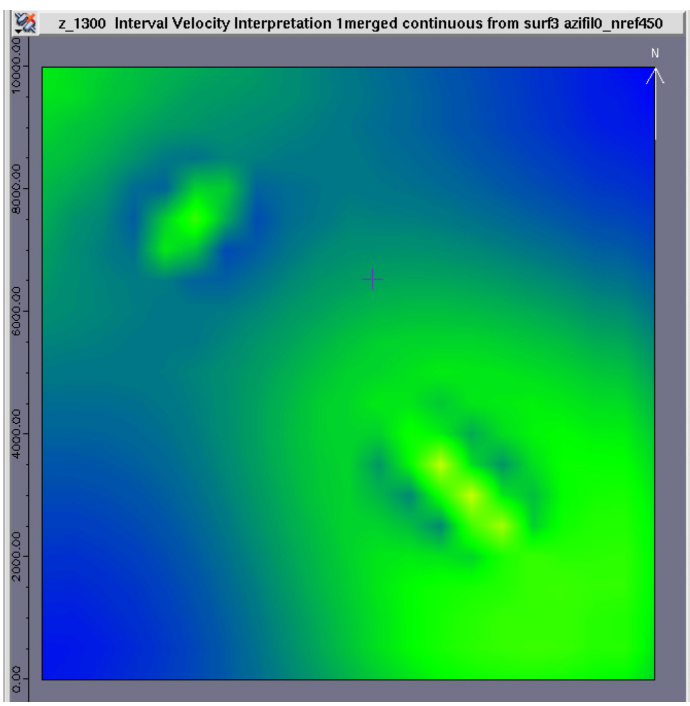

Fig 4a

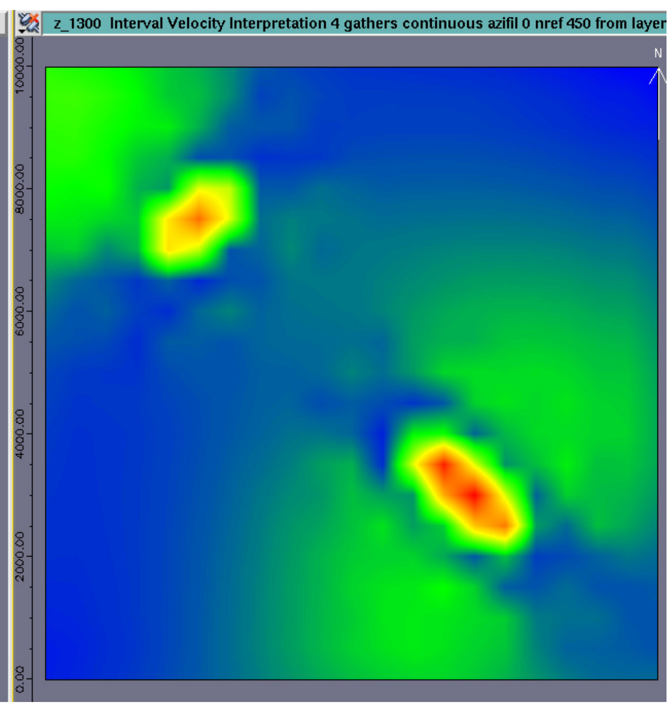

Fig 4b

EDITED REFERENCES

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