Sub-basalt imaging
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Sub-basalt imaging: the LITHOS approach

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Over the last four years, the LITHOS Group has focused on developing new methods for integrating different types of geophysical data - including borehole, electromagnetic, seismic reflection and refraction data - to address the sub-basalt imaging problem, with a particular emphasis on jointly inverting seismic reflection and wide-aperture data. First, we determine the general background velocity model using a tau-p method from picked arrival times, which forms a starting velocity model for tomographic inversion (Barker, Barton & Nicola-Carena, 2000). Our tomographic method is based on jointly inverting for interface and velocity using near-normal incidence, wide-angle reflections and refraction data (Hobro, 2000). The sub-surface model is parameterised using either fine regular or irregular grids (Trinks, 2001), and a shooting method is used to trace rays in 3D inhomogeneous media. An iterative conjugate gradient algorithm is implemented to update the model parameters. To constrain the solution, we have used regularised smoothing or prior information from boreholes. One of the main problems encountered when jointly inverting near-offset and wide-aperture data is anisotropy, which we obtain by jointly inverting traveltime and polarisation data (Cherrett, 2001). The final outcome is a smooth model with interfaces, which may be used for pre-stack depth migration or full waveform inversion.

For pre-stack depth migration of wide-angle, we have developed two types of algorithm, one using a 2D Maslov method in the *t-x* domain and the other using a 1D downward continuation method in the *tau-p* domain (Jones, 2001). These images provide insights into the detailed structure of the sub-surface, and can be used to constrain the computer-intensive waveform inversion step.

For full wavefield inversion, we have developed a set of inversion schemes to determine detailed P-wave and S-wave velocities (Shipp, 2001; Freudenreich, 2001). Our methods are based on minimizing an objective function that measures the fitness between observed data and synthetic data. To calculate synthetic data, we use reflectivity, finite difference or spectral element (Klien, 2001) methods, depending upon the requirement. To minimize the objective function, we use a conjugate gradient algorithm.

Starting from the tomographic results, we first invert the large offset and low frequency part of the data, and then slowly reduce the offsets and increase the frequency content. We pay particular attention to data around the critical distance, which are sensitive to the medium scale of velocity and depend on S-wave velocity. Finally, we invert all the seismic data simultaneously.

We have applied our approach to several data sets where basalts are present, inverting first for large-scale features using tomographic inversion and then for detailed structure using a combination of pre-stack depth migration and full wavefield inversion. We demonstrate that we can determine the precise thickness and 2D structure of a basalt sill where the sill is thin, and the internal structure of a basalt layer where it is thick. The joint analysis of magnetotelluric and seismic data demonstrates the ability of the two complementary methods to address sub-basalt imaging problem as a powerful combination (Pandey, 2001).

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