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Sub-basalt imaging from a wave propagation point of view

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The key to successful imaging below basalt is understanding the effect of the basalt on the passage of the seismic wave. Examination of flood basalt in the field show a high level of heterogeneity. The individual flows are highly fractured and are separated by layers of unconsolidated ash and earth layers. The top and bottom surfaces of the flows are highly irregular with each flow filling in topography left on the previous flow. It is clear from geological observation that a basalt cannot be thought of as a single homogenous layer nor can it be considered as a series of homogenous layers separated by simple interfaces. In short, basalt is a mess (Figure 1)!

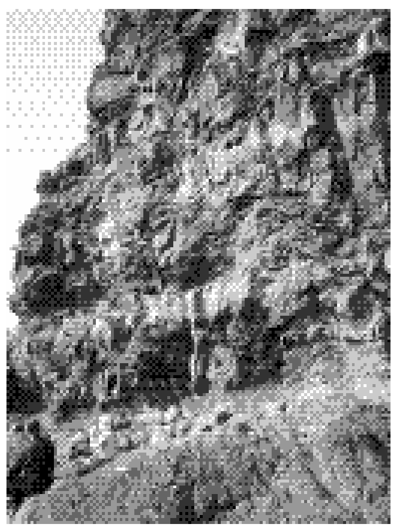

Figure 1. Example of basalt exposure on Skye

As heterogeneity increases the higher frequencies in the source wavelet will get preferentially scattered. So as the seismic wave passes through the basalt only the lower frequencies retain the coherency necessary for successful sub-basalt imaging. In addition, the irregular boundaries between the basalt layer and the surrounding sediments add extra distortion to the seismic wave front which further degrades the image. A key to unravelling the complex imaging issues caused by basalt is by detailed forward modelling using sophisticated models constrained by field data. These models seek to replicate the effects of the irregular boundaries and the high degree of internal heterogeneity in the basalt layers (Figure 2).

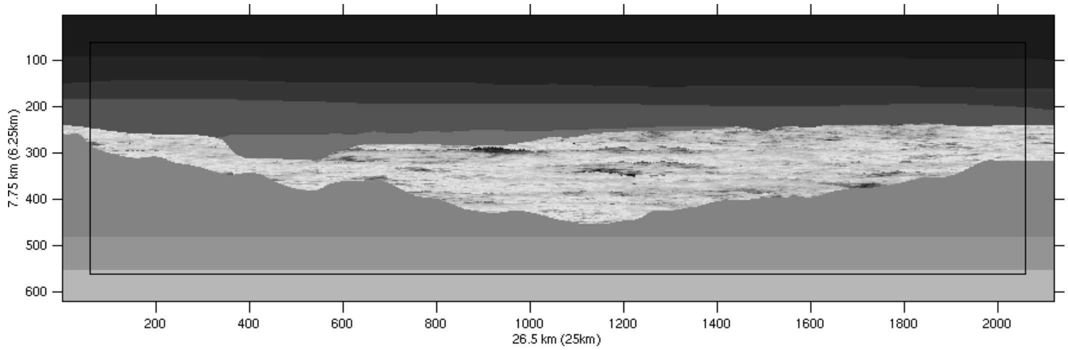

Figure 2. Velocity model with a basalt layer that includes severe boundary irregularity and complex internal structure.

Synthetic data were acquired over this model using both finite-difference and phase-screen based modelling codes (Igel, 1993; Wild et al., 2000) and the results analysed to understand the interaction of the seismic wavefield and the model (Martini et al., 2002). Figure 3 shows a stacked section generated from the synthetic shot data. As predicted, the coherent seismic wave that passes through the thicker basalt has preferentially lost high frequency energy, but in addition the wavefield is highly attenuated, distorted,and is seriously contaminated by the scattered energy as shown in Figure 4. For successful imaging of the sub-basalt structure these issues must be addressed.

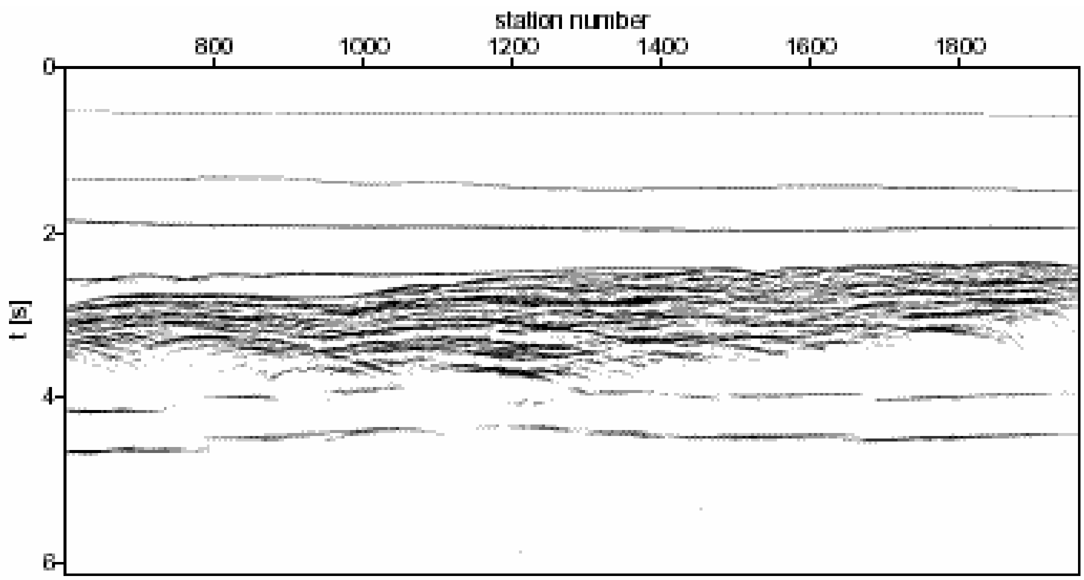

Figure 3. Stacked data from syntehtic shots computed using a phase-screen based method.

High frequency attenuation and contamination by the scattered wavefield can be solved by the use of seismic source rich in low frequencies similar to those used for regional profiling to image whole crustal structure. Effective acquisition coupled with aggressive filtering during processing can optimise the signal to noise ratio for the weak sub-basalt energy though at the cost of resolution (Hobbs, 2002).

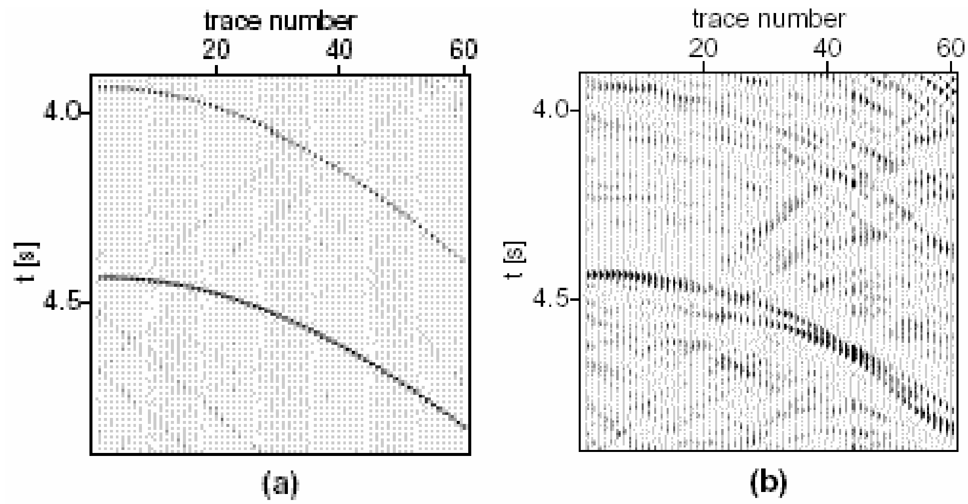

Figure 4. Synthetic CMP gathers from location 1400 (Fig.2 & 3) windowed to show the reflections from the two velocity boundaries beneath the basalt layer. (a) an ideal gather assuming a 1-D structure with no energy loss from scattering; and (b) the actual gather from the 2-D model. The pulse broadening is mainly due to scattering caused by the internal heterogeneity in the basalt layer and the complex multi-phase arrivals and non-hyperbolic behaviour is mainly caused by the irregular interfaces at the top and base of the basalt. (Maximum offset in both gathers is 6 km).

The effect of distortion caused by irregular surfaces is more difficult to solve. The ideal approach is through the use of pre-stack imaging. However, this method demands an accurate velocity model to be effective. Determination of this velocity model is not easy particularly for real data were the scattering surfaces are three dimensional and the most prominent sub-basalt reflections are probably caused by sills that may cut across geological boundaries. A simpler alternative approach is the use of wave-equation based datuming. This method replaces complex layers with smoother homogeneous layers and hence reduces the distortion in the deeper image. This approach is effective in areas where the velocity model is well constrained down to and including the top basalt surface but does not require a detailed velocity model for the sub-basalt (Martini and Bean, 2002).

Acknowledgements

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