Journal of Conference Abstracts
Volume 7(2), 199

Imaging and regional distribution of basalt flows in the Faroe-Shetland basin

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Introduction

Breakup of the northern North Atlantic in the early Tertiary was accompanied by massive production of molten rock, some of which was extruded as large basalt flows and the rest of which was intruded or underplated as sills in the crust. An estimated one million cubic kilometres of basalts were extruded within a period of 1–3 million years. The unusually large volumes of melt were generated because the mantle was 150–200 °C hotter than normal due to the presence of the Iceland mantle plume (Barton & White, 1997). The pile of extrusive lavas reaches more than 7 km thick on the Faroe Islands, which lay above the hottest part of the mantle thermal anomaly at the time of breakup.

The lava flows extend across the Faroe shelf, reaching the feather edge some 150 km to the southeast of the Faroe Islands. They overlie thick earliest Tertiary and Mesozoic sediments accumulated in basins formed by earlier episodes of stretching during the Permian through early Palaeocene. Pre-Tertiary sediment thicknesses reach a maximum of 8 km in the Faroe-Shetland Basin (Stoker *et al*., 1993), although they thin toward the present Faroe Islands.

Basalt properties

Details of the seismic velocity and its variation within the basalt flows are found from two sources. First from direct measurements from boreholes and outcrop where basalts have been sampled, and second from the detailed amplitude-versus-offset behaviour of seismic arrivals recorded on the wide-angle profiles across the in-situ basalt flows. Individual flows commonly exhibit weathered tops and more porous bases, which give lower velocities than the interior of the flows. Though individual flows are much thinner than the seismic wavelength, we show how the stack of flows may produce a characteristic response to seismic waves passing through it, which depends on the statistics of the thicknesses of the flows and their petrology. We show examples of the use of the variation of amplitude with offset to constrain details of the velocity variation in the offshore basalt flows, using first synthetic examples to examine the sensitivity of this method, and then apply it to real data.

For conventional seismic reflection profiles, there are many factors that work to make sub-basalt imaging difficult. The highly reflective top of the basalts, particularly where it is rough, scatters much of the seismic energy. Short-period ringing, simple and peg-leg multiples obscure weak sub-basalt reflections with similar move-out; the high-velocity basalt flows preferentially absorb the higher frequencies in the incident wavelet, degrading the achievable resolution of any sub-basalt arrivals; and strong ray-bending caused by large seismic velocity variations between the basalt and sediment may distort the seismic image.

Seismic imaging through basalts

The use of long-offset seismic data can help overcome some of the difficulties of sub-basalt imaging. We use grids of both conventional and long-offset seismic profiles to map the thickness and extent of sub-surface basalt flows that extend across the Faroe Shelf. Offsets up to 38 000 m were achieved in the Faroes Large Aperture Research Experiment (FLARE) using two seismic acquisition vessels shooting alternately (White *et al*., 1999). Wide-angle reflections and refractions from the basalt and underlying strata allow us to build a velocity model down to the basement Lewisian crust. The velocity models give a first-order picture of the geology, including the presence of low-velocity sediments beneath the basalt flows. They also provide velocity control for pre-stack depth migration of the entire seismic dataset, thus allowing us to produce good depth images of the structure (Fruehn *et al.,* 2001).

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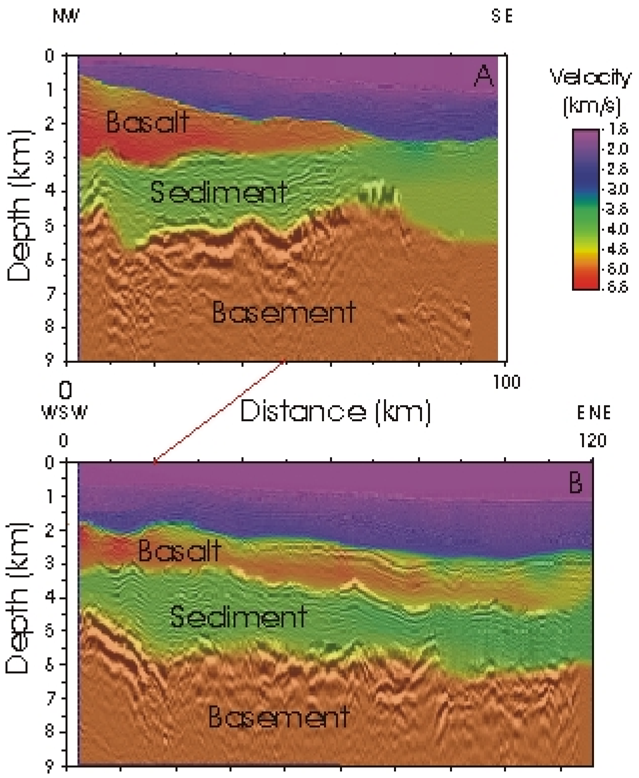

Figure 1: Dip (top) and strike (bottom) profiles across basalt flows on the Faroes shelf (from Fliedner & White 2001).

Pre-stack depth migration of selected wide-angle arrivals, such as those from the base of the basalt and the underlying basement, produce strong reflection images that allow these interfaces to be identified unambiguously on the higher resolution images produced from the entire dataset (figure 1): in particular, we can distinguish between the primary and multiple reflections. We thus use the very long offset arrivals to 'tag' the velocities of the geological interfaces from which they are returned, and hence to improve both the imaging and the interpretation of the basalt flows and the underlying structure.

Regional structure

We show the regional distribution of basalt derived from these studies, with the extra constraints imposed by gravity and magnetic modelling. Finally, we discuss how this approach may be taken forward to improve imaging both of the basalt flows themselves and their internal structure, and of the underlying sediments and basement, which is a primary aim of oil explorationists.

Acknowledgements

Much of the data in this presentation came from profiles shot by Western Geophysical and by Geco-Schlumberger as part of the Faroes Large Aperture Research Experiment (FLARE), funded by Amerada Hess and its partners LASMO, Norsk Hydro and DOPAS. We thank them and the European Union and Natural Environment Research Council for their support.

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