Processing low-frequency data from the Faroe-Shetland Basin for sub-basalt imaging

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Summary

Following the findings that one has to use low frequency data to image beneath a multi-layered basalt sequence (Mack, 1997), Veritas DGC and Texaco UK re-shot a profile in August 2001 using a solid streamer and an additional low-frequency setting (Ziolkowski et al., 2001). Comparing the new low-frequency data with the old data shows not only a superior data quality due to the solid streamer used but also improved low-frequency response from beneath the basalt.

Both data sets are strongly contaminated by free-surface multiples and additional strong interbedded multiples. Using a carefully chosen fk-filter, the Delphi predictive demultiple algorithm and additional Radon filters we suppressed this noise, revealing more energy from the weak primary sub-basalt reflections.

To image beneath highly scattering basalts along passive ocean margins source and receivers have to be lowered and the volume of used air-guns increased.

Introduction

Large areas of the North-East Atlantic Margin are covered by Early Cenozoic flood basalts extruded from igneous centres. They cover possible hydrocarbon reservoirs such as are found outside the basalt-covered area near the Shetlands (Figure 1). The underlying Mesozoic and Paleozoic sediments, which are proven to function as source and reservoir rocks (Stoker et al., 1993), could not hitherto be imaged mainly due to the high impedance contrasts and roughness of the volcanic sequence above. This causes severe multiple distortions throughout the whole recording interval as well as early refraction of incident waves.

Internally the velocity of a basalt flow increases slowly from the top and decreases rapidly at the bottom. Bergman (1997) reports basalt flows of 5-50 m thickness and these may be weathered and fractured. Interflow material usually takes up 5-10 % of the aggregate thickness and includes tuffs, volcanogenic sediments and soils (see also Gatilff et al., 1984). Apart from the high impedance contrast of basalt with the overlying sediments, the internal layering of the basalt sequence causes severe scattering of seismic energy.

Using data from a borehole through basalts for his model Mack (1997) concluded that acquisitions have to be designed to extend the spectrum to lower frequencies. To increase the amount of energy travelling through this iteration of low and high velocity layers, one has to use additional low frequencies. Ziolkowski et al. (2001) showed that amplitudes of sub-basalt reflections increase exponentially with lower frequencies.

Method

Because high frequencies are more affected than low frequencies, conventional reflection-seismic systems have to be modified for this type of geological setting. To produce lower frequencies one needs to use bigger air-guns.
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Figure 3: Comparison of two shot-gathers recorded at approximately the same position in the Faroe-Shetland Basin. The left shot was recorded in 2000 with a standard set-up and shows higher frequencies, less sub-basalt energy and more noise. The right shot was recorded in 2001 with the low-frequency set-up using a solid streamer shows greater low-frequency content, more energy from beneath the basalt below 4.5 s TWT and additionally less noise.

that have to be lowered deeper beneath the sea-surface than in a standard set-up (Ziolkowski et al., 2003). The streamer, too, has to be towed at a lower level to record lower frequencies. In August 2001 Veritas DGC implemented these settings and re-shot some of their speculative profiles in the Faroe-Shetland Basin. Source and streamer were used at depth around 15 m compared to 6-8 m for the old data. Additionally the source volume was increased from 3542 cu. inch to 7610 cu. inch. Figure 2 shows the resulting difference in frequency content as a normalized spectrum extracted from the data. Because of the new set-up, more energy below 30 Hz is recorded.

Results

The simple comparison of two shot gathers in Figure 3 clearly shows the different frequency content. The new data on the right shows more energy at low frequencies, especially from beneath the top-basalt, compared to the conventional recording on the left. The low-frequency data also show a better overall signal-to-noise ratio, which is partly due to the 12 km long solid streamer used. Here only offsets up to 6 km are plotted to compare them with the conventional 6 km data.

Both shot records show that multiple energy disturbs all offsets and recording times up to 9 seconds. Examining the multiple noise more closely shows that it not only contains simple reverberations between sea-surface, sea-bed and top-basalt but also strong interbedded multiple reflections. Especially for this dataset it is essential to reduce all multiple noise, where the first water-column reverberation coincides with the top-basalt P-wave reflection.

Figure 4 shows the NMO-corrected CDP-gathers and associated semblance plots of the original data (top) and the fk-filtered data (bottom). The semblance plot of the original data shows the velocity picks for seven horizons, which are
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coloured on the gather below. After reducing the free-surface multiples using an fk-filter we observe more energy below the top-basalt reflection. The energy of the water-column multiple is reduced but not eliminated. Also inter-bedded and primary reflections are not reduced and are now clearly visible (see ellipse).

Using multiple prediction and Delphi algorithms (Verschuur and Berkhout, 1997) we obtain similar noise reduced data. Additional Radon filters suppressed inter-bed reverberations and the results of these processing steps can be seen on the four sections in Figures 5 and 6.

Figure 5 compares conventional and low-frequency data from the Faroe-Shetland Basin. The 2001 line shows stronger reflections below the top of basalt that can be more readily identified than in the case of the older data obtained with the conventional acquisition configuration. Despite the demultiple algorithms we still observe relatively strong multiples beneath the top-basalt.

A parallel profile shot in the same area of the North-East Atlantic Margin is shown in Figure 6. Compared to the previous line, the top of the basalt reflection lies between 1.5 s and 2 s on the left and dips to 3 s in the direction of the basin centre. The low-frequency data provides a much clearer picture of the geology beneath the top of the volcanic sequence and now allows at least some speculative interpretation, where nothing could be ‘seen’ using conventionally recorded data.

Conclusion

About 70 % of the world’s ocean margins are covered with flood basalts and may conceal enormous reserves of hydrocarbons. The UK sector of the North-East Atlantic Margin is a huge area bigger than the North Sea. The discovery of hydrocarbons could ease the dependency of importing oil from foreign countries into the UK as North Sea production declines.

We have shown that it is necessary to extend the conventional seismic reflection systems to lower frequencies for basalt covered areas, because the basalts of passive ocean-margins are very heterogeneous. This causes more scattering of high frequencies than low frequencies, which should be enhanced by towing source and streamer at depths as great as 20 m and by increasing the volume of the air-guns by a factor of 5.

Because of the additional high impedance contrast the amplitudes of sub-basalt reflections will always be relatively weak. In consequence, not only free-surface multiples but also interbedded multiples have to be reduced. We have shown that predictive, fk and Radon demultiple algorithms reduce but cannot completely eliminate multiple noise.

Outlook

To further enhance the picture below basalts in offshore areas, early notches such as the 50 Hz gap in our data, can be avoided using different acquisition configurations. Ideally new source arrays should be tested, not to compromise the resolution of shallow structures by only emphasising on low frequencies. The next step forward in sub-basalt imaging for hydrocarbons will be the recording of 3D data. This is not only necessary due to the extremely heterogeneous flood basalt sequence but also to find reliable structures beneath them. Because 3D data is highly recommended for finding hydrocarbon traps in basalt-free areas of the same basin (Loizou, 2003), it will surely be essential to find hydrocarbons beneath basalts.
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acknowledgments

this research is funded by the sponsors of the project “seismic imaging of sub-basalt reflections in the north east atlantic margin” and the edinburgh anisotropy project. we are grateful to chevron texaco and the blast group (anadarko, statoil, enterprise oil, phillips, veba oil, and veritas dgc) for allowing us to show the data. this work is published with the permission of the executive director of the british geological survey and the eap sponsors: bp, bg group, chevron texaco, cnpc, conoco, dti, eni-agip, kerr-mcgee, landmark, marathon, norskhydro, petrochina, pgs, schlumberger, totalfinaelf, trade partners uk and veritas dgc.

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figure 5: Comparison of a conventional line shot 1997 in the Faroe-Shetland Basin (A) and the low-frequency line shot in the same location in 2001 (B). The new data was down sampled and both data sets processed in the same way.

figure 6: Comparison of a standard line shot 1998 in the Faroe-Shetland Basin (a) and its low-frequency counterpart from 2001 (b). Despite the down sampling of the new data more information is available from beneath the basalt to allow better interpretations.