Sub-basalt imaging
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Use of low frequencies for sub-basalt imaging

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Summary

Ocean margin basalts are extremely heterogeneous and scatter the seismic energy of the conventional seismic reflection system. To observe sub-basalt reflections the system should be modified to emphasize the low frequencies, using much larger air guns, and towing the source and receivers at about 20 m depth. The rationale for this approach is supported by synthetic seismograms over a realistic 1-D earth model. In the summer of 2001 we obtained data over basalt in the North-East Atlantic using a suitably-modified system.

Modelling of sub-basalt reflections

Ocean margin basalt is often interbedded with thin layers of other lithologies, such as claystone and siltstone (e.g. Gatliff et al., 1984). Following Mack (1997) we have generated synthetic seismograms using the full waveform OSIRIS code from Ødegaard A/S and a realistic model of the basalt. Figure 1 shows a composite basalt layer overlying a single deep reflector.

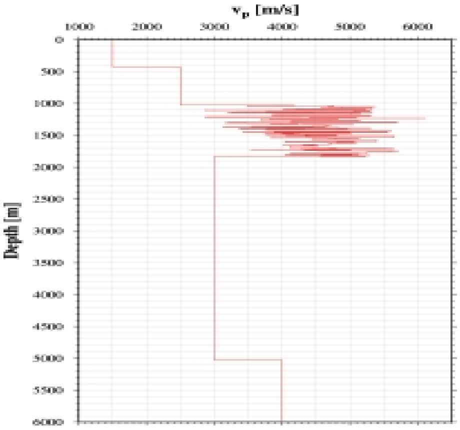

Figure 1: 1-D earth model for synthetic seismograms showing a heterogeneous basalt layer, 1000-1820 m, and a sub-basalt interface at 1000 m.

Figure 2 shows an offset-dependent synthetic seismogram, omitting the sea surface to enable the primary reflections to be seen. The centre frequency of the source time function was 35 Hz. Figure 3 shows the response for the same configuration, but with a centre frequency of 10 Hz. The lower frequency response of figure 3 clearly shows less scattering in the composite basalt layer and a much higher amplitude reflection from the sub-basalt interface at 3.5 s.

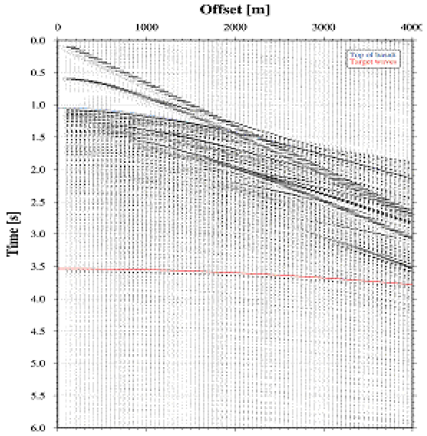

Figure 2: Synthetic seismogram for model shown in Figure 1 with 35 Hz source signal.

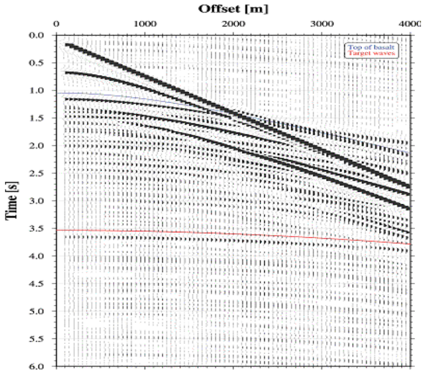

Figure 3: Synthetic seismogram for model shown in figure 1 with 10 Hz source signal. The reflection at 3.5 s is clearly visible.

Source and Receiver Depth

In conventional seismic reflection surveying, the source and receiver cable depths are typically about 5 m below the sea surface. The sea surface reflection effect at the source is of the form:

$$R_s(\omega) = 2\sin(\omega D_s \cos\theta / v_w), \tag{1}$$

in which D_s is the depth of the source, θ is the angle of incidence, and v_w is the velocity of sound in water. At the receiver the expression is identical, except that D_r, the receiver depth, replaces D_s. The system response is optimised for a given bandwidth by putting the source and receiver at the same depth D, when the combined response becomes

$$R_c(\omega) = 4\sin^2(\omega D \cos\theta / v_w). \tag{2}$$

For the source and receiver cable depth at 5 m this effect boosts the amplitude of reflected waves in the bandwidth 30-120 Hz. By placing the source and receiver cable at a depth of 15 m, the optimum bandwidth is shifted to 10-40 Hz.

The air gun source

In a normal air gun array the largest gun has a volume of not greater than about 6.4 l (400 cu. in.). At a depth of 5 m, and a pressure of 135 bar (2000 psi), a 6.4 l gun emits an air bubble which oscillates with a period of about 130 ms, corresponding to a fundamental frequency of 7.7 Hz. The bubble oscillation period is given by the well-known modified Rayleigh-Willis formula:

$$T = k\frac{P^{\frac{1}{3}}V^{\frac{1}{3}}}{\left(P_{atm} + \rho g D\right)^{\frac{5}{6}}}, \tag{3}$$

in which P is the gun pressure, V is the gun volume, P_{atm} is atmospheric pressure, ρ is the density of water, g is gravitational acceleration, D is the depth of the gun, and k is a constant. From the bubble period for one gun of known volume, pressure, depth, and bubble period, it is possible to determine the constant, and hence determine the bubble period of any gun of known volume, pressure and depth. For example, a 6.4 l gun at a depth of 15 m would have a bubble period of about 85 ms, corresponding to a fundamental frequency of about 11.7 Hz. The guns are already operated at close to the maximum safe pressure, so the only parameters that can be adjusted are the depth and volumes of the guns.

If a conventional air gun array is put at 15 m, instead of its normal depth of 5 m, the frequency of oscillation of every bubble in the array is increased by about 50%. In order to obtain low frequencies, say down to 5 Hz, we must use much bigger air guns (since the period is proportional to the cube-root of the volume), say 32 l (2000 cu. in.). Using the Rayleigh-Willis formula, we can calculate that a 2000 cu. ins. air gun at 15 m and 135 bar (2000 psi) would have a bubble period of about 145 Hz, corresponding to a fundamental frequency of about 7 Hz.

In summary, the air gun array must be re-designed, using air guns at least five times bigger than conventional guns, probably about 2000 cu. ins., and towed at a depth no shallower than 15 m. The receiver cable must be towed at about the same depth. We note that these large air guns are commercially available.

Conclusions

To increase the probability of obtaining detectable sub-basalt reflections it is essential to design the seismic reflection system to emphasize the low frequencies. The source and receiver must be towed deep (at least 15 m) and much larger air guns must be used than have been used so far: at least a factor of 5 increase in volume.

In the summer of 2001 Veritas DGC, together with Texaco, implemented these ideas in an experimental survey conducted over a basalt-covered area west of Shetland. Results comparing the low-frequency approach with those of conventional acquisition configurations will be presented at the meeting.

References

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