Z-99 AN EVALUATION OF PEAK AND BUBBLE TUNING IN SUB-BASALT IMAGING: MODELLING AND RESULTS

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Summary

As part of the iSIMM project (White et al. 2002), a 6,360 in^3 airgun source array was used to shoot twice a deep seismic profile into a 380 km array of Ocean Bottom Seismometers (OBS) east of the Faroe Islands. The first pass used peak tuning, and the second used bubble tuning, with other source parameters constant. The objective was to deliver low frequency energy for deep, long-offset, sub-basalt penetration. The results suggest that towing large guns deep is more important than the tuning method. However, for the gun configuration used, the bubble-tuned data are more compact, less reverberant and easier to pick.

Introduction

The iSIMM project seeks to characterise extruded and underplated material at magmatic margins to constrain the development of new geodynamic models simulating the thermal and structural evolution of such margins. In summer 2002, wide-angle data were acquired by 85 OBS deployed by RRS *Discovery* over two continental margins, one east of Faroes and the second across Hatton Bank. On the Faroes margin, the OBS acquisition was complemented by a 12 km, multi-streamer swath acquired by WesternGeco, while over the Hatton Bank margin, reflection seismic data were acquired with *Discovery's* 3 km streamer. The data will be integrated to develop a crustal model from seabed to upper mantle, building on previous work in the area such as FLARE (Fliedner and White 2001). Deep imaging requires return of seismic energy from below the basalt. Several authors (e.g. Mack 1997; Christie et al. *in press*) suggest the use of low frequency bandwidth to overcome the scattering and geometrical losses from rough, high-contrast impedance boundaries associated with stacked lava flows. For the Faroes OBS line, we designed a source of large, deep-towed guns and explored the relative benefits of two tuning strategies: synchronising the guns to time-align the primary pulses (peak tuning); and introducing delays to time-align the first bubble (bubble tuning).

Gun depth

From the Rayleigh-Willis relation, the dominant bubble period of a gun signature varies with the cube root of its volume: large guns produce low frequencies. However, the primary followed by the delayed ghost acts as a dipole filter at distances that are far compared to the source depth. This filter has a peak value of two at the frequency for which the source depth is a quarter-wavelength. The downward-travelling, far-field signature has a spectrum with "ghost notch" nulls at 0 Hz and at multiples of frequencies for which the source depth is a half-wavelength. Although depth affects the frequency of maximum ghost enhancement, it is important to note that depth does not affect the octave bandwidth of the ghost-enhanced frequencies: this is 2.32 octaves centred upon the quarter-wavelength frequency (Ziolkowski et al. 2001). A gun is most efficient at its quarter-wavelength depth. The optimum depth for a

1,000 in^3 gun, of which two were used in *Discovery's* source, fired at 140 bar is approximately 29 m, much deeper than conventionally deployed. However, the deeper a gun, the higher its dominant frequency, as the ambient pressure increases with depth. Figure 1 shows bubble frequency versus depth, estimated from a hydrophone located 1 m from a single 1,000 in^3 gun test-fired during the Faroes survey. Over the 11–23 m depth interval, the trend follows the Rayleigh-Willis prediction. Figure 2 shows cumulative energy as a function of frequency at three depths from Faroes data. Deeper tow increases gun output, but at the expense of the lowest frequencies. In production, the 1,000 in^3 guns were towed at 16–18 m to produce energy below 10 Hz, and to give good output up to 20 Hz.

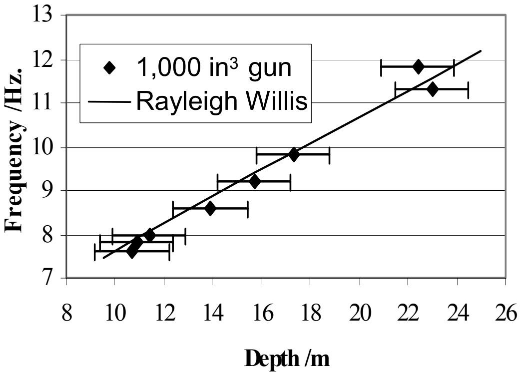

Fig.1. Observed bubble frequency-depth data.

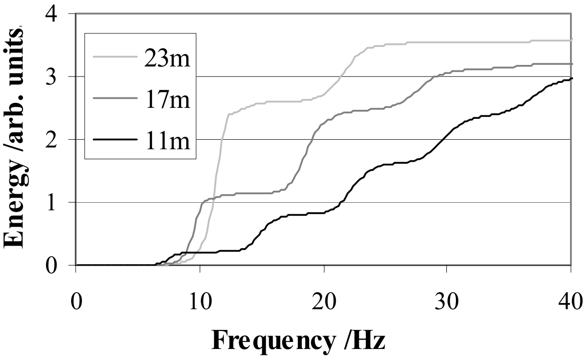

Fig.2. Cumulative energy variation with depth.

Bubble tuning

A single, free-field gun signature is shown in Figure 3, with no ghost. We carried out a time-frequency analysis by windowing the trace with a running Gaussian of half width 107 ms, and Fourier transforming the trace within each window. The spectral amplitudes are contoured, with the lowest contour at 20 dB, and the highest at 120 dB. The low frequency energy is centred upon the first bubble oscillation.

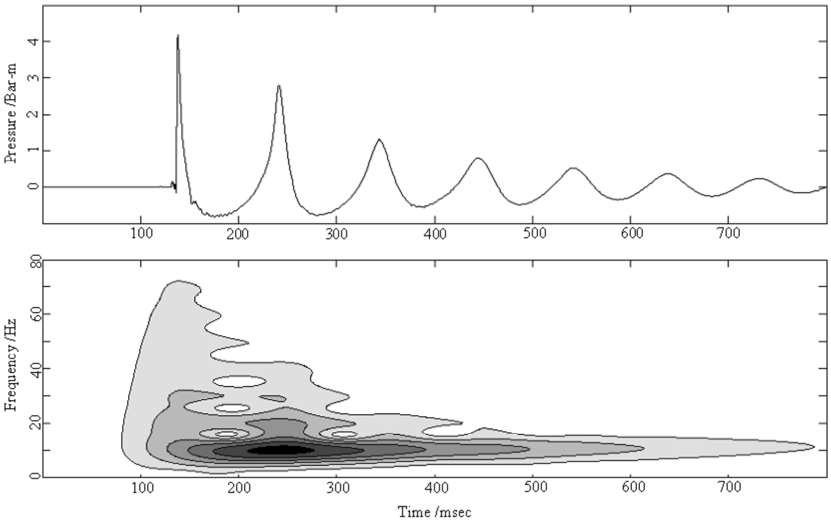

Fig.3. Upper: a single gun, free-field signature with no ghost.

Lower: the frequency-time plot showing that the peak amplitude is about 10 Hz and coincides with the first bubble at about 240 ms. Contour interval 20 dB.

Conventional peak tuning synchronises the guns so that the first pressure peaks coincide. In bubble tuning, firing delays are applied so that the first bubble oscillations coincide (Figure 4). Peak tuning guns of different sizes minimises the bubble oscillations by destructive interference, but this is not the most efficient use of the available energy. Bubble tuning should be more efficient if low-frequency energy is required. Figure 5 shows pre-survey modelled signatures for both peak and bubble tuning, after filtering through a 20 Hz, low-pass filter simulating earth attenuation. The bubble wavelet has a better peak-to-peak amplitude, is more compact, and should be easier to pick.

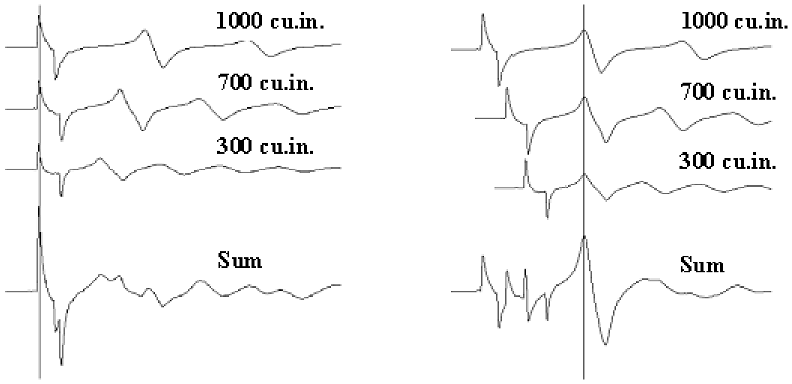

Fig.4. Left: tuning on the peak.

Right: tuning on the bubble.

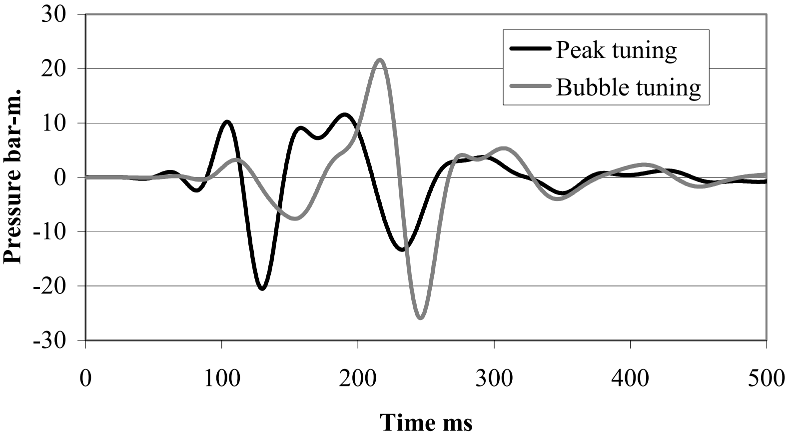

Fig.5. Pre-survey modelled signatures for peak and bubble tuning after the application of a 20 Hz, zero-phase, low pass filter. The bubble tuned signature is more compact and has a greater peak-to-peak amplitude.

Discovery shot the Faroes OBS line twice, with both peak and bubble tuning. All other source parameters were constant. Our bubble-tuning approach differed from that of Avedik (1993) in using Bolt LL guns instead of GI injector guns. The source comprised four sub-arrays (using 120, 160, 300, 400, 500 and 700 in^3 guns) at a constant 22 m depth, and two 1,000 in^3 guns at depths varying slightly with speed through the water. This was the first time variable tuning had been attempted with *Discovery's* acquisition system, and it proved remarkably stable. The timing delays were picked in the field using near-gun hydrophones.

Two profiles from an OBS at the northern end of the Faroes line over oceanic crust are shown in Figure 6. Identical processing has been applied: linear moveout at 7 km/s, band-pass filter 5–12 Hz, time-varying gain and range-dependent gain compensation. Both profiles have the same plot gain. Both sections show clear arrivals of similar amplitude and dominant frequency to over 100 km, suggesting that the tuning differences are less important than gun depth and volumes. The bubble-tuned profile is somewhat clearer at the farthest offsets, partly due to lower noise, possibly from different tidal flows. Examining the data after noise reduction shows upper mantle arrivals to 140 km. The bubble tuning shows some other advantages. As suggested by the modelling, its signature is more compact and easier to pick. It has one main peak rather than two; the ratio between the largest peak and the next largest one is 1.8 on the bubble-tuned data and 1.4 on the peak-tuned data in the 10–30 km range. Tracking the Moho reflection as it emerges through the crustal diving wave is much easier on the bubble tuned section, which also shows less reverberation at all offsets.

Conclusions

As part of the iSIMM project, we have evaluated peak and bubble tuned sources in generating a low-frequency wavelet that penetrates basalt in wide-angle OBS acquisition. Because the ghost operator allows 2.32 octaves of signal enhancement, regardless of source depth, we chose to enhance the low-frequency energy by using large guns, towing them deep and tuning on the first bubble. Pre-survey modelling of the peak and bubble-tuned arrays showed some

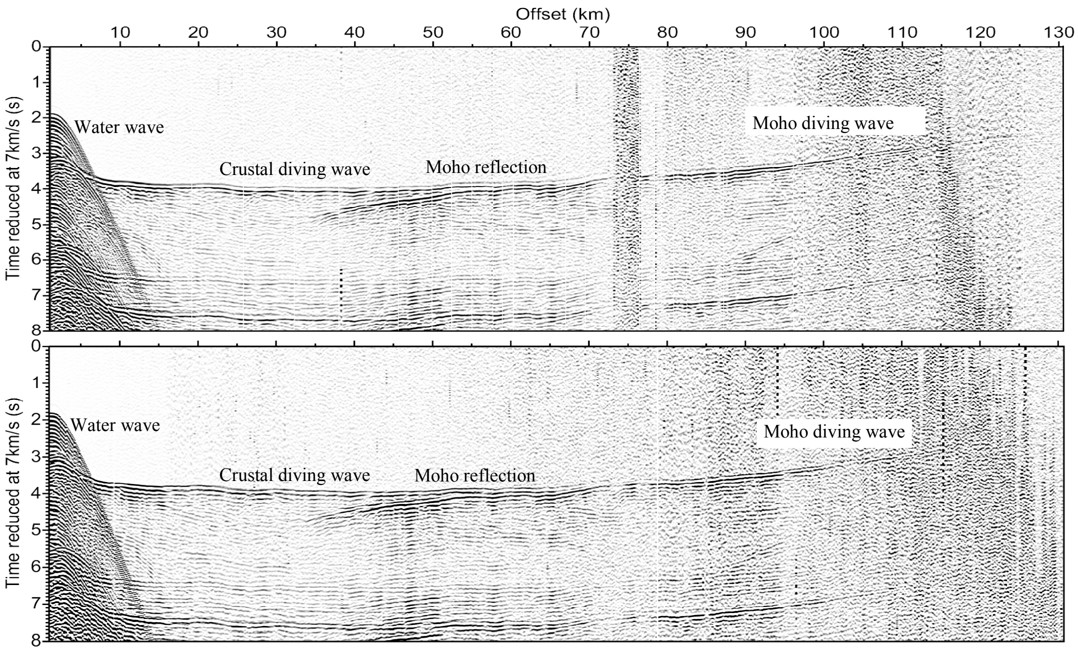

Fig.6. Upper: bubble tuning.

Lower: Peak tuning.

benefits for the bubble-tuned array. As expected, we find that the Rayleigh-Willis expression holds for a 1,000 in^3 gun fired at depths in the range 11–23 m. Our data also confirm that increasing source depth trades off improved low-frequency ghost notch response with shorter period bubble oscillation. For the OBS survey we used an array of large single Bolt LL guns, with sub-arrays towed at 22 m, and 1,000 in^3 guns towed at 16–18 m. With this modification to Avedik's approach, we found that while both sources gave good results with similar amplitudes and dominant frequencies, the bubble tuning had some benefits over peak tuning: the signal is more compact, shows less reverberation and is more persistent at long offsets.

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