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Seismic properties of the Faeroe basalt formations: the LOPRA-1 VSP case study

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Introduction

In this paper, we investigate the seismic properties of basalt flows and more particularly attenuation. To that effect, we chose to work on the Lopra-1 VSP data in order to evaluate the propagation properties of seismic signal through lava piles. This well, which penetrated 2.2 km of basalt, is located in the Suduroy' island that belongs to the "Faeroe Islands" area and to the Brito-Artic early tertiary Igneous Province.

Data acquisition and processing

The VSP data were collected in 1988 by the Geological Survey of Denmark (Kiørboe and Petersen, 1995). The source was an airgun array with a 4.9 l source volume. It was placed at 123 m offset and 5 m depth. Three-component geophones were positioned down hole along the well track from 220 to 2170 m every 30 meters. The z component was processed through a "preserved amplitude" 1C method, which has been developed in IFP (patent pending).

Results

The average P and S wave velocities are rather high with, respectively, around 5200 m/s and 2750 m/s. The P wave interval velocities have been derived from the first arrivals. The derivation of S interval velocities, from direct S arrivals, was not easy due to the presence of P-S wave conversions scattering the "direct" S energy. The P and S interval velocities follow the same main trend (figure 1) but the Vp/Vs ratio decreases slightly with depth from 2 to 1.85.

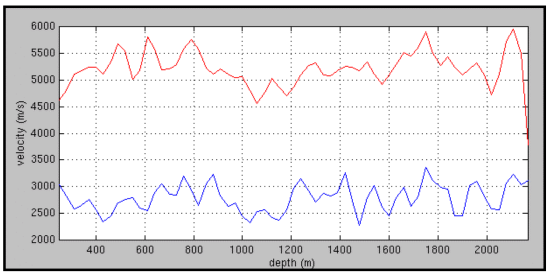

Figure 1: P and S interval velocities.

Intra-basaltic reflections are immediately observed, even on raw data. The data have been processed through a preserved amplitude workflow that allowed the determination of reflection coefficients under a normal incidence assumption. Several reflection coefficients are indicated on figure 2. The range of variation of this coefficient is between 1.2 and 2.7 %. These values show that the Lopra-1 lithology does not exhibit any significant impedance contrast. Some reflections are due to doleritic intrusions, others can reasonably be attributed to the changes in average flow thickness that introduce the impedance variations seen by the seismic waves.

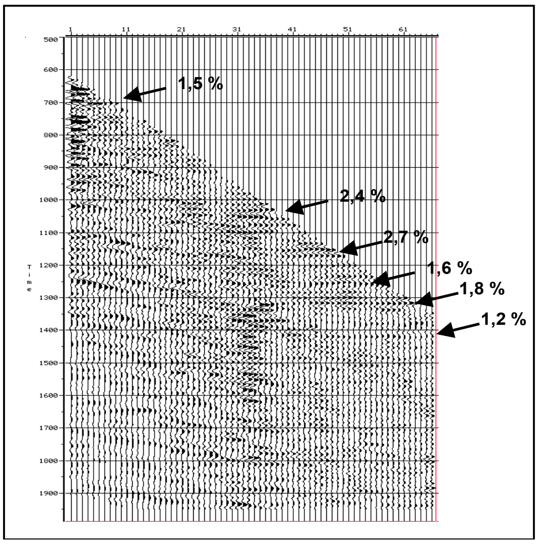

Figure 2: VSP processed with the PAM sequence.

Attenuation analysis

In the raw data, the first P arrivals show a drastic shape variation throughout the lava pile with strong reverberations in the shallow part of the vertical profile that disappear as we go deeper. The deeper arrivals have a lower frequency content. A quantitative approach was used in order to extract attenuation values from the data.

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Methodology

Our methodology to evaluate the plane wave attenuation is based on the transmitted wave amplitude measured in the time domain and corrected for the source variation, spherical spreading and local impedance effects. The last correction comes down to work on the energy flux. Direct P wave arrivals are studied after the application of different band pass filters. Thus, the attenuation can be computed in several frequency bands and no frequency assumption about Q is required. We compute an attenuation coefficient β in the time domain using a method inspired by Pujol and Smithson (1991):

$$20\log\frac{\sqrt{E_z}}{\sqrt{E_0}} = -\beta_t \delta z \quad \text{(i)}$$

where E_z is the energy flux of the wavelet at depth z. E_0 is the energy flux of the wavelet of reference and δz the interval between sensors.

Then, Q is obtained from

$$Q = \frac{20\log(e)\pi f}{\beta_t v} \quad \text{(ii)}$$

where *f* is the frequency and *v* is the P wave velocity.

Application to the Lopra-1 data

The methodology described above was applied to the Lopra-1 VSP data. We had to assume, though, that the source signature was stable, as the signature was not monitored. This is why, we do not think that the application, shown here, is optimal. Wireline logs were not available either. Log information is extremely useful for deriving the local impedance corrections, especially the density logs. Here, we used the interval velocity and considered the density almost constant in the lava pile to compute the local impedance. Such an assumption seems to us, however, quite reasonable in this context.

The profile can be divided in two distinct parts: first, from 200 m to 1300 m, the transmitted energy is strongly attenuated showing a trend which gets steeper as frequencies get higher. In table 1, the attenuation values derived by linear regression and Q factors are shown for the different frequency bands. The regression variance is not shown here because we are looking for a variation trend and not for an optimal function that could describe our measures. Despite the low Q value, the cumulative attenuation is not high (4 db) for the low frequency contents.

In the second and deeper part of the profile, the trend of the square root of the energy flux shows a pattern that is almost flat, especially for the frequencies below 100 Hz. The Q factor is one order of magnitude larger than in the first part of the profile (about 200).

Frequency band (Hz)	β_t (db/m)	Q
5-35	4.3 10^{-3}	24
20-50	8.9 10^{-3}	21
35-65	17.9 10^{-3}	15
50-80	25.8 10^{-3}	13
65-95	31 10^{-3}	14
80-110	33.8 10^{-3}	15
95-125	36.7 10^{-3}	16
110-140	38.8 10^{-3}	17

Table 1: Attenuation and quality factor versus several frequency bands.

Discussion

The high mean velocity value within the basalt has to be linked with the 20 m average thickness of the lava flows and the quasi-absence of intra-bedded sediments. As far as plane wave attenuation is concerned, the Lopra-1 well profile shows two aspects. One can be considered as a high attenuation zone that may be attributed, mainly, to scattering. The frequency dependence could confirm this hypothesis. The second relates to a zone where the quality factor is about 200 for the peak frequency. This value indicates that plane wave attenuation is not here a restrictive factor for the seismic signal propagation.

Conclusions

The Lopra-1 VSP gives some insights about seismic properties within the Faeroe basalt accumulations. Transmission into and propagation through the basalt do occur. The high frequency content of the seismic signal is strongly effected in the shallow part of the vertical seismic profile where intra-basalt fractures seem to be more present whereas low frequencies are much less perturbed by the scattering and propagate well through the 2.2 km of basalt materials.

Acknowledgements

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References

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