Sub-basalt imaging
9-11th April, 2002
Cambridge, UK

Journal of Conference Abstracts
Volume 7(2), 160

Effects of the lava pile structure on the seismic wave propagation: a modeling study

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Introduction

One dimensional impedance models of subaerial basalt flows based on typical wireline log responses, were investigated in order to identify their main characteristics in terms of geophysical properties. A macro model containing a basalt-layer, constituted by stacked lava flows, inserted between sedimentary formations has been produced as an input to seismic simulation. A study of propagation and attenuation of the seismic signal through basalt flows has been undertaken. This paper presents the current results.

Basalt-layer model

The model can be described through its medium and large scale parameters.

The subaerial basalt flow model

According to Planke (1994), downhole logs show a very characteristic pattern in subaerially emplaced flood basalt. P wave velocity increases gradually from the top of a basalt flow unit to its interior corresponding to a decreasing amount of voids and cracks in the flow top. The interior of thick basalt flows (homogeneous zone) shows high velocity ~5000 to 6000 m/s, while the velocity decreases rapidly near the base of a unit. The velocity gradient (400 s^{-1} 600 s^{-1}) at the top of the basalt flows is seemingly independent of unit thickness. This description was used to build a basalt flow model where the velocity increases from a starting value of 3000 m/s with a gradient of 400 s^{-1} until the velocity reaches a plateau at 5400 m/s. Then, near the base of a unit, the velocity decreases rapidly. The density is strictly correlated with the P wave velocity.

The lava pile model

Our lava pile model contains flow units with variable thickness which can be parameterised statistically. The lava flow average thickness is fixed to 10 m and the lava flow thickness follows a gaussian curve with a standard deviation of 3 m. The values of these parameters are inspired by the statistical analysis of the site 642 logs performed by Planke (1994). To control the role played by the statistical distribution of flow thickness on the propagation properties, three different realisations of this statistical description were performed.

VSP data simulation

We chose to simulate VSP experiments acquired in a simple sedimentary basin model composed of four layers: a 1000 m thick sedimentary layer (Vp:2500 m/s, ρ:1.8), a 1000 m thick lava pile (3 realisations) and two 500 m thick sedimentary layers (Vp:3000 m/s, ρ:2 and Vp:3500 m/s, ρ:2.2). We used a finite difference code (from SMAPP IFP modelling package) which was developed for a very detailed 1D medium with a 3D propagation (Jurado et al, 1995). Synthetic 1C VSPs have been simulated between 500 and 3000 m depth with 10 m interval between sensors. The source is a zero phase ricker with a variable peak frequency (15, 30 and 50 Hz).

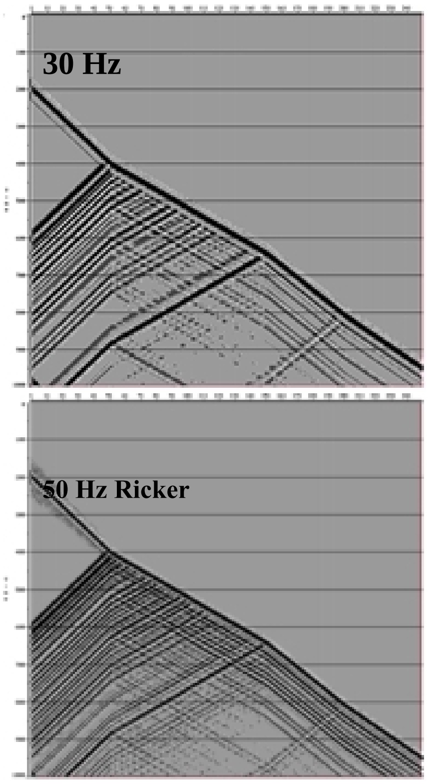

Figure 1: Synthetic VSPs modeled with a 30 Hz and a 50 Hz ricker source

Results

The mean velocity in the lava pile is quite similar for the three realisations (between 4100 and 4150 m/s). It can be derived from the following equation:

$$v_m = \frac{\sum h_i}{\sqrt{\sum h_i \rho_i \sum \frac{h_i}{\rho_i v_i^2}}} \qquad \text{(i)}$$

Where h, v, ρ are respectively the thickness, the velocity and the density of an element of the lava flow. In the lava pile interval a great number of interferences between reflections and multiples can be seen (figure 1). These interferences are more present when a higher peak frequency is used (50 Hz). After the signal has propagated through the lava pile, the transmitted wave is followed with a long-period coda. Thus, the lava pile which is composed of fine layers alters the waveform of the travelling signal. The effect of short-period multiples is to broaden the downgoing wavelet, which can no longer be considered a primary pulse.

Attenuation

The attenuation process here is not meant to be the intrinsic attenuation, which is characterised by dissipation, but the extrinsic attenuation due to internal scattering. Figure 2 presents the square root of the energy flux curve of the transmitted seismic signal. On this curve two main characteristics can be observed within the basalt interval: a downward trend which becomes steeper when the frequencies get higher and a strong oscillatory character that can be explained by both the effects of interfering reflections and transmission. The attenuation was easily derived from the amplitude in the sedimentary layer below the lava pile, which gives the cumulative attenuation, and from the knowledge of the transmission coefficients. The attenuation (0.07 db.s/1000 m or Q~100 for the example displayed) is more than 40 % higher for the 50Hz in comparison with the 30 Hz source. The same main trend is observed for the two other realisations.

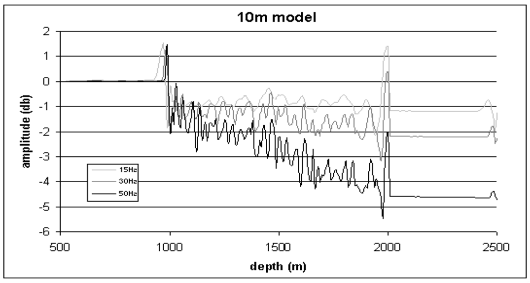

Figure 2: Square root of the energy flux versus depth for a 10 m mean thickness model

Impact of the lava pile velocity structure

The models, which we presented above, showed the properties of P-wave velocity and density in more primitive lava. Actually, the upper parts of flows in more mature lava stratigraphy may require steeper velocity gradient. To get some insight regarding the impact of the structure on the velocity and the attenuation for a more mature lava pile, we built a model with a 20 m average thickness and a steeper gradient in the lava top (1000 s^{-1}). The mean velocity for this lava pile is higher (4900 m/s). Figure 3 shows a smaller layering effect due to a velocity structure which is less heterogeneous. Nevertheless, the energy loss from transmission effect associated with the large impedance contrast is more severe.

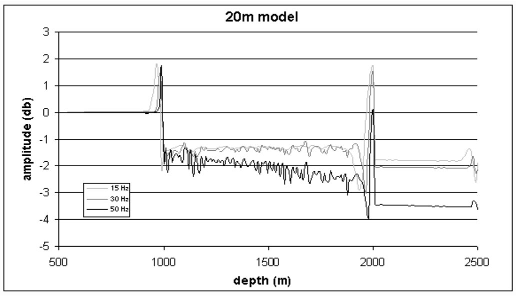

Figure 3: Square root of the energy flux versus depth for a 20 m mean thickness model

Conclusions

Although we know the limit of 1D models with regard to the basalt-layer complexity, we believe that our lava pile model provides a good first approximation analogue. These lava flow models that account for the zonation in subaerial basalt flows enable us to investigate the role played by the lava pile structure on the geophysical properties, especially the attenuation generated by layering. In the next step of this work, we will investigate the 2D and 3D lava pile structure, aiming at getting some insight on the interface rugosity, lateral heterogeneity of lava flows and possible intercalated sedimentary horizons.

References

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