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A study on the seismic AVO signatures of deep fractured geothermal reservoirs in an intrusive basement.

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Abstract

Amplitude-variation-with-offset (AVO) analysis of reflected waves has become an important tool for hydrocarbon prospecting. However, while the AVO responses of reservoirs in clastic lithologies (oil or gas bearing sands) are well known, the AVO behaviour of reservoirs hosted in the interconnected fractures of massive rocks are almost unknown due to the rarity of this type of reservoirs and the consequent lack of seismic and well log data.

Thanks to the availability of the data of boreholes that ENEL GreenPower drilled in the deep intrusive basement of the Larderello-Travale geothermal field, we have derived the expected AVO responses of the vapour reservoirs found in some intensely, but very localized, fractured volumes within the massive rocks.

Therefore we wish to determine what are the expected AVO responses of geothermal reservoirs inside fractured igneous rocks and we seek to find one or more AVO attributes that may help identifying fracture locations.

To this end, we have analysed the velocity (P-wave and S-wave) and the density logs pertaining to three wells which reached five deep fractured zones in the basement. However, comparing well log data with surface seismic data the known issues of the different scales and thus different resolutions arise. Therefore, making use of the Backus theory of the equivalent layer, we have downscaled the well logs, acquired at a decimetric scale, to a decametric scale typical of the wavelengths of seismic waves, producing a blocky model of the original logs.

Subsequently, we have followed two different approaches to estimate the expected responses. First, on the basis of the P and S velocities and densities of the fractured level and of the encasing rock, we have computed the analytical AVO response of each fractured zone. To this end we have made use of the linear Shuey equation that well describes the AVO response up to incident angles of 30 degrees. This would be the theoretical, noise free, response that perfectly describes the contrast in elastic properties at the interface massive rock–fractured zone.

However, this approach does not take into account the effects of wave propagation that occur in a real seismic experiment, such as multiple reflections, interference and converted-waves. Therefore, our second approach consists in modelling synthetic seismic experiments on the blocky models derived from the well logs and then measuring the actual AVO responses on the synthetic seismic data. To model the synthetic seismic gathers a reflectivity algorithm was used.

Comparing the analytical and the synthetic AVO responses we find a fair similarity and all the five fractured reservoirs show similar characteristics. In particular it results that the amplitude of the reflections from the fractured level should be characterized by negative values at near vertical incidence and by decreasing amplitudes with the increase of the source to receiver offset. This contrasts with most observations from hydrocarbon exploration where gas-sand reflections exhibit negative amplitudes at short offsets but increasing amplitude trends at increasing source to receiver offsets.

Thereby the most common AVO attributes, considered in silicoclastic lithologies, are worthless in this case, and would lead to erroneous fracture localization. For this reason we need to derive a new AVO attribute which may highlight fracture locations in this peculiar rock type.