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Seismic tomography and ambient noise reflection interferometry on Reykjanes, SW Iceland

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Recent advances in volcano-seismology and seismic noise interferometry have introduced new processing techniques for assessing subsurface structures and controls on fluid flow in geothermal systems. We present tomographic results obtained from seismic data recorded around geothermal reservoirs located both on-land Reykjanes, SW-Iceland and offshore along Reykjanes Ridge. We gathered records from a network of 234 seismic stations (including 24 Ocean Bottom Seismometers) deployed between April 2014 and August 2015. In order to determine the orientation of the OBS stations, we used Rayleigh waves planar particle motions from large magnitude earthquakes. This method proved suitable using the on-land stations: orientations determined using this method with the orientations measured using a giro-compass agreed.

We obtain 3D velocity images from two fundamentally different tomography methods.

First, we used local earthquakes to perform travel time tomography. The processing includes first arrival picking of P- and S- phases using an automatic detection and picking technique based on Akaike Information Criteria. We locate earthquakes by using a non-linear localization technique, as a priori information for deriving a 1D velocity model. We then computed 3D velocity models of velocities by joint inversion of each earthquake's location and lateral velocity anomalies with respect to the 1D model. Our models confirms previous models obtained in the area, with enhanced details.

Second, we performed ambient noise cross-correlation techniques in order to derive an S velocity model, especially where earthquakes did not occur. Cross-correlation techniques involve the computation of cross-correlation between seismic records, from which Green's functions are estimated. Surface wave inversion of the Green's functions allows derivation of an S wave velocity model.

Noise correlation theory furthermore shows that zero-offset P-wave reflectivity at selected station locations can be approximated by auto-correlating and stacking station ambient noise data for long periods of time. With few assumptions, single-station auto-correlations provide, underneath the station locations, local 1D high-resolution structural acoustic-contrast versus depth information. By applying the method to all network stations, a sparse map can thus be made of dominant zero-offset P-wave reflectivity in the upper few kilometres of the Reykjanes area. A logical further extension of this approach is to perform cross-correlation of all station-pairs in this seismometer network. In order to improve the lateral resolution of the subsurface structure, identifying non-zero-offset reflectivity in the pre-stack virtual source cross-correlation panels provides the opportunity to obtain subsurface reflectivity versus depth point information at locations in-between the seismic station positions. Time-lapse variations in these subsurface reflectivity can be studied by computing the correlations in different, but extended, time periods.

We present results of the here described methods on optimized station network data. We show that the application of ambient noise interferometry for reflection retrieval and comparison of the herewith obtained results with those from applying both classical and noise tomography methods reduces uncertainties in, for geothermal exploitation, relevant subsurface parameters. In particular it increases the spatial resolution of subsurface images as compared to tomographic imaging results.