

On the interrelation of fluid-induced seismicity and crustal deformation at the Columbo Submarine Volcano (Aegean Sea, Greece)

Abstract
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Joint seismological and deformation studies are a mighty tool to study the dynamic of magmatic systems at active volcanoes. While GPS measurements and InSAR are successfully applied at onshore volcanoes, the monitoring of submarine volcanoes is mostly restricted to island based or temporary seismological measurements. We therefor developed a free fall, self leveling Ocean Bottom Tiltmeter (OBT) to observe ground deformation on the seafloor, using a two component tilt sensor with a resolution of about 15nrad. The tiltmeter is mounted on the preexisting Hamburg Ocean Bottom Seismometer (OBS) carrier system. It is additionally equipped with a hydrophone to assess seismic data and an absolute pressure sensor to observe uplift and subsidence.

Between June 2006 and March 2007, four of these OBT systems were deployed along a profile over the slopes and on top of the Columbo Submarine Volcano. The network was completed by four OBSs in the vicinity of the seamount and additional land seismometers on the surrounding islands. Columbo is part of the Santorini volcanic complex, located in the center of the Hellenic Volcanic Arc, Aegean Sea (Greece), approximately 8km north-east of Thira island (Santorini). The volcano has attracted attention since island based monitoring indicates a high seismicity rate clustering around the seamount and possible crustal deformation which both might represent fluid migration in the subsurface.

Within this 10 months long local experiment, azimuthal gaps between the islands were closed and the magnitude threshold of the permanent network was significantly decreased. The installation of zero offset seismic stations on top of the volcano enabled us to derive high precise depth locations of the earthquakes. Purpose of the study was to find evidences for swarm triggers, such as possibly fluid migration, by precisely relocating the events by means of multiple events methods. About 4000 events have been manually picked and six earthquake swarms directly occurring at Columbo have been analyzed for migration velocities of seismic fronts. Four of these swarms were classified as supposedly dike-induced, both remaining swarms as the expression of increased hydrothermal activity. Moment tensor solutions of stronger earthquakes ($M_w > 3$) were calculated to evidence our findings in terms of possible stress field perturbations induced by the postulated triggers.

Simultaneous to the seismological observations, general unrest in terms of noise increase was found on the tiltmeters for all earthquake swarms, predominantly orientated radial to the earthquake cluster centroid. For one swarm occurring close to the tiltmeter profile, strong near-field terms were observed and successfully modeled as an ascending volume source. Both findings are discussed exhaustively regarding a possible linkage between the seismic cluster and the origin of the deformation signals. Further points of discussion are the general technical functionality of the newly developed OBT as well as additional findings like long period deformation signals and trends suggesting the uplift of the complete region between Columbo and Santorini.

We conclude with a hypothetical model on deformation signals accompanying the ascent of a volumetric source. The hypothesis bases on our preexisting model on the pattern of dike-induced earthquake swarms. We show, that migration velocities found by seismological observations can be redundantly observed for the propagation of the suggested volumetric source. Finally, we evidence that our approach is sufficient to estimate source depth, ascent velocity and the crude source volume by analyzing spatial and temporal tilt maxima, as well as their amplitudes.