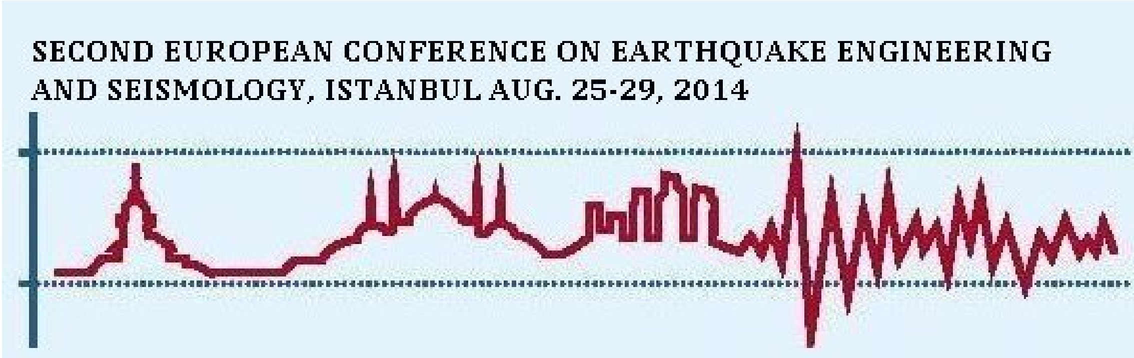

A SEISMOLOGICAL STUDY IN THE SANTORINI VOLCANIC COMPLEX AREA DURING 2011 - 2012

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The Hellenic Quaternary volcanic activity, well known as the South Aegean Volcanic Arc (SAVA), extends from Methana peninsula to Nisyros Island. Along the SAVA, the most active known features, either with historic eruptions or hydrothermal explosions, are Methana, Santorini, Nisyros and Milos. The Santorini Volcanic Center is one of the most active features of the Hellenic volcanic arc, which is a major geotectonic feature of the southern Aegean. The movement of the fluids in the Santorini Volcanic Complex (SVC) has been strongly infected by regional tectonics. The current geodynamic status of the SVC is controlled by two major volcanoes, the Nea Kammeni and the submarine Columbo ones. Respectively, two major fault lines, Kammeni and Columbo, cross the volcanoes in a NE-SW direction.

The Santorini volcano has erupted many times, with different degree of explosivity. At least twelve large explosive eruptions have been listed in the bibliography, at least four of which formed a caldera. The earliest eruptions occurred on the Akrotiri Peninsula, 650,000 to 550,000 years ago, which are geochemically distinct from the later volcanism, due to their amphibole content. Over the past 360,000 years there have been two major cycles, each culminating with two caldera-forming eruptions. This eruptive history is also divided in a series of sub-cycles. Lava flows and small explosive eruptions built up cones. The most famous eruption occurred during the Late Bronze Age (mid of the second millennium BCE) and is widely-known as the Minoan one. Post-Minoan eruptive activity is concentrated on the Kammeni islands, in the centre of the caldera, with Palaia Kammeni being formed in 197 BCE. Nine sub-aerial eruptions were recorded since historical times, with the most recent ending in 1950.

The seismicity in the SVC area can be characterized as moderate. The exact seismicity level cannot be precisely estimated due to the absence of local seismological networks. However, the seismicity is mainly concentrated along the Santorini - Amorgos Fault Zone. It should also be mentioned that in the Columbo volcano several earthquake swarms have occurred (Hatzfeld et al., 1993; Delibasis et al., 1995; Bohnhoff et al., 2006; Dimitriadis et al., 2009; Kolaitis, 2011). Furthermore, the activity within the Santorini Caldera was very low. This pattern was reversed in 2011 and 2012, since the low seismicity areas (Santorini Caldera and Christiana Islands) were activated, while simultaneously the Santorini - Amorgos Fault Zone exhibited low seismicity.

Additional local seismological stations were installed in 2011, in the framework of the Hellenic Unified Seismological Network (HUSN), to monitor in detail the seismic activity in the SVC

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area. More than 1300 events have accurately been located. These events can be separated in 5 spatial groups, in the Caldera region, 40 km SW of Santorini Island, around the submarine Columbo volcano, around Anydros Island, NE of Columbo and south of Santorini Island. For each of the five groups a specific velocity model was determined to reduce the location errors. Following, the manually located events were relocated using the HYPODD (Waldhauser and Ellsworth, 2000) algorithm and the events of each group were classified into multiplets according to the degree of their similarity. The spatial hypocentral distribution of the relocated events appears less dispersed.

In February 2011 intense seismic activity was observed for the first time within the Santorini Caldera, which lasted until March 2012. The hypocentral depths are shallow, with the vast majority until 10 km, while the magnitudes are relatively small, with the strongest events reaching M_L=3.5. The spatial distribution revealed that most of the events lie between the Palea and Nea Kammeni Islands and in the vicinity of the central-west scarp of Santorini Island.

In volcano-tectonic regions, the determination of fault plane solutions has been proven of significant importance for understanding their regime. P-wave first-motion polarities were used to determine 131 focal mechanisms inside the Santorini Caldera, revealing strike-slip type faulting. Nevertheless, a complexity of the fault plane solution pattern was observed towards the SW and NE edges, where the highest deformation was recorded by GPS measurements (Newmann et al., 2012; Lagios et al., 2013). The 131 focal mechanisms were grouped in 9 clusters using waveform similarity, as well as the epicentral spatial distribution. In addition, composite fault plane solutions were also determined for each cluster. The obtained results indicate that one of the two sub-vertical planes, that strikes NE-SW, is almost parallel to the mean direction of the events spatial distribution, implying that it is probably the fault plane, characterized by dextral slip.

The examination of the volcano state was among the main scopes of the present study. For that purpose, several methodologies were applied, including polarization analysis and spectrograms, anisotropy and tomography studies. An algorithm was developed to perform polarization analysis, taking into account the covariance matrix methodology (Montalbetti and Kanasewich, 1970; Jurkevics, 1988; Jepsen and Kennet, 1990) based on the procedure described by Ereditato and Luongo (1994). In addition, volcanic signal analysis was carried out using spectrograms of different signals recorded by at least two local stations. The results indicated that the majority of the events located within the Caldera are characteristic examples of high frequency volcano-tectonic type. Different types, such as spasmodic bursts, LF events and volcanic tremors, have been identified that can be related to the activation of the magmatic chamber, as well as to changes in magma properties and to variations of the pressure in the conduit.

During the analysis of the recordings of the three-component stations of the SVC area the shear-wave splitting phenomenon was observed, initiating an anisotropy study. The polarigram and the hodogram representations, which have successfully been applied in several anisotropy studies performed in the Greek territory (Papadimitriou et al., 1999, 2010; Kaviris et al., 2008, 2010), were used to determine the anisotropy direction, the time delay between the two split shear waves and the source polarization. The obtained results can be explained by the APE model (Crampin and Zatsepin 1997; Zatsepin and Crampin 1997).

Finally, a tomographic study was performed using a dataset comprising of more than 1300 earthquakes, including P and S arrival times with at least 8 phases and ratio of S to P residual smaller than 2.5. Inversion was performed both for Vp, Vs and Vp–Vp/Vs, in order to obtain additional constraints concerning the Vp and Vs anomalies. Synthetic testing (checkerboard) was performed to define the area of fidelity. The results revealed an area of low Vp, Vs and high Vp/Vs anomaly located north of Nea Kammeni, between 4 km and 7 km depth that can directly be related with the magmatic chamber.

Taking into account all results of the present study, it can be concluded that the central part of the Santorini Caldera was activated during the 2011-2012 unrest period, with the majority of focal depths ranging between 4 km and 8 km. The intense deformation, observed by GPS measurements was accompanied by high microseismicity, related to strike-slip faulting. Nevertheless, the outcome of the multimethod approach indicated that the volcano was not in a critical state. It is crucial that such efforts for the monitoring of the volcano must continue to detect possible changes of the volcano state.

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