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# The January 2012 earthquake sequence in the Cretan Basin, south of the Hellenic Volcanic Arc: Focal mechanisms, rupture directivity and slip models

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ABSTRACT

The January 2012 moderate-size (Mw5.3) sequence in Cretan Basin is studied, in an attempt to shed light to the deformation pattern along the central part of the southern Aegean Sea, south of the Hellenic Volcanic Arc. The two strongest events of the earthquake sequence, occurred on January 26 (UTC 04:24 Mw5.0) and on January 27 (UTC 01:33; Mw5.3), with epicenters lying 25 km and 50 km SW of the Christiani Isles and Santorini volcanic fields, respectively. Moment tensor inversions revealed the operation of pure strike–slip motions, along N–S and E–W trending vertical planes. The deviatoric moment tensor solutions, in a number of cases, involved more than 30% non-double couple component. The seismicity was confined in a vertical column of small (~5 km) horizontal extent, whereas the best constrained depths were in the range of 5 to 14 km. The good station coverage and the striking similarity of the waveforms permitted directivity effects to be resolved, from the shape and amplitude of the apparent Source Time Functions (STFs), obtained through an empirical Green's function approach. The rupture directivity towards south, resolved the N–S trending plane as the fault plane for both of the two strongest events. This sequence provided evidence that the WNW–ESE trench-parallel extension accommodated within the overriding Aegean plate, which so far was well documented in the western and eastern parts, it is also operating in the central part of the southern Aegean Sea. The slip models for the two strongest events were simple, single patched and the calculated static stress drop was of the order of 35 bars, in agreement with the average value in the back-arc Aegean Sea region.



## 1. Introduction

In January 2012 a moderate-size earthquake sequence initiated in the southern Aegean Sea, south of the volcanic arc, and close to the northern slope of the deep Cretan Basin (Fig. 1). The Cretan Sea is considered as a back-arc type basin where extension is occurring (Mascle and Martin, 1990). The Cretan Basin itself and the adjacent regions are filled with layers of pyroclastic and volcaniclastic sediments from the activity of the nearby Santorini volcanic centers. The upper two layers of the marine volcaniclastic sequence, extensively sampled by coring, are considered similar in texture, petrography and stratigraphy, to the deposits of the last two phases of the Late Bronze Age Minoan eruption of Santorini volcano (Anastasakis, 2007; Piper and Perissoratis, 2003; Sparks et al. 1983 and references therein), which took place around 1627–1600 BC (Friedrich et al., 2006). The sequence even though moderate in size is significant because it occurred in a region where we seek information related to regional tectonics.

The retreat of the subducting Africa (Nubia) slab below the Aegean controlled the present geometry of the curved, southward convex, Hellenic Arc, and is related to the observed back arc Aegean extension. South of the volcanic arc, the deformation within the material of the overriding Aegean plate is mainly taken up by trench-parallel extension. This has been documented in the past (Benetatos et al., 2004; Kreemer and Chamot-Rooke, 2004; Lyon-Caen et al., 1988; Shaw and Jackson, 2010). Earthquake focal mechanisms, south of the volcanic arc, are either pure normal faulting, or normal faulting combined with considerable strike–slip motions. The faulting pattern shows the operation of N–S and E–W trending normal faults. The former are considered younger and were developed at 0.6 to 0.8 Ma in the western part of the South Aegean arc, whereas the latter, e.g. the E–W trending faults, are considered older, of early Quaternary and Pliocene age (Piper and Perissoratis, 2003, 2007). In this context, the 2012 earthquake sequence is important because it provides evidence for the type and orientation of faulting operating within the central Aegean Sea.

The earthquake sequence started with the occurrence of an Mw5.0 event on January 26 (UTC 04:24:59) which was followed by an Mw5.3 event on January 27 (UTC 01:33:24), and many aftershocks. Fig. 2 shows the seismicity of the region for the period 1 January 2011 to 10 October 2012, depicting with separate symbols the seismicity prior to the occurrence of the first 2012 event. Earthquake epicenters are aligned along the NE–SW trending Santorini–Amorgos zone (Dimitriadis et al., 2009) and in particular, along its south-western

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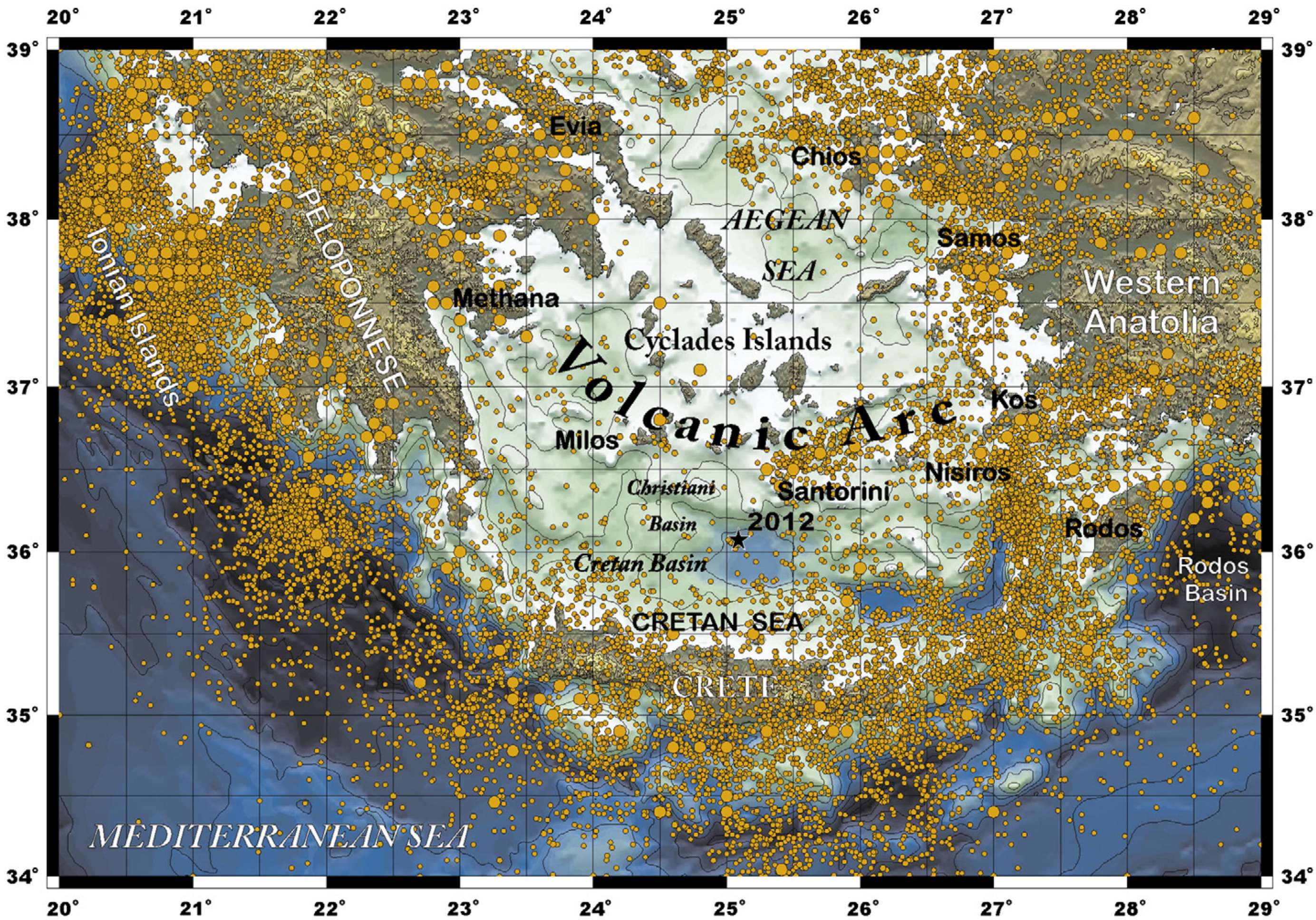


**Fig. 1.** The south Aegean Sea region showing the Hellenic Volcanic Arc, which extents along the Methana, Milos, Santorini, Nisiros Islands, the location of the Cretan Basin south of Santorini, and the locus of the 2012 sequence (marked with the asterisk).The seismicity plotted (Mw > 4.0) covers the period −550 BC to 10 October 2012, with the events larger than Mw6 plotted with large circles.

extension. The northern edge of this zone is marked by the locus of the strongest event of the Aegean region to be instrumentally recorded, e.g. the 9 July 1956 Mw7.6 Amorgos earthquake (Bohnhoff et al., 2006; Konstantinou, 2010; Papazachos and Papazachou, 2002), which was accompanied by a strong tsunami (Okal et al., 2009).

The sequence had an optimum location in terms of the geometry of the Hellenic Unified Seismological Network (HUSNET) and the coastal cross-border Turkish stations, and was well recorded in all azimuths around the source region. The broad band waveforms of these stations are used here to study firstly the focal mechanisms of the strongest events using time-domain moment tensor inversion. Then, directivity effects are retrieved for the two strongest events, in an attempt to identify which is the fault plane, from the N–S or E–W trending nodal planes. Slip models are calculated to seek for the slip pattern onto the fault planes and determine other source parameters. Finally, the connection to the regional tectonics is discussed.

## 2. Computation and distribution of focal mechanisms

### 2.1. The inversion method

The Time-Domain Moment Tensor inversion method (Dreger, 2002) was applied in order to estimate the moment tensors of the strongest events of the sequence, a procedure now routinely applied in Greece (e.g. Roumelioti et al., 2010 and references therein). Full waveforms of the 3- recorded components of motion are low-pass filtered and inverted to derive the moment tensor (MT), which is decomposed into an isotropic part, a double couple (*DC*) and a compensated linear vector dipole (*CLVD*). Here, the fit is constrained to only the deviatoric tensor, neglecting volumetric changes of the source. The assumptions of the inversion include a point source and a source time function that is synchronous for all moment tensor elements and approximated by a delta function. The Variance Reduction, VR, defined as: $\mathrm{VR} = \left(1 - \frac{\int [d-s]^2 \mathrm{d}t}{\int \mathrm{d}^2 \mathrm{d}t}\right) \times 100$ determines the quality of the solution, as it quantifies the goodness of the fit between the data (d) and the synthetic Green's function time series (s), and the summation is performed for all stations and components (Dreger, 2003). The optimal source depth is determined through an iterative process by choosing the solution that yields the maximum overall variance reduction, *VR*.

### 2.2. Application

Three component broad band velocity waveforms were retrieved from HUSNET and the Turkish network, and manually checked to select waveforms with good signal to noise ratio. The synthetic Green's functions were constructed using the frequency-wavenumber integration code of Saikia (1994) and the velocity model of Novotný et al. (2001). This velocity model and for the long-periods employed, computes Green's functions which adequate explain the near-field and regional waveform characteristics in the broader Aegean Sea