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The gravimetric picture of magmatic and hydrothermal sources driving hybrid unrest on Tenerife in 2004/5

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ABSTRACT

We present results from the inversion of gravity changes observed at the central volcanic complex (CVC) of Tenerife, Canary Islands, between May 2004 and July 2005. Marking a period of elevated activity and a reawakening of the volcanic system, the data depict spatial and temporal variations in the sub-surface processes that defined this period of unrest at the Pico Viejo (PV)–Pico Teide (PT) complex, after the last volcanic eruption on Tenerife in 1909. An initial non-linear inversion, based on 3D line segments approximation, yielded three line segments at depths between 1 km a.s.l. and 2 km b.s.l. Our interpretation of the initial inversion results is that the line segments represent apparent composite sources, a superposition of deep and shallow seated sources. We therefore decomposed the gravity changes into shallow and deep parts (fields) using a procedure based on triple harmonic continuation. The shallow and deep fields could then be inverted separately, using the same inversion methodology. The deep field constrains two connected line segments at the depth of about 6 km b.s.l., in the center of the NW seismogenic zone of VT event swarm of the seismic unrest, that we interpret as magma input. The inversion of the shallow field images three weak line segments that are all situated at very shallow, near-surface depths. We interpret the weak segments as hydrothermal sources potentially excited by the deeper magma injection. Our results indicate no significant input into the shallow phonolitic plumbing system of the PV–PT complex, but rather a deeper-seated rejuvenation of the mafic feeder reservoir. The emerging picture from our analysis is that the 2004/5 unrest on Tenerife was of a hybrid nature due to the combination of a deep magma injection (failed eruption?) coupled with fluid migration to shallow depths. The identified causative link between deep and shallow unrest sources indicates the presence of permeable pathways for shallow fluid migration at the CVC.

1. Introduction and background

The central volcanic complex (CVC) on Tenerife (Fig. 1), Canary Islands, is a young (<175 ka) volcanic complex situated within the Las Cañadas caldera (LCC), dominated by the twin-volcanoes of Pico Viejo (PV) and Pico Teide (PT). The complex has erupted rock suites from basanitic to phonolitic compositions (Ablay and Martí, 2000). In contrast, the Santiago rift zone (SRZ), which extends towards the NW from the PV–PT complex, is dominated by mostly monogenetic mafic volcanism. The most recent magmatic eruption on Tenerife was the formation of the Chinyero scoria cone in 1909 in the center of the SRZ. A notable deviation from the background on-shore seismic activity started in April 2004 including a number of felt earthquakes (García et al., 2006; Tárraga et al., 2006; Almendros et al., 2007; Cerdeña Domínguez et al., 2011). Other indicators for volcanic unrest were anomalous gas emissions (Pérez et al., 2005; García et al., 2006; Melián et al., 2012), and spatio-temporal gravity changes (Gottsmann et al., 2006). Despite marked changes in these monitoring parameters, no statistically significant surface deformation (either inflation or deflation) was observed. Unrest continued through 2005 along with a significant decrease in the number of recorded earthquakes from a peak of more than 400 events in May 2004 to around 100 events per month by mid-2005 (e.g., Cerdeña Domínguez et al., 2011).

Simultaneous to the increased seismic activity, a bulk gravity increase was recorded across a network of observation points at the CVC by Gottsmann et al. (2006), who attributed the mass changes between May 2004 and July 2005 to the migration of fluids as a result of a tentative dyke intrusion into the CVC in April 2004. Almendros et al. (2007) proposed a model for the unrest based on seismic data whereby a deep magma injection triggered a release of fluids into an overlying aquifer. Exploiting a new seismic catalog, Cerdeña Domínguez et al. (2011), propose a multiple source model for the 2004/5 unrest, and suggest a complex succession of deep and shallow seated magmatic intrusions beneath the CVC between 2001 and 2005. The initial interpretation of the spatio-temporal gravity changes by Gottsmann et al.

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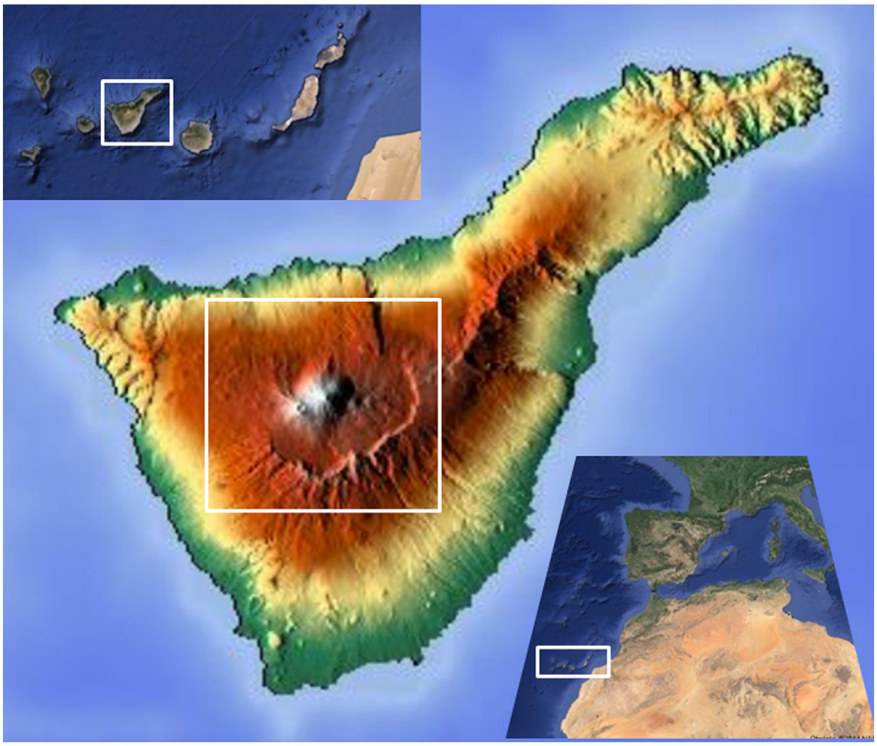

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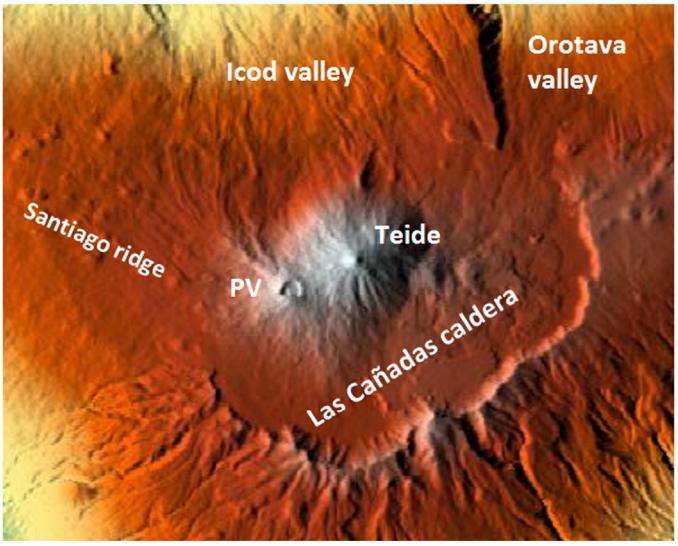

b

Fig. 1. a. Geographical location and topography of the Tenerife island, the largest and central island of the Canary Islands (Spain) archipelago about 200 km westward of the coast of Morocco (Africa), with the central volcanic complex (CVC) dominated by the Teide summit (N 28.27°, W 16.6°, 3718 m a.s.l.). Rectangle delineates the area of the CVC portrayed in panel b. b. The CVC with twin stratovolcanoes Teide and Pico Viejo (PV) located inside the Las Cañadas caldera (LCC) that is roughly 16 km wide. The Santiago ridge corresponds with the NW (Santiago) rift zone (SRZ) characterized by vents respective to fissure-type eruptions.

(2006) was based on a single source inversion of gravity changes, neglecting the possibility of multiple causative sources for the observed unrest. Multiple sources contributing to unrest were identified for example at the Campi Flegrei, caldera from spatio-temporal gravity and deformation data (Gottsmann et al., 2006), where shallow-seated and quickly evolving sources appear to dominate gravity variations along the structural borders of the caldera, most probably related to fluid flow. Here, we test the hypothesis of source-multiplicity for the recorded gravity time series on Tenerife to shed further light on the cause and nature of the unrest in 2004/5 using a nonlinear inversion method based on 3D line segment approximation. A thorough exploitation of the limited available data documenting this non-eruptive unrest is vital for the understanding of source processes and the characterization of future unrest events on Tenerife, where geophysical time series spanning pre-eruptive and eruptive activity are absent.

2. Observations and data reduction

A joint ground deformation/microgravity network was installed on the island in early May 2004, two weeks after the start of increased seismicity. The network consists of 14 benchmarks, which were positioned to provide coverage of a rather large area (>500 km^2) of the CVC,