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Assessment of ground deformation following Tenerife's 2004 volcanic unrest (Canary Islands)

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ABSTRACT

After the 2004 unrest on Tenerife (Canary Islands), the Global Navigation Satellite System (GNSS) network called TEGETEIDE was designed and deployed with seven survey mode stations to contribute to a volcanic alert system. Starting in 2008, public access data from continuous GNSS stations, managed by public institutions, were included in this network allowing measurement of ground displacement at 14 locations in Tenerife. Data acquired from 2005 to 2015 was analysed to assess ground deformation in Tenerife following the 2004 volcanic unrest. The overall ground deformation depicted compression in the central Las Cañadas Caldera possibly caused by gravitational subsidence of the high central volcanic cone. This sinking is generalised around the whole island but is less in the northeast (Anaga Massif) where we found an extension rate close to 200 strain/y that could be related to a secondary submarine fault accommodating rifting to the northeast and isolating the behaviour of this massif. At the south volcanic field (south rift), another localized area with an extensional deformation was detected, possibly resulting from the subsurface fluid migration or mass addition that caused the 2004 volcanic unrest because is located following the seismic swarm alignment along Icod Valley towards Roque del Conde massif that persists since that event. We also detected residual plate velocity indicating movement of Tenerife towards Gran Canaria that should be studied in the context of the entire Canary Islands archipelago.

1. Introduction

Tenerife is the largest island of a volcanic complex with seven islands called the Canary Islands situated in the Atlantic Ocean close to the African passive continental margin and therefore within the Nubian tectonic plate (Fig. 1). The island's active volcano is Teide, the world's third-highest volcanic structure with a height of 7200 m from the seafloor, 3718 m above sea level. The origin of the Canary Islands and its volcanism is still a matter of controversy with evidence for a mantle plume (Geldmacher et al., 2001; Mériaux et al., 2015), regional tectonics (Mezcua et al., 1992; Mantovani et al., 2007; Domínguez-Cerdeña et al., 2011) or a combination of both.

Volcanic activity at Teide's central phonolitic edifice, Las Cañadas Caldera (LCC), started around 3 Ma, and the caldera was formed by vertical collapses produced after intense explosive volcanic activity (Martí et al., 1997; Piña-Varas et al., 2015). The collapse scar is a preferred magma upwelling site, which likely explains the growth of Tenerife on its northern flank (Blanco-Montenegro et al., 2011). On this flank, the Teide-Pico Viejo stratovolcano complex started around 0.15 Ma. In the last 300 years, six effusive eruptions have been reported, with the last occurring in 1909. After forming the stratovolcano, the volcanic activity clustered along Tenerife's volcanic axes: NE–SW (Dorsal Rift, DR) and NW–SE (Teno-Santiago del Teide Rift, SR).These directions are in accordance with the strike of the Mid-Atlantic Ridge (MAR) and its perpendicular direction, which is reflected in Tenerife´s faults (Rodríguez-Pascua et al., 2015). Furthermore, several landslides which have been or are currently active and related to the volcanic flanks can be found on Tenerife, mostly in the northern part and occurring after the caldera formation by collapses. Landslides have configured the LCC northern slope and the present morphology of northern Tenerife with the definition of the Teno, Icod, La Orotava and Anaga valleys (Ablay and Hürlimann, 2000; Walter and Schmincke, 2002; Hunt et al., 2011), as well as the Güimar valley in the east and some scattered areas in the south (Harris et al., 2011), see Fig. 1.

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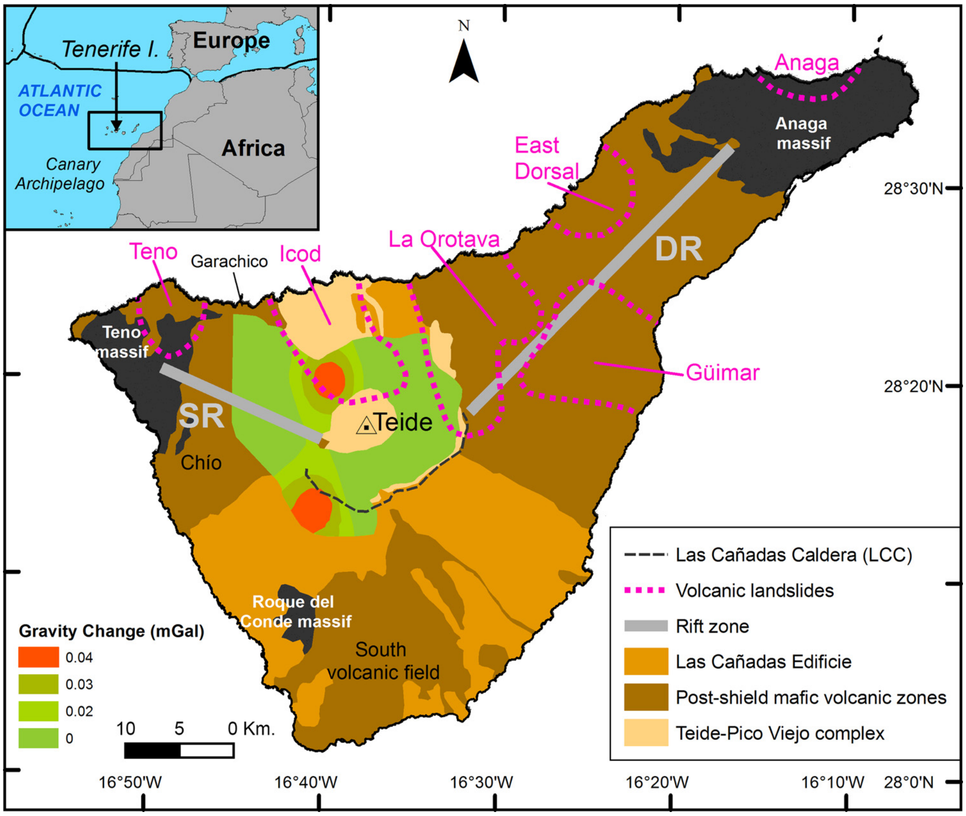

Fig. 1. Schematic geological map of Tenerife Island. Rift trends: NE-SW (Dorsal Rift, DR) and NW-SE (Teno-Santiago del Teide Rift, SR). The scale bar (green to red) shows temporal changes in gravity between May 2004 and July 2005, corrected for the effect of water table changes derived from Gottsmann et al. (2006). Geological data is based on the 1:2,000,000 scale geological map of the Spanish Geology and Mining Institute (*Instituto Geologico y Minero de España*: IGME).

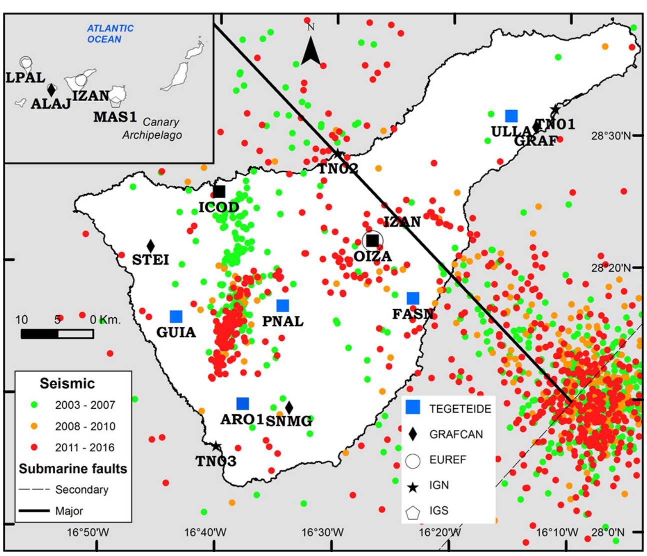

Fig. 2. CGNSS (black) and cGNSS (blue) stations used in this study classified by managing institution: TEGETEIDE network Spanish National Geographic Institute (IGN), EUREF Permanent Network (EUREF), Government of Canaries (GRAFCAN) and International GNSS Service (IGS). When the stations are shared between several institutions, a mixed symbol has been drawn. Dots represent seismic events in different periods (source: http://www.ign.es/web/ign/portal/sis-catalogo-terremotos, IGN, Feb 2018). Submarine tectonic information from Romero-Ruiz et al. (2000).

The unusual increase in seismic events in 2004, with some earthquakes (M > 3, with depths between 0–17 km) felt by the population (Almendros et al., 2007; Domínguez-Cerdeña et al., 2011, 2017), was focussed in a swarm along Icod valley towards the Roque del Conde massif (Fig. 2, green dots) near Teide and has continued to this day (Fig. 2, red dots). Repeated gravity surveys revealed fluid migration, about 3–4 km of deep, from the SR to DR in the same area the seismic swarm was defined without widespread significant surface deformation (Gottsmann et al., 2006, 2008). Before 2004, epicentres only clustered in an offshore area southeast of Tenerife, still seismically active today and associated with regional tectonic stresses (Mezcua et al., 1992; Canas et al., 1998; Romero-Ruiz et al., 2000). After the 2004 reawakening, seismic activity in Tenerife has decreased, based on the seismic station readings called CCAN (Domínguez-Cerdeña et al., 2017).

This reawakening, later reinforced by the 2011 volcanic eruption on El Hierro, the westernmost island of the Canary Islands, increased volcanic hazard awareness in the region, including a renewed interest in monitoring of ground deformation (García et al., 2014). Although previous studies of ground deformation on Tenerife were carried out between 1980 and 1990, mainly in the LCC, using classic geodesic observations, they did not detect a previous significant ground deformation (Sevilla et al., 1986; Vieira et al., 1986; Sevilla and Romero, 1991; Fernández et al., 2014). In 2005, a new Global Navigation Satellite System (GNSS) network, consisting of seven survey mode GNSS stations, was designed to give support to the TEGETEIDE project whose objective is the study of the origin, evolution and consequences of the seismic activity detected in 2004 (García et al., 2006). The first results of this network, for the short period 2006–2008, detected the presence of horizontal ground displacement along a NW–SE axis, aligned with the most seismically active areas on the island and associated with the 2004 seismic unrest (NW) and tectonics (SE) (Berrocoso et al., 2010).

A combined Differential Interferometric Synthetic Aperture Radar (D-InSAR) and GNSS study carried out with data collected between 1992 and 2005, a period which included the 2004 unrest, revealed two subsiding areas, Garachico and Chío, in the northwest area of the island and around Teide (Samsonov et al., 2008), confirmed by GNSS techniques (Fernández et al., 2014); see Fig. 1. These height variations were partially attributed to a decrease of the groundwater level due to water extraction in times of scarcity from some of 1052 horizontal underground galleries in Tenerife (Fernández et al., 2003, 2004; Custodio