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Array analyses of volcanic earthquakes and tremor recorded at Las Cañadas caldera (Tenerife Island, Spain) during the 2004 seismic activation of Teide volcano

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Abstract

We analyze data from three seismic antennas deployed in Las Cañadas caldera (Tenerife) during May–July 2004. The period selected for the analysis (May 12–31, 2004) constitutes one of the most active seismic episodes reported in the area, except for the precursory seismicity accompanying historical eruptions. Most seismic signals recorded by the antennas were volcano-tectonic (VT) earthquakes. They usually exhibited low magnitudes, although some of them were large enough to be felt at nearby villages. A few long-period (LP) events, generally associated with the presence of volcanic fluids in the medium, were also detected. Furthermore, we detected the appearance of a continuous tremor that started on May 18 and lasted for several weeks, at least until the end of the recording period. It is the first time that volcanic tremor has been reported at Teide volcano. This tremor was a small-amplitude, narrow-band signal with central frequency in the range 1–6 Hz. It was detected at the three antennas located in Las Cañadas caldera. We applied the zero-lag cross-correlation (ZLCC) method to estimate the propagation parameters (back-azimuth and apparent slowness) of the recorded signals. For VT earthquakes, we also determined the S–P times and source locations. Our results indicate that at the beginning of the analyzed period most earthquakes clustered in a deep volume below the northwest flank of Teide volcano. The similarity of the propagation parameters obtained for LP events and these early VT earthquakes suggests that LP events might also originate within the source volume of the VT cluster. During the last two weeks of May, VT earthquakes were generally shallower, and spread all over Las Cañadas caldera. Finally, the analysis of the tremor wavefield points to the presence of multiple, low-energy sources acting simultaneously. We propose a model to explain the pattern of seismicity observed at Teide volcano. The process started in early April with a deep magma injection under the northwest flank of Teide volcano, related to a basaltic magma chamber inferred by geological and geophysical studies. The stress changes associated with the injection produced the deep VT cluster. In turn, the occurrence of earthquakes permitted an enhanced supply of fresh magmatic gases toward the surface. This gas flow induced the generation of LP events. The gases permeated the volcanic edifice, producing lubrication of pre-existing fractures and thus favoring the occurrence of VT earthquakes. On May 18, the flow front reached the shallow aquifer located under Las Cañadas caldera. The induced instability constituted the driving mechanism of the observed tremor.

Keywords: Teide volcano; Tenerife Island; volcanic earthquakes; volcanic tremor; seismic arrays; apparent slowness estimates

1. Introduction

The Teide–Pico Viejo–Cañadas volcanic system is probably one of the most important volcanic complexes

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of Canary Islands. It is located in the center of Tenerife Island (Fig. 1), and constitutes the highest elevation (Teide, 3718 m) of the region. In the last 300 years, six effusive processes have been reported, being the last eruption that of Chinyero in 1909. There are evidences of explosive eruptions as well, for example the sub-plinean eruption occurred around 2000 years ago in Montaña Blanca, in the SE flank of Teide (Ablay et al., 1995). The presence of densely populated areas around the volcano edifice places this area among the most vulnerable regions in the Canary Islands archipelago.

Many studies have been carried out at Tenerife to investigate the volcanic structure and dynamics. We can mention gravimetric and geodetic surveys (Sevilla and Romero, 1991; Watts, 1994; Ablay and Kearey, 2000; Araña et al., 2000; Yu et al., 2000; Fernández et al., 2003); geochemical analyses (Hernández et al., 2000, 2004); magnetotelluric (Ortiz et al., 1986; Pous et al., 2002) and magnetic (Blanco, 1997; Araña et al., 2000) surveys; and regional and local seismicity studies (Mezcua et al., 1992; Del Pezzo et al., 1997; Canas et al., 1998; Canales et al., 2000; Almendros et al., 2000, 2004). All these works document the absence of evidences pointing to a reactivation of the volcanic system. However, in 2004 an unusual increment of seismic activity was detected by the IGN (Instituto Geográfico Nacional, Spain's National Geographic Institute) seismic network monitoring Tenerife Island. In Fig. 1b we show the recent seismicity around Tenerife, as reported in the IGN catalog (http://www.ign.es). Before 2004, epicenters clustered in an offshore area southeast of Tenerife. These earthquakes have been interpreted as a consequence of regional tectonic stresses (Mezcua et al., 1992; Canas et al., 1998). Very few earthquakes occurred in other areas, including Teide volcano. Starting in April 2004, there was a significant increase of the number of earthquakes in the vicinity of Teide (Fig. 1b,c). Some earthquakes were large enough ($M>3$) to be felt by population in nearby villages. As a consequence of this activity, the first steps of the emergency plans were activated, including meetings of a scientific committee, and civil protection consultations. The level of seismicity in the area stayed high up to September 2004. During the remaining of 2004 and the first half of 2005, the activity decreased (M. J. Blanco, personal communication).

In May 2004, as a response to the increment of seismicity detected, a temporary survey involving three seismic antennas was carried out at Las Cañadas caldera. In this paper, we present the analysis of seismic data obtained from this survey. We report not only the occurrence of earthquakes related to Teide volcano, but also the appearance of fluid-related seismicity, including volcanic tremor. We interpret these signals as the

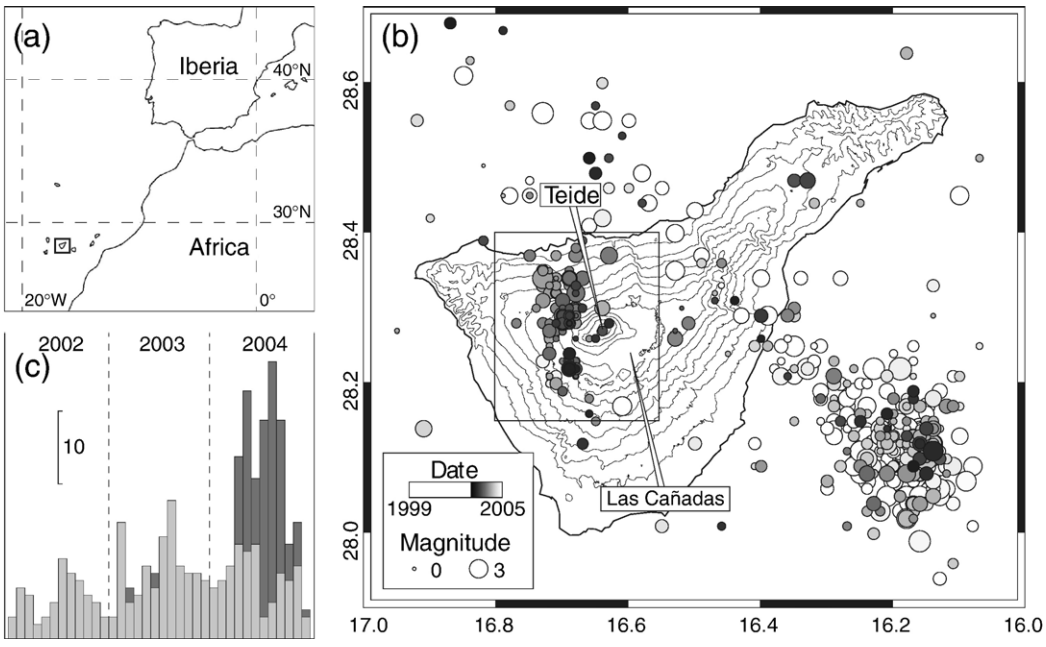

Fig. 1. (a) Location of Canary Islands archipelago in the northwest margin of the African plate. (b) Map of Tenerife Island, showing the epicenters provided by IGN for the period 1999–2005. Colors and sizes of the dots are related to the earthquake origin times and magnitudes, respectively. The box around Teide volcano marks the epicentral area of the 2004 seismic swarm. (c) Histogram of the number of earthquakes per month during the period 2002–2004. Light and dark gray respectively represent earthquakes occurring outside and inside the Teide volcano region (the box in (b)).