Scientific Report

Loan 812: TOM-TEIDEVS, Seismic Tomography of Teide Volcano, Spain

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Abstract

The TOM-TEIDEVS project is an active seismic experiment carried out on the volcanic Island of Tenerife, Canary Islands, Spain, to study the internal structure of Teide Volcano. The multinational experiment involved institutes from Spain, United Kingdom, Italy, Ireland and Mexico. The main objective of TOM-TEIDEVS is to obtain a 3-D structural image of Teide Volcano using seismic tomography, seismic reflection/refraction, and receiver function imaging techniques. During the active seismic experiment in January 2007 more than 6,500 air gun shots were recorded on a dense local seismic network consisting of 150 independent seismic stations (Figure 1). The Spanish oceanographic research vessel "Hespérides" fired shots, which were recorded (with a sampling rate of 200 Hz) on Guralp 6TD short period instruments provided by SeisUK. In total ~75, 000 seismic traces have been recorded during the active experiment and first arrival times are currently being determined. Additionally, recordings from one teleseismic event at 26 sites were used to infer significant variations in the upper most structure of the volcano edifice.

Background

Tenerife is one of the largest islands of the Canary volcanic archipelago (Spain). It is the most inhabited, with a population of more than 700,000 and in excess of 3.5 million tourists visit the island annually. The volcanic complex of Las Cañadas-Teide-Pico Viejo is situated in the centre of the island. Teide volcano is a strato-volcano with the highest elevation (3,718 m) in the archipelago. The Las Cañadas caldera is a caldera system more than 20 km wide: at least four individual caldera processes have been identified. Evidence for many explosive eruptions has been found; the last noticeable explosive eruption (sub-plinean) occurred at Montaña Blanca around 2,000 years ago. During the last 300 years six effusive eruptions have been reported, the last of which took place at Chinyero Volcano on November 18th, 1909.

In spring 2004 an unusual increase in seismic activity was observed on Tenerife Island. More than 500 earthquakes were recorded before the activity decreased in the first half of 2005: some of the larger earthquakes (M>3) were even felt by residents. The seismic activity comprises not only volcano-tectonic events but also long period events and volcanic tremor. On the basis of this activity a reawakening of the volcano has been suggested. The cause of this unusual activity remains controversial and the TOM-TEIEDVS project was initiated to study the internal structure of the upper volcano edifice.

Seismic experiment

During the active seismic experiment in January 2007 more than 6,500 air gun shots were recorded on a dense local seismic network consisting of 150 independent seismic stations (Figure 1). The Spanish oceanographic research vessel “Hespérides” fired shots using 6 BOLT 1500LL air-guns giving a maximum power of 3,520 cubic inches for every shot. Air gun shots were fired every minute giving a shot interval of ~150 m. The air gun shots were recorded on 103 seismic sensors (Guralp CMG-6TD, Lennartz 1Hz, and GEOTECH 519) with a sampling rate of 200 sps. All instruments were buried and powered by a battery pack. The station distribution was chosen according to the following criteria: a) High density station coverage in the area of Las Cañadas – Teide – Pico Viejo; b) At least two straight reflection/refraction lines crossing the island in the N-S and E-W directions to be used as 2-D profiles; c) Easily accessible site locations that avoided cultural noise where possible. Most of the sites were accessible by cars; the remaining 10 sites were only accessible by foot along tracks (especially at the top of the volcano). At the top of Teide volcano the National Park authority provided 4WD cars and park rangers during the experiment.

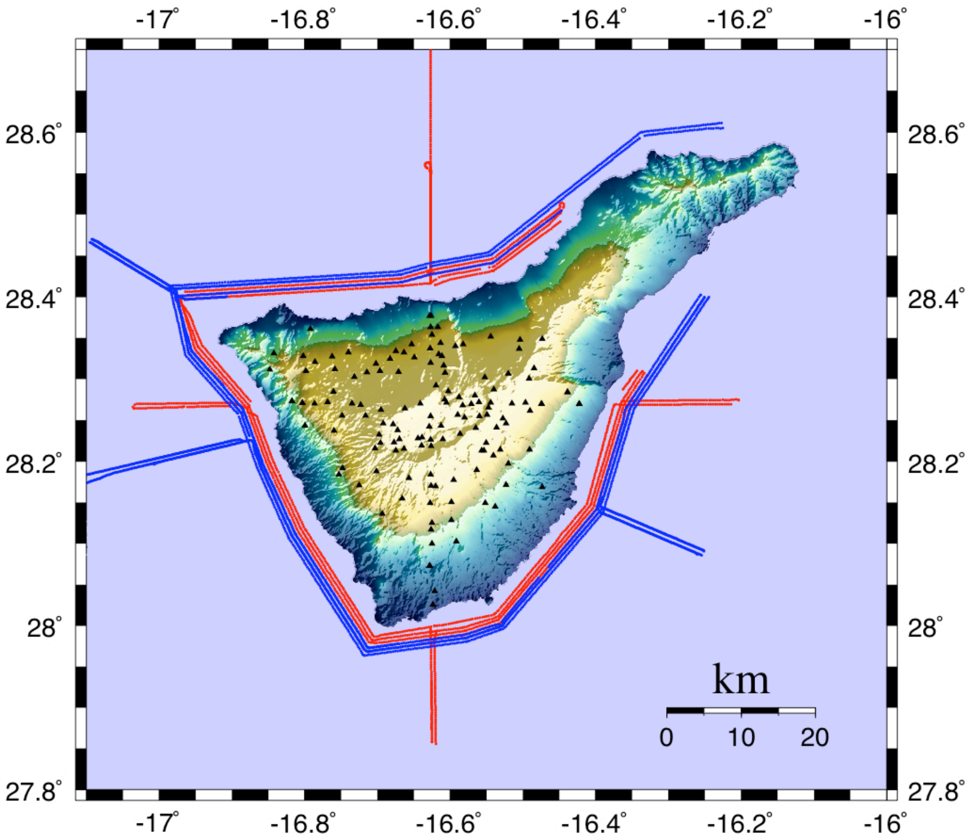

Fig.1: Map of Tenerife Island. The positions of seismic stations are shown as black triangles and the profiles of air-gun shots as coloured lines (red: first week, green: second week). 50% of the stations were relocated after the first week to increase the station coverage. Air gun shots were fired every minute giving a shot interval of approx. 150 m.

After the first week of shooting half of the sensors were moved to new locations, to obtain a denser coverage. Most instruments recorded continuously and data recovery rate was acceptable. Due to heavy snowfall in the second part of the experiment, seismic stations at the top of Teide volcano were decommissioned 4 days early. The full recording geometry is given in Figure 1. The data were processed following the SEIS-UK instructions described in the fieldwork and data processing manuals provided. Dr. Brisbourne helped converting the original Guralp raw format into station gathers in SEGY format. The continuous data stream was converted to mseed and archived at SeisUK and the University of Liverpool.
The quality of the recorded data is generally good and P-wave arrivals are identified up to an offset of 30-40 km, and in some cases up to 60-70 km. An example from one of the stations located at the south-eastern rim of the Las Canadas Caldera is shown in Figure 2.

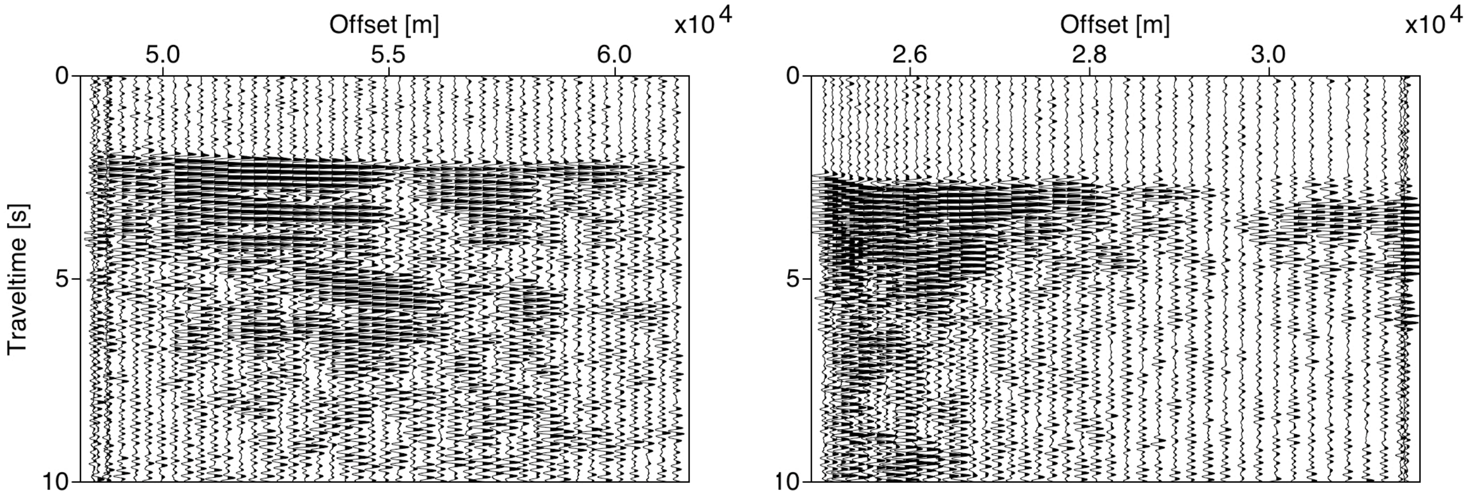

Fig.2: Reduced seismic record sections recorded at station 557 located at the south-western rim of the Las Canadas Caldera. Left and right panels show shot gathers from the north-west and south-east, respectively. Clear first arrivals can be identified up to 62 km.

Preliminary results

During the 3 weeks observation period one teleseismic event from the Scotia subduction zone in the Southern Atlantic could be used for a detailed receiver function analysis (Lodge et al., 2007). Only recordings with a clear P-wave arrival were used for the receiver function (RF) analysis following the multiple-taper spectral correlation method (Park & Levin, 2000). RFs were selected for further analysis on the basis of two main factors: 1) low pre-signal noise and 2) the vertical RF is approximately a delta function. Following these criteria, 26 records could be used for detailed modelling. Initial forward modelling began with two layers, before gradually increasing the number of layers to fit more and more of the arrivals in the RF (e.g. Lodge & Helffrich, 2006). As the number of layers increased, it became clear that to improve the fit to the RF, the boundaries needed to be more gradational and therefore the number of layers needed to be increased even further. Thus to find the full range of models that would produce RFs that fit the data, we implemented an inversion procedure based on a real valued genetic algorithm (RGA).

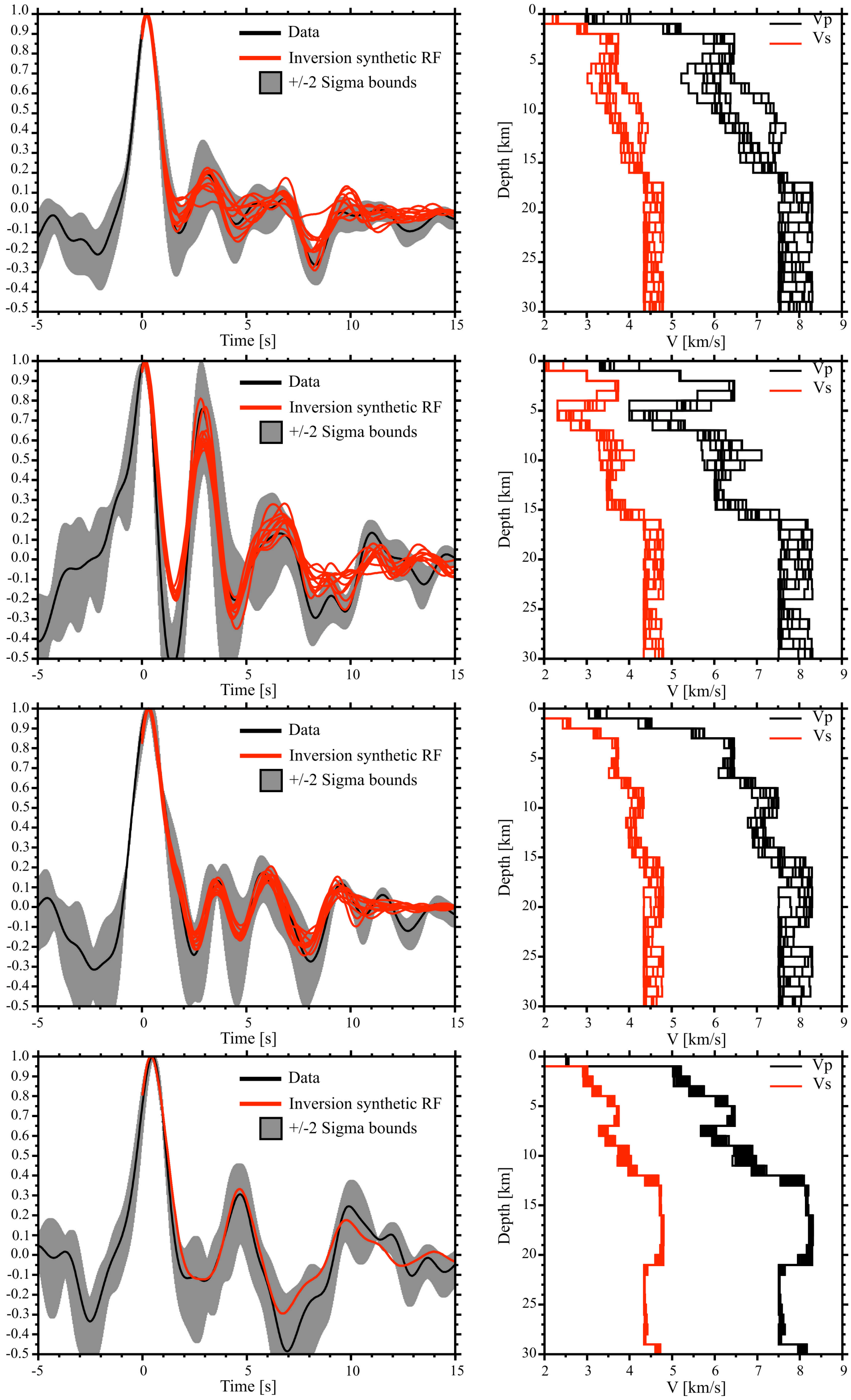

Fig. 3: RGA inversion results for TEIDE. RFs (left panel) and velocity models (right panel). Average azimuthal stack (top panel), northern stations (2nd panel), caldera stations (3rd panel) and north-western stations (bottom panel). Exact station locations for the different groups are shown in Fig. 4.

At first all RFs from the 26 sites were stacked to increase the signal to noise ratio and the inversion result is shown in the top panel of Fig.3. Two classes of velocity models fit the azimuthally averaged stacked waveform equally well. Re-examining the individual RFs we find significant regional variations and therefore decided to group them into three different sets, northern, caldera and north-western (Fig. 4), based on waveform similarity. For each group individual inversions were carried out using the same starting model and the results are shown in Fig. 3.

Beneath the northern stations, there are two LVZs, one at ~ 5km depth and one at ~13 km depth, whereas beneath the caldera stations only the ~13 km depth LVZ is present. The Moho beneath both groups is observed at 15-16 km depth. The north-western stack on the other hand has no LVZs at ~5km and ~13km depth, instead there is a very thin LVZ at 7 km depth and the Moho is shallower at ~13 km depth. Fig.4 shows the locations of the corresponding piercing points and station locations. The location of the piercing points for the Tenerife stations suggest the existence of a shallow magma chamber (between ~3-5 km below sea level (b.s.l)) beneath the northern stations only and a second deeper magma chamber (LVZ) at ~8-12 km depth b.s.l. beneath both northern and caldera stations: in agreement with inferred structure beneath Tenerife from previous studies, characterised by shallow ~4-5 km depth, phonolitic magma chambers linked to the volcanic evolution of Las Cañadas edifice and a deeper (~13-15 km) reservoir containing basaltic magma (Almendros et al., 2007 and references therein). Thus, the location of the piercing points supports the interpretation that the RFs beneath all three groups are sampling structure independently of one another.

In 2004, Tenerife experienced one of the most active seismic episodes reported in the area, except for the precursory seismicity accompanying historical eruptions (Almendros et al., 2007). Using array analysis from three seismic antennas deployed in Las Cañadas caldera, Almendros et al., (2007) suggest that the initial seismicity is related to deep (>14 km) magma injection beneath the northwest flank of Teide volcano (Fig. 4), related to a basaltic magma chamber inferred by geological and geophysical studies (e.g., Martí et al., 1994; Ablay & Martí, 2000; Araña et al., 2000). Combining our RF results with those from the array analysis of Almendros et al., (2007) suggests we are observing the deep basaltic magma chamber and that the plumbing system is such that initial injection occurs beneath the north west of the island, before migrating beneath the caldera. Furthermore, the majority of historical eruptions on Tenerife have all occurred in the north-west rift zone (Carracedo et al., 2007), along with the majority of historical earthquakes (Gonzalez de Vallejo et al., 2003) thus we may tentatively suggest that the LVZ we observe beneath the northern stations may be the shallow magma chamber associated with this historical activity

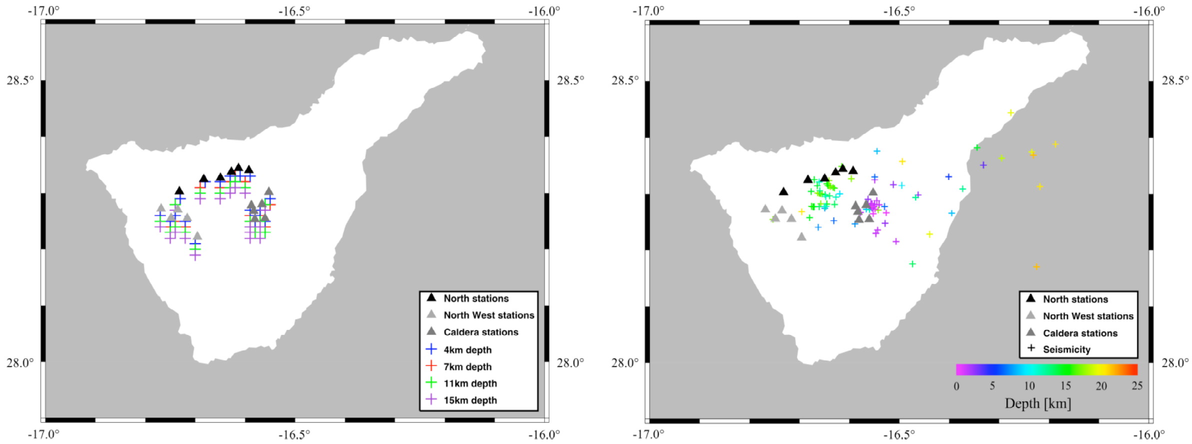

Fig.4: Piercing points beneath Teide showing the top and bottom of the LVZ layers identified in Figure 3 (left panel). Earthquake locations from the 2004 seismic episode (Almendros et al., 2007) (right panel).

Presentations, publications and research progress

Lodge, A., S. E. J. Nippress, & A. Rietbrock (2007), Crustal and upper mantle structure beneath the Canary islands from teleseismic receiver functions, Eos Trans. AGU, 88(52) Fall Meet. Suppl, Abstract V33B-1381.

Ibáñez, J., A. Rietbrock, & A. García-Yeguas (2008), Imaging an Active Volcano Edifice at Tenerife Island, Spain, *Eos*, **in press**.

A. Lodge, S.E.J. Nippress, and A. Rietbrock (2008), Crustal structure beneath the Canary Islands derived using teleseismic receiver functions, *GJI*, **in preparation**.

Future Research

A joint research proposal headed by Prof. Chris Bean titled “Towards improved imaging of magma chambers” (Science Foundation Ireland) has been successful and work will start early 2009. The project focuses on applying advanced pre-stack depth migration techniques and together with the ongoing velocity tomography at Granada University and the RF study will give a detailed image of the volcano edifice.

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