Tectonophysics 672–673 (2016) 121–128

Contents lists available at ScienceDirect

Tectonophysics

journal homepage: www.elsevier.com/locate/tecto

Multiparametric statistical investigation of seismicity occurred at El Hierro (Canary Islands) from 2011 to 2014

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ARTICLE INFO

Article history:
Received 23 June 2015
Received in revised form 9 January 2016
Accepted 12 January 2016
Available online 11 February 2016

Keywords:
El Hierro
Seismic unrest
b-value
Coefficient of variation
Scaling exponent
Schuster's spectrum

ABSTRACT

A detailed statistical investigation of the seismicity occurred at El Hierro volcano (Canary Islands) from 2011 to 2014 has been performed by analysing the time variation of four parameters: the Gutenberg-Richter *b*-value, the local coefficient of variation, the scaling exponent of the magnitude distribution and the main periodicity of the earthquake sequence calculated by using the Schuster's test. These four parameters are good descriptors of the time and magnitude distributions of the seismic sequence, and their variation indicate dynamical changes in the volcanic system. These variations can be attributed to the causes and types of seismicity, thus allowing to distinguish between different host-rock fracturing processes caused by intrusions of magma at different depths and overpressures. The statistical patterns observed among the studied unrest episodes and between them and the eruptive episode of 2011–2012 indicate that the response of the host rock to the deformation imposed by magma intrusion did not differ significantly from one episode to the other, thus suggesting that no significant local stress changes induced by magma intrusion occurred when comparing between all them. Therefore, despite the studied unrest episodes were caused by intrusions of magma at different depths and locations below El Hierro island, the mechanical response of the lithosphere was similar in all cases. This suggests that the reason why the first unrest culminated in an eruption while the other did not, may be related to the role of the regional/local tectonics acting at that moment, rather than to the forceful of magma intrusion.

1. Introduction

Almost all active volcanoes worldwide are characterized by seismic activity, nature and characteristics of which are deeply influenced by the peculiarities of each volcanic system. Studying volcanic seismicity allows us to infer important physical characteristics about the dynamics of magma movement inside the volcanic system. Magma migrates towards the surface thought a network of fractures exceeding the failure threshold of the crust and thus producing volcano-tectonic events (VT) (e.g. Chouet and Matoza, 2013). These VT can be registered at the earth surface by means of seismic stations and represent one of the most important signatures of the brittle failure of the volcano structure in response to the magmatic intrusion forces.

The 2011–2012 submarine eruption on El Hierro (Canary Islands, Spain) provides a good case study to improve our knowledge on VT fracturing. During the unrest episode that preceded this eruption, a batch of deep magma accumulated for nearly two months at the north of the island at a shallower depth of about 15 km b.s.l. Then during one month magma migrated south for more than 21 km keeping more or less the same depth, before the onset of the eruption on October 10, 2011 (Martí et al., 2013a, 2013b; Becerril et al., 2013). This unrest episode was linked to almost 10,000 located VT events and centimetric local deformations (López et al., 2012) presenting changes in the fracturing pattern before eruption (Domínguez Cerdeña et al., 2014; López et al., 2014). During the syn-eruptive phase and after the end of the eruption in March 2012 the seismic activity continued for some years (2012–2014) with variable intensity. During the whole period more than 22,000 VT events were recorded and located by the volcano monitoring network of the Spanish Instituto Geográfico Nacional deployed in El Hierro (IGN, Spain).

The study of the seismicity registered from 2011 to 2014 in El Hierro offers the opportunity to better understand the dynamics associated with the preparation, development and relaxation of a volcanic system in relation to an eruption. In this study, we apply independent statistical tools to the IGN seismic catalogue to calculate, 1) the *b*-value of the Gutenberg-Richter magnitude distribution, 2) the coefficient of variations of the time occurrences, 3) the scaling exponent of the magnitude series, and 4) the Schuster's spectrum of the earthquake time series. All

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http://dx.doi.org/10.1016/j.tecto.2016.01.045
0040-1951/

these parameters represent statistical properties and their joint analysis allows us to approach to the mechanical behaviour of the volcanic system (i.e. the magmatic plumbing system) immediately before and during a volcanic eruption, thus enabling the determination of possible predictable patterns.

2. Data

We used the seismic catalog of the IGN (www.ign.es) performed with the temporal and permanent seismic network installed on the Canary Islands and, in particular, on the island of El Hierro. The mean horizontal uncertainty in event location was 3 km for the entire seismic series. Seismic depth uncertainty was over 5 km The IGN seismic catalog for this period includes the hypocenter and size of the located events and provides insights into the available energy during the fracturing process. The El Hierro seismic network was composed by one three components (3CC) broad-band station (CTIG) and eight short- and medium-period (natural periods of 1 s and 5 s) 3CC stations, distributed all around the Island (López et al., 2012). This network allowed the location of 22,000 VT since the beginning of the unrest in July 2011, being almost 10,000 located before the onset of the submarine volcanic eruption on 10 October 2011. The rest of earthquakes were recorded during the syn-eruptive period and the subsequent reactivations registered in the Island. In Fig. 1, we show the time evolution of seismicity from 2011 to 2014, distinguishing different phases in their occurrence.

The pre-eruptive seismic unrest started in July 2011, showing an increasing seismic rate with time. All the events were located at the north of the Island at a depth of about 15 km b.s.l. and had low magnitude. From September 4–26, 2011, seismicity migrated to the south along the crust/mantle boundary, increasing the seismic energy released. From 27 September to 7 October 2011, seismic rate and the seismic energy increased; events were located mostly offshore to the SW coast of El Hierro. On 8 October, 20:34 h (GMT), a 4.3 ML earthquake (the highest magnitude recorded up to that moment) occurred 1.5 km from the SW coast of the island at a depth of 12 km. Its mechanism is a pure double-couple strike-slip motion (P axe: strike 156°, plunge 25°; T axe: strike 41°, plunge 41°) (Del Fresno et al., 2015). From that date on, shallow and low magnitude seismicity was located offshore at the south of the island, about 5 km from the coast (López et al., 2012; Martí et al., 2013a).

The syn-eruptive activity started on 10 October 2011, with the beginning of a seismic tremor (recorded in all stations on the island) increasing in intensity during the first two days. From 22 October to 20 November 2011, concurrent with the tremor, strong earthquake sequences were located at the north of the Island at a depth of 20–25 km. On 16 November, the maximum expression of the eruption observed at the sea surface with the formation of giant bubbles and other visible manifestations coincided with a significant increase of the tremor intensity. These observables have been interpreted as a result of a tectonic and gravitational readjustment of a deeper reservoir following decompression after the first few days of the eruption (Martí et al., 2013a; Tárraga et al., 2014). On 20 November 2011 the tremor amplitude decreased drastically and remained low until the end of the eruption at the end of February 2012 (Martí et al., 2013a; Tárraga et al., 2014; López et al., 2014). After that, several new unrest episodes, none of them in an eruption, have occurred with high seismicity and surface deformation affecting different parts of the island (García-Cañada et al., 2014; García et al., 2014; IGN web page www.ign.es/ign/resources/volcanologia/HIERRO.html).

3. Methodological procedure

In this paper we analyzed the seismicity recorded at El Hierro from July 19, 2011 to December 10, 2014 (Fig.1) applying several and independent statistical tools, aiming at getting the most complete picture of the dynamics underlying the seismic phenomenon. Before performing the multiparametric statistical investigation of the time dynamics of the seismicity, the analysis of the completeness magnitude was carried out. The completeness magnitude M_c of the whole sequence was calculated by using the method of the maximum curvature (MAXC) (Wiemer and Wyss, 2000); this method provides a fast and reliable estimate of M_c as that matching the magnitude with the highest

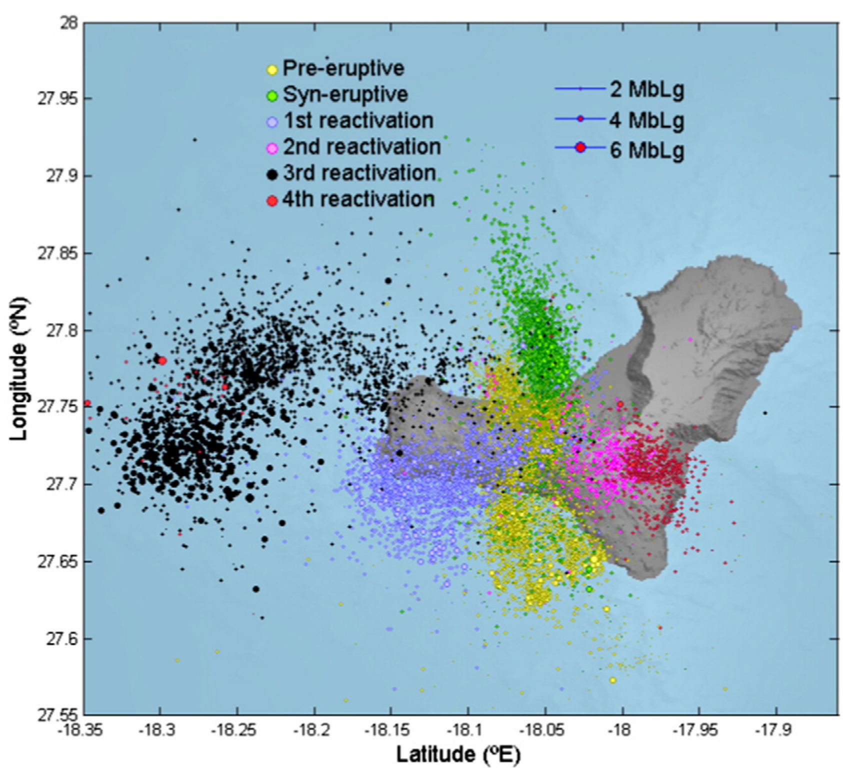

Fig. 1. Map of the seismicity occurred at El Hierro from 2011 to 2014.