Tectonophysics 679 (2016) 125–139

Contents lists available at ScienceDirect

Tectonophysics

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

First-order estimate of the Canary Islands plate-scale stress field: Implications for volcanic hazard assessment

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ARTICLE INFO

Article history:
Received 29 September 2015
Received in revised form 3 April 2016
Accepted 4 April 2016
Available online 11 April 2016

Keywords:
Canary Islands
Plate-scale tectonic stress field
Volcanic activity
Numerical modelling
Volcanic hazard assessment

ABSTRACT

In volcanic areas, the existing stress field is a key parameter controlling magma generation, location and geometry of the magmatic plumbing systems and the distribution of the resulting volcanism at surface. Therefore, knowing the stress configuration in the lithosphere at any scale (i.e. local, regional and plate-scale) is fundamental to understand the distribution of volcanism and, subsequently, to interpret volcanic unrest and potential tectonic controls of future eruptions. The objective of the present work is to provide a first-order estimate of the plate-scale tectonic stresses acting on the Canary Islands, one of the largest active intraplate volcanic regions of the World. In order to obtain the orientation of the minimum and maximum horizontal compressive stresses, we perform a series of 2D finite element models of plate scale kinematics assuming plane stress approximation. Results obtained are used to develop a regional model, which takes into account recognized archipelago-scale structural discontinuities. Maximum horizontal compressive stress directions obtained are compared with available stress, geological and geodynamic data. The methodology used may be easily applied to other active volcanic regions, where a first order approach of their plate/regional stresses can be essential information to be used as input data for volcanic hazard assessment models.

1. Introduction

The evaluation of the present-day stress field at different scales has been the focus of several recently published research works (e.g. Dyksterhuis et al., 2005a; Dyksterhuis and Müller, 2004; Gölke and Coblentz, 1996; Jarosiński et al., 2006; Jimenez-Munt and Negredo, 2003). The stress on a specific location can be subdivided into plate-, mountain- and fault-scale (Zang and Stephansson, 2010). In this sense, plate-scale tectonic stresses tend to be uniform over large areas of continents, whereas the other two can vary significantly over short distances. The complex tectonic plate movements and their interactions originate a particular regional and local stress field in each tectonic setting and volcanically active area, which may be eventually modified due to more specific and smaller-in-scale structural elements.

Magmatism and tectonism in volcanically active areas are strongly related to the regional and local stress fields, affecting the orientation of faults and fractures and the location of volcanic vents, two fundamental aspects when interpreting volcanic unrest and forecasting volcanic eruptions. The Canary Islands is one of the largest active intraplate volcanic regions of the World. Located at the Nubia plate, their plate-scale stress field, and partly also the regional one, is presumably controlled by the Eurasia-Nubia kinematics, the Middle Atlantic Ridge (MAR), and other more regional structures such as the Terceira Ridge (TR), the Gloria Fault (GF), the Transmoroccan (Transalboran) Fault System (TFS), the Gibraltar Arc (GA) and probably, to a lesser extent, the Gorringe Thrust (GT) (Jimenez-Munt et al., 2001; Jimenez-Munt and Negredo, 2003; Mantovani et al., 2000) (Fig. 1a). Additionally to these tectonic features, some authors have also indicated the presence of a mantle plume beneath this region that may importantly influence the stress field at a regional or even plate-scale level (Fullea et al., 2015; Hoernle and Schmincke, 1993).

In the last decades, several studies have investigated the neotectonics of the Africa-Eurasia plate boundary from the Middle Atlantic Ridge to the Iberian Peninsula and Tell Atlas mountains including the Terceira Ridge, the Gibraltar Arc and the Ibero-Maghrebian region (southern part of the Iberian Peninsula and northwestern Africa) (Jimenez-Munt et al., 2001; Jimenez-Munt and Negredo, 2003; Mantovani et al., 2000). Nevertheless, none of these models extends south of the 30°N parallel, leaving the Canary Islands always out of the computational domain.

The objective of this work is to provide a first-order estimate of the plate-scale tectonic stresses acting on the Canary Islands, modelling numerically the distribution of the minimum and maximum horizontal compressive stresses (S_{hmin} and S_{Hmax}, respectively) and the tectonic regime in the area. For this, we have performed a series of 2D finite element models of plate scale kinematics assuming plane stress approximation as previously adopted by other authors (e.g. Hu et al., 1996; Mantovani et al., 2000). Results obtained are used to design a regional scale stress field model for the Canary Islands aimed to evaluate the

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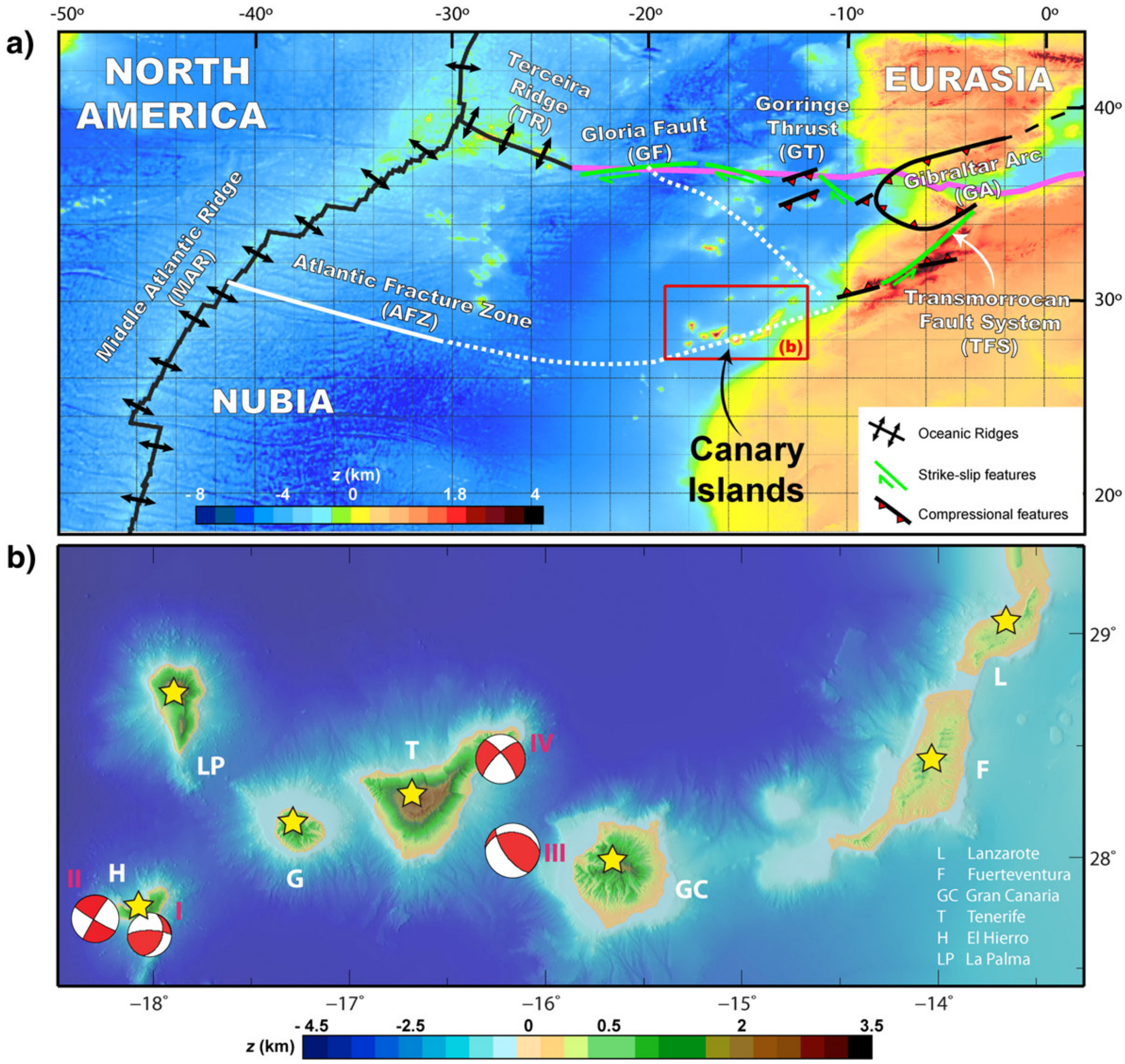
http://dx.doi.org/10.1016/j.tecto.2016.04.010



Earthquake nº	Lon (º)	Lat (º)	Location	Year	Nodal plane s	d	r	Mw	TF	SS	NF	P-axis a	p
I	-18.01	27.65	El Hierro	2011	270	74	128	4.0	0.53	0.35	0.12	-27.6	19.9
II	-18.28	27.69	El Hierro	2013	121	85	-4	5.1	0.00	0.99	0.01	76.2	6.4
III	-16.17	28.03	Tenerife-Gran Canaria	1989	273	34	45	5.0	0.75	0.16	0.09	37.7	17.9
IV	-16.23	28.44	Tenerife	1997	321	75	-162	4.5	0.00	0.84	0.16	4	23.2

Fig. 1. a) Digital Elevation Model (DEM) of the modelled area obtained from ETOPO 1 Global Relief Model (http://www.ngdc.noaa.gov/mgg/global/global.html), with WGS84 as geographic horizontal datum (Amante and Eakins, 2009). Main tectonic features are also indicated based on the work by Mantovani et al. (2007). Dashed white and pink lines indicate presumed tectonic features and broad plate limit, respectively. b) Focal mechanism of the four moderate earthquakes occurred in the Canary Islands between 1989 and 2013 obtained from the Spanish National Geographic Institute (http://www.ign.es) (Earthquake I) and the Global Centroid Moment Tensor Project (http://www.globalcmt.org) (Dziewonski et al., 1981; Ekström et al., 2012) (Earthquakes II–IV). Yellow stars indicate the location of the points used for evaluating the results obtained in the area of study. For each earthquake, information concerning nodal plane, magnitude, percentage of faulting mechanism and P-axis orientation is also indicated. A: azimuth; d: dip, Mw: Moment Magnitude; NF: normal; p: plunge; r: rake; s: strike, SS; strike-slip; TF: thrust.

effect of archipelago-scale structures on the distribution of the maximum horizontal compressive stress and related stress regime. Calculated S_{Hmax} orientations are consistent with stress, geological and geodynamic data available for the area of study. We consider that results obtained here are useful: 1) as input data for more detailed regional models that may be capable of considering the influence of other processes affecting the state of stress in the area; 2) to define potential tectonic controls of future volcanism; and 3) to cover volcanic hazard assessment necessities, especially the development of volcanic susceptibility maps used to identify those areas with greatest likelihood of hosting new vents. The methodology used here may be easily applied to other active volcanic regions in order to obtain a first order approach of their plate/regional stresses.

2. Geological setting

The Canarian archipelago, a roughly linear 500 km long chain formed by seven islands, is the result of a long volcanic and tectonic activity that started ~60 Ma ago (Marinoni and Gudmundsson, 2000; Marinoni and Pasquarè, 1994; Robertson and Stillman, 1979). During