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The distribution of basaltic volcanism on Tenerife, Canary Islands: Implications on the origin and dynamics of the rift systems

A. Geyer [a,*], J. Martí [b]

[a] Department of Earth Sciences, University of Bristol, Wills Memorial Building, Queen's Road, BS8 1RJ, Bristol, UK
[b] Laboratory of Simulation of Geological Processes (SIMGEO), Department of Geophysics and Geohazards, Institute of Earth Sciences "Jaume Almera", CSIC, Lluis Solé Sabaris s/n, 08028 Barcelona, Spain

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ABSTRACT

One of the most characteristic features of volcanic islands is the existence of rift zones defined commonly as orientated eruptive fissures or parallel rows of elongate cinder cones and dyke swarms. Occasionally, these rifts can appear at the birth of the volcanic island and persist until the last episodes of its constructions, controlling the form and structure of the island (e.g. Azores Islands). In the case of Tenerife (Canary Islands), it is possible to observe two rift zones (Santiago del Teide and Dorsal rifts) running NW–SE and ENE–WSW, marked by parallel rows of aligned cones and eruptive fissures. Additionally, at the southern part of the island (Southern Volcanic Zone) basaltic volcanism is characterized by scattered vents and apparently non-coherently orientated eruptive fissures. Some authors relate the existence of the latter volcanism to a N–S running rift zone that defines the third branch of a three-armed rift system in the island. In the present paper, we first investigate the tectonic controls on the distribution of basaltic volcanism at the Southern Volcanic Zone, and their relation with the NW–SE and ENE–WSW rifts. The numerical results obtained suggest that basaltic volcanism of the southern part of Tenerife can be easily explained as the result of a extensional stress field derived from the combined effects of the NW–SE and ENE–WSW rifts. As a second objective, we have also investigated the origin of the Santiago del Teide and Dorsal rift zones and their role on the formation of the original shield volcano and the subsequent evolution of the whole island. Our numerical results contrast with previously published explanations on the origin of the Tenerife rifts that included fracturing due to volcano spreading or to deformation of the volcano due to magma intrusion. We consider that volcanic activity in Tenerife began throughout fissural volcanism along these structures that were already present in the oceanic basement, progressively accumulating the basaltic series that gave rise to the construction of the composite shield volcano.

1. Introduction

Ocean volcanic islands show a relatively common evolution that includes: (i) ascent of deep sourced basaltic magmas, (ii) eruption and accumulation at surface constructing a volcanic shield, (iii) occasional construction of a central volcanic edifice, and (iv) possible initiation of gravitational spreading at the base of the island and erosion of the whole volcanic complex in combination with a progressive decrease of the magma production at depth. This is the case of Hawaii (e.g. Fiske and Jackson, 1972; Swanson et al., 1976; Wyss, 1980; Nakamura, 1980; Decker, 1987; Walker, 1992) and Reunion (Chevalier and Bachelery, 1981; Lenat and Aubert, 1982).

One of the most characteristic features of this evolution is the existence of rift zones defined as dilatational ground cracks that drive the ascent and eruption of mantle-derived magmas (Walker, 1999). The origin, position and orientation of rift zones may be controlled principally by deep crustal structures or tectonic activity such as faulting and plate motion (Walker, 1999), and their expression at surface consists of sub-parallel orientated eruptive fissures or rows of elongate cinder cones. The sub-surface structural characteristics of the rift zones are invariably defined by the presence of a dense network of dyke swarms aligned parallel to the tectonic trend of the rift (Marinoni and Gudmundsson, 2000; Walter and Schmincke, 2002; Walter et al., 2005). Moreover, according to the definition of Walker (1999), areas with scattered vents and apparent lack of orientation of the eruptive fissures and vent alignments, may be considered also to proxy for a rift zone based on the idea that it is still a region wherein repeated magma ascent and lava emission events occur. In these cases, the area over which vents are scattered probably reflects the size and form of the source of magmatic anomaly. Vogt and Smoot (1984) stated that magmatism has to be frequent and intense enough for the rift zones to stay hot to influence and localise successive injections.

* Corresponding author. Now at CIMNE International Center for Numerical Methods in Engineering, UPC Campus Norte, Edificio C1, C/ Gran Capitán s/n, 08034 Barcelona, Spain.
E-mail addresses: A.GeyerTraver@bristol.ac.uk, ageyer@cimne.upc.edu (A. Geyer), joan.marti@ija.csic.es (J. Martí).

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Occasionally, rifts may appear at the birth of the volcanic island and last until the last episodes of its constructions, controlling the form and structure of the island (e.g. Azores Islands, Searle, 1980; Haase and Beier, 2003). Rift zones may localise volcanic hazards, and can induce sector collapse, or they may buttress and effectively strengthen a volcanic cone (e.g. Walker, 1999; Gee et al., 2001).

The significance of rift zones in controlling the shape and structure of oceanic volcanoes has been reviewed for Hawaii (e.g. Fiske and Jackson, 1972; Swanson et al., 1976; Wyss, 1980; Nakamura, 1980; Decker, 1987; Walker, 1992), Gough Island (Chevalier, 1987), Marion and Prince Edward Islands (Chevalier, 1986), Reunion Island (Chevalier and Bachelery, 1981; Lenat and Aubert, 1982) and for the Canary Islands (Ancochea et al., 1990; Carracedo, 1994, 1996; Walter, 2003).

In the case of Tenerife (Canary Islands) (Fig. 1), it is possible to observe two rift zones running NW–SE and ENE–WSW, marked by parallel rows of aligned cones and eruptive fissures (e.g. Ancochea et al., 1990; Carracedo, 1994, 1996; Martí et al., 1996; Carracedo et al., 2007) and fault/dyke swarms (Walter and Schmincke, 2002; Walter et al., 2005). These are the Santiago del Teide (STR) and the Dorsal rifts (DR), respectively (Fig. 2a). In the southern part of the island, referred as the Southern Volcanic Zone (SVZ), basaltic volcanism is characterized by scattered vents and non-coherently orientated eruptive fissures. Some authors have associated the Southern Volcanic Zone to a third rift zone orientated N–S, which may describe with the Dorsal and the Santiago del Teide rifts, a three-armed or "Mercedes Star" rift structure (e.g. Carracedo, 1994, 1996; Walter, 2003). Contrasting genetic explanations have been proposed to understand the origin and evolution of this three-armed rift system. In short, the rift zones are believed to result from inflation of the volcano due to mantle upwelling (Carracedo, 1994, 1996), or due to volcano spreading (Walter, 2003). Since the structure and origin of rift zones is a key factor in the development of oceanic-island volcanoes (Walker, 1992), these genetic explanations of the rift zones are closely related to the possible hypotheses on the origin and structural evolution of Tenerife. The most controversial point between both genetic explanations is to consider whether the rift zones are present during the whole history of Tenerife as a response to mantle upwelling (Carracedo, 1994, 1996) or, by contrast, they develop later due to processes of volcano spreading (Walter, 2003). In the last case, the rift structures would not be directly related to the origin of the island and their effect on the evolution of Tenerife would be restricted to more evolved stages.

The objective of this paper is twofold. First, we develop a series of numerical models to study the distribution of the basaltic cones and eruptive fissures on Tenerife and we show how these models are consistent with recent surface structures and how the basaltic volcanism at southern part may be tectonically controlled by the Santiago del Teide and the Dorsal rifts. Second, we combine these numerical results and the available structural gravity data on Tenerife (Araña et al., 2000; Ablay and Kearey, 2000; Gottsmann et al., 2008) in order to characterise the role of the Santiago del Teide and the Dorsal rifts on the formation of the original shield volcano and the subsequent evolution of the whole island. Understanding the origin and evolution of the NW–SE and the ENE–WSW running rift zones is of primary relevance to characterise the tectonic controls on the distribution of basaltic volcanism and its hazard implications.

2. Geological and tectonic framework

2.1. Origin and structural control of the Canary Islands

The Canary Islands are a roughly linear 500 km long chain formed by seven islands located few hundred kilometres from the coast of Northwest Africa (Fig. 1). The Canarian archipelago is the result of a long volcanic and tectonic activity that started at around 60 Ma ago (Robertson and Stillman, 1979; Le Bas et al., 1986; Marinoni and Pasquarè, 1994; Marinoni and Gudmundsson, 2000).

Regional and local tectonics is of high relevance when trying to understand the evolution of the Canary Islands (Hérnandez-Pacheco and Ibarrola, 1973; Anguita and Hernan, 1975, 2000). In the African continent (Fig. 1a), the Atlas chain, built through the tectonic inversion of a Triassic and Jurassic intracratonic rift (Jacobshagen et al., 1988) associated with the opening of the North Atlantic, is characterized by post-Cretaceous Atlas thrusts faults (Proust et al., 1977; Mattauer et al., 1977; Binot et al., 1986) and strike-slip faults (mostly sinistral) (Herbig, 1988; Jacobshagen, 1992). Most faults strike NNE (in the High Atlas), NE (in the Middle Atlas), or NW (dispersed though less marked), although abundant N–S structures were detected in a morphometric survey (Deffontaines et al., 1992). More concretely, the South Atlas lineament is described as a discontinuous NNE structure (Proust et al., 1977; Jacobshagen et al., 1988) or as a megashear active from Palaeozoic times on, first as a right-lateral, then left-lateral, then (during the Tertiary) a reverse fault, and now represented as a set of en echelon structures (Anguita and Hernan, 2000). This lineament is considered to be a part of a newly defined strike-slip sinistral megastructure more than 1000 km long, the Trans-Alborán Fault system (TAF) (Bousquet and Montenat, 1974; Sanz de Galdeano, 1990), which runs along the High Atlas and Middle Atlas and crosses the Alborán (Sea Mediterranean) up to the Spanish town of Alicante (Fig. 3a).

In the open sea, the marine geophysicists have found an array of tectonic structures, such as antiforms, synforms and unconformities (Dillon, 1974; Uchupi et al., 1976; Dañobeitia and Collette, 1989). Most submarine fractures are transcurrent (Le Bas et al., 1986) or normal (MacFarlane and Ridley, 1968; Bosshard and MacFarlane, 1970; Banda et al., 1992) faults. Additionally, a NE striking submarine fault some 50 km long, with transcurrent (left-lateral) and reverse components is located between Tenerife and Gran Canaria (Mezcua et al., 1992) (Fig. 1b). This fault is of the same kind as the sinistral transcurrent faults associated with folds located at the border of the Atlas (Piqué et al., 1998).

Regarding the volcanism at the continent, there are a number of volcanic areas in the Atlas Mountains and adjacent zones (Fig. 3a). The magmatism took place in three different time periods separated by substantial hiatus. The oldest magmatism is Eocene to Oligocene (45–35 Ma); the next active period, in the nearby Middle Atlas took place until the Miocene (14–6 Ma, nephelinites) (Anguita and Hernan, 2000) and the activity finished with Pleistocene basalts, basanites and nephelinites (1.8–0.5 Ma). All those rock types present in the Atlas volcanism are represented in the Canary Islands. The rock ages (beginning in Early Cenozoic, with the bulk activity centred in the Miocene–Pliocene) are roughly similar as well.

Regarding the origin and the structural evolution of the Canary Islands there exist several contrasting models that mainly include: i) a hotspot (Schmincke, 1982; Hoernle and Schmincke, 1993; Carracedo et al., 1998), ii) a propagating fracture from the Atlas (Le Pichon and Fox, 1971; Anguita and Hernan, 1975), and iii) mantle decompression melting associated with uplift of tectonic blocks (Araña and Ortiz, 1991). However, each model is somehow inconsistent with the local and regional geology, as will be discussed in more detail in a subsequent section.

A more likely model has been proposed by Anguita and Hernan (2000). In this comprehensive model, the authors consider the existence of a residual fossil plume under North Africa, the Canary Islands, and western and central Europe identified through seismic tomography (Hoernle et al., 1995) (Fig. 3b). Thus, volcanism is assumed to occur there where an efficient fracture system allows the magma to ascent (Anguita and Hernan, 2000), i.e. the central European rift system, the volcanic provinces of the westernmost Mediterranean (Balearic and Alborán basins), Iberia, the Canary Islands and Cape Verdes (Hoernle et al., 1995).

Magmatism in the Canary Islands is explained through the tapping of the old thermal anomaly by the fractures inherited from a Mesozoic