Tectonophysics 608 (2013) 586–599

Contents lists available at ScienceDirect

Tectonophysics

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

Seismic evidence of a regional sublithospheric low velocity layer beneath the Canary Islands

Carmen Martinez-Arevalo [a,*,1], Flor de Lis Mancilla [b], George Helffrich [c,d], Alicia Garcia [a,2]

[a] Museo Nacional de Ciencias Naturales, Consejo Superior de Investigaciones Científicas, C/ José Gutiérrez Abascal, 2, 28006 Madrid, Spain
[b] Instituto Andaluz de Geofísica, Universidad de Granada, C/Profesor Clavera No. 12, Campus Universitario de Cartuja, 18071 Granada, Spain
[c] Earth Sciences, University of Bristol, Wills Mem. Bldg., Queen's Road, Bristol BS8 1RJ, UK
[d] Lab. Tectonophysique, Géosciences Montpellier, U. Montpellier II, 34095 Montepellier, France

ARTICLE INFO

Article history:
Received 2 April 2013
Received in revised form 15 August 2013
Accepted 18 August 2013
Available online 28 August 2013

Keywords:
Canary Islands
Receiver function
Low velocity layer
Upper mantle discontinuities

ABSTRACT

We report the finding of a regional sub-lithospheric low velocity layer through the analysis of P-receiver functions in the Canary Islands, a volcanic archipelago in the east central Atlantic. The Moho discontinuity deepens towards the east, varying in depth from 11.5 to 12.5 km beneath the western islands up to 20–30 km beneath the eastern islands. The low velocity layer underneath the lithospheric mantle is located about 45–65 km of depth. This layer produces a delay of the arrival times of the converted phases at 410- and 660-discontinuities relative to the standard earth models. Other than the delays induced by the shallow low velocity material, there is no evidence of thickness variations in the mantle transition zone, indicating no upper mantle thermal perturbations. Beneath the majority of the islands, the low velocity layer is characterized by V_P/V_S greater than 1.81, suggesting the ubiquitous presence of melt (higher than 3%) beneath the islands. Our results support geodynamic models for the Canaries region that include a low velocity layer in the upper mantle, without a thermal anomaly perturbing the mantle transition zone discontinuities (410 and 660 km).

1. Introduction

The Canary archipelago is located in the eastern central Atlantic, lying off the western African passive continental margin (Fig. 1). This archipelago is composed of seven major volcanic ocean islands and several islets with an extension of 450 km east-to-west. The islands are built on Jurassic oceanic crust (e.g. Steiner et al., 1998) around 150–170 Ma old according to the paleomagnetic anomalies S1 and M25 (Klitgord and Schouten, 1986; Roeser, 1982). The islands have a long eruptive history with eruptions on all the islands in the last million years with the exception of La Gomera. A west–east age progression is suggested from radioisotopic measurements of the oldest exposed volcanic rocks on each island. Lanzarote and Fuerteventura islands, in the east, are 20 Ma old (Coello et al., 1992), Gran Canaria is 15 Ma old (McDougall and Schmincke, 1976), Tenerife is 12 Ma old (Guillou et al., 2004), La Gomera is 11 Ma old (Ancochea et al., 2006), while the islands in the west, La Palma and El Hierro, are younger than 2 Ma, and are still in their shield stage of growth (Ancochea et al., 1993; Guillou et al., 1996).

The geodynamic complexity of the Canary Islands is reflected in the diversity of the hypotheses formulated about their origin. Apparently contradictory geological, geochemical, geodetic and geophysical observations make it difficult to find a satisfactory model able to interpret all their main features. The different proposed models can be divided into three main groups depending on their main mechanism: thermal, tectonic or edge-driven convection. Among the thermal models, we find the hot spot idea (Morgan, 1971) and its variants formulated for the Canary region, specifically the blob model (Hoernle and Schmincke, 1993), and the rolling-hinge model (Oyarzun et al., 1997). The blob model proposes the existence of a plume beneath the Canary Islands composed of a cylindrical conduit at a depth that supplies blobs of deeper mantle material into a wide head dipping to the east and located at the lithosphere base. Volcanic activity periods can be explained by the ascent to the surface of mantle material from individual magma blobs. Volcanic hiatuses happen when there is cooler asthenosphere or there are few hot blobs inside the melting zone beneath an island. On the other hand, the rolling-hinge model proposes a two-stage scenario to explain the volcanism in the Canary Islands in Western North Africa and southwestern Europe (Oyarzun et al., 1997). Their model supports the presence of the central Atlantic plume together with a sub-lithospheric channelling to explain the magmatism. In the initial stage, the central Atlantic plume was located in the triple junction among the North American, South American, and African plates and then extended to the northeast. This plume was the origin of a larger concentration of the magmatism in the west of Africa. In the second

---

* Corresponding author.
E-mail address: carmen.martineza@upm.es (C. Martinez-Arevalo).

[1] Present address: Departamento de Ingeniería Mecánica y Construcción, Escuela Técnica Superior de Ingeniería y Diseño Industrial, Universidad Politécnica de Madrid, C/ Ronda de Valencia, No. 3, 28012 Madrid, Spain.

[2] Present address: Instituto de Geociencias IGEO, (CSIC-UCM), Avda. José Antonio Novais, 2, 28040 Madrid, Spain.

0040-1951/$ – see front matter © 2013 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.tecto.2013.08.021

stage, the plume activity and sublithospheric channelling continued from Cape Verde to Europe. A large-scale sheet-like mantle upwelling beneath western Africa to Europe imaged by Hoernle et al. (1995) might represent a track of the spatial evolution of the magmatism.

The tectonic models have the aim of explaining the similar directions of the alignment of the islands and volcanic cone alignments, faults, fractures, and linear swarms of dikes in the region (e.g. Anguita et al., 1991; Robertson and Bernoulli, 1982; Staudigel et al., 1986). Moreover, many of these structures have the same orientation as the main Atlantic and African tectonic units. In these models, the magmatism is guided by tensional stress in the propagating fractures (Anguita and Hernán, 1975), or due to regional compression between uplifted tectonic blocks (Araña and Ortiz, 1991). A critique of this class of models is that they imply a static melting regime. If extension opens fractures and permits magma escape, the magma compositions should be similar in each extension episode. If compression uplifts blocks, causes decompression melting, and the melt escapes along block margins, magmas should become increasingly refractory and infertile with each reactivation due to remelting of the same mantle. Neither of these scenarios is characteristic of Canarian magmatism (Hoernle and Schmincke, 1993).

The third group of models includes the edge-driven convection model proposed by King and Ritsema (2000) to explain intraplate volcanism of South American and African regions, among them the Canary Islands volcanism. Edge-driven convection flow is caused by a sharp change in the lithospheric thickness beneath stable, cold and thick continental root next to a warmer and thinner (probably oceanic) plate. This configuration generates a thermal instability at the ocean-cratonic boundary and evolves to a small-scale flow in the upper mantle. The downwellings occur at the lithospheric discontinuity and upwellings at about 500–1000 km away from the ocean-cratonic boundary.

Models combining tectonic, thermal and edge-driven convection mechanisms have arisen to reduce inconsistencies or unknowns originally left by these three concepts. Thermal and tectonic hypotheses are combined in the unifying model of Anguita and Hernán (2000). This model suggests a magmatic and tectonic connection between the Canaries region and the Atlas Mountains system. The magmatism in the Canary Islands is explained with the existence of a thermal mantle anomaly extended under the African margin and Europe (Hoernle et al., 1995; Oyarzun et al., 1997). Magma reaches the surface through a fracture system that during tensional periods works as its plumbing system. In compressional periods, these fractures cause the uplift of the islands. Geldmacher et al. (2005) combine the edge-driven convection processes and a mantle plume located to the west of Canaries to model the recurrence of the volcanic activity observed in this region. The movement of cold/hot mantle material at the top of the convection cell generates periods of calm or activity, respectively. Additionally, the compositional variety of magmas could be attributed to convective flow, which causes the mixing of the asthenospheric and plume material.

Duggen et al. (2009) take up the idea of a mantle plume beneath the western Canary Islands to account for the common geochemical characteristics between the lavas found in the Canary Islands and in the north-western African volcanism. The material flows from the plume to the east, crossing the north-western African continent, travelling along the base of the oceanic lithosphere below the Canary Islands, into a sub-continental lithospheric corridor beneath the Atlas Mountain system.

The lack of consensus on the origin and evolution of the Canaries arises in part because knowledge of the structure at depth is scarce and inconclusive. The current deep Earth structure information in this region is derived from teleseismic studies. Global tomographic images of seismic P-wave velocity suggest a 400 km wide plume beneath the Canary archipelago that extends down into the lowermost mantle (1450 km deep), where it joins the Azores plume reaching the bottom of the mantle (Montelli et al., 2004, 2006). The presence of a plume is

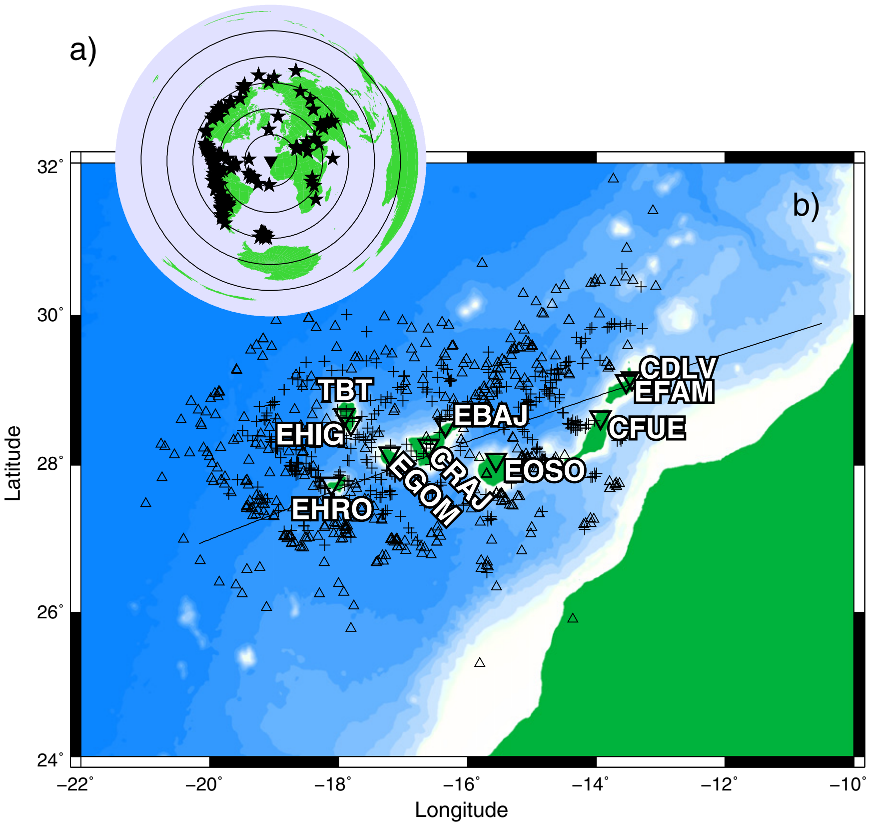

Fig. 1. a) Global map showing the epicentral location of the teleseismic events used in this study. Rings are spaced every 30°. b) Map of the Canary Island region displaying the station locations. Dark triangles mark the station locations of the IGN broad-band seismic network and dark squares of the two temporary stations from GSN-IRIS and Midsea network. Ray piercing points from 410-(crosses) and 660-(triangle) discontinuities are also shown. The dotted lines indicate the position of the cross-section used to display spatial variation of the analysis.