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The role of continental margins in the final stages of arc formation: Constraints from teleseismic tomography of the Gibraltar and Calabrian Arc (Western Mediterranean)

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ABSTRACT

The deep seismicity and lateral distribution of seismic velocity in the Central Western Mediterranean, point to the existence under the Alboran and Tyrrhenian Seas of two lithospheric slabs reaching the mantle transition zone. Gibraltar and Calabrian narrow arcs correspond to the slabs. Similarities in the tectonic and mantle structure of the two areas have been explained by a common subduction and roll-back mechanism, in which the two arcs are symmetrical end members.

We present a new 3-D tomographic model at mantle scale for the Calabrian Arc and compare it with a recently published model for the Gibraltar Arc by Monna et al. (2013a). The two models, calculated with inversion of teleseismic phase arrivals, have a scale and parametrization that allow for a direct comparison. The inclusion in both inversions of ocean bottom seismometer broadband data improves the resolution of the areas underlying the seafloor networks. This additional information is used to resolve the deep structure and constrain the reconstruction of the Central Western Mediterranean geodynamic evolution. The Gibraltar tomography model suggests that the slab is separated from the Atlantic oceanic domain by a portion of African continental margin, whereas the Calabrian model displays a continuous oceanic slab that is connected, via a narrow passage (~350 km), to the Ionian basin oceanic domain. Starting from the comparison of the two models we propose the following interpretation: within the Mediterranean geodynamic regime (dominated by slab rollback) the geometry of the African continental margin, located on the lower plate, represents a critical control on the evolution of subduction. As buoyant continental lithosphere entered the subduction zones, slab pull caused tears in the subducted lithosphere. This tectonic response, which occurred in the final stages of arc evolution and was strongly controlled by the paleogeography of the subducted plates, explains the observed differences between the Gibraltar and Calabrian Arcs.

1. Introduction

One of the outstanding and controversial features of the Mediterranean region is the presence of large-scale extensional basins within a convergent domain located between the African and European plates. Early studies recognized that the Central Western Mediterranean (CWM) extensional basins (Fig. 1) developed in a backarc setting (Dewey et al., 1973, 1989; Horvath and Berckhemer, 1982; Rehault et al., 1984), and also hypothesized that outward migration of subduction, due to slab sinking and retreat, was the most likely explanation for the observables (Malinverno and Ryan, 1986). Several papers stemmed from these early concepts, with progressive refinement of the timing and kinematics of backarc extensional and outward migration of the fold-and-thrust belt (e.g., Royden, 1993; Lonergan and White, 1997; Séranne, 1999; Argnani and Savelli, 1999).

A remarkable lateral variability in the character of the fold-and-thrust belts, timing of extension of backarc basins, and so on, is present in the Mediterranean orogen. Two main factors contributed to this result: i) nonlinear continental margins of the converging plates; and ii) gravitational instability of the subducted lithosphere.

The land-locked condition of the Mediterranean plate boundary, due to the presence of the Adriatic promontory, enhanced the effects of slab rollback (Le Pichon, 1982; Mascle et al., 1988). In fact, the collision of the Adriatic promontory with Eurasia around the Paleocene caused a slowdown in the Africa–Eurasia plate convergence, particularly for the N-ward component (Le Pichon et al., 1988; Dewey et al., 1989). This, in turn, promoted the activation of processes operating within the orogen, such as lithospheric root detachment, lithosphere delamination, lateral escape towards areas of depressed topography and rollback of dense

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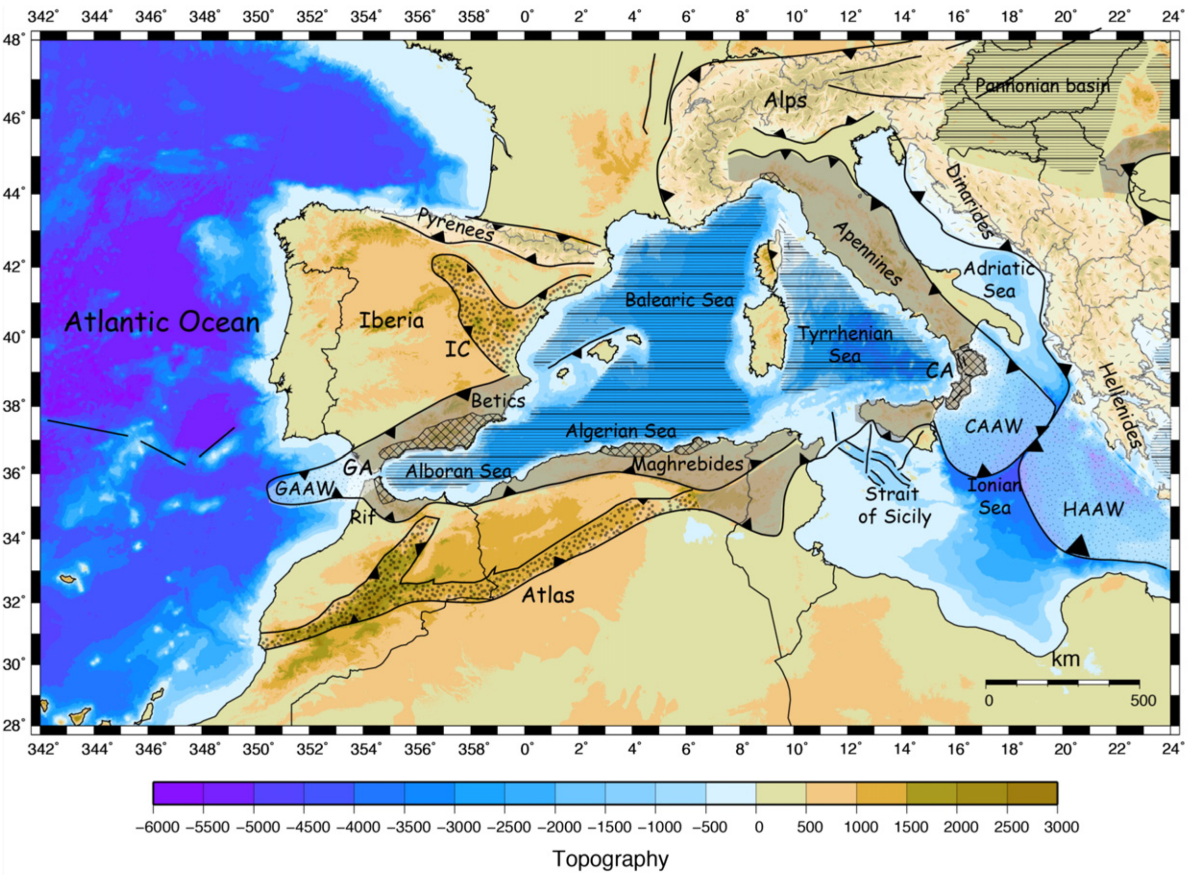

Fig. 1. Simplified geological map of the CWM region. The system of fold-and-thrust belts, indicated in gray, formed from Late Oligocene to Pliocene, during the opening of the backarc basins (horizontal rules; also including the volcanic arcs). The accretionary wedges related to oceanic subduction are indicated with fine dots (GAAW: Gibraltar Arc Accretionary Wedge; CAAW: Calabrian Arc Accretionary Wedge; HAAW: Hellenic Arc Accretionary Wedge). The units belonging to the internal domain are shown with cross hatching. The collisional belts are indicated with random dashes, whereas the Atlas and Iberian Chain (IC) intracontinental belts are indicated with coarse dots. BF: Bradanic foredeep basin; GCF: Gela–Catania foredeep basin.

oceanic slab, which are responsible for the origin of the Mediterranean extensional basins (i.e. Le Pichon, 1982; Dewey, 1988; Le Pichon et al., 1988; Otsuki, 1989; Argnani, 2000; Jolivet and Faccenna, 2000).

An additional important aspect is the interaction between lithospheric slabs and asthenosphere which could possibly result into slab breakoff or detachment and delamination of continental lithosphere. Lateral migration of slab breakoff has been proposed as a key factor for lithosphere dynamics in this region in the last 20–30 Ma, especially in the final stage of subduction (Wortel and Spakman, 1992, 2000; Carminati et al., 1998; Faccenna et al., 2004; Rosenbaum et al., 2008; Argnani, 2009). Within this setting, mantle flow possibly played a role in the deformation of the Gibraltar and Calabrian slabs (Gvirtzman and Nur, 1999; Faccenna et al., 2004; Baccheschi et al., 2008). Delamination of continental lithosphere is a process that likely operated within the Mediterranean orogens, following the subductional consumption of oceanic lithosphere (e. g., Serri et al., 1993; Fillerup et al., 2010; Argnani, 2012; Levander et al., 2014). Although it is known that continental rocks can experience subduction to depth over 100 km, before returning to shallow depth and becoming exhumed to the surface (e.g., Hacker et al., 2010; Butler et al., 2014), continental subduction is likely to be limited, both in extent and rate of subduction, as suggested by the overall stability of continents (Cloos, 1993). The tectonic evolution of the Mediterranean type orogen suggests that when a continental margin enters a retreating subduction zone (soft collision), the processes of subduction and slab retreat get to the end (e.g., Burchfiel and Royden, 1991; Wortel and Spakman, 2000; Argnani, 2009).

The present structure and origin of the Gibraltar Arc–Alboran Basin system (GA) (Fig. 1) does not fit well in this unifying picture based on slab subduction and rollback, and alternative evolution scenarios have been proposed. Several authors do suggest that subduction of oceanic lithosphere (active or extinct) caused extension within the Alboran Basin in the Miocene by slab rollback (Royden, 1993; Lonergan and White, 1997; Bijwaard and Spakman, 2000; Gutscher et al., 2002) or by slab detachment (Zeck, 1996). Alternatively, another group of authors presents an evolution for the Alboran basin initiating with lithospheric thickening during the Paleogene caused by the collision of Europe and Africa. The thickened continental lithosphere was later (ca. 25 Ma) detached by convective removal (Platt and Vissers, 1989) or by delamination (Calvert et al., 2000), leading to recycling of continental material (Levander et al., 2014). The collapse of this lithosphere caused extension of the Alboran and Algerian basins and uplift around the margin, edge delamination under the Betics and Rif margins and mixed continental-oceanic subduction (Booth-Rea et al., 2007; Duggen et al., 2005; Medaouri et al., 2014).

On the other hand, there is a general consensus that the Calabrian Arc–Tyrrhenian Basin system (CA) (Fig. 1) does fit well in the unifying picture: subduction with slab rollback has been the main factor in the opening of the Tyrrhenian Sea (Malinverno and Ryan, 1986), a well-defined Wadati–Benioff zone is contained in a high seismic velocity body (Cimini and Marchetti, 2006, and references therein), and subduction-related magmatism is active under the CA (Barberi et al., 1974; De Astis et al., 2003).

Several tomography studies have concentrated on the Mediterranean mantle at different scales. They range from the global (e.g., Bijwaard and Spakman, 2000), to the European (e.g., Koulakov et al., 2009), to the Mediterranean scale (e.g., Piromallo and Morelli, 2003), down to a