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The transition from Alboran to Algerian basins (Western Mediterranean Sea): Chronostratigraphy, deep crustal structure and tectonic evolution at the rear of a narrow slab rollback system

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ABSTRACT

The eastern Alboran basin and its transition to the Algerian basin is a key area in the Mediterranean realm where controversial kinematic and geodynamical models are proposed. Models imply striking differences regarding the nature of the crust, the prevalence of brittle faulting and ductile shear, the origin of magmatism, the style of Miocene deformation and the driving mechanisms of the Alboran plate kinematics. Combining a new chronostratigraphic chart of the Alboran and Algerian basins based on the Habibas (HBB-1) core drill, deep seismic sections striking WSW-ENE and SSE-NNW, and potential field data, we re-assess the tectonic evolution that controlled the sedimentation and basement deformation of the westernmost limit of the Algerian basin and its transition with the Alboran domain. A WSW-directed extensional tectonic phase has shaped a stretched continental crust with typical tilted blocks along ~100 km from Burdigalian to Tortonian times, which is assumed to result from the WSW-directed migration of the Alboran block driven by a narrow slab rollback. In the Algerian basin, this event was followed by the emplacement of an oceanic-type crust. Potential field signatures of the deep basin as well as geometrical correlations with onland outcrops of inner zones suggest a minimum WSW-directed displacement of the Alboran terrane of ~200 km. At the southern foot of the Algerian basin, the continent-ocean transition is sharp and may result from the westward propagation of a slab tear at depth, forming two segments of STEP (Subduction-Transform Edge Propagator) margins. Our results support models of intense shear tractions at the base of an overriding plate governed by slab rollback-induced mantle flow. Finally, Messinian salt tectonics affected overlying deposits until today. A late Tortonian to Quaternary dominantly transpressive tectonic episode linked to the Africa-Iberia convergence post-dates previous events, deforming the whole margin.

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1. Introduction

The Alboran and Algerian basins are two domains of the westernmost Mediterranean Sea that formed within the zone of convergence between the African and Eurasian plates. The Alboran domain locates at the center of the Gibraltar Arc System, an arcuate Alpine range comprising the Betic and Rif mountains (Fig. 1). Both basins are often assumed to have developed until Early Miocene time in response to a westward slab rollback (Réhault et al., 1985; Lonergan and White, 1997; Gueguen et al., 1998; Jolivet and Faccenna, 2000; Faccenna et al., 2004; Bezada et al., 2013), a process which would have favored late (post-orogenic) lithospheric and crustal thinning (Platt and Vissers, 1989; Comas et al., 1992, 1999; García-Dueñas et al., 1992; Maldonado et al., 1992; Watts et al., 1993) coeval with widespread magmatism and volcanism (Duggen et al., 2004, and references therein) and also with thrusting and shortening of the external zones of the Betic and Rif belts (e.g., García-Dueñas et al., 1992; Comas et al., 1992) (Fig. 1). Since Late Miocene, extension has been followed by NW-SE shortening responsible for basin inversion, folding and reverse or strike-slip faulting, mainly expressed in the Alboran domain and still active today (Comas et al., 1992, 1999; Watts et al., 1993; Chalouan et al., 1997; Fernandez-Ibanez et al., 2007; Martínez-García et al., 2011, 2013). Further eastwards, the Algerian basin

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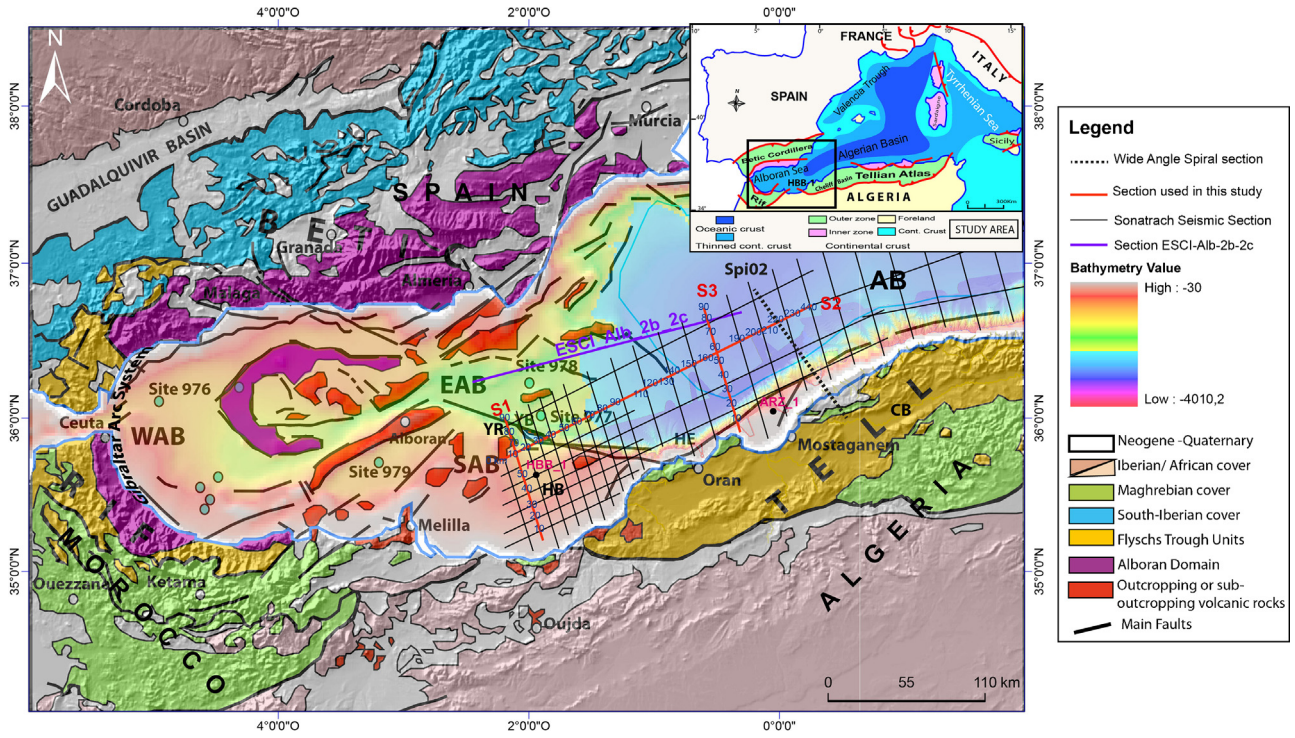

Fig. 1. Geological map of the Alboran Sea and major tectonic features of the Gibraltar arc formed by the Betic Rif and Tell mountain belts (modified from Comas et al., 1992). WAB = West Alboran Basin; EAB = East Alboran Basin; SAB = South Alboran Basin; AB = Algerian Basin; YR = Yusuf Ridge; YB = Yusuf Basin; HE = Habibas Escarpment; HB = Habibas Basin; CB = Chellif Basin. Some drilling sites correspond to the 1995 Ocean Drilling Program proposal (holes 976, 977, 978 and 979); other ones are HBB-1 (Habibas-1 Sonatrach commercial well) and ARZ-1 (Arzew-1 Sonatrach core drill). ESCI-Alb2b-2c is the Spanish Alboran experiment multichannel seismic reflection line (Comas et al., 1995; Booth-Rea et al., 2007). Spi02 is the wide-angle seismic line of SPIRAL project ("Sismique Profonde et Investigation Régionale de la marge ALgériennne). S1, S2 and S3 are Sonatrach seismic sections (2002 Survey) shown in this study. Other sections (black lines) were used for interpretation.

corresponds to an abyssal plain generally assumed to be floored by an oceanic-type crust formed during the Middle to Late Miocene as the result of crustal backarc extension (Réhault et al., 1985; Dewey et al., 1989; Mauffret et al., 2004; Booth-Rea et al., 2007; Leprêtre et al., 2013). Both areas depict Plio-Quaternary witnesses of shortening or uplift of the basin margins and also contrasting imprints in the present-day seafloor physiography (Woodside and Maldonado, 1992; Campos et al., 1992; Déverchère et al., 2005; Gracia et al., 2006; Ballesteros et al., 2008; Mauffret et al., 2007; Fernandez-Ibanez et al., 2007; Domzig et al., 2009; Yelles et al., 2009; Strzerzynski et al., 2010; Martínez-García et al., 2011). The floor of the Alboran sea is morphologically complex, with isolated highs or seamounts of volcanic origin and locally emerged ridges more than 100 km long (e.g. the Alboran Ridge and the Habibas Escarpment), whereas the Algerian basin is flat, much deeper (~2800 m) and surrounded by relatively steep margins, except at the junction with the Alboran domain (Camerlenghi et al., 2009; Martínez-García et al., 2011).

Although numerous data sets are available (see e.g. Comas et al., 1992, 1995; Booth-Rea et al., 2007; Martínez-García et al., 2013), the complexity of the evolution of the Alboran domain results in several debates focusing on:

(1) the geodynamic processes responsible for the opening of the Algerian-Alboran deep basins: subduction rollback, detachment and/or STEP (Subduction-Transform Edge Propagator) tearing slab and delamination, convective removal, mantle diapirism, double vergence subduction zones, poloidal and toroidal mantle flows, etc. (see e.g. summaries in Michard et al., 2002; Spakman and Wortel, 2004; Govers and Wortel, 2005; Valera et al., 2008; Vergès and Fernandez, 2012; Duarte et al., 2013; Schellart and Moresi, 2013; Meyer and Schellart, 2013);

(2) the Tertiary kinematics of the Alboran block (timing and amount of westward displacement, see e.g. Gueguen et al., 1998; Jolivet and Faccenna, 2000; Mauffret et al., 2004, 2007; Duggen et al., 2004; Platt et al., 2006);

(3) the amount, timing and nature of the magmatic and volcanic activity which has considerably (and extensively) modified and altered the crustal structures (e.g. Duggen et al., 2004; Booth-Rea et al., 2007) and may mask the importance of tectonic features and the nature of the basement.

Therefore, the Alboran Sea and the Algerian basin constitute a nice example of a backarc domain where competing hypotheses on driving processes can be investigated. However, many hypotheses are poorly supported by data, especially regarding extensional structures, kinematic indicators and timing of deformation. One of the main interests of the Alboran-Algerian offshore transitional domain is that it offers the opportunity to identify intense crustal thinning and shearing supposed to have occurred in a narrow slab backarc (rollback) setting using stratigraphic controls, original seismic data and potential field data.

The points we address in this study aims at: (1) re-assessing the chronostratigraphy of the Alboran domain and discuss the timing of sedimentation and of deformation phases versus the ones occurring in the Algerian basin; (2) clarifying the issues regarding the nature of the crust and the style and amount of thinning, by better describing the 3D architecture of the basin and deep crust at the transition of the Alboran and Algerian domains; and (3) examining kinematic and geodynamic implications (dismembering and displacement of the Alboran microplate; rollback effects on the style, distribution and amount of crustal thinning of the overriding plate; timing of the different steps of tectonic evolution and comparison with models of narrow slab rollback and STEP propagation).

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