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Tectonic and stratigraphic evolution of the Western Alboran Sea Basin in the last 25 Myrs

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ABSTRACT

The Western Alboran Basin (WAB) formation has always been the subject of debate and considered either as a back-arc or a forearc basin. Stratigraphic analyses of high-resolution 2D seismic profiles mostly located offshore Morocco, enabled us to clarify the tectonic and stratigraphic history of the WAB. The thick pre-rift sequence located beneath the Miocene basin is interpreted as the topmost Malaguide/Ghomaride complex composing the Alboran domain. The structural position of this unit compared with the HP–LT exhumed Alpujarride/Sebtide metamorphic basement, leads us to link the Early Miocene subsidence of the basin with an extensional detachment. Above the Early Miocene, a thick Serravallian sequence marked by siliciclastic deposits is nearly devoid of extensional structures. Its overall landward to basinward onlap geometry indicates that the WAB has behaved as a sag basin during most of its evolution from the Serravallian to the late Tortonian. Tectonic reconstructions in map view and in cross section further suggest that the basin has always represented a strongly subsiding topographic low without internal deformation that migrated westward together with the retreating slab. We propose that the subsidence of the WAB was controlled by the pull of the dipping subducting lithosphere hence explaining the considerable thickness (10 km) of the mostly undeformed sedimentary infill.

1. Introduction

Post-Eocene Mediterranean geodynamics is governed by the northward subduction of the African plate and coeval slab retreat causing the formation of back-arc basins together with extension and collapse of internal zones of orogens (Réhault et al., 1984; Malinverno and Ryan, 1986; Dewey, 1988; Royden, 1993; Wortel and Spakman, 2000; Jolivet and Faccenna, 2000; Faccenna et al., 2001) after a major change in the subduction regime during the Oligocene (Faccenna et al., 1997; Jolivet and Faccenna, 2000). The present-day complex geometry of these subduction zones results from progressive slab tearing and detachment (Carminati et al., 1998a, 1988b; Wortel and Spakman, 2000) associated with a complex 3D mantle convection pattern (Faccenna et al., 2004; Spakman and Wortel, 2004; Jolivet et al., 2009, 2013; Faccenna and Becker, 2010; Sternai et al., 2014).

In the western Mediterranean, several back-arc basins have opened since the Oligocene following the retreat of the Tethyan slabs: the Liguro-Provençal basin, Algerian basin, Alboran Sea and Tyrrhenian Sea (Fig. 1, Faccenna et al., 2001). Among these basins, the Alboran Sea basin remains one of the most controversial issues in western Mediterranean geodynamics. Several hypotheses have been proposed so far to explain its formation by extension in the internal zones of the Betics–Rif orocline: (1) extensional collapse of a thickened crust due to convective removal of the continental lithospheric mantle (Platt and Vissers, 1989; Platt et al., 2003a) or (2) a delamination process (Seber et al., 1996; Calvert et al., 2000) or (3) the westward retreat of the subduction zone (Royden, 1993; Lonergan and White, 1997; Gutscher et al., 2002). Several authors pointed to the relation linking the behavior of Mediterranean slabs in the upper mantle and the tectonic history recorded in the crust (Faccenna et al., 2004; Spakman and Wortel, 2004; Jolivet et al., 2006, 2008; Booth-Rea et al., 2007). In more detail, the stretching

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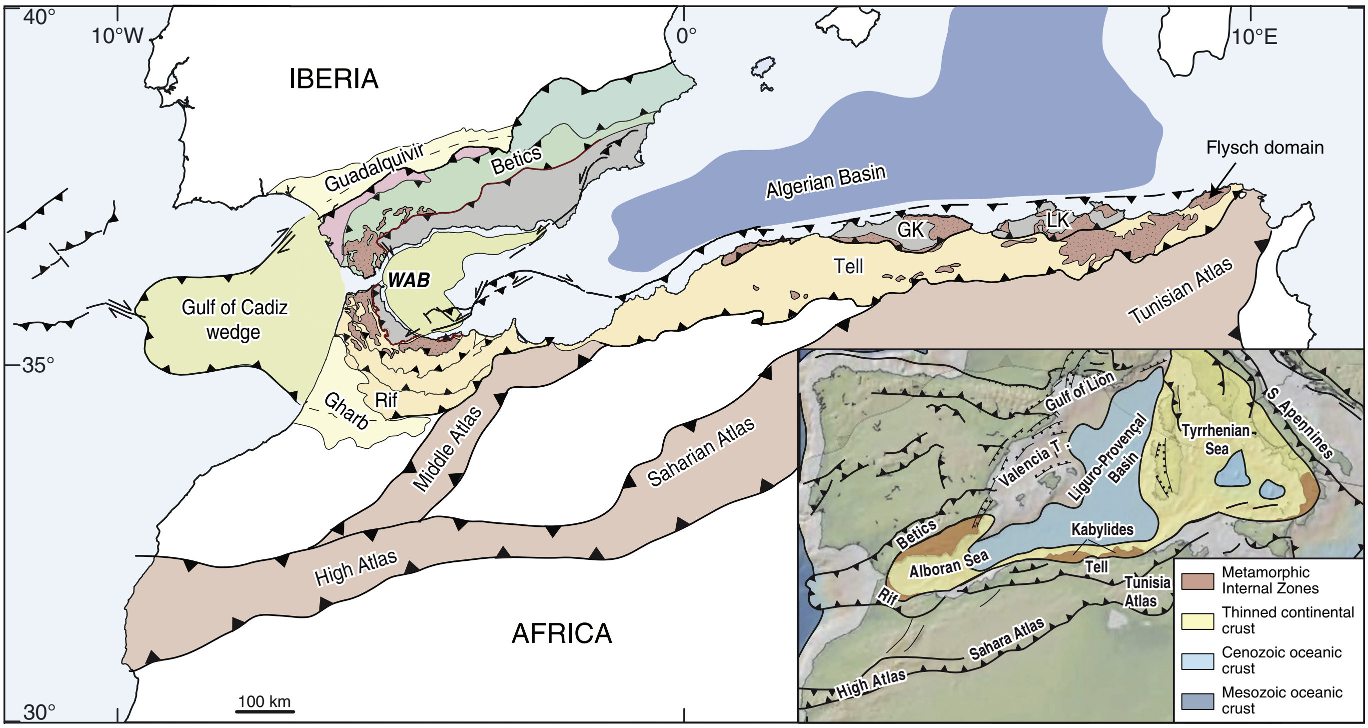

Fig. 1. Structural maps of the southern margin of the western Mediterranean Sea representing the main tectonic units and the location of the Western Alboran Basin (WAB). GK: Greater Kabylide; LK: Lesser Kabylide. The inset map shows the location of the Apennines, Tellian, Rif and Betic fold and thrust belts in the western Mediterranean.

of the continental crust composing back-arc regions appears to follow the mantle stretching during slab retreat (Jolivet et al., 2009), suggesting that back-arc extension was partly driven from below (Sternai et al., 2014).

The Alboran domain represents the westernmost termination of the peri-Mediterranean Alpine belt orogeny. Its arcuate shape, delimited by the Betic and Rif fold-and-thrust belts, is the result of subduction, collision and slab migration processes that mainly occurred during the Miocene (Faccenna et al., 2004; Spakman and Wortel, 2004; Jolivet et al., 2008). During the Neogene, several sedimentary basins were formed on top of the Alboran metamorphic basement. The thickest and oldest sedimentary depocenter, the Western Alboran Basin (WAB; Fig. 2A), was created and developed coeval with the exhumation and denudation of its underlying metamorphic continental crust (Soto et al., 1996; Comas et al., 1999). Different views of the basin fill geometry over time led to a variety of tectonic scenarios for the WAB inception: a pull-apart mechanism in a regional strike-slip setting (Bourgois et al., 1992), a sag basin (Morley, 1992, 1993) or a half-graben asymmetric basin (Mauffret et al., 2007).

The aim of this paper is to re-assess the architectural evolution of the Western Alboran Basin in relation to major geodynamic events through a comprehensive seismic analysis of the most complete dataset of seismic profiles available in the area (Fig. 2B). We then correlate this new tectonostratigraphic framework of the WAB with the onshore stratigraphic sequence and tectonic data covering both southern Spain and northern Morocco, with a more specific view from the Moroccan margin. Our final objective is to propose a coherent geodynamic model for the formation and evolution of the WAB based on our observations but also on the vast amount of information available on the surroundings, especially regarding the tectonic and sedimentary history of the peri-Alboran sedimentary basins.

Following up on this new set of observations at the scale of the whole basin, we illustrate the tectonic evolution with a series of palaeogeographic reconstructions and discuss the possible causes of the rapid subsidence and weak deformation observed on the Moroccan margin. We show that the evolution of the WAB was first controlled by a regional extensional phase in the Early Miocene, followed by a period of quiet tectonics and intense sedimentation and rapid subsidence in the Middle Miocene. The Western Alboran Basin subsidence most likely migrated hundreds of kilometers westward without significant deformation above a retreating slab and its subsidence may be due to the persisting density anomaly of the underlying dipping slab.

2. Geological settings and tectonic framework

2.1. Western Mediterranean geodynamic models and mantle structures

The complexity of the Betic–Rif orogenic system led to different types of geodynamic reconstructions that are still debated today (Lonergan and White, 1997; Jolivet et al., 2009; Vergés and Fernàndez, 2012; Platt et al., 2013). Most propose subduction models involving slab roll-back, delamination, slab break-off or slab tearing (Royden, 1993; Lonergan and White, 1997; Gueguen et al., 1998; Calvert et al., 2000; Rosenbaum et al., 2002a; Faccenna et al., 2004; Spakman and Wortel, 2004; Jolivet et al., 2006, 2008; Vergés and Fernàndez, 2012). In the past few years, based on tomographic imagery, the analysis of mantle seismic anisotropy and modeling, a rather consensual model has emerged of the presence of a E–SE dipping slab beneath the Gibraltar–Betics area and retreating westward (Wortel and Spakman, 2000; Spakman and Wortel, 2004; Levander et al., 2014; Thurner et al., 2014).

Tomographic studies revealed the presence of an arcuate, vertical high-velocity anomaly located beneath the western Alboran Sea and southern Spain (Gutscher et al., 2002; Faccenna et al., 2004; Spakman and Wortel, 2004; Bezada et al., 2013). This anomaly, which has been interpreted as a remnant of the Alpine Tethys slab, extends continuously from a depth of 50 km to a depth of more than 600 km (Bezada et al., 2013). It is curved below the Gibraltar Arc and is partially detached from the surface below the eastern Betics (Spakman and Wortel, 2004; Bezada et al., 2013).