The Balearic Basin in the West-Mediterranean: A Back-arc Basin or a Foreland-Foredeep Basin?

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Summary
In this paper we question the origin of the Balearic Basin, univocally described in literature as a back-arc basin, which opened during the Oligocene-Miocene rift. Our interpretation highlighted the presence of an extensive Mesozoic basin, re-shaped during the Paleogene compression and uplift. The deepest units show polyphasic folds and thrusts, characterized by different structural styles, active mostly during the Paleogene. In the Early Miocene (Burdigalian-Serravallian), the gradual decrease in tectonic activity developed the final bathymetric setting of this basin.

We propose to reclassify the Balearic Basin as foreland-foredeep basin, deformed between the frontal thrusts of the Betic Cordillera and the Pyrenees. A preliminary regional kinematic model has been presented as an alternative to the back-arc model, rearranging the evolution of this basin with the regional tectonic of the circum-Mediterranean orogens.

Introduction
The West Mediterranean is classified as an episutural basin related to the circum-Mediterranean orogens (Bally and Snelson, 1980), that resulted from the convergence of Africa and Europe, the subduction of the western Tethys Ocean, and the collision of continental margins (Stampfli et al. 2002, Golonka 2014) (Figure 1). The Balearic Basin, within the West Mediterranean, has previously been described as a back-arc extensional basin, related to eastward trench rollback and slab retreat during the Miocene-Pliocene subduction in the Italian Apennine Arc (Gueguen et al. 1998). Resultant crustal stretching caused a Late Oligocene-Early Miocene rift, separation of the Sardinia-Corsica block from the European Margin, and oceanic crust formation. This tectonic model takes into account the 30-35° anti-clockwise paleo-magnetic rotation of the Sardinia-Corsica continental block during the Aquitanian-Burdigalian (Speranza et al. 2002, Gattacceca et al. 2007), assuming a rotation pole in the northern apex of the block near the Italian coast.

Figure 1 Schematic sketch showing the onshore and offshore regional structural trends reconstructed in this work. The white lines represent the seismic grid.
In this work, we reconstruct the offshore structural setting at the Oligocene-Miocene transition, focusing on the relationship between the rifting described in the back-arc model, and compressional structures active in the Pyrenees during the Eocene-Oligocene and the Betic Cordillera during the Oligocene-Miocene (Azañon et al. 2002, Capote et al. 2002, Verges et al. 2002).

**Method**

We interpreted approximately 20,000 km of 2D marine seismic data, acquired from the 1970s to 2012 in several regional grids (Figure 1); all lines were reprocessed in 2011 to 2013. The data are distributed around the Balearic Archipelago and along the Spanish and French offshore. More than thirty years of exploration provide good well control, allowing calibration of the seismic data with time-depth curves and checkshots. The interpretation focused on the distinctive Oligocene-Miocene sequence boundary observable across the Balearic Basin. This event is calibrated by wells and separates an underlying highly deformed, seismic unit consisting of discontinuous reflectors, from the overlying almost undeformed unit characterized by continuous reflectors.

Figure 2 The analogy between the onshore crustal section (A), and the interpreted offshore seismic (B and B') shows the possible continuation of the Pyrenees in the deep offshore of the Gulf of Lion. Lines of sections are shown in Figure 1.
Results

Two different structural domains exist within the Balearic Basin: the Gulf of Lion and the Valencia Trough. The Gulf of Lion well data offer a sparse calibration of the pre-Tertiary substratum, marked by an erosional surface at the top, which allows correlation of the Late Oligocene-Early Miocene unconformity from the nearshore (Figure 2A) to deep water areas (Figure 2B). Along the coast between Spain and France, the erosion reaches Paleozoic strata, where the offshore continuation of the Pyrenees exists (Figure 1). In the deep water, the substratum descends along an escarpment where wells have intersected Mesozoic sediments (Figure 2B and B’).

In the Valencia Trough, Mesozoic sediments can be calibrated in most of the wells, and consist mainly of shallow water carbonates. The seismic data indicate this sequence is up to 5000m thick and deformed in kilometre-scale detachment folds, detaching either at the base of the Mesozoic or within Paleozoic strata. The shortening is Paleogene-Early Miocene in age, coeval with the Betic Cordillera, which shares the east-west trend. The deformation is more pronounced towards the Balearic Archipelago. Along the Spanish shoreline, carbonates form an undulated monocline and thrust fault propagation folds. The structures are incised by canyons several hundred metres deep, and intense karstification of sediments suggests subaerial exposure during the Paleogene. Neogene shallow water carbonates and clastic deposits lie unconformably on the deformed substratum, indicating a relatively quiescent tectonic phase occurred from the Miocene. No evidence of Early Miocene rifting was seen. Listric normal faults

Figure 3 Indentation model showing the tectonic evolution of the Balearic Basin during the Tertiary and the rotation of Sardinia-Corsica microcontinent. (a) and (b) represent continental crust and margins; (c) is thin continental crust or oceanic crust related to the Mesozoic Tethys Ocean.
or diapiric structures are locally active during the Late Miocene-Pliocene, detached or rooted at the base of the Mesozoic, suggesting the presence of mobile evaporites analogous to the Keuper Fm. in the nearshore.

Structures resulting from several phases of compression can be seen within the Paleozoic to Oligocene substratum on the seismic data, typical of pelagic accretionary wedges. The age of the aforementioned unconformity is thought to be Late Oligocene-Early Miocene, coeval with the end of the Pyrenean orogeny (Figure 2). The level of shortening between the onshore and offshore Pyrenees cannot be compared, but several thousand metres of difference in morphology can be explained with variable crustal thicknesses in the orogens. This interpretation implies a thin continental or oceanic crust, present in the deep water sector since the Mesozoic, which became part of the Pyrenees and its foreland.

Conclusion
The structural setting and evolution described is incompatible with extension required by a back-arc model. An alternative kinematic model to the back-arc has been based on a process of indentation (Sokoutis et al. 2000) of the Sardinia-Corsica block during the Africa-Europe convergence (Figure 3).

This model presents the Balearic Basin as a remnant of the western Tethys, and the Sardinia-Corsica block as an isolated micro-continent in place since the Mesozoic. The Early Miocene rotation has been re-arranged using a rotation pole located offshore Barcelona. The block is pushed northwards during the formation of the Northern Apennines, forming an indenter within the Piemont-Liguria Ocean. Approximately 300 km of northward migration has been inferred, compatible with the 30-35° anti-clockwise rotation and palinspastic reconstruction in the Northern Apennines (Cerrina Feroni et al. 2004, and reference therein). The abrupt onset of diapirism in the Messinian evaporites may reflect deformation in underlying units caused by a transcurrent-transpressive lineament in the deep water Gulf of Lion.

In this model, the Balearic Basin remains trapped in the external sectors of the Betic Cordillera and the Pyrenees as a relict foreland-foredeep basin of these orogens.

References


