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Evolution of rifted continental margins: The case of the Gulf of Lions (Western Mediterranean Basin)

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ABSTRACT

The formation of rifted continental margins has long been explained by numerous physical models. However, field observations are still lacking to validate or constrain these models. This study presents major new observations on the broad continental margin of the Gulf of Lions, based on a large amount of varied data. Two contrasting regions characterize the thinned continental crust of this margin. One of these regions corresponds to a narrow rift zone (40–50 km wide) that was highly thinned and stretched during rifting. In contrast with this domain, a large part of the margin subsided slowly during rifting and then rapidly after rifting. The thinning of this domain cannot be explained by stretching of the upper crust. We can thus recognize a zonation of the stretching in both time and space. In addition, the Provencal Basin is characterized by a segmentation of the order of 100–150 km. These observations have important consequences on the formation and evolution of the Gulf of Lions margin. Independently of the geodynamic context, we can propose some general features that characterize the formation of rifted continental margins.

1. Introduction

The formation of continental margins and rift basins is classically explained by lithospheric extension. McKenzie (1978) quantified the vertical motions that result from a uniform and passive extension of the crust and lithosphere. The two main contributions to these motions are subsidence, caused by crustal thinning, and uplift, caused by lithosphere heating. The combination of these two factors explains an initial rapid subsidence during rifting, followed by a slower thermal subsidence after rifting as the lithosphere cools down and returns to its original thickness. However, this pattern is not always observed on continental margins. For example, studies have demonstrated a rift flank uplift of up to 1000 m in the Gulf of Suez (Steckler, 1985) or uplift and erosion landward of a narrow hinge zone in the US Atlantic and eastern Australian continental margins (Weissel and Karner, 1984; Steckler et al., 1988). A greater degree of extension at depth rather than in the upper crust has been proposed to account for these observations (Royden and Keen, 1980; Steckler, 1985; Steckler et al., 1988; Davis and Kusznir, 2004; Reston, 2007; Huismans and Beaumont, 2008). Recent studies on different margins allow us to compare the observations of late synrift sediments deposited under shallow-water conditions offshore from the hinge zone to the oceanic domain (Moulin et al., 2005; Dupré et al., 2007; Péron-Pinvidic and Manatschal, 2008; Aslanian et al., 2009; Labails et al., 2009). However, the great diversity of margin morphologies leads us to consider firstly the influence of the local geodynamic context (included inheritance) before proposing general dynamic models of lithospheric extension. Unfortunately, this task is made more difficult by the long and complex pre-rift history, often combined with poor-quality and scattered geophysical and subsurface data. This last point has been repeatedly emphasized by Watts (1981): "unfortunately, there is presently too little seismic and lithologic information on the actual proportion of pre-rift and synrift to post-rift sediments (…) to constrain these models".

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This study presents the young and weakly deformed Gulf of Lions continental margin, which is covered by a dense network of observations. These data lead to a new model for the formation of this margin and allow us to identify some major characteristics that can be compared with observations made on other rifted continental margins.

2. Geodynamic context and subsidence studies in the Gulf of Lions

2.1. The basin and its margins

In the western Mediterranean, the Provencal Basin is a young oceanic basin created by a Miocene counter-clockwise rotation of Corsica–Sardinia micro-plate (Smith, 1971; Auzende et al., 1973; Dewey et al., 1973; Olivet, 1996; Gueguen et al., 1998; Gattacceca et al., 2007). Along the north-western edge of this basin, the broad Gulf of Lions margin is bordered on either side by the narrow Provence and Catalonian margins. On the south-eastern conjugate edge, the broad Sardinian margin is intercalated between the narrow Nurra and Iglesiente margins. In this way, the Provencal Basin is characterized by a segmentation of the order of 100–150 km (Fig. 1).

The central part of the Provencal Basin shows magnetic anomalies and velocities related to the presence of a typical oceanic crust (Le Douaran et al., 1984; De Voogd et al., 1991; Pascal et al., 1993). This central oceanic domain (Fig. 1) is separated from the continental margins by two domains of unknown nature without magnetic anomalies (or with low-amplitude anomalies). These transitional domains appear to be an equivalent of the Ocean–Continent Transition (OCT) as described on the Galicia margin (Boillot et al., 1980).

The opening of the Provencal Basin, followed by the Tyrrhenian Sea, took place in the back-arc region of the south-eastward retreating Apennines-Maghrebides subduction zone (Réhault et al., 1984; Malinverno and Ryan, 1986; Jolivet and Faccenna, 2000). Furthermore, the Gulf of Lions is located at the eastern end of the Pyrenees and the southern end of the West European Rift system (Rhine Graben, Bresse, Fig. 1). This margin is therefore the result of a complex but well-known tectonic evolution (see Gorini et al. 1993; Séranne, 1999; Guennoc et al., 2000 for reviews).

2.2. Pyrenean inheritance

The Pyrenean orogeny affects the northern boundaries of the Iberian plate (Pyrenees) and the Corsica–Sardinia plate (Languedoc–Provence) at the end of the Eocene (Arthaud and Séguret, 1981). In the Pyrenees, a shortening of 100 km or 150 km has been estimated, respectively, by an analysis of the Ecors seismic profile (Roure et al., 1989) and by kinematic studies (Sibuet and Collette, 1991; Olivet, 1996). Eastward of the Pyrenees, in the Languedoc–Provence domain, various authors have estimated a shortening of the order of 50 km (Arthaud and Séguret, 1981; Guieu and Roussel, 1990). Moreover, no deformation linked with this phase has been reported in Corsica–Sardinia. NE–SW-trending Variscan and Tethyan structural directions are preserved in the Gulf of Lions, thus corroborating these differences of shortening. One important consequence is the activation of a major N–S strike-slip fault between the Iberian and

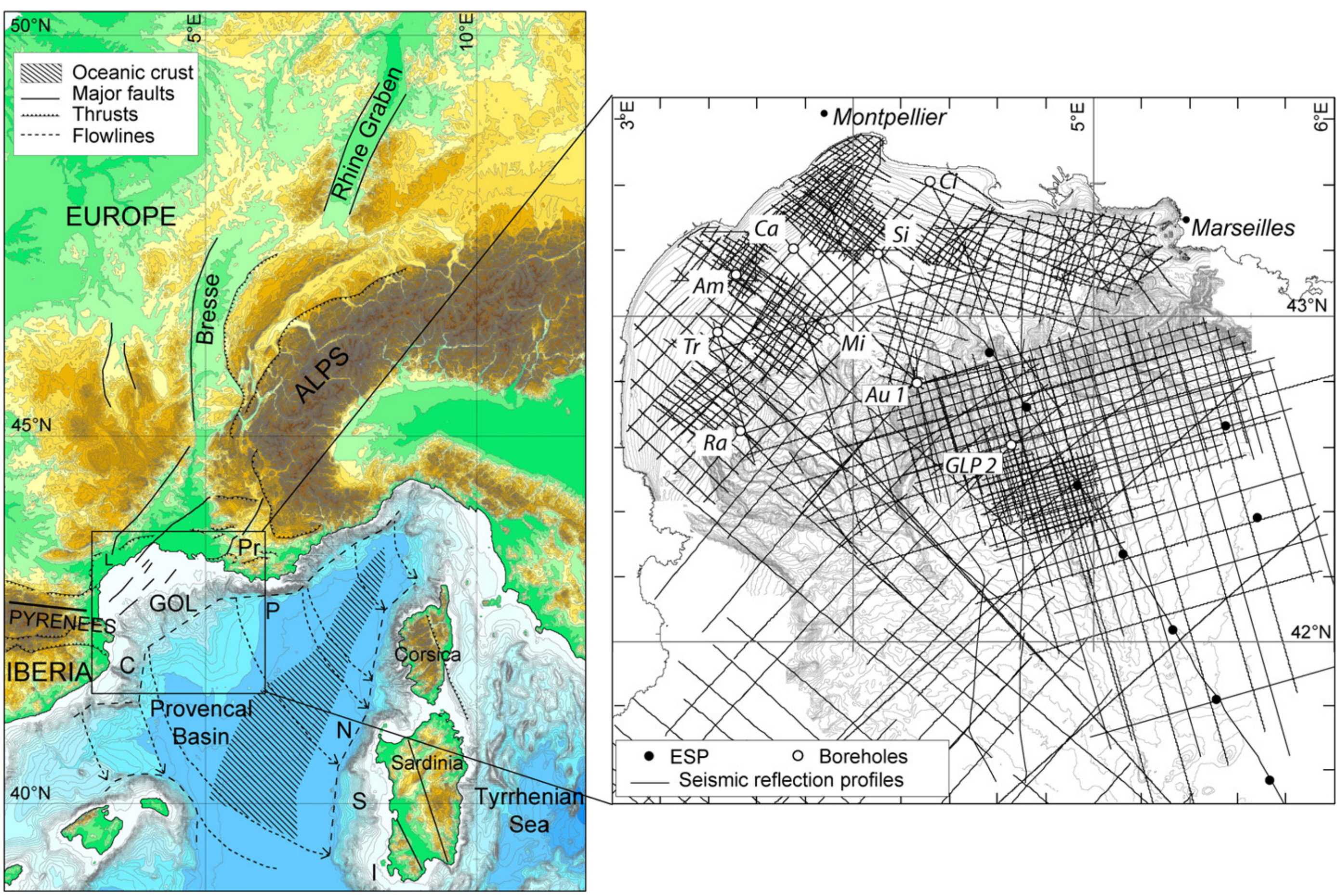

Fig. 1. Topographic and bathymetric map of the West European Rift system and the Provencal Basin (IOC et al., 2003), along with data base used for this study (detail inset). The Provencal Basin was created by counter-clockwise rotation of Corsica–Sardinia micro-plate during the Miocene (see flowlines). Typical oceanic crust is shown at the centre of the basin. Along its north-western edge, the Gulf of Lions margin is bracketed by the narrow Provence and Catalonian margins. The Gulf of Lions represents a 150-km wide segment. GOL. Gulf of Lions, P. Provence Margin, C. Catalonian Margin, N. Nurra Margin, S. Sardinian Margin, I. Iglesiente Margin, L. Languedoc, Pr. Provence. Boreholes: Ci. Cicindelle, Si. Sirocco, Ca. Calmar, Mi. Mistral, Am. Agde Maritime, Tr. Tramontane, Ra. Rascasse, Au1. Autan 1, GLP2. Golfe du Lions Profond 2.