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Analogue modelling of Late Miocene–Early Quaternary continental crustal extension in the Tunisia–Sicily Channel area

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ABSTRACT

We adopt analogue modelling to investigate continental crustal stretching by simulating a Late Miocene–Early Quaternary extensional event occurred in Tunisia and in the Sicily Channel. The analogue model of the continental crust is composed of a lower ductile crust and an upper brittle crust including a low-viscosity layer to simulate the presence of evaporites. In our models, the extension is driven by tectonic stresses and not solely by gravity. All models are run under the same boundary conditions with a moveable lateral edge. Different physical hypotheses are tested to interpret the origin and geometry of this rifting event that affected the SW sector of the Mediterranean basin. The modelling of the continental crustal stretching produces small tectonic troughs with regular spacing that simulates the pattern observed in the Atlasic Rift System (Tunisia) as well as a large rift zone involving bulk crust thinning simulating the features of the Sicily Channel Rift Zone. In accordance with geological and geophysical data, extension in the Atlasic Rift Zone is controlled at depth by the Triassic evaporite layer and by inherited diapiric structures that create rheological "soft points" in the upper crust. The best accordance between models and nature are thus obtained when combining crustal-scale stretching, decoupling level within the upper-crust and pre-structuration (inheritance) of the evaporitic layer. We propose that the NE-trending extensional event occurring since the Pliocene to the early Quaternary in the Tunisian–Pelagian Sea area was driven by a transient eastward migration of the Tunisia–Pelagian–Ionian area (acting as a micro-plate with an undefined southern boundary) due to a far-field pull of the Western-Hellenic/Dinaride subduction.

1. Introduction

In Tunisia, the Atlasic structural domain is affected by a Late Miocene–Early Quaternary rift system characterized by a set of NW-trending tectonic troughs (Fig. 1). These extensional structures are distributed also in the offshore of the Pelagian Sea (e.g. Ben Romdhan et al., 2006; Fig. 1). These tectonic troughs show a very similar geometry: their length varies between 20 and 30 km, with a length/width ratio ranging between 2 and 2.5 and a constant N130–150° orientation (Belguith et al., 2011). The average spacing between the tectonic troughs is of 50 ± 3 km (Fig. 1), and they are frequently associated with outcrops of salt diapirs. Seismic data show that these evaporites, which are attributed to the Triassic (e.g. Belguith et al., 2011; Chihi, 1995), are found at shallow depth within most of the rifts, suggesting extrusion and/or sill-like intrusion of evaporites during rift genesis (Belguith et al., 2011). In the Tunisian Atlas, Triassic halokinesis (including diapirism) actually began during the Mesozoic (e.g. Hlaiem, 1999; Rigane et al., 2010), and it is clearly responsible for strong lateral variations of thickness in the Tunisian succession of the Atlasic zone (e.g. Kamoun et al., 1998). It could therefore have played an important role in localizing the development of more recent tectonic structures in the Atlasic structural domain, both compressive and extensional. It should also be noted that Triassic evaporites appear to be missing beneath at least part of the Pelagian Sea (Bouaziz et al., 2002; Civile et al., 2010).

The Late Miocene–Early Quaternary Atlasic Rift System and the Sicily Channel Rift Zone (e.g. Catalano et al., 2008; Chihi, 1995; Civile et al., 2008) may have been generated by the same extensional tectonic phase. These rift systems show a NW-trending and developed from Late Miocene times onwards, after the major Tortonian compressional event that occurred in Tunisia (Belguith et al., 2011) and after the opening of the Back-arc Tyrrhenian Basin (e.g. Faccenna et al., 2001). The continental crust shows a continuous thinning gradient from Tunisia towards the Sicily Channel (Buness, 1992; Della Vedova et al., 1995; Dèzes and Ziegler, 2004), in a direction sub-orthogonal to the trend of the rifts (Fig. 1). This suggests that crustal stretching was greater in correspondence of the Sicily Channel Rift Zone. Accordingly, the Sicily Channel Rift Zone is composed of much wider, longer and deeper tectonic troughs compared to the Atlasic Rift System of Tunisia (Fig. 1). It is

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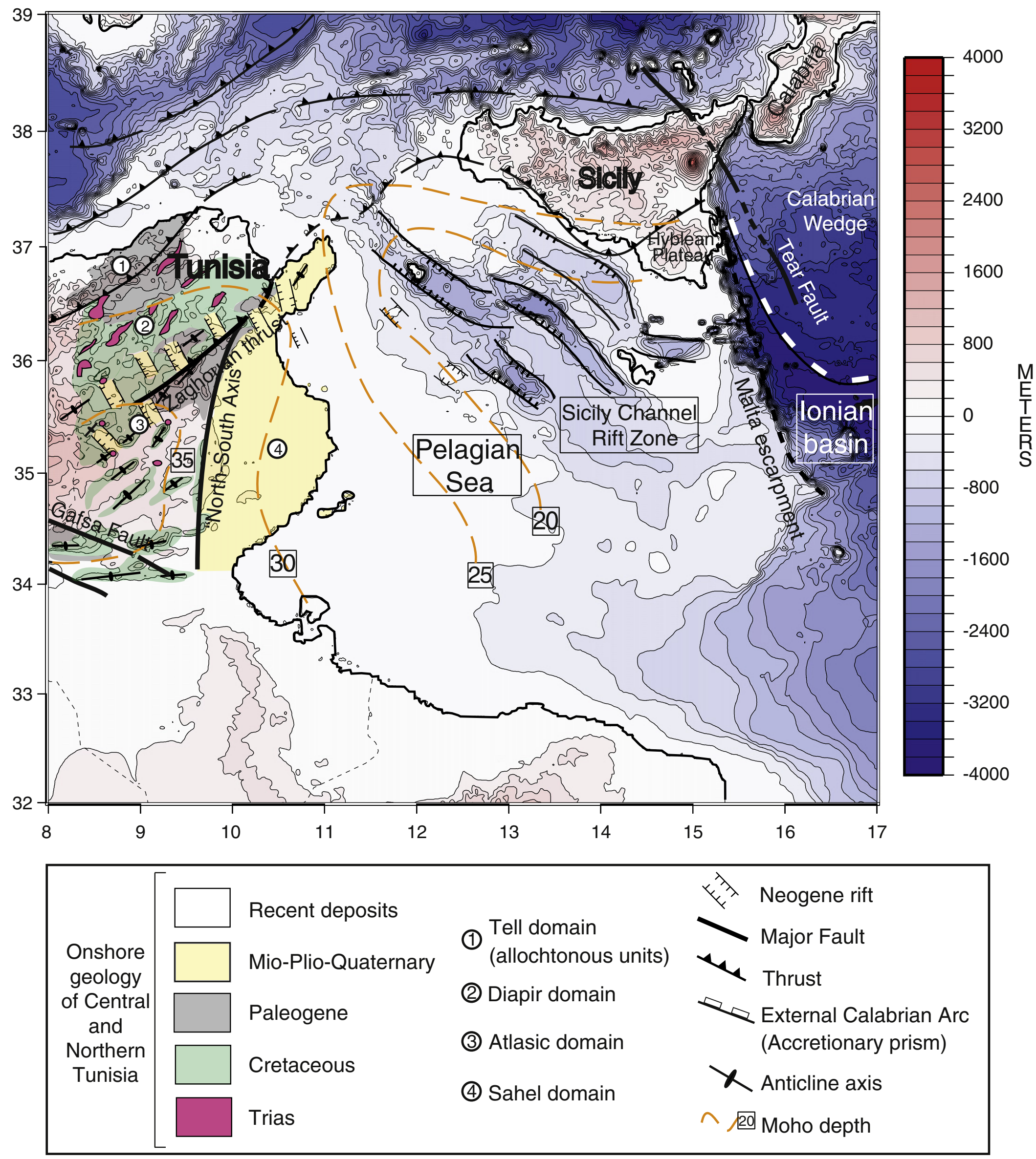

Fig. 1. Topographic and bathymetric map of the Central Mediterranean showing the main structural features (The structural features had been taken from Faccenna et al. (2001), Goes et al. (2004), Argnani and Bonazzi (2005), Argnani (2009), Belguith et al. (2011), D'Agostino et al. (2011) and Gallais et al. (2013)). The figure also indicates Moho isobaths from the European Geotraverse Programme (data from Buness (1992) and Dèzes and Ziegler (2004)).

made up of three principal grabens (Pantelleria, Linosa and Malta Grabens) bounded by N120–130°E trending faults (compared to the N130–150°E trending of the Atlasic tectonic troughs). The degree of crustal attenuation reaches up to 40% within the Pantelleria and Linosa Grabens. The Sicily Channel Rift Zone is also associated with a volcanic activity mainly consisting of alkaline basalts and hawaiites of Plio-Pleistocene age (Civile et al., 2010; Corti et al., 2003, 2006; Rotolo et al., 2006). This magmatic activity (which locally continues to the present day; see Civile et al., 2010), absent within the Atlasic Rift System, suggests a lithospheric thinning and a moho uplift in the Sicily Channel Rift Zone.

Therefore, both lithosphere (or crustal) stretching and halokinetic activity seem to play a role in the development of the two rift systems. Nevertheless, we have little understanding of their respective roles in controlling the localization and pattern of the extensional structures. In the present study, we adopt analogue modelling as an experimental approach to test different physical hypotheses to interpret this recent rifting event developed in the SW Mediterranean Basin.

A complete analogue model of lithospheric extension and continental break-up involves a modelling of the compositional lithosphere over a low-viscosity layer (asthenospheric mantle) (e.g. Benes and Davy, 1996; Brun, 1999; Brun and Beslier, 1996; Callot et al., 2001; Corti et al., 2003; Vendeville et al., 1987). Such models emphasize the important structural and rheological role of decoupling levels within lithosphere undergoing extension (such as between the ductile crust and the frictional crust, or between the rigid upper lithospheric mantle and the ductile crust), which is otherwise demonstrated by analytical and numerical modelling (Burov and Diament, 1995). They also highlight the importance of viscous anomalies (e.g. soft points, see Gac and Geoffroy, 2009) in initiating and localizing lithospheric extension (Callot et al., 2002; Corti et al., 2003). However, these models can hardly account for the existence of smaller-scale decoupling levels within the upper crust, such as thin evaporite layers. For this reason, analogue extensional models involving evaporites are restricted to the crustal scale. Most of these models are gravity-driven and do not include a ductile crust in addition to the evaporite layer (e.g. Brun and Mauduit, 2008;