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Evidence for an east–west regional gravity trend in northern Tunisia: Insight into the structural evolution of northern Tunisian Atlas

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ABSTRACT

The Atlas orogeny in northern Algeria and Tunisia led to the destruction of Tethys oceanic lithosphere and cumulated in a collision of microplates rifted off the European margin with the North African continental margin. The location of the boundary between African plate and Kabylian microplate is expressed in northern Algeria by a crustal wedge with double vergence of thrust sheets, whereas in northern Tunisia the geologic environment is more complex and the location of the plate boundary is ambiguous. In this study, we analyzed gravity data to constrain the crustal structure along the northern margin of Tunisia. The analysis includes a separation of regional and residual gravity anomalies and the application of gradient operators to locate density contrast boundaries. The horizontal gradient magnitude and directional gradient highlight a prominent regional E–W gravity gradient in the northern Tunisian Atlas interpreted as a deep fault (active since at least the Early Mesozoic) having a variable kinematic activity depending on the tectonic regime in the region. The main E–W gravity gradient separates two blocks having different gravitational and seismic responses. The southern block has numerous gravity lineaments trending in different directions implying several density variations within the crust, whereas the northern block shows a long-wavelength negative gravity anomaly with a few lineaments. Taking into account the geologic context of the Western Mediterranean region, we consider the E–W prominent feature as the boundary between African plate and Kabylian microplate in northern Tunisia that rifted off Europe. This hypothesis fits most previous geological and geophysical studies and has an important impact on the petroleum and mineral resource prospection as these two blocks were separated by an ocean and they did not belong to the same margin.

1. Introduction

The crustal structure of northern Tunisia (Fig. 1) is thought to be the result of the tectonic interaction between the Eurasian and African plates and is considered to be part of a broad boundary plate zone in northern Africa (Billi et al., 2011; Bouaziz et al., 2002; Capitanio and Goes, 2006; Carminati et al., 1998; Faccenna et al., 2001; Frizon De Lamotte et al., 2000, 2009; Gueguen et al., 1998; Mauffret, 2007; Meghraoui and Pondrelli, 2012; Morgan et al., 1998; Piqué et al., 1998; Rosenbaum et al., 2002; Wortel and Spakman, 2000). The general sequence of tectonic events within the western Mediterranean region includes: 1) Early Mesozoic rifting forming the Tethys Sea where a passive margin sequence was developed; and 2) northward convergence of the African plate relative to Eurasia since the Late Cretaceous. This convergence evolved into Cenozoic subduction and formed the Western Mediterranean back-arc basin known as the Algero-Provencale basin (Fig. 1). However, the structure of the Cenozoic subduction in northern Africa was not similar to a Pacific-style subduction, as it was more complex. This Cenozoic subduction zone may have produced a slab detachment with the subduction zone migrating toward the east over time (Capitanio and Goes, 2006; Carminati et al., 1998; Faccenna et al., 2001, 2004; Frizon De Lamotte et al., 2000, 2009; Goes et al., 2004; Mauffret, 2007; Morgan et al., 1998; Piqué et al., 1998; Spakman and Wortel, 2004; Wortel and Spakman, 2000).

As consequence of the above convergence, thrust faults and folds were developed in northern Africa with a southward vergence (Fig. 1). Even though northward vergence of thrust faults is not observed at the surface, Mauffret (2007) proposed a wedge model with double directional vergence with a northern vergence occurring over a much narrower zone than the southern region. This wedge is related to transpressional forces that formed within the Maghreb margin in Algeria and Tunisia. Although the convergence eventually evolved into

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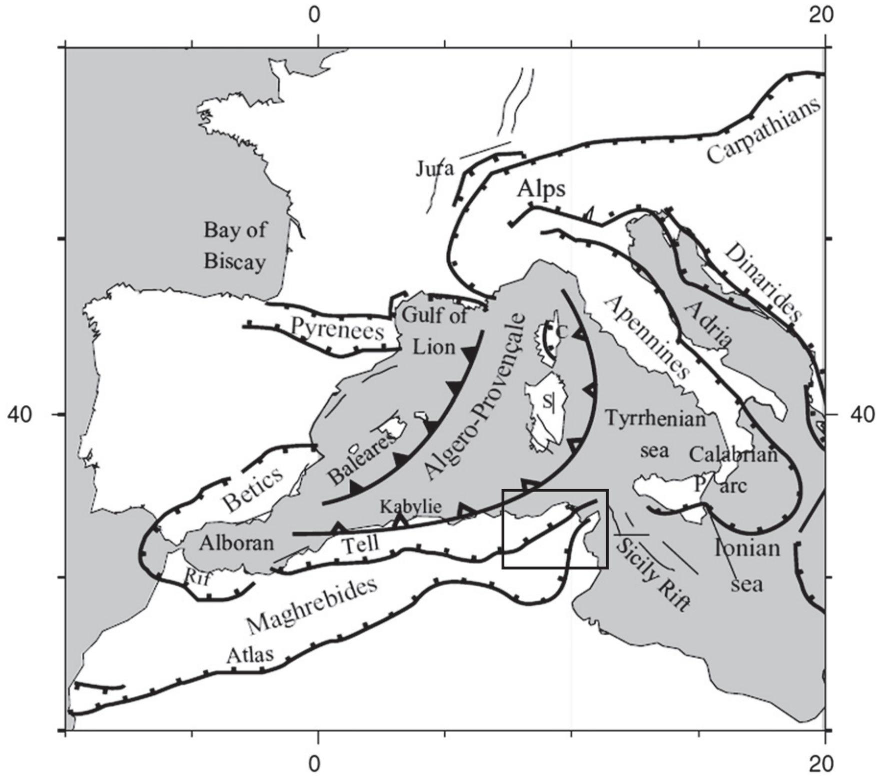

Fig. 1. Location of the study area on a map showing the tectonic setting of the western Mediterranean (from Capitanio and Goes (2006), based on reconstructions by Gueguen et al., 1998; Frizon de Lamotte et al., 2000; Faccenna et al., 2001). Lines with small squares show current position of the Maghrebian–Apenninic–Alpine convergence front. Thin lines mark extensional faults. Lines with triangles mark Cenozoic migration of the Maghrebian–Apenninic trench (solid triangle: 35 Ma, open triangles: 16 Ma). P—Peloritani block, S—Sardinia, C—Corsica.

a collision between the Kabylian block and the African plate, the crust beneath the Sardinia Channel and northern Tunisia and Algeria is thin (Blundell et al., 1992; Jallouli and Mickus, 2000; Mickus and Jallouli, 1999). However, Tricart et al. (1994) considered that a thickening of the crust as a result of collision during the Miocene is probable and after this collision, the crust was thinned by the collapse of the orogen. There is evidence of thinning crust related to the opening of the Tyrrhenian Sea during the Late Miocene (Mascle et al., 2004). Also, a thinning of the crust since the Middle Miocene related to the opening of the Algerian basin has been imaged by seismic reflection profiles (Catalano et al., 2000), whereas, the mechanism that caused crustal thinning within northern Tunisia remains unclear.

Northern Tunisia contains a variety of complex tectonic features. Based on surface geological observations, the simplified geological map of northern Tunisia (Fig. 2) shows in addition to southward verging thrust faults, Neogene volcanic activity, Triassic rocks (including evaporites) which intrude younger sedimentary layers and trend in a SW–NE direction, SW–NE trending folds, SE–NW trending grabens and a variety of faults striking in different directions.

Within the above complex geological environment, a gravity data analysis was attempted by Jallouli and Mickus (2000) and Jallouli et al. (2002). These gravity analyses revealed a regional E–W trending anomaly. Given its potential significance and importance in the understanding of the geological evolution of northern Africa, the E–W trending gravity anomaly has to be better defined through appropriate data enhancement methods (e.g., horizontal gradient) allowing one to emphasize such anomalies. Such trends will help in providing insights into the regional structure and geodynamic evolution of the Alpine chain in northern Africa.

Our analysis involves separating the observed complete Bouguer gravity anomalies into regional and residual gravity anomalies, and by applying enhancement methods to locate and highlight principal density heterogeneities that could be related to major density variations. The results are then discussed within the context of the western Mediterranean tectonic evolution.

2. Structural overview and previous work

Northern Tunisia is located at the eastern edge of the Cenozoic Alpine orogenic belt of northern Africa known as the Tell Atlas and the Maghrebides Atlas. This belt is the result of the convergence between Africa and Europe and has been subject to numerous investigations (e.g., Amiri et al., 2011; Ben Ayed, 1993; Ben Ferjani et al., 1990; Bouaziz et al., 2002; Boukadi, 1994; Burollet, 1991; Chihi, 1995; Cohen et al., 1980; Dewey et al., 1989; Dlala, 1995; Frizon De Lamotte et al., 2009; Jallouli and Mickus, 2000; Jallouli et al., 2002, 2003; Jolivet and Faccenna, 2000; Khomsi et al., 2009; Mauffret, 2007; Meghraoui and Pondrelli, 2012; Morgan et al., 1998; Piqué et al., 1998; Rouvier, 1977; Serpelloni et al., 2007; Slim, 2010; Turki, 1985; Zargouni, 1985).

Based on surface observations, the uppermost crust in northern Tunisia is composed of Mesozoic and Cenozoic sedimentary rocks (Ben Haj Ali et al., 1985). Previous analyses of the structural features led workers to divide northern Tunisia into two structural zones: 1) the Tell, located in northernmost Tunisia (Rouvier, 1977) and 2) the northern Tunisian Atlas (Fig. 2) (Burollet, 1991).

The major structural features within the Tell Atlas are thrust faults within the Oligo-Miocene Numidian flysch deposits and SW–NE trending folds (Ben Ferjani et al., 1990; Cohen et al., 1980; Rouvier, 1977). The Northern Atlas is characterized by numerous northeast-trending exposures of Triassic rocks intruded into younger Cenozoic and Mesozoic sedimentary rocks (Fig. 2). The Triassic rocks which consist mainly of evaporites are thought to have been emplaced by diapirism during the Atlas and the Alpine orogeny (Benassi et al., 2006; Chikhaoui et al., 2002; Jallouli et al., 2005; Perthuisot, 1981;