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The three main steps of the Marrakech High Atlas building in Morocco: Structural evidences from the southern foreland, Imini area

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ABSTRACT

The timing of Cenozoic deformation in the intraplate orogen of the High Atlas of Morocco is still a matter of debate. In this work, the deformation calendar has been studied in the southern foreland of the Marrakech High Atlas. Using a structural approach and the mapping of the Cenomanian–Turonian reference layer, we propose a coherent chronology of deformation that proceeded in three stages: (i) a Late Eocene event that set local and minor structures, barely visible nowadays, but important enough to trigger the record of a first detrital pulse; (ii) an Early(?)–Middle Miocene event that is not related to important shortening, setting gravity "sheets" that provoke cover deformation and feed a second detrital pulse; (iii) a Late Pliocene–Quaternary event that is mainly observed through the activity of basement features like the South Atlas Front of the Imini Fault in our studied area and reworks earlier structures. This calendar can partially fit to the geodynamic changes occurring in the western Mediterranean realm during the Cenozoic. Specifically, the Early(?)–Middle Miocene stage of deformation is suggested to be intrinsic to Morocco.

1. Introduction

The active plate boundary between Africa and Europe is complex and mixes large-scale tectonic structures located either at the locus of the plate boundary (e.g. the Alps), or in regions where this boundary is more diffuse, with the setting of intraplate tectonic structures (e.g. the Pyrenees, the Atlas) (see Ziegler et al., 1995 for a review of alpine Europe). The intraplate Atlas system results from the inversion of Triassic–Jurassic rifted basins during the Cenozoic across the whole Maghreb area, but is geomorphologically distinct in Morocco compared to Algeria and Tunisia. In Morocco, peaks culminating at more than 4000 m in its western domain (Jbel Toubkal, 4167 m and Jbel Mgoun, 4071 m, Fig. 1) and the lack of crustal root led several authors to propose that an upper mantle anomaly (lithospheric thinning) supports the relief (Seber et al., 1996; Zeyen et al., 2005; Teixell et al., 2005; Missenard et al., 2006; Fullea et al., 2007). This lithospheric thinning is thought to be superimposed in the Anti-Atlas, the High Atlas of Marrakech and the Middle Atlas (Fig. 1A) and partly explains the high topography of the Atlas belt in Morocco (Teixell et al., 2005; Missenard et al., 2006; Fullea et al., 2007, 2010; Jimenez-Munt et al., 2011). Thus, in Morocco the Atlas building results from the Cenozoic tectonic inversion but was also imprinted by the thermal uplift which does not exist in the eastern Maghreb. This thermal uplift dismantled foreland basins, partly removing the sedimentary record of tectonic events. This particularity significantly challenges the reconstruction of a proper tectonic calendar in Morocco. The complexity of this calendar is also highlighted by the apparent contradiction between (1) the post-Messinian surface uplift evidenced by Babault et al. (2008) and (2) the Early Miocene in age denudation recorded by thermochronological data (Missenard et al., 2008; Balestrieri et al., 2009).

In Algeria and Tunisia subsurface data (seismic lines and boreholes) clearly show unconformities between Eocene and Oligocene, and between Pliocene and Pleistocene (Vially et al., 1994; Mekireche et al., 1998). Accordingly, Frizon de Lamotte et al. (2000) proposed a comprehensive history of deformation with a two-step chronology beginning with: (1) a first step – the so-called "Atlasic phase" during Late Eocene, well evidenced in Algeria by Laffitte (1939), Ghandriche (1991) and in Tunisia by El Euchi (1993) and Khomsi et al. (2006), followed by a "quiescent"

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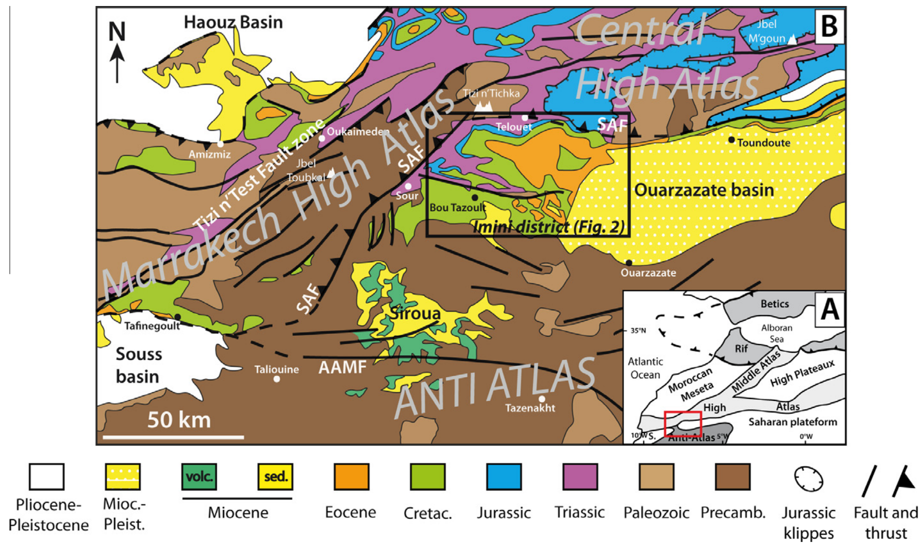

Fig. 1. (A) Geodynamic situation of the Atlas in the Western Mediterranean frame (modified from Frizon de Lamotte et al. (2000)). Location of the studied region presented in (B) is indicated with the red window. (B) Schematic geological map of the studied part of the Atlas orogen and localization of Fig. 2. SAF: South Atlas Front; AAMF: Anti-Atlas Major Fault. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

phase until (2) a second Pliocene–Pleistocene phase. In Morocco, the chronology is still debated: are the two steps identified eastward also relevant in Morocco, as suggested by Görler et al. (1988), Frizon de Lamotte et al. (2000), and El Harfi et al. (1996, 2001) or was the High Atlas built from a single tectonic episode during Neogene times, as proposed by Morel et al. (1993), Beauchamp et al. (1999), Benammi et al. (2001), Tesón and Teixell (2008), and Tesón et al. (2010)?

The present study focuses on the Marrakech High Atlas (Fig. 1). We investigated the Imini district, situated south of the Marrakech High Atlas (Fig. 1B). This region is located at the intersection between the Variscan fold-and-thrust belt of the Anti-Atlas, the uplifted Panafrican basement of the Marrakech High Atlas, the Neogene Siroua (or Sirwa) volcano and the Ouarzazate basin (Saddiqi et al., 2011) (Fig. 1B). The area is well known for its economic manganese ore deposit (Pouit, 1964; Gutzmer et al., 2006; Dekoninck et al., 2015), but has not been thoroughly investigated from a structural point of view (Moret, 1931; Pouit, 1964; Errarhaoui, 1998; Missenard et al., 2007), maybe due to its low grade deformation: one observes a monoclinal Cretaceous–Tertiary plateau (Imini plateau Fig. 2) slightly inclined toward the south and limited to the north by the South Atlas Front (SAF, Fig. 1B). The main outcropping feature is the N90° Imini anticline (Fig. 2) which has an Ordovician shale core and which is surrounded by an apparently poorly deformed plateau of Meso-Cenozoic sedimentary rocks (Fig. 2).

In this study, we present a structural analysis of the Imini district combining fieldwork and elevation maps of the Cenomanian–Turonian layer (CT layer), which is the most prominent benchmark of the region. This new data reveals that the tectonic history in the Atlas of Morocco is more complex than elsewhere in the Maghreb with the occurrence of three distinct Cenozoic tectonic events, separated by apparent quiescent phases. The peculiar position of the Moroccan Atlas with respect to the rest of the Atlas belt in the Maghreb is then discussed in the light of these results.

2. Geological setting

2.1. High Atlas – South Atlas Front

The Triassic–Liassic rifting events are linked to the opening of the Neo-Tethys and Atlantic oceans (Medina, 1991; Le Roy et al., 1997; Hafid et al., 2006; El Arabi et al., 2003, 2006; El Arabi, 2007). In Morocco, the basins are filled by Triassic red coarse clastic sediments, interbedded with evaporitic levels and basaltic flows. Deposition of massive quantities of carbonates occurred during Early to Middle Jurassic (Choubert and Faure-Muret, 1960–1962; Jacobshagen et al., 1988; Jabour et al., 2004; Laville et al., 2004 and references therein for the Atlas rifting). The Bathonian–Barremian interval corresponds to the deposition of continental red beds probably over the whole of Morocco (Faure-Muret and Choubert, 1971; Charrière et al., 1994, 2005; Haddoumi et al., 2008, 2010). In contrast, the Cenomanian–Turonian shows a major transgression over north-west Africa with the extensive deposition of shallow water carbonates (Zouhri et al., 2008 and references therein). The Coniacian to Paleocene period is dominated by continental influences including evaporitic redbed deposits (Wurster and Stets, 1992; Ennslin, 1992; Charrière, 1996; Charrière et al., 1998; Ettachfini et al., 2005; Haddoumi et al., 2008; Saddiqi et al., 2011). The end of the Cretaceous and Cenozoic periods corresponds to the beginning of the orogenic processes, linked to the Africa–Eurasia convergence. The timing of this inversion is still highly debated between two main models: a single phase or a two step orogeny.

There is a consensus that the Atlas system in Morocco (Fig. 1A) mainly results from the Cenozoic inversion of the Triassic–Jurassic basins described above (Mattauer et al., 1977; Dewey et al., 1989; Frizon de Lamotte et al., 2000; Hafid et al., 2006; El Arabi, 2007). The role of a Mesozoic transpressional event was suggested by some authors (Piqué et al., 2002; Laville et al., 2004), but has been discarded on the basis of field and seismic profile evidence (Frizon de Lamotte et al., 2008, and reference therein; Saddiqi et al., 2011). The high elevation of the belt, particularly in its western part, results from the influence of an upper mantle anomaly at the time of the convergence between Africa and Europe (Teixell et al., 2005; Zeyen et al., 2005; Missenard et al., 2006; Fullea et al., 2007).

The orogen is bounded to the south by the South Atlas Front (SAF), a crustal scale fault partly superimposed on older Variscan faults on its western part (the Tizi n'Test fault zone, see Proust et al., 1977; Ounaimi and Petit, 1992; Qarbous et al., 2003, 2008; Michard et al., 2008). The SAF was probably the main southern boundary of the Mesozoic rift, likely controlling the Mesozoic sedimentation, as witnessed by the small thickness and extension of