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Thick-skinned tectonics in a Late Cretaceous-Neogene intracontinental belt (High Atlas Mountains, Morocco): The flat-ramp fault control on basement shortening and cover folding

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ABSTRACT

Most of the structural studies of the intracontinental High Atlas belt of Morocco have dealt with the central part of the belt, whose basement does not crop out. Here we study the Alpine deformation of the North Subatlas Zone, which is the part of the Western High Atlas (WHA) Paleozoic Massif that involves both Paleozoic basement units and remnants of their Mesozoic-Cenozoic cover formations. Our aim is to better constrain the geometry and kinematics of the basement faults during the Alpine shortening. Based on detail mapping, satellite imagery and field observations, we describe an array of sub-equatorial, transverse and oblique faults between the WHA Axial Zone and the Haouz Neogene basin. They define a mosaic of basement blocks pushed upon one another and upon the Haouz basement along the North Atlas Fault (NAF). The Axial Zone makes up the hanging-wall of the Adassil-Medinet Fault (AMF) south of this mosaic. The faults generally presents flat-ramp-flat geometry linked to the activation of multiple décollement levels, either within the basement where its foliation is subhorizontal or within favourable cover formations (Jurassic evaporites, Lower Cretaceous silty red beds, Upper Cretaceous evaporitic marls, Neogene basal argillites). The occurrence of the North Atlas detachment (NAD) allowed folded pop-up units to develop in front of the propagating NAF. Shortening began as early as the Campanian-Maastrichtian along the AMF. The direction of the maximum horizontal stress rotated from NNE-SSW to NNW-SSE from the Maastrichtian-Paleocene to the Neogene. The amount of shortening reaches 20% in the Azegour transect. This compares with the shortening amount published for the central-eastern High Atlas, suggesting that similar structures characterize the Paleozoic basement all along the belt. The WHA thick-skinned tectonics evokes that of the frontal Sevier belt and of the external Western Alps, although with a much minor pre-inversion burial.

1. Introduction

The 2000 km-long Atlas System extends from the Atlantic coast of Morocco to Tunisia (Fig. 1A). This Mesozoic-Cenozoic orogenic system includes intracontinental, double-verging fold belts and tabular, rhomboidal “mesetas” or plateaus. The Atlas System is overthrust in the north by the Alpine-type Maghrebide belt (Rif-Tell-Kabylias), and bounded in the south by the Sahara Platform. Morocco has the highest segment of the Atlas System, i.e., the High Atlas, whose most scenic part is the Marrakech High Atlas (MHA, Fig. 1B), which includes the highest peak of North Africa (Jebel Toubkal, 4167 m a.s.l.). The area attracted the earliest geological study ever performed in Morocco and published in 1878 (see historical review by Missenard et al., 2008). The intracontinental

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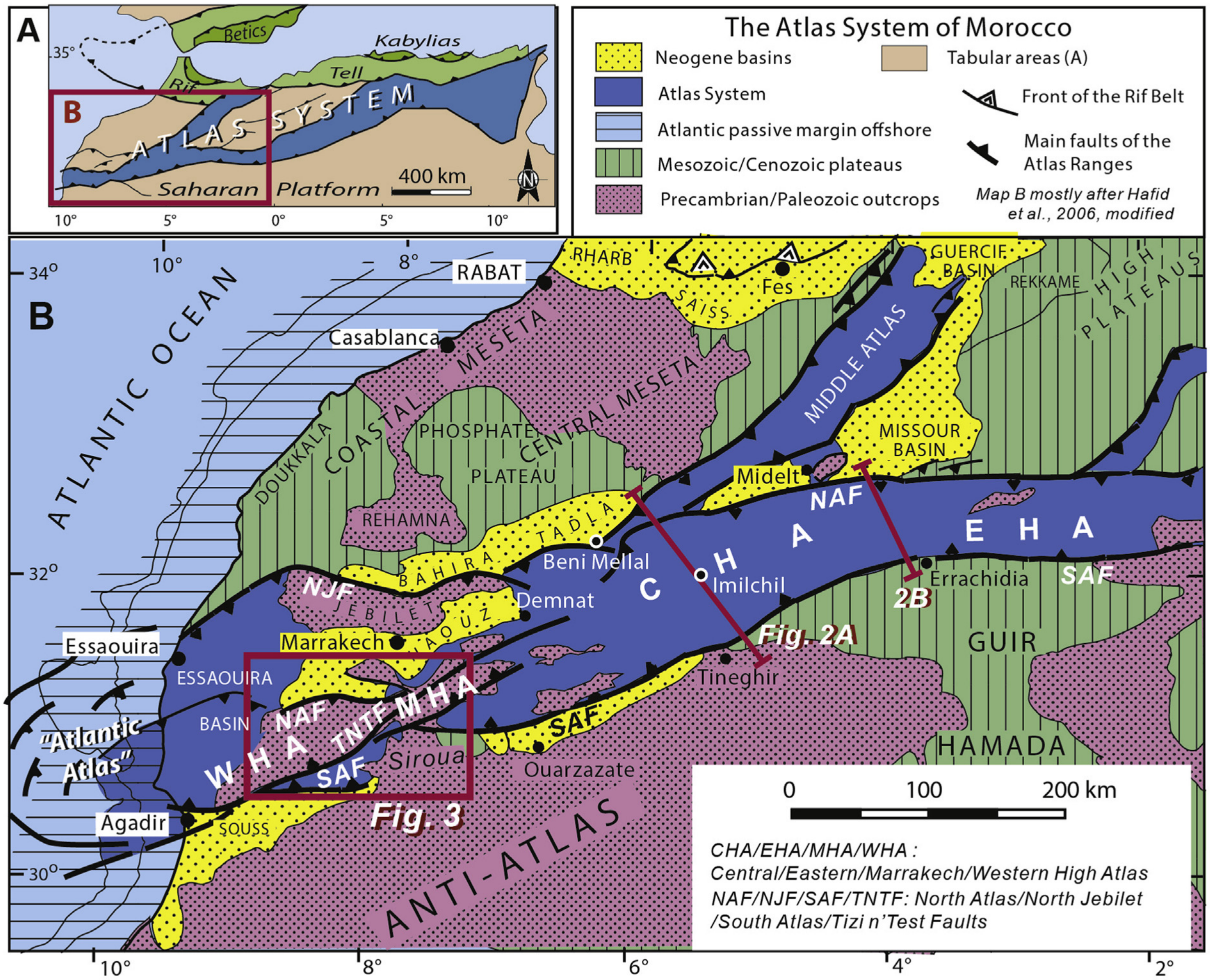

Fig. 1. A: The Atlas System of North Africa (after Frizon de Lamotte et al., 2008; 2011). B: The Atlas System of Morocco, after Hafid et al. (2006) and Benabdellouahed et al. (2017), modified, with location of Figs. 2A and B, 3.

nature of the belt and its recent, Alpine age were progressively established during the 20th century (Gentil, 1912; Moret, 1931; Roch, 1950; Choubert and Faure-Muret, 1960-62; Mattauer et al., 1977). The Atlas System is currently seen as the result of the Cenozoic inversion of a Mesozoic rift system extending on the North-African crust south of the Alpine Tethys domain in the framework of the Africa-Europe convergence (e.g. Giese and Jacobshagen, 1992; Poisson et al., 1998; Beauchamp et al., 1999; Frizon de Lamotte et al., 2000, 2004, 2008, 2011; Ayarza et al., 2005; Ellero et al., 2012; Domènech et al., 2015, 2016).

In recent years, the most debated issues about the High Atlas have concerned orogenic timing and shortening estimate. The hypothesis of a Jurassic shortening event in transpressive conditions (Mattauer et al., 1977; Laville and Harmand, 1982) was reaffirmed by Laville and Piqué (1992), but discarded by Gomez et al. (1998, 2000, 2002) and Frizon de Lamotte et al. (2000, 2008). The latter authors show that compressional deformation began essentially during the Late Eocene on the basis of stratigraphic and seismic studies performed north and south of the belt in Morocco and Algeria (Morel et al., 1999; El Harfi et al., 2001; Bracène and Frizon de Lamotte, 2002). Part of the pre-Cenozoic deformations observed in the Central High Atlas (CHA, Fig. 1B) are also accounted for by diapiric phenomena (Ettaki et al., Michard et al., 2011; Saura et al., 2014; Teixell et al., 2017). However, Froitzheim (1984) and Froitzheim et al. (1988) described compelling evidence of Upper Cretaceous compressional event in the Paleozoic massif of the Western High Atlas (WHA), a fact poorly taken into account up to now and that we revisit in this paper.

On the other hand, shortening of the High Atlas was firstly regarded as almost null or very limited. The deep structure of the belt was described in terms of vertical faults inherited from Hercynian structures (Schaer, 1964, 1987) or in terms of steeply dipping faults originating from the inversion of the Triassic rift paleofaults (Stets and Wurster, 1982; Froitzheim et al., 1988). A wide-angle seismic refraction profile across the CHA (Wigger et al., 1992) allowed Giese and Jacobshagen (1992) to propose a significant thickening of the Atlas crust after its thinning during the rifting stage. Interpretations involving moderately to shallow-dipping reverse faults beneath the whole belt have been proposed by Poisson et al. (1998) (Fig. 2A) and Errarhaoui (1998) in the CHA and MHA segments of the belt, respectively. Based on a balanced geological cross-section of the CHA, and taking into account overthrusting at its margins, Beauchamp et al. (1999) nearly tripled the accepted 10% magnitude of horizontal shortening of the belt. They emphasized that thin-skinned tectonics along the belt margins was necessarily linked to thick-skinned tectonics in its axis, but were not able to described the actual geometry of the basement faults due to lack of basement outcrops in the area. Teixell et al. (2003) calculated that total shortening across the CHA would vary from 26 km (24%) to 13 km (15%) from east to west. They concluded that