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Stress field variations along the Maghreb region derived from inversion of major seismic crisis fault plane solutions

Farida Ousadou [a,*], Louis Dorbath [b], Abdelhakim Ayadi [a], Catherine Dorbath [b,c], Sofiane Gharbi [a]

[a] Centre de Recherche en Astronomie Astrophysique et Géophysique (CRAAG), Bouzareah, 16340 Alger, Algérie
[b] Ecole et Observatoire des Sciences de la Terre, Université de Strasbourg, 5, rue Descartes, 67084 Strasbourg Cedex, France
[c] Institut de Recherches pour le Développement, UR234 (GET), Toulouse, France

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ABSTRACT

This study is devoted to the analysis of the stress state along the Maghreb region based on the inversion of focal solutions. We have inverted the main shock and aftershock focal mechanisms of the strongest seismic events that occurred in five seismogenic zones, from west to east: Al Hoceima (2004), Cheliff (1980), Tipasa–Chenoua (1989), Zemmouri (2003) and Constantine (1985). Most of the focal mechanisms of the aftershock sequences have been constructed within this study. Compressive stress regime is observed in the central part of Algeria between Cheliff and Zemmouri. On both edges of the Maghreb region, the stress regime becomes strike-slip in the Constantine region and in the Moroccan Rift. These different regimes seem to be linked to the free-edge effect (Ionian slab subduction) and to the dynamics of the Alboran Sea in the eastern and western parts of the study area respectively. The σ1 directions experience an anticlockwise rotation of about 20° from eastern to central Algeria. We observe that the direction of σ1 and the direction of convergence are the closest in central Algeria, where the collision is not perturbed by edge effect.

1. Introduction

The continental tectonic deformation observed along the Ibero-Maghreb region is the expression of the convergence since the Cretaceous between the Eurasia and Africa plates (Le Pichon et al., 1988). The boundary between the two last plates is well delimited from the Azores triple junction to the strait of Gibraltar. To the east, the boundary becomes more diffused and forms a larger region of complex deformation (Buforn et al., 2004). The Maghreb area is part of this diffuse boundary and consequently displays a complex pattern of active deformation, which is partly taken up seismically. Deep basins and fault-and-thrust belts characterize the morphology of this area.

The main tectonic domain in the Maghreb region is the Atlas Mountains, consisting of the Moroccan Middle and High Atlas, the Algerian Sahara and Tellian Atlas and the Tunisian Atlas, which were uplifted during the Cenozoic (Fig. 1). To explain the complex tectonics of this region, based on the spatial distribution of seismicity, several authors have suggested the existence of several micro-plates and relative motion between them (Anderson and Jackson, 1987; Dewey et al., 1989; McKenzie, 1972; Sengör and Canitez, 1982). The kinematic of the Africa and Eurasia plates defined by the position of rotation poles and the angular velocities have been determined using slip vectors of large earthquakes, sea floor spreading rates and transform fault trends (Anderson, 1985; Argus et al., 1989; DeMetz et al., 1990, 1994; McKenzie, 1972; Minster and Jordan, 1978). More recently, GPS data were added to the same information (McClusky et al., 2003; Nocquet, 2012; Nocquet and Calais, 2004; Sella et al., 2002; Serpelloni et al., 2007). As a conclusion, all these studies indicate that these poles are situated in the central Atlantic, however, with large discrepancies in the latitude, from 20°N to 20°S. Along the plate boundary, from Tunisia to Gibraltar, the convergence direction presents an anti-clockwise rotation and the velocity decreases.

The general stress pattern shows extension in the Azores region, right-lateral strike slip motion in the Gibraltar strait and Alboran Sea, and compression in the Maghreb Area (Buforn et al., 2004). More recently, de Vicente et al. (2008) performed an active stress inversion around and within the Iberian peninsula. They concluded that from the Terceira Ridge to the Gulf of Cadiz, the stress progressively changes from triaxial extension to uniaxial compression while in the Betics–Alboran–Rift zone and in northern Algeria uniaxial extension and uniaxial compression respectively predominate.

The recent seismic activity gives us the opportunity to determine the stress field in the Maghreb region more accurately. In this work, we present results obtained from the inversion of the focal mechanism of the 5 strongest seismic events that occurred in the region and their aftershocks during the time span of 1980–2004. These are the only earthquakes that were the object of aftershock studies conducted with a dense network of seismic stations that allow a precise determination of the focal mechanisms. The selected events are those of El Asnam 1980, Ms 7.3; Constantine 1985, Ms 6.0; Chenoua–

* Corresponding author.
E-mail addresses: f.ousadou@craag.dz, f.ousadou@gmail.com (F. Ousadou).

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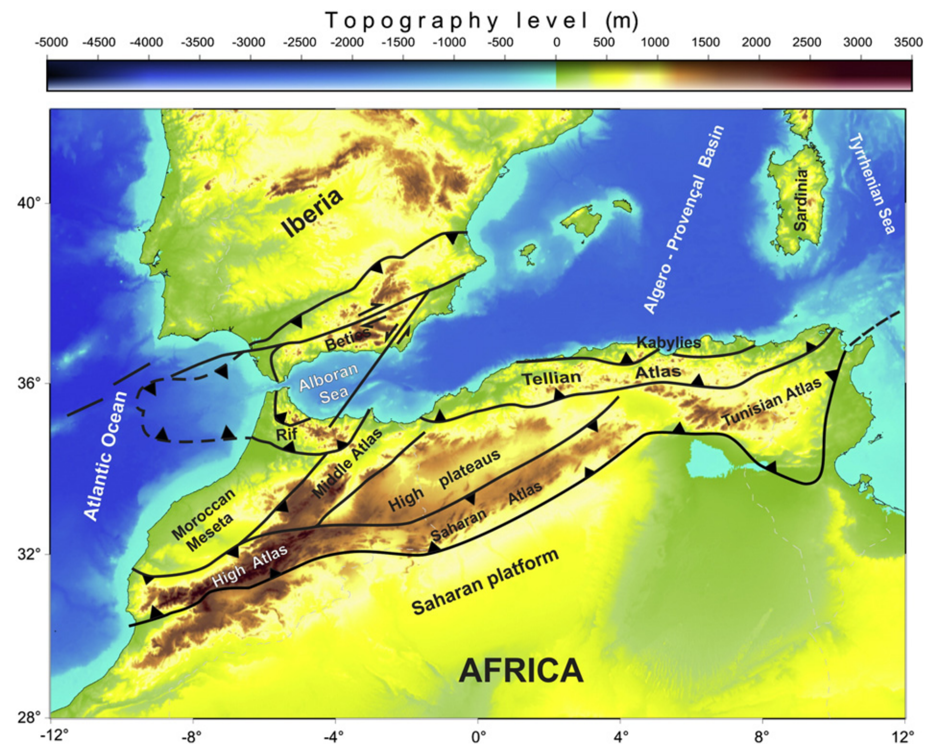

Fig. 1. Main tectonic domain in the Ibero Maghrebian region.

Tipasa 1989, Ms 5.8; Zemmouri 2003, Mw 6.8 and Al Hoceima 2004, Mw 6.4.

2. Tectonic setting and seismicity

During the Mesozoic and Cenozoic periods, the Mediterranean region experienced, complex tectonic events and associated collisions that resulted in mountain building, plateau formation, foreland and hinterland deformation, foreland flexure and sedimentary basin evolution (Dilek, 2006). The Maghreb region is commonly divided into specific structural domains: the Atlas Mountains, the High Plateau rigid cores and the Tell–Rif system bordering the Mediterranean Sea (Fig. 1). The Atlas Mountain system (comprising the Middle Atlas and High Moroccan Atlas, the Saharan Atlas in western Algeria, the Aurès in eastern Algeria, and the Tunisian Atlas) was uplifted during the Cenozoic under the N–S stress regime induced by African and Eurasian plate convergence (Frizon de Lamotte et al., 2000).

In Morocco, the South Atlas front follows, in a certain way, the southern boundary of the Mesozoic Atlas basin, whereas in Algeria the South Atlas front cuts across the basin. The Rif Mountain belt, where the main

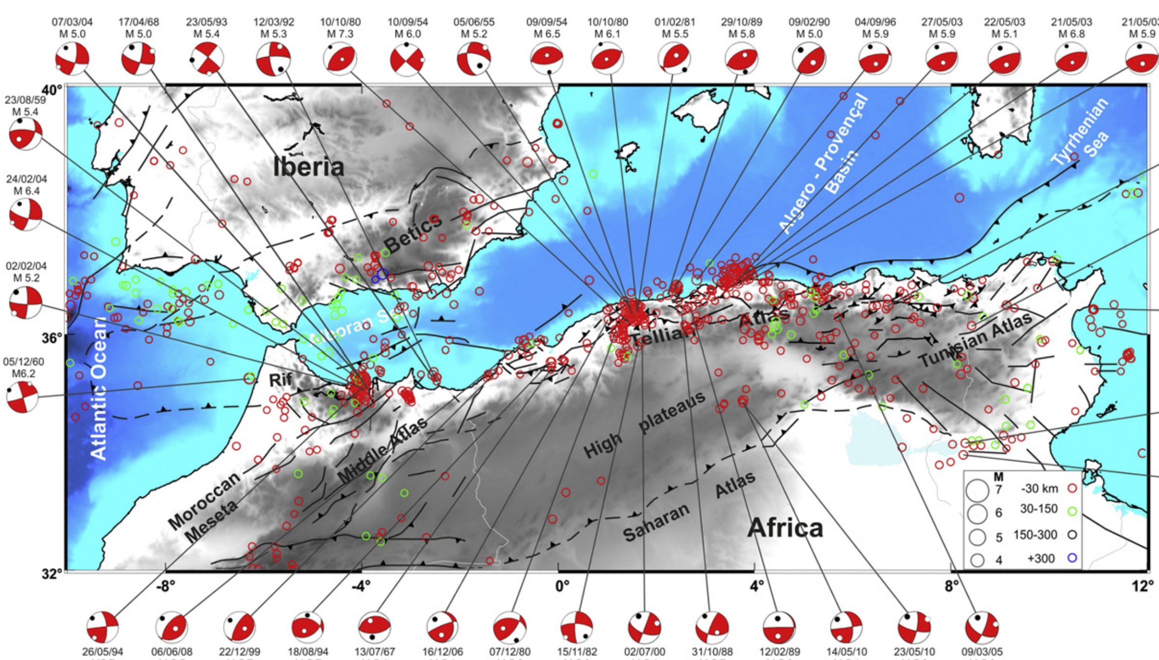

Fig. 2. Ibero Maghrebian tectonic (Morelli and Barrier, 2004). Seismicity with M ≥ 4 (NEIC database from 1973 to 2012), color-coded with respect to the epicenter depth. Focal solutions for events with M > 5.0 (Harvard database).