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Study of relief changes related to active doming in the eastern Moroccan Rif (Morocco) using geomorphological indices

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ABSTRACT

This work studies the influence of active tectonics in the drainage networks and topography of the eastern Rif belt, eastern Middle Atlas, and Rekkame high plateau. We have performed a trend-topographic surface analysis at small to medium scales, several landscape analyses at medium scale, and the slope analysis of the relief. Furthermore, we have determined several geomorphic indices in the drainage networks of the study area: hypsometric curve analysis and normalised stream-length gradient (SLk) estimations. The trend-topography surface analysis identifies a NE–SW trending undulation that correspond to the positive topography of the Middle and High Atlas mountain ranges and the Rekkame high plateau as well as an E–W elongated dome in the eastern Rif-Beni Snassen massif. The geomorphologic indices indicate that drainage network is strongly deformed in the vicinity of the Trougout-Nekor active fault system. Furthermore, the Oued Molouya catchment is deformed in the northern limit of the Beni Snassen massif by active deformations accommodating a roughly N–S shortening. According to the available geochronological data from volcanic rocks as well as from Neogene to Quaternary sediments, the most likely age for the deformation of the drainage network producing the anomalous high geomorphic indexes was Placenzian to Present.

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1. Introduction

The drainage networks of fluvial systems in tectonically active regions are very sensitive to active processes producing regional uplift, with responses of river incision. However, other processes such as stream piracy, base-level lowering, and climatic episodes may also be responsible for accelerated river incisions (e.g., Hancock and Anderson, 2002; Starkel, 2003; Pérez-Peña et al., 2010; Barbero et al., 2011). Moreover, drainage networks can also be sensitive to differential uplifts produced by active tectonic structures such as folds and faults generating differential river incision, asymmetries in catchments, and river diversions, among other effects (e.g., Cox, 1994; Jackson et al., 1998; Clark et al., 2004; Salvany, 2004; Schoenbohm et al., 2004; Pérez-Peña et al., 2010).

The boundary between the Eurasian and African plates is a broad band of deformation and strain partitioning including both oceanic and continental lithospheres (e.g., Udías and Buforn, 1991; Buforn et al., 1995; Stich et al., 2003). The boundary also includes the westernmost extreme of the Mediterranean Alpine chains the orogenic arc defined by the Betic chain to the north and the Rif belt to the south (e.g., Balanyá and García-Dueñas, 1987; Platt et al., 2013) (Fig. 1).

The Betic-Rif orogen developed while the African and Eurasian plates converged (e.g., Jolivet et al., 2003; Chalouan and Michard, 2004). At present-day, the relative velocities between both plates determined by GPS (see McClusky et al., 2003; Vernant et al., 2010) and estimated (Model NUVEL 1A; DeMets et al., 1994) indicate a convergence with roughly WNW–ESE trends and ~5 mm yr^{-1} (Fig. 1) average velocities. Furthermore, the GPS studies indicate that the Western and Central Rif belt is now moving independently at around 4–6 mm yr^{-1} towards the WSW with respect of the stable Africa (Vernant et al., 2010) (Fig. 2).

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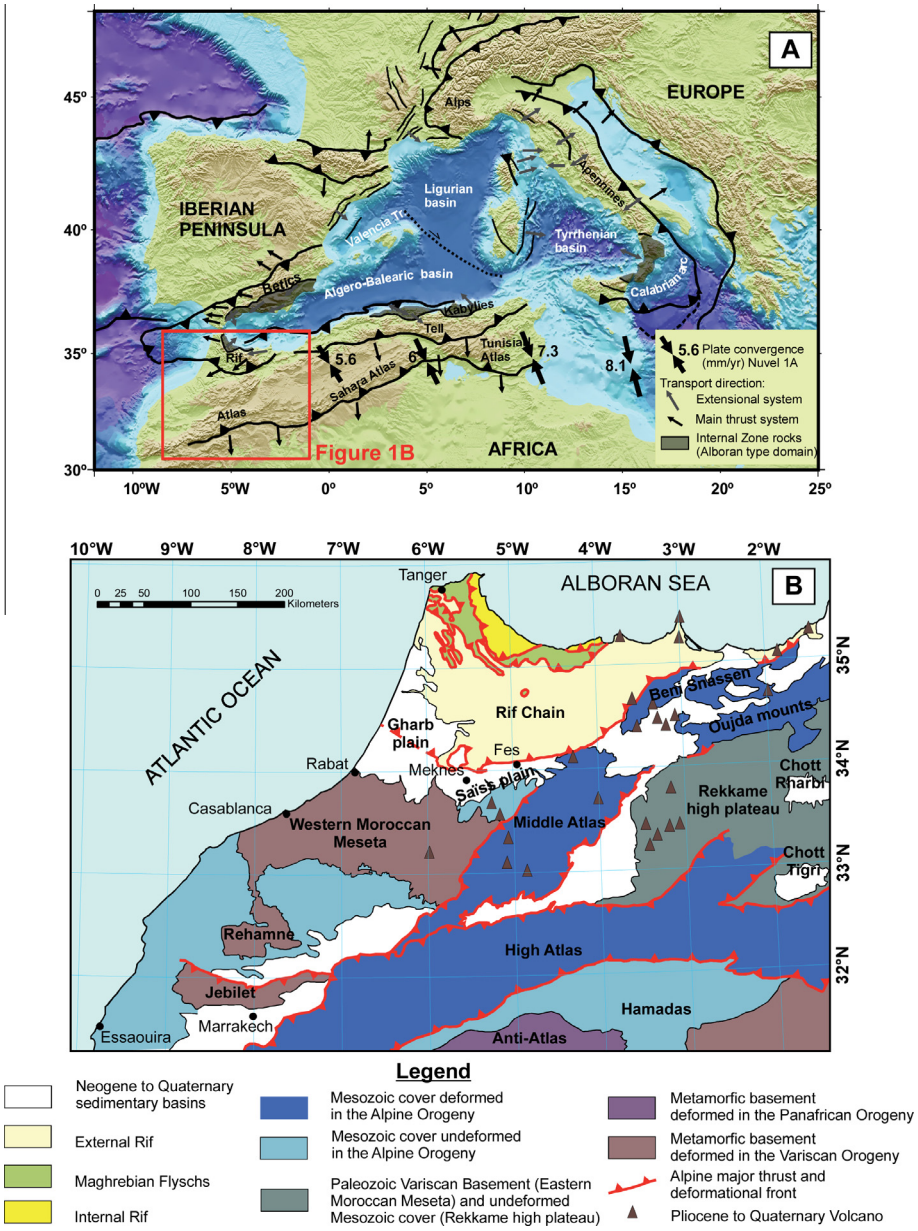

Fig. 1. (A) Geological sketch of the Western Mediterranean area with the present-day relative velocities between the African and European plates estimated by Model NUVEL 1A (DeMets et al., 1994). The red square marks the location of (B). (B) Tectonic sketch of the Alpine mountain ranges in northwestern Africa. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

The active structures in the Rif belt include the Nekor sinistral strike-slip fault (Asebriy et al., 1993; Galindo-Zaldívar et al., 2009) and its prolongation into the Trougout sinistral–normal fault (Poujol et al., 2014). The latter authors indicate that the Trougout-Nekor transtensional active system accommodates most of the present-day movement between the movable Western and Central Rif and the eastern Rif area. Another active structures are the active thrust faults and folds in the front of the Rif orogen (Bargach et al., 2004; Chalouan et al., 2014), that can accommodate most of the convergence between the Western and Central Rif and the foreland represented by the Western Moroccan Meseta. However, there are few geomorphological studies that can help to characterise the drainage network of the northwestern African continent and how they are influenced by the previously mentioned recent tectonic activity in the area.

The main aim of this paper is to determine the influence of tectonic activity in the drainage networks of the eastern Rif belt through superficial topographic changes. In order to do so, we will determine different geomorphological indices using ArcGIS, such as hypsometric curves, longitudinal river profiles, basin morphology, and variations in slopes. This work is the first study on landscape analysis in the eastern Rif area, and will help to determine the most deformed catchments and to establish the basis for future detailed studies.

2. Geological setting

The geology of eastern Morocco includes, from south to north: (1) the Saharian *Hamadas* (high mesetas with average elevations around 1000 m) formed by Mesozoic cover undeformed in the Alpine Orogeny that overlay the slightly deformed Palaeozoic successions of a Variscan foreland belt, which, in turn, cover the Precambrian Pan-African basement cropping out in the Anti-Atlas mountain range (that can reach average elevations 1800 m), (2) the High Atlas (with mean elevations of around 2600 m) and Middle Atlas (average elevations of over 2000 m) Alpine intracontinental

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