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Evidence for surface uplift of the Atlas Mountains and the surrounding peripheral plateaux: Combining apatite fission-track results and geomorphic indicators in the Western Moroccan Meseta (coastal Variscan Paleozoic basement)

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ABSTRACT

This work represents an initial attempt to link the evolution of the topography in relation to the general tectonic framework of western Morocco. For this purpose, in a section of the Western Moroccan Meseta different tools are combined in order to attain the general objective. Apatite fission-track (AFT) data of granitic rocks of the Rabat–Khenifra area give ages around 200 Ma with track length distributions which are compatible with the thermal models already established for the area. An inverse correlation between AFT ages and elevation is observed which is compatible with previous models indicating northward tilting of the whole Western Moroccan Meseta which is younger than 20–25 Ma. In order to test this possibility a detailed analysis of the topography at different scales in the Western Moroccan Meseta has been performed. Results indicate that two open folds with different amplitudes are recognized and that the one with wider wavelength could correspond to a lithospheric fold as previously stated by other authors on the basis of independent geological arguments. The northward tilting proposed based on the AFT data agrees with the results obtained in the analysis of the topography which reinforces the presence of a very open fold with a wavelength of 200–300 km in the north-western limb of the Western Moroccan Meseta.

1. Introduction

The northern part of Morocco comprises the Atlas mountains and several mesetas with a flat morphology. All of them constitute the foreland of the Alpine Rif–Tell orogen, located at the southern margin of the Western Mediterranean (Fig. 1).

The Atlas is a linear mountain belt trending SW–NE which in its central part is divided into two branches: the so-called Middle Atlas which follows a SSW–NNE direction and the High Atlas trending approximately E–W. The Atlas can be considered as a typical intracontinental orogen (Laville, 1985) related to the far-field effects of the NW–SE movement of the European plate with respect to the African plate (Teixell et al., 2008). For these authors, the evolution and chronology of the Atlas is relatively independent of the evolution of the Rif–Tell orogen. The so-called Anti-Atlas, located southwards of the Atlas, represents an extensive massif with a characteristic topography not characterized by high elevations in comparison to the High Atlas and related to scarce Alpine activity.

The Western Moroccan Meseta has a central part with reliefs higher than 1600 m. Fullea-Urchulutegui et al. (2006) performed a model of the crustal and lithospheric thicknesses in Morocco that indicates a relatively thin crust below the Moroccan Meseta (around 26–28 km) and a crustal thickening increasing up to 38 km below the highest parts of the High Atlas. Recent studies demonstrate that the High Atlas crustal root is not thick enough to isostatically explain the high topography of this mountain range (Teixell et al., 2003; Teixell et al., 2005; Zeyen et al. 2005; Ayarza et al., 2005; Missenard et al., 2006; Fullea et al., 2007). These studies propose that a NE–SW trending uplift of the asthenosphere below the Western High Atlas, central Anti-Atlas and Middle Atlas exists, and that thermal doming accounts for the elevation of the area, in addition to the moderate shortening and crustal thickening (Zeyen et al., 2005; Teixell et al., 2005; Ayarza et al., 2005; Missenard et al., 2006; Fullea et al., 2007). Also, this model explains the presence of alkaline magmatism coeval with the main compression event, and the scarce sedimentary record found in the small foreland basins to the north and south of the Atlasic system.

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Recently, Babault et al. (2008) have demonstrated that the Atlas Mountains have been uplifted by two mechanisms: Cenozoic thickening of the crust and thinning of the mantle lithosphere due to a buoyant thermal anomaly. This rising of the asthenosphere has been inferred, by indirect criteria, to have started around 15 Ma. The indirect geological evidences are the presence of elevated marine sediments, tilted paleohorizontal markers, and drainage-network reorganization in the southern margin of the Saïss Basin and the northern middle Atlas regions (Figs. 1 and 2). Moreover, in a recent paper Ghorbal et al. (2008) documented unexpected stages of subsidence and exhumation affecting the whole Moroccan Meseta from the Jurassic to Tertiary and this is challenging the traditional stability of NW Africa (Michard, 1976; Michard et al., 1989; Guiraud et al., 2005).

In this context, the relief of the Western Moroccan Meseta and its evolution has not been studied in depth. The main aim of this work is to analyze of Neogene–Quaternary landscape evolution, and we present here two different approaches that indicate that this relief is recent and active. We present here new apatite fission-track data from apatites recovered in granitoids from the Western Moroccan Meseta in a cross section from Rabat to Khenifra (Fig. 2). Moreover, the present-day topography is studied by the combination of a trend-topographic surface analysis (large scale) and a hypsometric analysis of its drainage network (medium scale). All these data combined help to determine the recent evolution of the Western Moroccan Meseta and to assess the presence of active folding within the area.

2. Geological setting, topography and geomorphic indicators

Between the Rifean orogen and the Atlas chain, several massifs of metamorphic and granitic rocks of Palaeozoic age are found. They constitute the massifs of Rehamna, Jebilet and the Western and Eastern Moroccan Mesetas (Figs. 1 and 2). Ait Brahim et al. (2002) made a study on the tectonic evolution of the North African margin from late Paleozoic to present based on paleo-stress data. They conclude that the evolution of north Morocco is characterized by a NW–SE to NE–SW extensional period from late Triassic until Early Cretaceous related to the opening of the Atlasic and Atlantic rift systems. From the Late Cretaceous to Late Paleocene, a compressional regime with E–W to WNW–ESE directions evidenced by the presence of strike–slip faults in the northwestern part of the Atlas Mountains is recognized. This compressional event continued during the Eocene but following an N–S direction as evidenced by the presence of inverse faults and folds in the Atlasic areas. From the Oligocene to Middle Miocene, the compression continued but changing to NE–SW trends in relation with the continuous collision between the African and European plates.

The Moroccan Meseta is composed by two main outcrops of Paleozoic rocks deformed during the Variscan orogeny; the Western and the Eastern Meseta, separated by the Middle Atlas Alpine chain. The Western Meseta (WM) presents a general low relief that increases eastwards from the seal level up to 1600 m of altitude in its central part.

The southern limit of the WM corresponds to the northern flank of a very open synform formed by Middle Cretaceous to Paleogene deposits that unconformably cover Paleozoic rocks. The southern limb of this synform includes detritic red facies from the Late Jurassic to Early Cretaceous. Southwards from this synform the Paleozoic rocks crop out again in the so-called Rehamna region. The western limit of the WM is a group of Paleozoic outcrops known as the Coastal Block that is covered by thin Quaternary deposits of coastal terraces and dunes. Towards the north, the WM lose elevation and the Paleozoic rocks are unconformably covered by the Neogene to Holocene deposits of the Gharb plain. This plain, together with the Saïs plain, constitutes the foreland basin of the Rif system and it is deformed in the area of the Volubilis basin by very recent thrusts as a continuation of the Rif deformational front (Bargach et al., 2004).

The Paleozoic rocks of the WM, Rehamna region, and Coastal Block include mainly siliciclastic rock (shales and quartzites) with small intercalations of sedimentary carbonatic rocks and basalts. This sequence presents ages ranging from Early Cambrian to Early Permian, and it was deformed essentially during the Westphalian–Stephanian times (320 to 290 Ma, El Hadi et al., 2006, and references therein). Late Carboniferous to Early Permian rhyolites filling dykes or as lava levels outcrop near the Middle Atlas deformational front, in the surroundings of the locality of Khenifra. The top of this Paleozoic sequence is formed by detritic rocks with red beds facies of Permian ages present in some outcrops within the WM.

The Coastal block is characterized by weak Variscan deformation and is limited eastwards by a narrow fault zone that dips towards the east and that is known as the West Meseta Shear Zone (WMSZ in Figs. 2 and 9B) (i.e. Hoepffner et al. 2005; Michard et al., 2008). In the central part of the WM, outcrops the hanging wall of the West Meseta Shear Zone called the Central Meseta Block. This Central Meseta Block is characterized by strong Variscan shortening accommodated by thrusts, SE-vergent folds and internal deformation. The thrusts dip towards the southeast and the most important ones are the Smaala–Oulmez Fault Zone (SOFZ in Figs. 2 and 9) and the Tizi n'Tretten Fault (TTF in Figs. 2 and 9B) (i.e. Hoepffner et al. 2005; Michard et al., 2008). This later thrust has as hanging wall the Nappe Zone, formed by several thrust units. Towards the east, the Nappe Zone is separated from the Eastern Meseta by an NNE–SSW striking fault zone that dips towards the SSE called the Tazekka–Bsabis–Bekrit fault zone (TBBFZ in Figs. 2 and 9B) (i.e. Hoepffner et al. 2005; Michard et al., 2008). The Eastern Meseta is characterized by lower and middle Paleozoic deformed by eovariscan events and small carboniferous basins with calcalkaline volcanism (i.e. Hoepffner et al. 2005; Michard et al., 2008).

Near Rabat, outcrops the Sehoul Block that is an allochthonous terrane deformed during the Caledonian orogeny (i.e. Hoepffner et al. 2005; Michard et al., 2008). This allochthonous terrane thrust over the Central Meseta Block and below the main thrust surface outcrops a thin unit in the Tiflet area composed by the Proterozoic basement of the Central Meseta block (Tahiri et al., 2009).

There are several granite bodies that intrude this Paleozoic sequence. In the WM can be recognized three larges bodies that correspond to the batholites of Zaër, Oulmès, and Ment (Fig. 2). These granite bodies are biotite granodiorites to two micas monzogranites (Mahmood and Bennani, 1983). In the Rehamna region there is also the Rehamna Batholit formed by monzogranites and leucogranites. The ages for the WM granites obtained by Rb–Sr range between 330 to 260 Ma, however, U–Pb ages in zircons and monazites indicate ages between the 315 ± 9 Ma to 291 ± 16 Ma for the Zaër granite (Chèvromont et al., 2001), and between 308 ± 8 Ma to 296.2 ± 2.9 Ma for the Oulmès granitic body (Baudin et al., 2001), while the Ment granite lacks U–Pb ages for the moment.

Apart of these three large bodies, there are also several small bodies with generally less than 1 km^2 in the Tiflet area and the Sehoul Block. The studied samples (samples BJE and TA) are only from the two Tiflet granitoid bodies (namely Taïcha: TA, and Bou Jemaa, BJE, Tahiri et al., 2009), as those of the Sehoul block are much fractured and their apatites were not suitable for fission tracks. The zircons of these samples have been recently dated by Laser Ablation-ICPMS analyses (Tahiri et al., 2009) and yield a mean U–Pb age of 606 ± 6 Ma for the sample TA from Taïcha body, and a mean U–Pb age of 605 ± 4 Ma for the sample BJE of the present study near Rabat. Both granitoids as other from the Tiflet area are Proterozoic granitoids with many features typical of Andean-arc granitoids, with an important crustal component (Tahiri et al., 2009).

Scarce previous thermochronological data on the region have been provided by Ghorbal et al. (2008). They provide one AFT data on the Zäer granitic body with an age of 148 ± 6 Ma with a mean track length