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Ramp folds and fracturing in the Southern Rifian Ridges between autochthonous Atlasic domain and allochthonous formations of the Rif Cordillera (Northern Morocco)

EL HASSANIA HABIBOU[1], NAWAL BOUYA[1], HMIDOU EL OUARDI[1] and ERIC MERCIER[2]

[1]GéoTech groupe, Moulay Ismail University, Faculty of Sciences,
Department of Geology, PB 11201, Zitoune, Meknes, Morocco;
hassania-habibou@hotmail.com; nawal_geol@hotmail.fr; hmidouelouardi@yahoo.fr;
[2]University of Nantes, UMR-6112 du CNRS, Planetology and Geodynamic laboratory,
Nantes, France; eric.mercier@univ-nantes.fr

Abstract

Through geometrical modelling of fold-thrust structures in the Southern Rifian Ridges (Northern Morocco), we propose a new kinematic evolution of the southwestern front of the Rif Cordillera. Our reconstruction implies a generalized detachment within the Triassic evaporites. The Miocene--Pliocene fault-propagation folds were confronted with the theoretical results of kinematic model (Suppe, 1985) as well as the mechanical model (Mercier and Mansy, 1995; Salvini and Storti, 1997), developed above inherited extensional faults. The E–W trending normal faults inherited from Jurassic determine the position of the ramps and folds, whereas the N–S trending faults are reactivated lateral ramps. These compressive structures were reactivated during Plio-Quaternary as a sinistral strike-slip overthrusts. We analysed tectonics of the frontal faults from the southern boundary of the Jebel Zerhoune (20 km north of Meknes). This fault considered by Moratti et al. (2003) as a surface rupture originating due to the earthquake of November 18, 1755, two weeks after the Lisbon earthquake. The structural analysis done on the mirror of this fault shows the calcareous crusts and Quaternary formations bear no trace of friction. Similarly, the axis of principal stresses determined from measurements on the mirrors of this fault indicates a NNE–SSW shortening direction compatible with the regional Plio-Quaternary shortening phase. The Plio-Quaternary limestones of the Saïss basin located on the northern side at the Jebel Aïcha Mouguettaya are verticalized and affected by submeridional vertical faults. The latter are interpreted by Ahmamou and Chalouan (1988) as synsedimentary normal faults due to an extensive Pliocene phase. Previously, Ait Brahim (1983) has considered these fractures as a dextral strike slip faults. Our works in this region, based on analysis of fracturing, show that these faults affect both sub-vertical and tabular limestones. These fractures are mainly concentrated in the surrounding Oudaya diapir and gradually diminish towards the Saïss basin. This geometry corresponds probably to salt tectonics during regional compressive phases.

Key words: modelling, fault-propagation folds, tectonic inversion, microtectonics, South Rifian Ridges, Morocco

Introduction

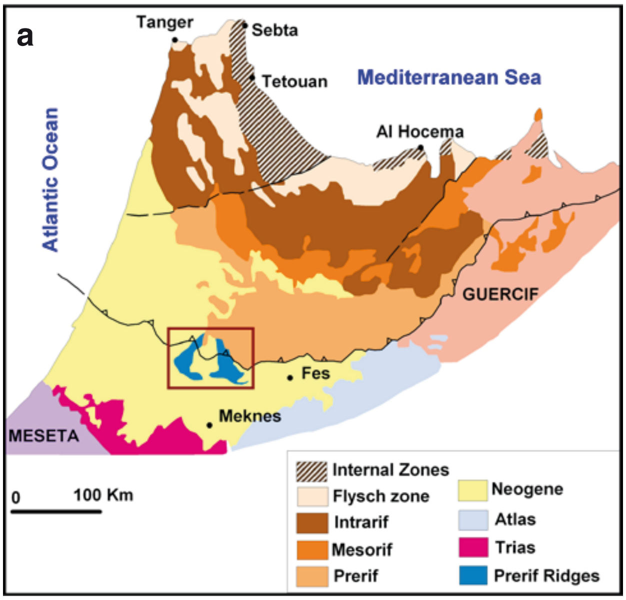
The Neogene deposits of the western part of northern Morocco are often at the periphery of the Rif chain and are well developed in the furrow southern Rif. The Saïss Basin, constituting the middle part of that groove is characterized by thick formations of Neogene, corresponding to the blue marls deposits, sands and lacustrine limestones, directly overlying the Liasic dolomitic limestones.

At the northern edge of Saïss basin, South Rifian ridges form two more or less concentric arcs, forming the most external reliefs of the Rif cordillera. They are formed mainly by Jurassic deposits involving an extensive context related to the Atlantic and Thetyan oceans.

After a long period of emersion, the Mio-Pliocene sedimentation was performed as part of a general compression due to the closure of the Mesogean and the opening of the Mediterranean Sea during the construction of the surrounding Mediterranean Alpine chains.

In previous work, the structural models proposed for the contact between these Ridges and the Saïss Basin the different tectonic setting. Two structural models were presented, one assumes that the ridges overlapping of Saïss basin (Delga Durand et al., 1960–1962; Leblenc, 1986), and the other considers these ridges as a simple monoclinal, with flanks slightly inclined towards the North and the contact with the Saïss basin corresponds to a vertical fault (Vidal and Faugères, 1975; Faugères, 1978).

Through a structural analysis and microtectonics, as well as geological surveys in Jebel Zerhoune and Jebel Aïcha Mouguettaya, we present new observations and we propose a reinterpretation of the northern edge of the Saïss basin and its transition with the front of the Rif chain.



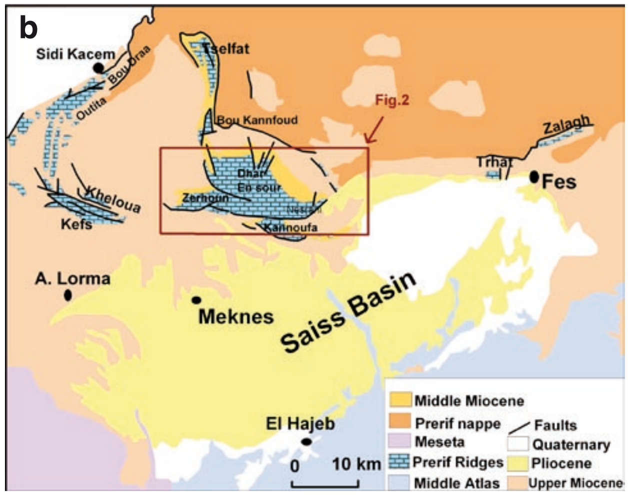


Fig. 1. a – geological map of northern Morocco and location of the study area; **b** – detailed map of the Prerif ridges.

Jebel Zerhoune

The Zerhoune ridge is the principal relief of the Eastern Arc of the Southern Rifian Ridges and forming the transition between the Rif in the north and Saïss basin in the south (Figs. 1 and 2). It corresponds to an E-W anticline interpreted as a fault-propagation fold (Haddaoui, 2000; Sani et al., 2007). The oldest outcrops are Aaleniano--Bajocian, they are overlain by a slight unconformity of Upper Miocene detrital series.

Microtectonic analysis

The work in this Ridge aimed to study the fault front which makes the ridge of Zerhoune in contact with the Saïss basin. The observations were made in two sectors at the western end and in the middle part of this ridge for several reasons. First, because of the outcrop conditions allowing observation, and also because the recent work have focused on the region deserve to be clarified (Moratti et al., 2003; Sani et al., 2007; Chalouan et al., 2007). Indeed, in the west end of the ridge of Zerhoune (Fig. 2 site 1), the E–W trending fault that can be observed along the road Meknes-Moulay Idriss Zerhoune, which crops out as a trench in the same direction. It was considered by Moratti et al. (2003) as a surface rupture due to an earthquake of 18. November 1755. The earthquake, which devastated two cities of Meknes and Fez, occurred few days after the earthquake of 1. November 1755, known as the Lisbon earthquake. Moratti et al. (2003) suppose

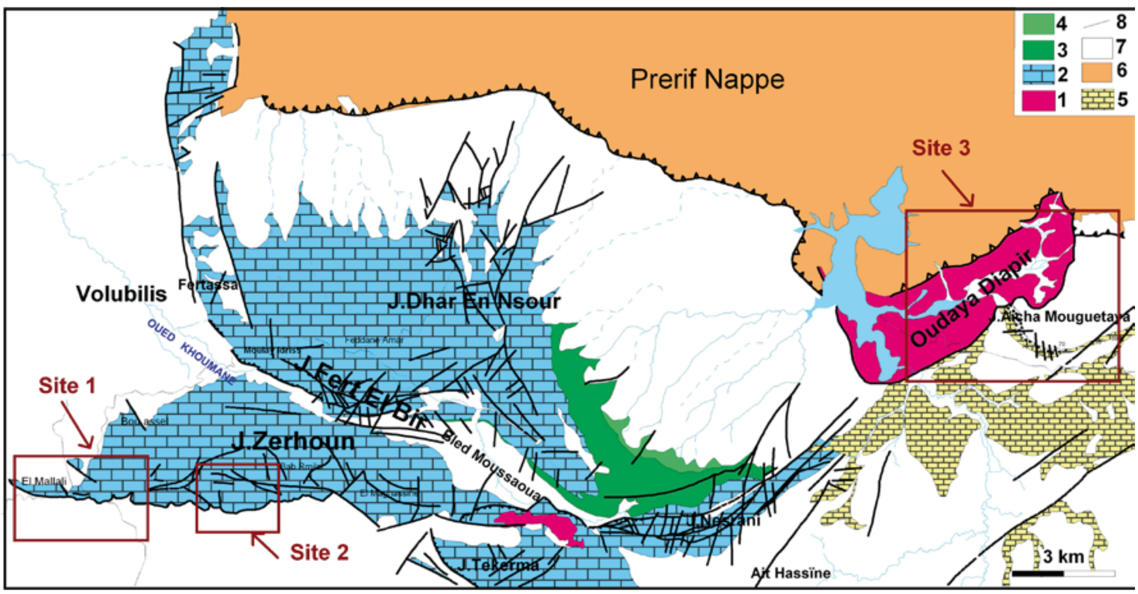
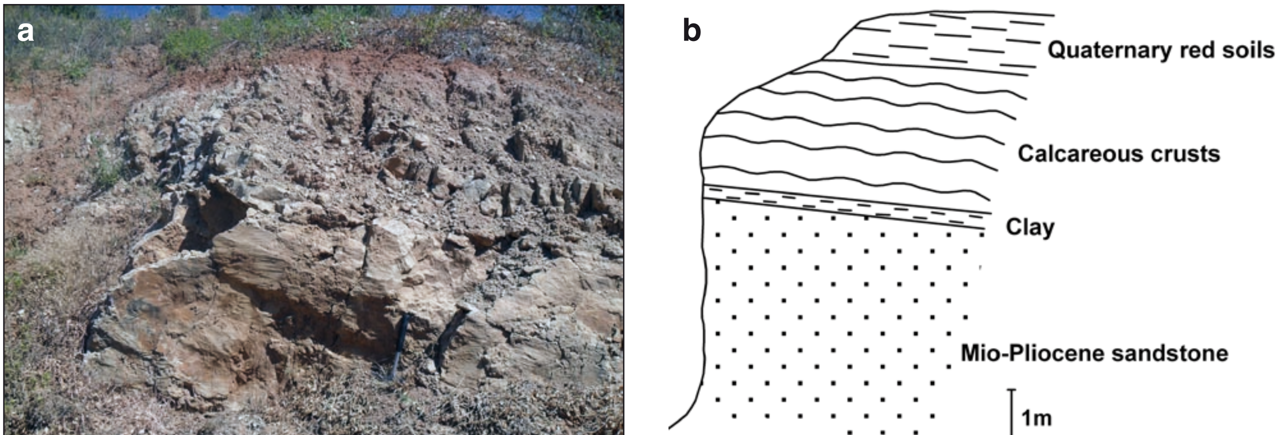


Fig. 2. Structural map of the Eastern Arc of the Southern Rifian Ridges. 1 – Triassic, 2 – Jurassic, 3 – Cretaceous, 4 – Paleocene, 5 – Pliocene, 6 – Prerif nappe, 7 – Quaternary, 8 – faults.



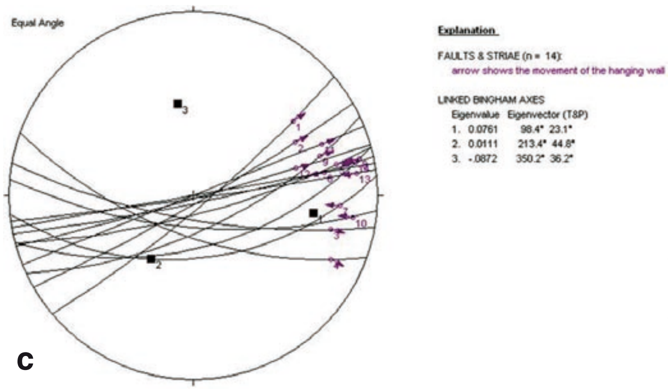


Fig. 3. a – mirror front of the fault at the western end of J. Zerhoune; **b** – log series flush; **c** – stereogram on the fault.

that during this earthquake, the southern front ridges of pre-Rif were reactivated at the ridge Zerhoune of north Meknes and the ridge Zalagh close to the city of Fez. Our research, based on the analysis of different microtectonics fractures, observed in the site, searching their geometric relationships and their relationship to the known regional stress field of the region (cf. Aït Brahim, 1983; Haddaoui, 2000; Faugères, 1978) and detailed observations made along the mirrors of this fault clearly visible in the sandstone facies, has brought new details for earlier considerations.

At the outcrop, the stratigraphic sequence includes sandstone, overlain by calcareous crusts and Quaternary red soils. This frontal fault, considered as a surface rupture and marking the boundary between the Saïss basin and Jebel Zerhoune, affects the stratified sandstone, being attributed to the Mio-Pliocene (Fig. 3b). This subvertical mirror of this fault shows horizontal sliding streaks, benches and stylolitic streaks (between 5 and 30°; Fig. 3a). However, the calcareous crusts and Quaternary soils appear to be intact and bear little evidence of friction, suggesting that this event was sealed by Quaternary deposits. Different markers are observed in the mirror indicating sinistral strike-slip movement. The microtectonic measurements permit to determine a NNE–SSW shortening direction (Fig. 3c). Not far from this site, in another outcrop, the same sandstone series, intercalated with red clay layers, are affected by apparent normal faults. The set of measurements on these faults indicate a NW–SE extensional direction (Fig. 4).

In the second site at the Sidi Ali town (Fig. 2 site 2), we observed an N-S fault along the road between Jurassic sandstone and heterogeneous breccia which determine the limit of the Sais Neogene basin. In previous works, N–S faults were considered as normal faults compatible with N–S shortening phases (Faugeres, 1978; Haddaoui, 2000). We had been modelling these structures and we remark that this N–S direction is exceptional and requires

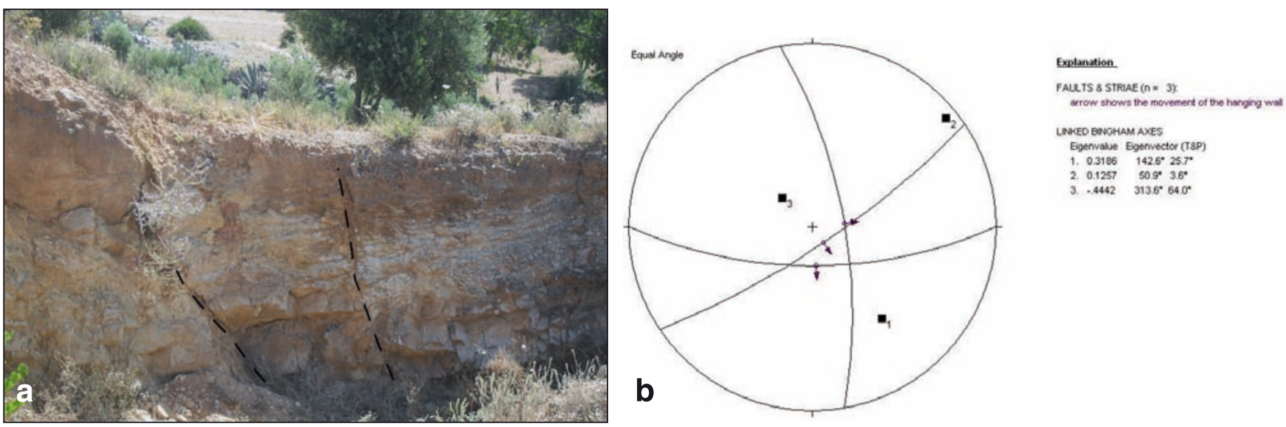


Fig. 4. a – normal faults at the northern edge of Saïss; **b** – stereogram on these faults.

much more attention. In the field, we observed that many markers (sigmoïds, striae, etc; Photo 1) indicate that these faults correspond essentially to reverse faults orthogonal to the E–W major frontal fault. So, we consider that this direction is a minor oblique ramp which develops N–S axis folds during the sub NE–SW shortening phases of Miocene and Plio-Quaternary stages.

Photo 1. Reverse fault trending N-S at the Jebel Zerhoune.

Jebel Aïcha Mouguettaya

Located about 30 km west of Fez, the Jebel Aïcha Mouguettaya forms a ridge oriented approximately E–W to WNW–ESE, striking geographical boundary between the Rif and Saïss (Fig. 2 site 3).

In this massif, the series shows the stratigraphic base to the top of the grey marls of Tortonian. A river--lake formation consists of calcarenites with interbedded conglomeratic, and beige to pink limestone beds 50 m thick, being attributed to Upper Pliocene. North of this massive, the post-nappe marl is unconformably based on red clay gypsiferous Triassic sequence. Southward, the vertically dipping lacustrine limestones, forming the crest of Jebel Aïcha Mouguettaya, display gradual transition to white marl, interbedded with conglomeratic bands in the Quaternary.

Structures

The Pliocene lacustrine limestones of Aïcha Mouguettaya Mts. have different geometries of both sides of the highway linking Fez and Nzala Beni Ammar (Fig. 5). In the immediate contact with the Oudaya Triassic diapir, these limestones are verticalized and sometimes even reversed. They are affected by many sub-N-S trending faults, interpreted as the dextral shears (Ait Brahim, 1983; Ahmamou and Chalouan, 1988). On the southern side of the road, these limestones are affected by very open folds with N60 to N75 oriented axis and become tabular towards Saïss.

In their works in the region, Ait Brahim et al. (1983) and Ahmammou and Chalouan (1988) were observed especially in the events that involved apparent dextral shift of these limestones, forming the crest of the massif. They considered the overprint by the strike-slip faults (Ait Brahim et al., 1983), or the normal faults developed during Pliocene extensional phases (Ahmammou and Chalouan, 1988). These authors, giving much importance to these faults in relation to the regional geodynamic setting in the Late Pliocene and Quaternary, have more or less underestimated the presence of a characteristic diapiric structure in the region that would cause the origin of brittle structures in the region.

Fracturing

The Plio-Quaternary palustrine-lacustrine formations of Saïss, located on the northern edge of the basin at the peak of Jebel Aïha Mouguettaya, are verticalized and affected by vertical submeridian events (Photo 2). These accidents are interpreted by Ahmamou et al. (1988) as synsedimentary normal faults due to an extensive phase trending WNW–ESE in the Upper Pliocene. Previously,

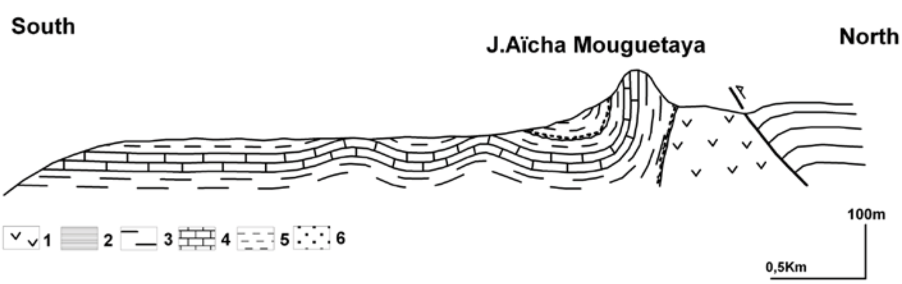


Fig. 5. Geological section of Jebel Aïcha Mouguettaya (location in Fig. 2a). 1 – Triassic gypsiferous red clay, 2 – Prerif nappe, 3 – Tortonian grey marls, 4 – Lacustrine limestones, 5; White marl, 6 – Conglomerates.

Photo 2. The crest of Jebel Aïcha Mouguetaya.

Photo 4. Oudaya salt diapir.

Aït Brahim et al. (1983) have considered these fractures as the dextral strike slip faults related to a sub-meridian compression phase.

Our work in this area allowed us to document the vertical faults oriented N155 to N–S as well as a network of fractures in the limestones. North of the ridge in Miocene marl, we observed fractures of the same direction as those affecting limestone. The south subhorizontal lacustrine limestones are affected by vertical fractures oriented N30 with striated mirrors indicating the strikeslip (Photo 3). Although the sense of shearing in these mirrors we were not been able to determine with certainty, some offset strata indicate sinistral shearing.

Photo 3. Vertical faults with horizontal striae. South of Jebel Aïcha Mouguetaya.

Triassic salt dome

The Jebel Aïcha Mouguettaya is limited to the west by the fault of the Nzala Oudaya, oriented N50-70, being one of the main structural features of the region. This fault took advantage of the Triassic salt diapir (Fig. 2 and Photo 4), constituting the recent important salt deposits overlapping to the SE and S the lake limestone of the Jebel Aïcha Mouguettaya. The presence of this overlap allowed Ahmammou and Chalouan (1988) to assume a shorter regional NW-SE trending deformation phase, being later compared to Pliocene extensional phases.

Discussion and conclusion

Our observations aimed to contribute for better understand of the transition zone between the ridges of South Rif and Saïss Basin. They allowed clarification on earlier interpretations. Indeed, the E–W fault considered by Moratti et al. (2003) as a recent surface rupture appears to be the oldest fault, which was during the Plio-Quaternary compression phases responsible for the reactivation of structures, bordering the basin and the verticalization of the Plio-Quaternary formations of the region (Ait Brahim, 1983; Ahmamou and Chalouan, 1988; Haddaoui, 2000; Sani et al., 2007). The structural analysis done on the mirror of this fault showed that the calcareous crusts and Quaternary formations bear no trace of friction. Similarly, the axes of principal stresses determined from microtectonic measurements on the mirrors of the fault (slip striae, benches and tearing stylolites) determined a regional NNE-SSW shortening direction, being consistent with known regional upper Miocene-Pliocene phase.

At Jebel Aïcha Mouguettaya, fractures affecting the Plio--Quaternary limestones have been interpreted in different manners (Aït Brahim, 1983; Ahmammou and Chalouan, 1988). Our research permitted to observe vertical faults affecting both vertical and sub-tabular limestone formations. The spatial distribution of these faults as radial fractures in the surrounding of diapiric structure of Oudaya, suggests that these faults are contemporaneous with the establishment of this salt Triassic core. Although, the direct relationship between these fractures and the halokinetic movements of Triassic salts is difficult to demonstrate (Zizi, 2002), we note that these fractures are mainly concentrated near the diapir and decrease progressively towards the Saïss basin. Similarly, the recovery and even the overthrow of the series near the diapir argues for a local salt tectonics probably in a regional compressional context.

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