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# Evidence of flexural extension of the Rif foreland : The Rharb-Mamora basin (northern Morocco)

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*Key words*. – Prerifean, Nappe, Blind thrust, K2SF, Flexural, Morocco.

*Abstract*. – The Rharb-Mamora basin is the foreland of the Rif Cordillera (orogenic belt). The Mamora area (northern Morocco) is located at the southern border of the Rharb basin and intercalated between the Alpine Rif Mountains to the north and the Hercynian Moroccan Meseta domain to the south.

Analysis and interpretation of seismic lines, hydrogeological and oil wells, have allowed to precise the major structural elements of the Mamora area, which is covered by late Neogene sediments.

The structure of the area is controlled by faults that also affect the Paleozoic basement. The NE-SW and NW-SE trending faults induce the palaeogeographical evolution and control, the facies distribution and the thickness variations. The most important or relevant structural feature of the Mamora area is the Kenitra-Sidi-Slimane fault (K2SF) [Zouhri *et al*., 2001]. This fault N110°E trending is south of the Rif Alpine thrust front and is marked by a progressive deepening of its northern compartment, at least since Cretaceous time. Thus the Mamora appears as a hinge between the Rharb Basin and the Moroccan Meseta from Cretaceous to Neogene time.

## Preuves d'extensions flexurales dans l'avant-pays rifain : le bassin du Rharb-Mamora (Nord Maroc)

*Mots clés*. – Nappe Pré-Rifaine, Chevauchement aveugle, FK2S, Flexure, Maroc.

*Résumé*. – Le bassin du Rharb représente l'avant-pays de la Cordillère du Rif. La Mamora (nord du Maroc) correspond à la bordure méridionale de ce bassin entre les nappes pré-rifaines alpines au nord et la Meseta hercynienne au sud.

La Mamora, largement couverte par des formations actuelles, l'analyse du potentiel des ressources naturelles, leur exploitation et leur gestion cohérente nécessitent une bonne connaissance des diverses formations et de leurs structures.

L'analyse et l'interprétation de profils sismiques, de forages hydrogéologiques et pétroliers ont permis de préciser les structures majeures de la Mamora, largement recouvertes par des sédiments néogènes.

La structure de cette région est contrôlée par des failles au moins hercyniennes, bien connues dans le substratum paléozoïque. Les deux grandes familles, NE-SW et NW-SE, ont contrôlé l'évolution paléogéographique (répartition des faciès et variations de la puissance des formations). La faille majeure dans cette région est la faille Kénitra – Sidi-Slimane (FK2S) [Zouhri *et al*., 2001]. Cette faille N110°E, à fort pendage N, est localisée au S du front de la nappe pré-rifaine dont l'amortissement est aveugle. Elle se traduit par un effondrement progressif vers le N. Il pourrait s'agir d'une réplique de la faille Rabat – Tiflet. La Mamora apparaît ainsi comme une charnière entre le Rharb subsident et la Meseta marocaine stable depuis le Mésozoïque.

## INTRODUCTION

The northwestern corner of Africa is characterized by the presence of an Alpine belt named Rif belt in Morocco, which developed during Mesozoic and Tertiary times as a result of the convergence of African and European plates more and less at the same time that the development of the Mediterrranean sea [Fernandez *et al*., 1998 ; Frizon de Lamotte *et al*., 2000 ; Chalouan *et al*., 2001 ; Michard *et al*., 2002]. In Morocco, during the latest stages of the Rifean compression, i.e. the Tortonian, Messinian, the Alpine foreland was located in the Rharb zone (fig. 1), along the front of the south-vergent Rif nappes [Feinberg, 1978 ; Faugères, 1978, 1981 ; Cirac, 1990 ; Flinch, 1993].

The Mamora, located south of the Rharb Basin and north of the Hercynian Moroccan Meseta [Piqué and Michard, 1989], is a very flat plain, almost everywhere covered by Quaternary fluvial-alluvial deposits. Its structure can only be studied by subsurface data (seismic and wells). The aim of the present paper is to determine its structure, principally from the study of seismic profiles, hydrogeological and oil wells, in order to discuss the structural evolution of the outermost part of the Rharb foreland basin and to permit a

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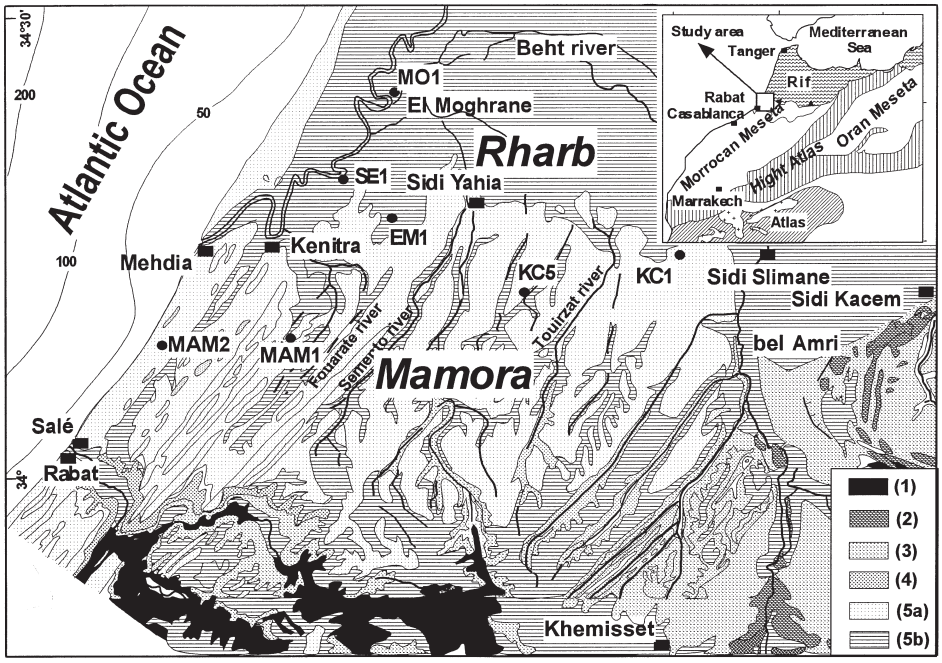


FIG. 1. – Location and geology of the Rharb-Mamora basin 1: Paleozoic, 2: Mesozoic (Middle and Upper Liassic, Middle Jurassic), 3: Miocene (Tortonian), 4: Pliocene, 5: Quaternary : 5a: marine and beach formations (Middle to Upper Quaternary), 5b: continental formations (Moghrebian, Villafranchian, Lower to Upper Quaternary), **KC5**. oil wells.
FIG. 1. – *Localisation et géologie du bassin du Rharb-Mamora* 1: *Paléozoïque*, 2: *Mésozoïque (Lias inférieur et supérieur, Jurassique moyen)*, 3: *Miocène (Tortonien),* 4: *Pliocène*, 5: *Quaternaire* : 5a: *formations marines et dunaires (Quaternaire moyen et récent),* 5b: *formations continentales (Moghrebien, Villafranchien, Quaternaire ancien et récent),* **KC5**: *forages pétroliers.*

subsequent evaluation of its potentialities as a water reservoir.

## THE MAMORA ZONE : SEDIMENTARY AND REGIONAL SETTING

The Mamora basement crops out at Tiflet (fig. 1). It consists of Cambrian sedimentary sequences deformed prior to the emplacement of granitoids dated as old as 430 ± 2 Ma [Piqué, 1982]. The folds and thrusts exhibit WNW-ESE trends and a south vergence. The rocks have been subsequently refolded during the Hercynian orogeny and affected by the N110°E right-lateral Rabat-Tiflet fault.

The Morrocan Meseta is overlain by Upper Triassic and lowermost Liassic shales and evaporitic formations [Laville and Piqué, 1991]. These basins are trending N020-040°E direction in the western part [Burger *et al*., 1960-1962] and N080°E in the eastern part of northern Meseta [Salvan, 1974].

Cretaceous sequences have been encountered in several wells above Paleozoic and Triassic to Liassic rocks.They are thicker and better developed towards the northern part of the basin, with about 155 m in MO1 and, in the southern part, about 50 m in MAM1. The Miocene, often absent in the Meseta, is well represented in the Rharb Basin and particularly in the Mamora. It is composed of marine formations, principally blue marls with a thickness ranging from about 99 m in southern country of Kenitra (MAM1) and in an average to 1676 m in its northern part (SE1). The Mio-Pliocene formations have been stratigraphically studied and dated [Cirac, 1990 ; Faugères, 1981; Feinberg, 1978 and Wernli, 1977, 1978, 1979, 1987].

The stratigraphic columns of the Rharb Basin established on the analysis of selected wells, with variations are summarized in figure 2. This figure shows a brutal increase in the total thickness of sedimentary Meso-Cenozoic rocks. Such thickening is partially due to the Alpine Pre-Rifean Nappe, a middle to late Miocene olistostrome intercalation [Suter, 1980] in the northern area and shown in several columns (fig. 2, MO1 and MA101) above sub-autochthonous Meso-Cenozoic sequences. The Supra-Nappe complex consists of a sea-ward prograding wedge that ranges from late Miocene to Holocene. Seismic data in fact shows that this unit is mostly an accretionary wedge.

## GEOMETRY OF THE MAMORA BASIN

In the eastern zone, the analysis and interpretation of the LO1, LO2 and LO3 seismic lines and wells data (fig. 3), enable to define three units :

– a lower unit $U_1$ (Triassic, Cretaceous, Miocene), subautochthonous, unconformably overlying the Mesetian Paleozoic basement ;

– an intermediate unit $U_2$ of strongly altered and deformed formations (mainly composed of Triassic and Cretaceous sequences). This $U_2$ overlies the Upper Miocene of $U_1$ by a thrust surface. Its thickness is between a few (LO1, LO2 and LO3) to four hundred meters as well as in N-S direction than in E-W one. So, such variations give to this $U_2$ a lenticular shape. According to Flinch [1993, 1996], it corresponds to the allochthonous Pre-Rifean Complex. The thrust contact between units $U_1$ and $U_3$ is followed along a few kilometers to the south of KC6 well, but it is not longer

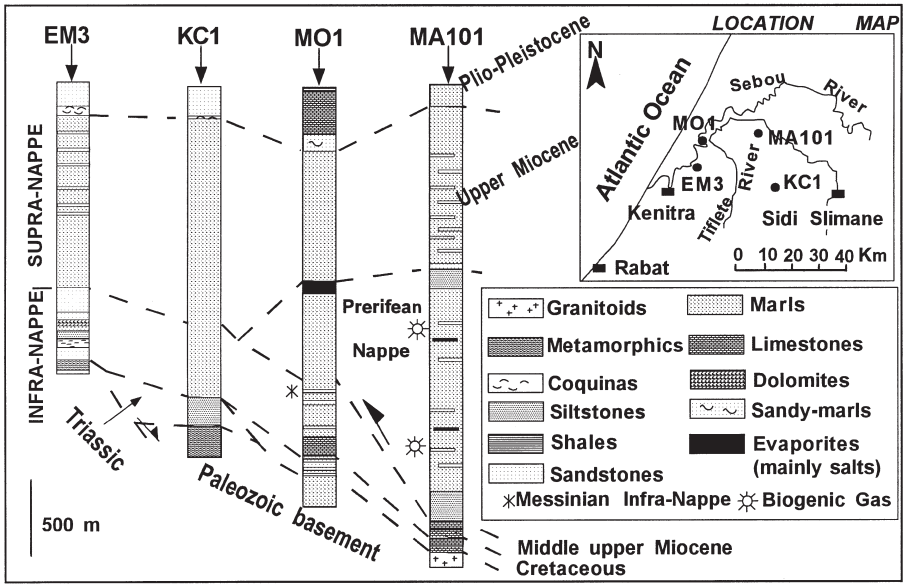


FIG. 2. – Stratigraphical correlation of selected wells of the Rharb-Mamora Basin [after Flinch, 1996; modified].
FIG. 2. – *Corrélations stratigraphiques des forages pétroliers réalisés dans le bassin du Rharb-Mamora [d'après Flinch, 1996 ; modifié].*

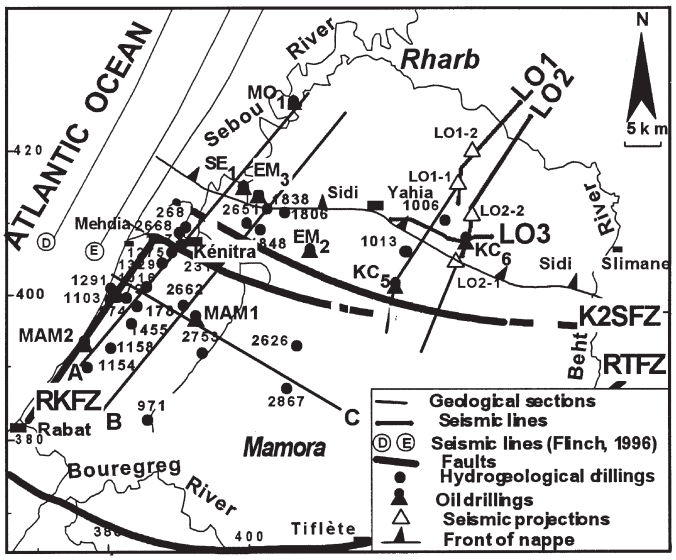


FIG. 3. – Seismic lines, geological sections, and drilling location map (**RTFZ** : Rabat-Tiflete faulting zone, **RKFZ** : Rabat-Kenitra faulting zone; **K2SFZ** : Kenitra-Sidi Slimane faulting zone).
FIG. 3. – *Localisation des profils sismiques, des coupes géologiques et des forages* (**RTFZ** : *faille de Rabat-Tiflete,* **RKFZ** : *faille de Rabat-Kenitra;* **K2SFZ** : *faille de Kenitra-Sidi Slimane).*

observable in KC5, probably because the overlapping complex thins along a blind thrust (**R** : fig. 4) ;

– an upper unit $U_3$, with the younger Cenozoic (Mio-Pliocene) formations at the base of K6 well, Helvetian sandstones (130 m), Tortonian sands and marls (649 m) and on top Pliocene sands. $U_3$ lies either on the unit $U_1$ or the unit $U_2$.

All the youngest formations (Tortonian to Quaternary) are affected by normal synsedimentary faults.

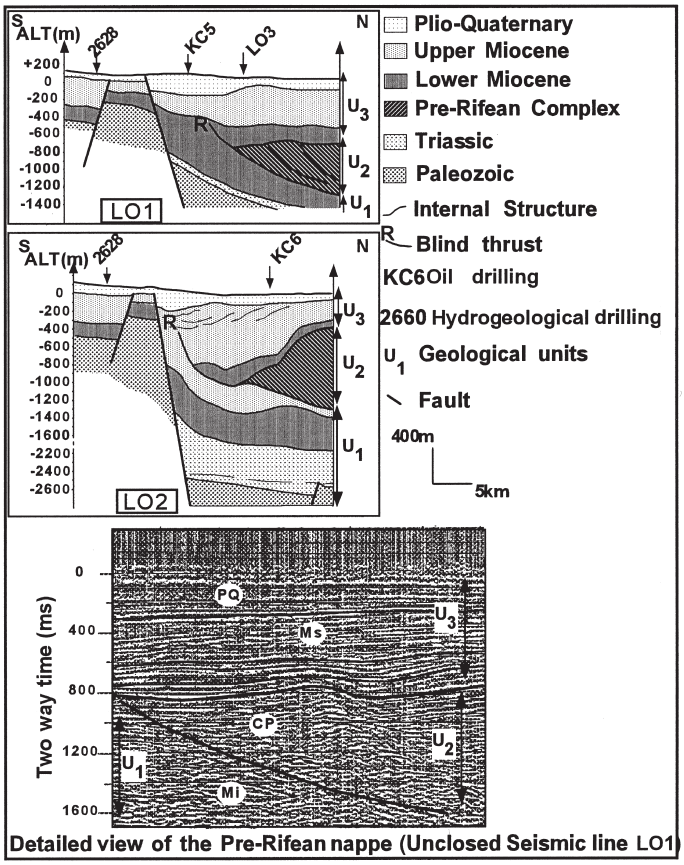


FIG. 4. – Seismic line interpretation LO1 and LO2 (Mi : Lower Miocene, CP : Pre-rifean Complex, Ms : Upper Miocene, PQ : Quaternary Pliocene).
FIG. 4. – *Interprétation des profils sismiques LO1 et LO2 (Mi : Miocène inférieur, CP : complexe pré-rifain,* Ms.: *Miocène supérieur,* PQ : *Plio-Quaternaire).*

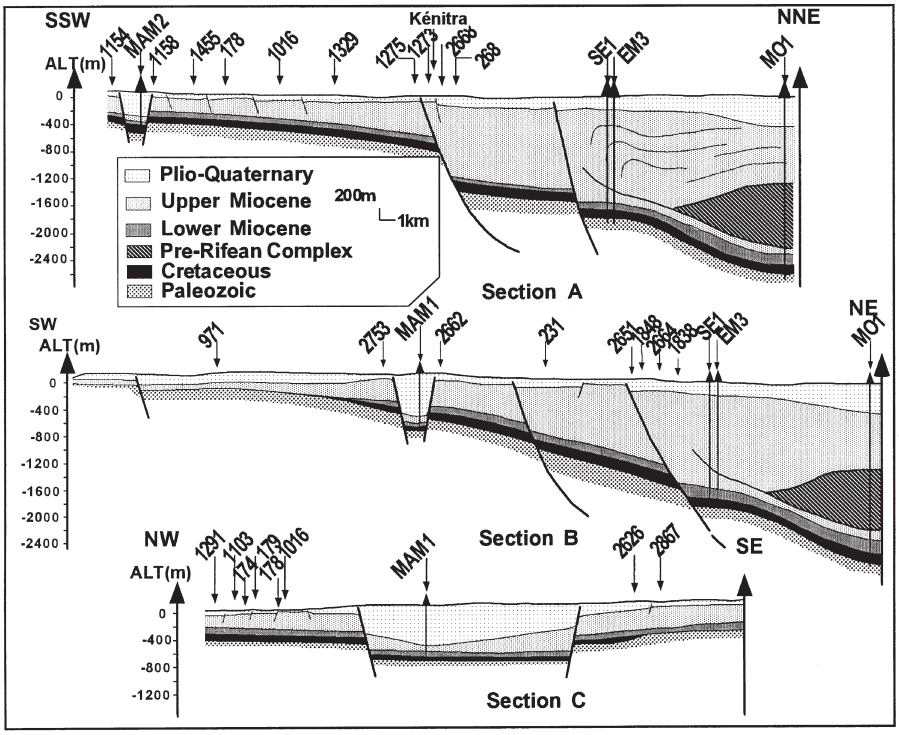


FIG. 5. – Geological sections (A, B, C) in the western area.
FIG. 5. – *Sections géologiques* (A, B, C) *réalisées dans la zone occidentale.*

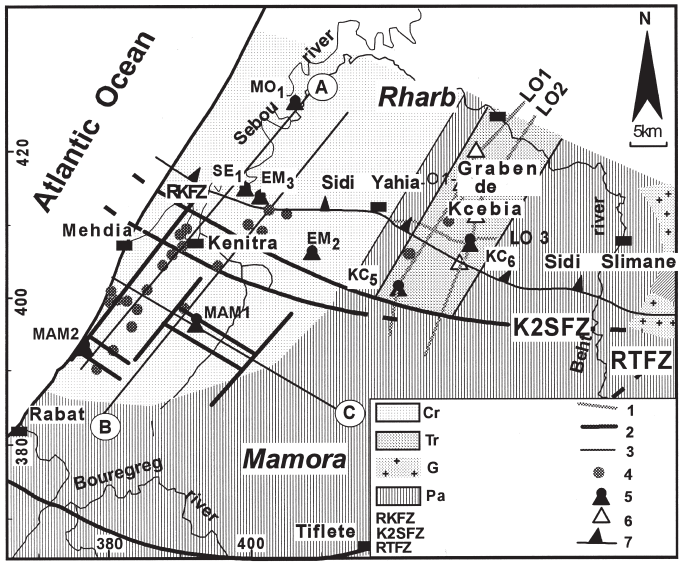


FIG. 6. – Kcebia graben and the Miocene basement in the Rharb-Mamora basin [according to Zouhri *et al.*, 2001, modified]. 1 : seismic lines, 2 : faults (RTFZ : Rabat-Kenitra faulting zone, K2SFZ : Kenitra-Sidi-Slimane faulting zone, RTFZ : Rabat-Tiflete faulting zone), 3 : sections géologiques, 4 : hydrogeological wells, 5: oil wells, 6 : seismic projections, 7 : nappe front, Cr : Cretaceous, Tr : Triassic, G : granitoids, P : Paleozoic.
FIG. 6. – *Graben de Kcebia et substratum du Miocène dans le bassin Rharb-Mamora [d'après Zouhri* et al., *2001, modifié]*. 1: *sections sismiques*, 2: *failles* (RTFZ : *Rabat-Kenitra,* K2SFZ : *Kenitra-Sidi-Slimane*, RTFZ : *Rabat-Tiflete)*, 3 : *sections géologiques*, 4 : *forages hydrogéologiques*, 5: *forages pétroliers*, 6 : *projection sismiques*, 7 : *front de la nappe*, Cr : *Crétacé*, Tr : *Trias*, G : *granites*, P : *Paléozoïque.*

The structure of the southwestern Rharb area (fig. 5) has a similar frame to those seen in Sidi Yahia country, east of the study area. It is marked by a northward deepening of the Paleozoic basement through several N090-110°E northward dipping normal faults. This structural pattern gives way to an increase in that direction of the thickness of the Neogene and Quaternary sequences. The WNW-ESE oriented C section crosses faults that delimit a central graben, where the MAM1 well has been drilled.

## DISCUSSION

The interpretation of the geological and seismic sections reveals the existence of two sets of normal faults that affect the Mio-Pliocene series.

In the east part of this study, we identified normal N090-110°E faults that were active during Cenozoic. But their geometry indicates an initial dextral shear component, probably older than opening of the El Kcebia Triassic and Liassic Basin which is bounded by a fault zone (fig. 6). These faults have been defined as the Kenitra-Sidi-Slimane faulted zone [K2SFZ : Zouhri *et al.*, 2001]. The southern compartment of this is a complex strip of extensional horsts and grabens. Its northern part is characterized by thick post-Paleozoic formations. Section C shows N030°E trending faults, recognized as the Rabat-Kenitra fault zone (RKFZ).

Both sets of faults are parallel to major Hercynian structures visible to the south, in the Moroccan Meseta. The RKFZ is parallel to the Western Meseta shear zone (WMSZ) [Piqué *et al.*, 1980] that acted during the Paleozoic [Piqué and Michard, 1989] and then controlled the opening of late Triassic-early Liassic basins of western Morocco during the Central Atlantic intracontinental rifting [Laville and Piqué, 1991] as El Kcebia Basin, and the Cenozoic sinking of western Morocco. The K2SFZ is parallel to

the Rabat-Tiflet fault active during early and late Paleozoic [Piqué, 1982] and was reactived during Triassic rifting.

So this frame suggests that the RKFZ, RTFZ and K2SFZ, in this part of Rharb basin, are re-activated Hercynian faults. They were revived as normal faults due to flexural extension in the Rharb foreland basin [Flinch, 1996] due to the tectonic loading of the orogenic Rifean zones during Neogene time. In the Rharb basin itself, and even in the northern parts of the Mamora, the Paleozoic basement is deeply buried and the structures of its Neogene cover are at ductile-brittle limit in low cohesive force materials. By contrast, South of the Mamora, the Meseta behaved at that time as a rigid block. Between these two areas, the Mamora is a transition zone which allows demonstration that Hercynian structures control the subsidence of the Rif foreland.

## CONCLUSION

The Rharb foreland basin and its southern Mamora sub-basin developed in the course of the late events of the Rif orogeny. In the Mamora, the relatively smaller thickness of the post-Paleozoic cover does not mask the importance of the bordering faults trending N030°E and N090- 100°E, that limit the Rharb basin to the west and to the south. These are former Hercynian wrench faults reactivated as normal fault zones during the Neogene due to flexural extension. Three phases of fault activity are identified :

- Paleozoic (K2SFZ, RTFZ and RKFZ), with probably left component along N110°E fault zones ;
- Triassic-Jurassic rifting associated to basin opening (horst and graben structures) and sinistral component along N110°E fault zones ;
- late Neogene normal fault (flexural extension) in the whole Rharb Basin, syn- to post-thrust of Rif nappes.

The thickening of the permeable formations towards the north and the Atlantic Ocean is controlled by normal faulting. These formations constitute the Plio-Quaternary aquifer of the Rharb-Mamora and characterize the potential of the basin as water reservoir. In a next paper, we will study their hydrogeology and establish the relation between normal faulting and groundwater flow.

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