International Journal of Innovation and Applied Studies
ISSN 2028-9324 Vol. 6 No. 4 July 2014, pp. 825-838

http://www.ijias.issr-journals.org/

The fracturing role in the conditioning of karst groundwater circulations in the calcareous Dorsal (Northern Rif, Morocco)

Rabie El Bardai, Kamal Targuisti, Rachid Hlila, and Khadija Aluni

Laboratory of Geology of the Environment and natural resources,
Faculty of Sciences, University Abdelmalek Essaâdi, B.P. 2121,
Tetouan, Morocco

ABSTRACT: Natural fracturing includes all the mechanical discontinuities affecting the rock matrix. These natural fractures usually constitute preferential drains or permeability barriers which partially control the movement of fluids during production. The fracturing map of the Calcareous Dorsale in the Northern Rif was established using remote sensing (photo-interpretation) and GIS techniques, as well as field measurements of fractures randomly distributed in six microtectonic stations.

Firstly, using the above mentioned approaches the main sets of fractures are detected. The dominant direction of fractures corresponds to the NE-SW direction which also coincides with the dominant orientation of the hydrographic network. Thus, the results from these two methodological approaches permit the development of a hypothetical scenario of karst groundwater circulations between the different units of the study area and other nearby units.

KEYWORDS: Fracturing, photo-interpretation, orthorectification, water flow, Calcareous Dorsal, Rif

1 INTRODUCTION

The fracturing studies are conducted by a variety of simple or complex methods. Although the study area presents a very difficult access due to the much accentuated relief and the high density of vegetation (forest area very important), two methodological approaches were used to analyze the fracturing process. These are, firstly, the cartography based on photo-interpretation (aerial photography) and secondly, the field microtectonic analysis.

The study is carried out on fracturing carbonate formations of the limestone ridge which, together with Ghomaride and Sebtide nappes, form the Rifian internal domain. The Sebtides consist of varied metamorphic nappes, including a granulitic-mantle ultramafic unit, which are underlain (Sebta massif) and overlain (Beni Bousra massif) by gneiss and schist of upper-crustal affinities. The Ghomarides nappes form the uppermost nappes in the Rifain Alpine belt. Paleozoic rocks constitute the prominent part of these nappes, together with Triassic and younger cover sediments. The Calcareous Dorsale is a complex tectonic domain, but its Mesozoic-Paleogene paleogeographic evolution is well constrained by many paleontological and sedimentological data. The Calcareous Dorsale stratigraphy corresponds to three contrasting sequences, which encompass the Triassic-Miocene time interval. The oldest, late Triassic-Liassic sequence forms the competent part of the nappes, and on the other hand, allowed the authors to classify the varied nappes into "Internal Dorsale" and "External Dorsale" although, in some cases, this traditional classification does not correspond to the actual position of the nappes. The intermediate, Liassic-Paleocene sequence records the evolution of a Tethyan paleomargin, and finally the youngest, Eocene-Miocene sequence records that of the Alpine orogeny [1].

Indeed, the polyphased tectonic have controlled the genesis and the evolution of the fissured networks as well as the karstification in carbonate domain. The Calcareous Dorsale object of this study provides a good example of karst massif with a high water potential. However, the boundary between the internal zones and the external zones of the Rifian domain are affected by strike-slip faults, including the Jebha-Chrafate fault which makes one of the major transcurrent faults of the Rif Cordillera. This is a sinistral strike-slip fault of which the main left lateral displacement is at least 50 km ([2], [3], [4]).

The aim of this study is to establish the role of fracturation in determining the flow conditions of groundwater and surface water, together with the relation between karstic aquifers. It is shown that tectonic and karsts are related [5].

On a regional scale, the fracturing was analyzed using aerial photography to bring out a thematic fracturing map of large scale. Moreover, more than 500 lineaments were located. However, at outcrop scale, the fracturing was analyzed in six microtectonic stations randomly selected due to the inaccessibility of some area, together with the important forest density.

1.1 Geological setting

The study area forms part of the Septentrional Internal Rif. It corresponds to the segment of the external Calcareous Dorsale located precisely between the Oued Laou valley in the north, and the major fault of Jebha-charafate in the south (Fig. 1). It consists of three stacked tectonic units: Jbel Tissouka unit, Jbel Lakraa unit, and the Jbel Bouslimane unit, where some peaks exceed 2000 meters in high (2122 m in Jbel Tissouka and 2159 m in Jbel Lakraa).

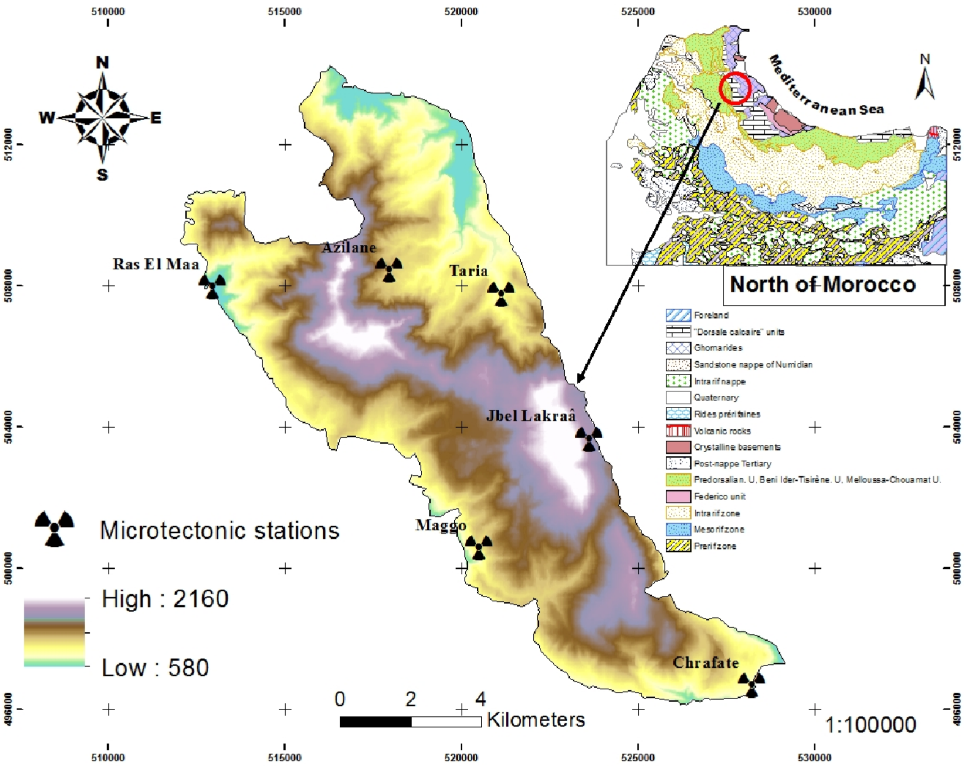

Fig.1. General Localization of the study area and DTM (Digital Terrain Model)

These units are stacked in nappes with tectonic contacts dipping westward (Nold et al., 1981). They are separated from the massif of Jbel Tazout by the directed NW-SE fault of Jbel Lakraa. The stratigrafic successions of the Calcareous Dorsal are described from bottom to top as [6] (Fig. 2):

- Up to 900 m in thick of Carnian to Norian stromatolitic dolstones with intercalations of marly limestone.
- 80 to 300 m of limestone and dolomite alternation (Rhetian),
- Massive limestone and/or dolomite, their attribution to the Hettangian age is not strictly deducted;
- Flint limestone with marls and bituminous facies and intraformational breccias (from Sinemurian to Pliensbachian);
- The radiolarites and breccias of Dogger-Malm age;
- The conglomeratic and brecciated formations of Tertiary.

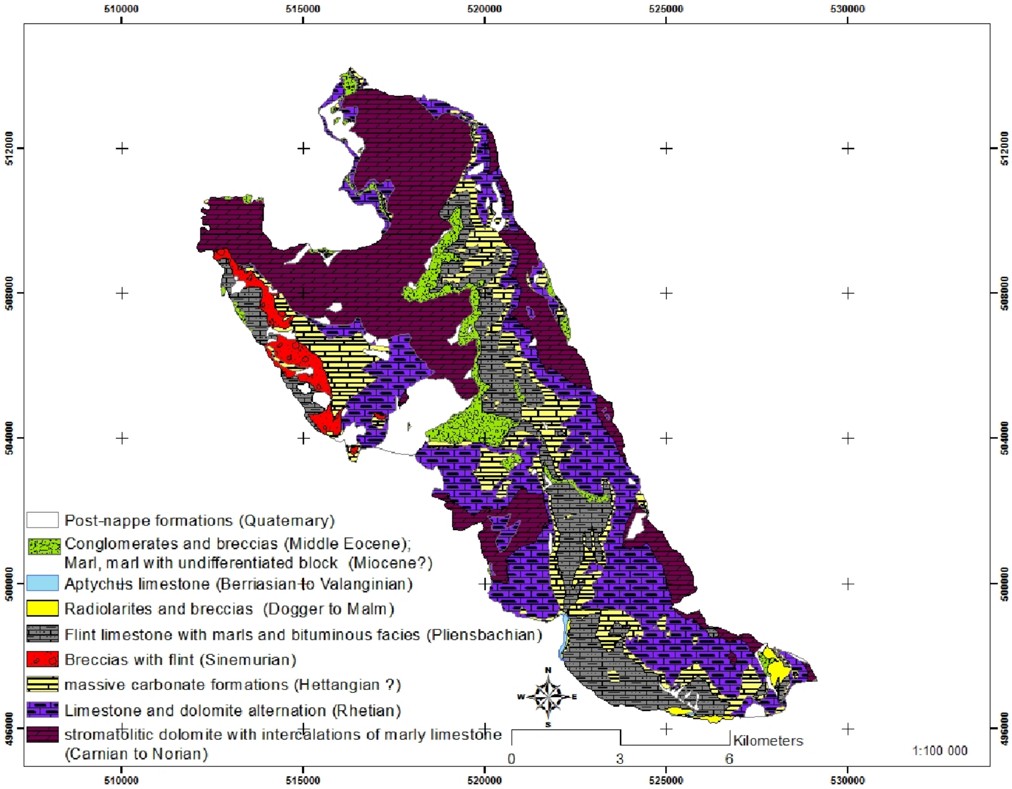

Fig.2. Schematic Simplified geological map of the study area

1.2 Hydrogeological setting

The study area is crossed by many superficial streams. In addition, several springs gush at the foot of the limestone ridge, while others are dispersed geographically in the different formations. The most important springs are: Ras El Maa Spring located at west of the Jbel Tissouka unit whose it rises in the flint limestone; Ahramen and Aayaden Springs welling in massive carbonate formations of Hettangian age; and Chrafate Spring which is part of the Bouslimane unit and that gushes in the flint limestone of Pliensbachian age.

For the whole area, these sources are the main water resources for both drinking water and irrigation. Aquifers are karstic, this can be proved by the presence of morphologically karst forms such as lapies, sinkholes, dry valleys, canyons and caves.

2 Methods

The methodology used in this paper consists of establishing a fracturing map essentially based on the analysis of aerial photographs, combined to a microtectonic field study of fractures. Six stations were chosen to measure fracture orientation.

The data include 22 aerial photographs at 1/20000 acquired in 1986, across five transverse bands covering the study area, and topographical and geological maps of Bab Taza and Chefchaouen (scale 1/50000). In addition, we used a 90-meters resolution DTM (Digital Terrain Model) from the SRTM database (Schuttel Radar Thematic Mapper) and a 30-meters resolution DTM created from digitizing contour lines of topographical maps. From a planimetric point of view, the orthorectified images show the field reality since they show the details in their real geographical coordinates (X and Y). The 22 aerial photographs were digitized, georeferenced and geometrically corrected using image processing software.

The process of geometric correction is also known as “orthorectification”. During this process, data is corrected according to the user's ground reference system. Since the resulting output images are geometrically correct, they can then be used as maps. The technique of orthorectification implies the existence of a DTM and the focal length of the camera while introducing fiducial markers which is in the calibration certificate of the flight mission. Thus, we have chosen six control points on aerial photographs and their counterparts in the maps.

The orthorectified aerial photographs were already processed by subtracting the contours, and were then assembled into a single image called orthomosaic. This latter integrated in a GIS, served as the main support on which were presented all the fractures that were identified in the stereoscopic observation. The rose diagram for the azimuth of fractures was made employing the method of "REDES DE BÚSQUEDA" elaborated by Galindo-Zaldivar and González-Lodeiro [7]. This method is based on the principle of BOTT [8], which considers the striae fault is parallel to the direction of maximum shear stress.

3 RESULTS AND DISCUSSION

3.1 PHOTO-INTERPRETATION

Firstly, we tried to map the rock fracturing without using the orthorectified images. The results did not match, however, the field observations since they present several inherent errors such as:

- The same object shows at least two different directions (Fig. 3);
- A spatial offset between the object image and its counterpart on the topographic map or aerial photograph (Fig. 3);
- Changing real direction of the fractures.

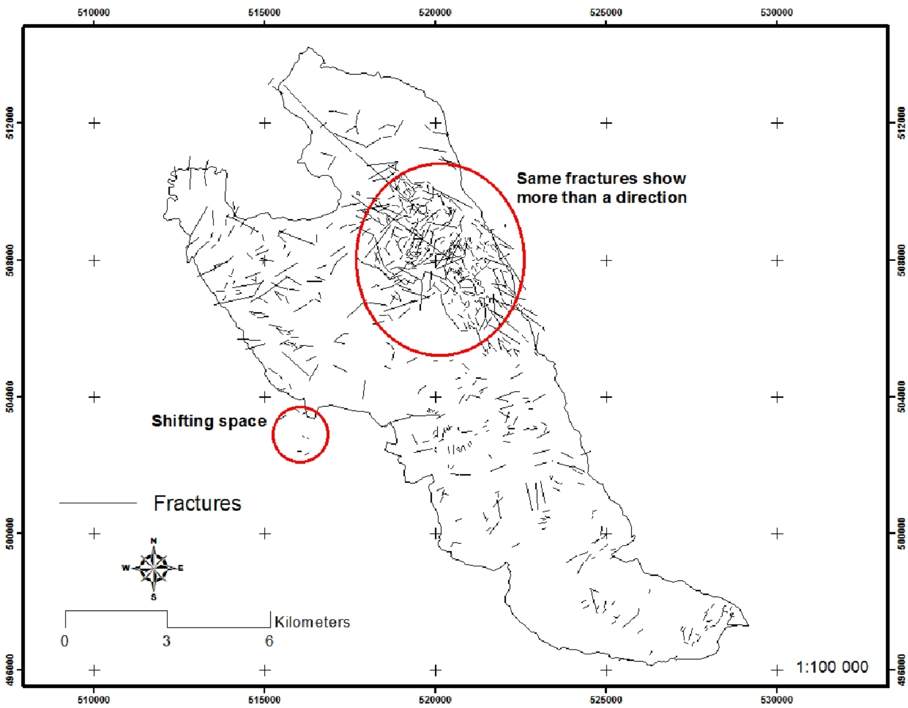

Fig. 3. The summary map of fracturing before orthorectification

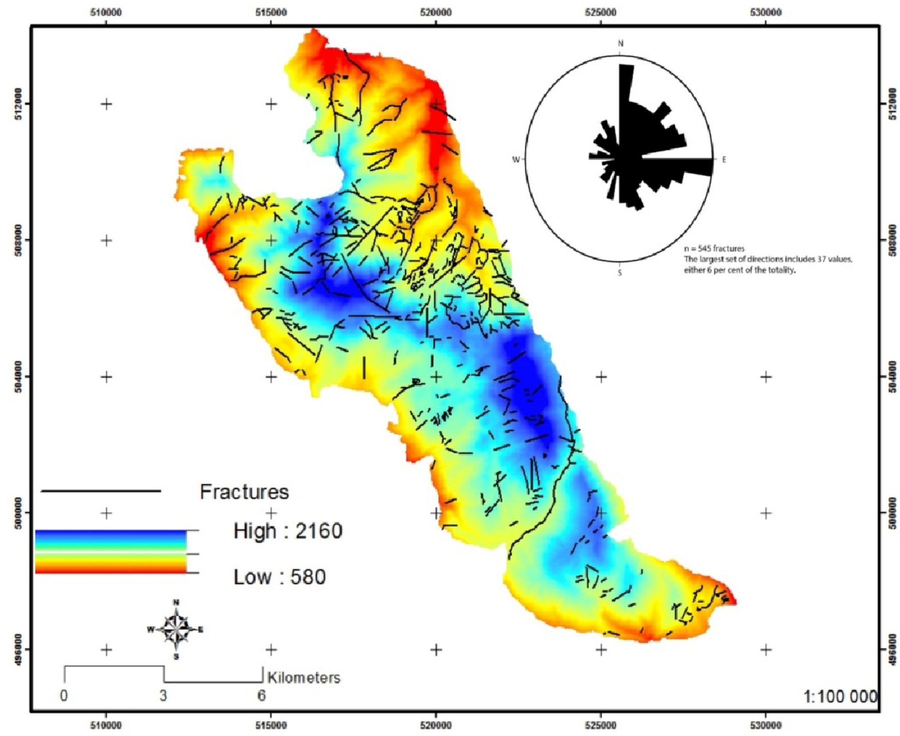

Fig. 4. The summary map of fracturing after orthorectification and its rose diagram of the azimuth data.

Fig. 4 represents a map with 543 fractures plotted on a simplified Digital Terrain Model where the altitude varies from 580 to 2160 m. The distribution of these fractures is heterogeneous. This disproportion seems likely to be caused by the extensive forest cover in the study area rather than particular tectonic shifting.

The rose diagram of fractures in Fig. 4 shows 10 fracture patterns, which can be categorized into four classes according to their direction: NE-SW, NW-SE, N-S, and E-W.

- Fracture set oriented NE-SW: this is the main direction of the fractures in the study area. It brings together 112 measurements (20% of all measured fractures). This set of direction (N40-N50) is approximately parallel to the Jebha-Chrafate Major Fault, and seems to be related to the transversal network faults and joints associated with a N60-N80 direction of this major fault. The Jebha-Chrafate fault is a sinistral strike-slip fault that played a key role in structuring the Rif belt during the Neogene ([9], [10], [11], [12]). On the other hand, the rose diagram of hydrographic network (Fig. 5) shows that the N40-N50 oriented fractures represent the predominant direction, probably due to the existence of a relationship between the development of the hydrographic network and setting up of the Jebha-Chrafate fault.
- Fracture set oriented NW-SE: these fractures are precisely oriented N130-N140. According to reference [6], they are parallel to the Jbel Lakraa Fault, which had a normal movement at some point of its geological history revealed by the presence of fault striae with a high rake indicating significant vertical component of the fault setting. The Jbel Lakraa fault had left locally secondary normal faults associated with the main fault setting steeply dipping N120-N168 with a dip of 50º-80º (synthetic) and normal faulting N135-N150 with a dip of 25º-60º (antithetic) affecting the Triassic dolstones of the Jbel Lakraa unit [13].
- Fracture set oriented N-S: the fractures with this direction may be related to a recent extension step associated with the uplift of the Rif Cordillera [4].
- Fracture set oriented E-W: it is consistent with the shortening direction of the Eurasian and African plates, without any influence of the movement being detected at the west of the Alboran domain [4].

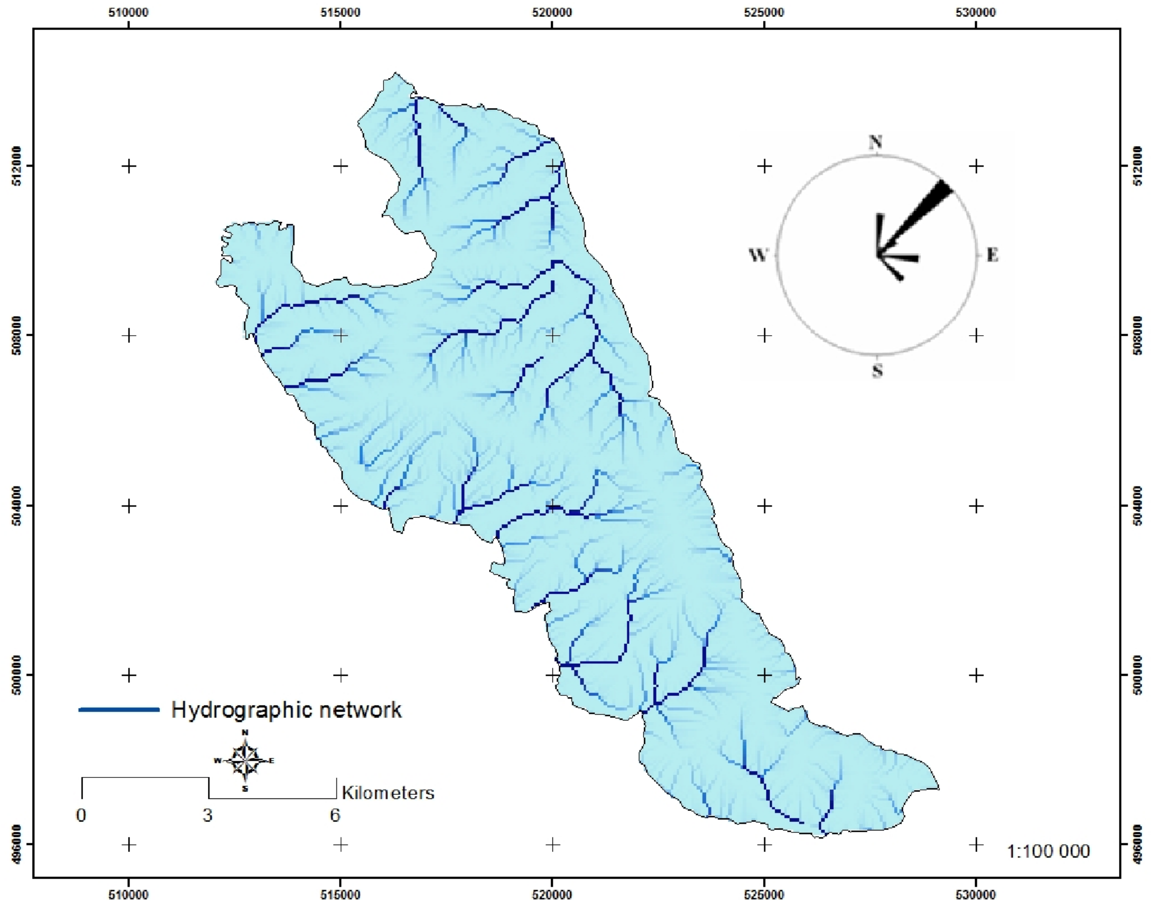

Fig. 5. Map and rose diagram of hydrographic network

3.2 MICROTECTONIC ANALYSIS

The distribution of microtectonic stations shown in Fig. 6 is not made homogeneously. This is due to the inaccessibility of some areas, and the presence of a very high forest density with forest covers more than 70 per cent of the study area and that makes it difficult to choose a favorable site for such study.

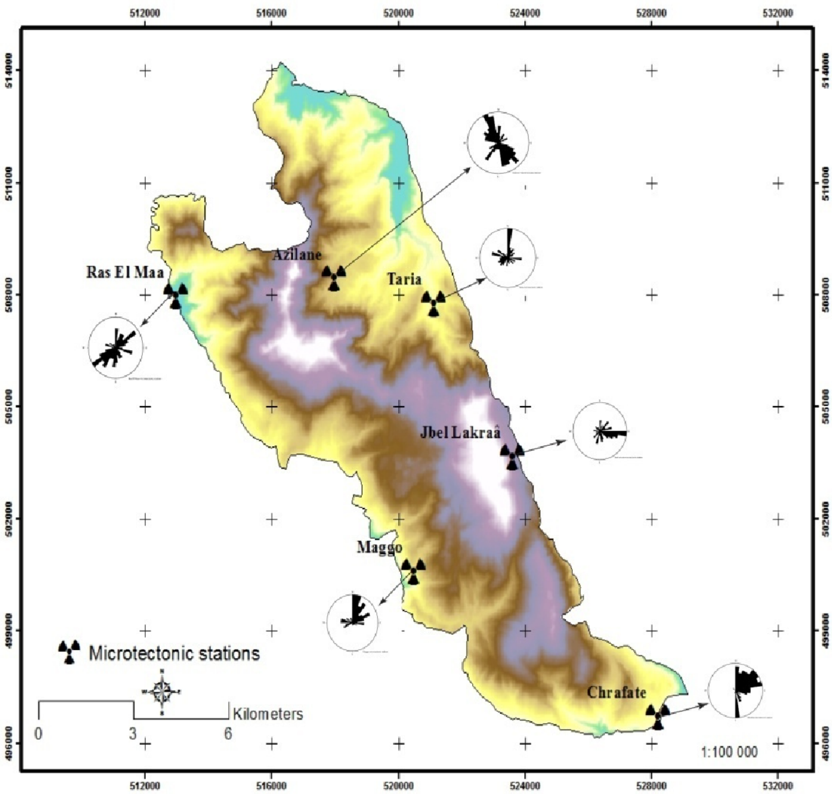

Fig. 6. Map of the microtectonic stations positioning

► **Ras El Maa microtectonic station**

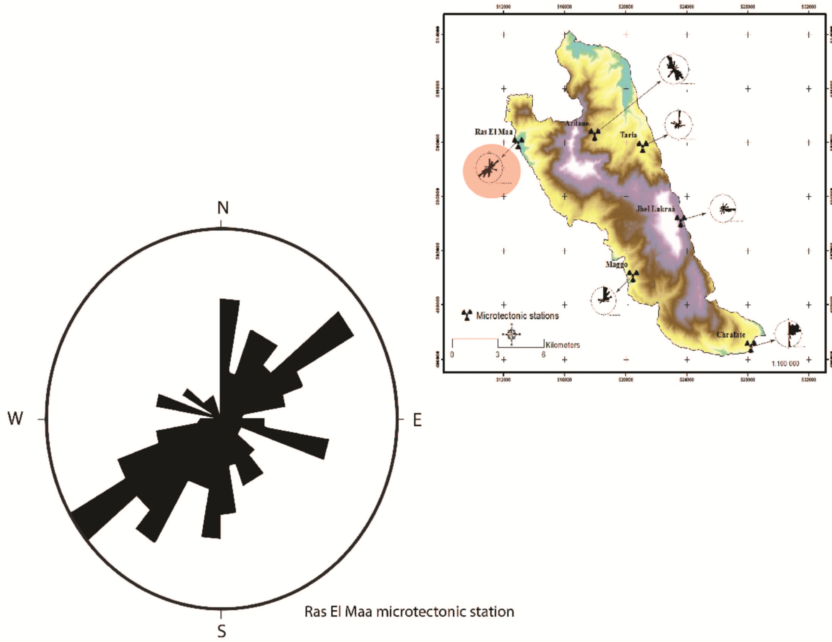

Fig. 7. Rose diagram of Ras El Maa micrtectonic station

Field surveys at Ras El Maa station microtectonic show that the set of direction NE-SW is clearly predominant (Fig. 7). This could be explained by the Jbel Tissouka Unit supply by groundwater directly from the Jbel Tazoute unit; therefore the groundwater flow direction is guided by a NE-SW fracture network. The N-S fractures direction appears less important than the NE-SW dominate direction, it could be responsible for a supply of Jbel Lakraa unit by groundwater of Jbel Tissouka unit, which it may cause a partial flow northward.

- **Maggo microtectonic station**

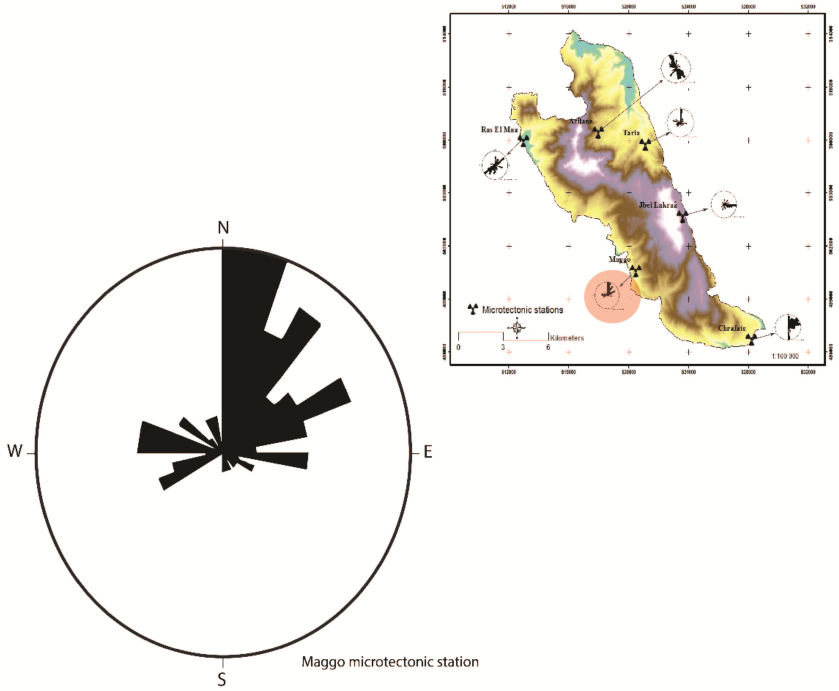

Fig. 8. Rose diagram of Maggo micrtectonic station

Field surveys at Maggo microtectonic station shows a dominance in N-S direction and then of NE-SW direction. Finally the E-W fractures remain the least significant ones (Fig. 8). Moreover, the sustainability and very marked karst objects of Ahramen and Aayaden springs demonstrate the existence of a purely karst groundwater flow.

Pursuant to the diagram rose of directions, it can be concluded that there is an N-S groundwater flow direction from Jbel Tissouka unit. This suggests that the groundwater reserve of Jbel Tissouka unit is supplied from a groundwater of Jbel Lakraa unit.

Another groundwater flow in direction NE-SW seems to be related to the presence of a large number of caves and sinkholes in north-east of Maggo village (Jbel Lakraa massif). These can directly contribute to the recharge of the karst groundwater above all that infiltration is concentrated and faces no impermeable barrier. The karstification was responsible for this flow direction.

To the east of the village, the existence of lapiaz and some sinkholes may suggest a partial groundwater flow in an E-W direction.

► **Chrafate microtectonic station**

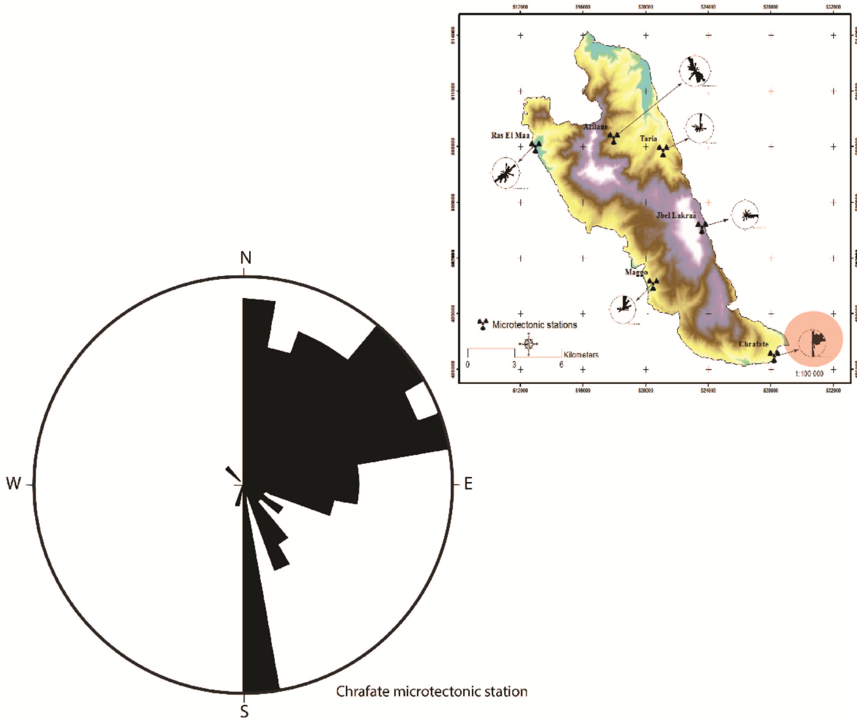

Fig. 9. Rose diagram of Chrafate micrtectonic station

The Chrafate spring is a Vauclusian spring formed by the culmination of a subvertical conduit that can be the ascending branch of a reverse siphon and penetrable only by underground diving. A fluorescence staining experience being made into the Taghobaït sinkhole located a few kilometers of the spring. It had demonstrated its participation in supplying the vauclusian springs of Chrafate [14].

The diagram rose of directions shows the predominance of fractures in a NE-SW direction, followed by N-S direction (Fig. 9). Indeed, the NE-SW fractures seem to be responsible for groundwater flow that circulates from northeast to southwest.

Moreover, the N-S fractures can cause groundwater flows which circulate from carbonate formations in the north to the impermeable substratum of Predorsalian unit in the south.

► **Jbel Lakraâ microtectonic station**

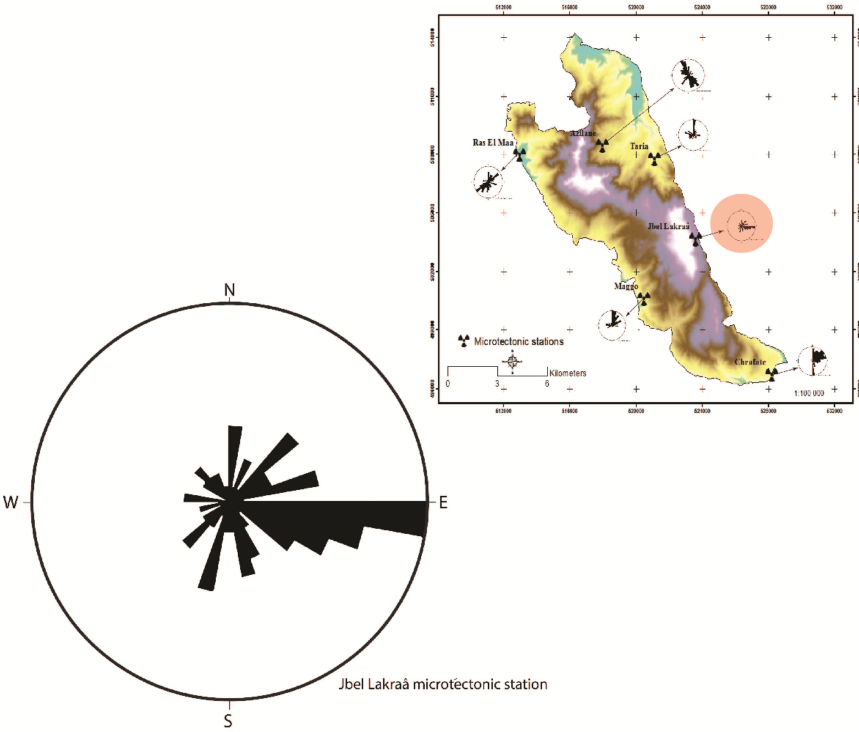

Fig. 10: Rose diagram of Jbel Lakraâ micrtectonic station

The Jbel Lakraa microtectonic station was choosen in the alternating calcareous-dolomitic formation considered to be of Rhetian age, near a forest warden's house. This massif is characterized by the absence or scarcity of karst springs. However, there are several sinkholes. The predominant fractures are E-W oriented (Fig. 10), and this fracturing is responsible for communication between the Jbel Lakraa and the Jbel Talassemtane units. According to reference [15], the unit of Jbel Lakraa contributes to water supplying of the other units. He conducted a hydrochemical study to achieve this result based on the chemical facies of Ain Danou spring (X = 520000, Y = 509600, Z = 900) that gush in the Farda riverbed and which is comparable to the Onsar el Khwa and Haouta Dra facies (X = 525700, Y = 504850, Z = 1260) gushing in Jbel Talassemtane unit and to the Onsar Azarhar spring (X = 524750, Y = 515600, Z = 980) emerging from Jbel Tazoute unit. The sustainability of the Farda River is ensured through this water output.

► **Azilane microtectonic station**

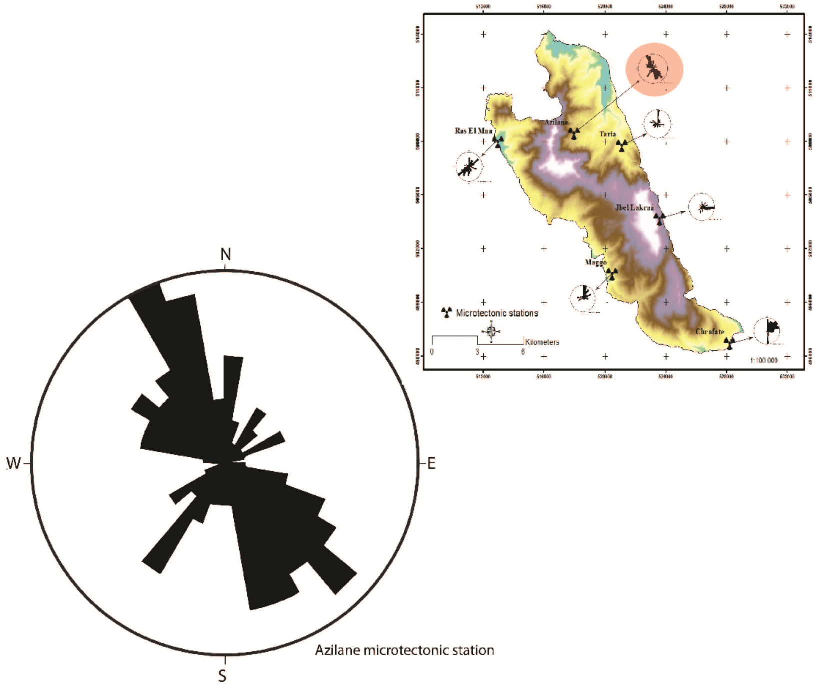

Fig. 11. Rose diagram of Azilane micrtectonic station

This microtectonic station is selected in stromatolitic dolomite with marl-limestone formations (Norian to Carnian) located western of the Azilane village. It has a very limited number of springs (3 or 4) which are relatively a low flow, but of great importance to their inhabitants. Field surveys have shown a predominance of fractures trending NNW-SSE (Fig. 11), which can lead to groundwater flow in the same direction. This direction joined what was said previously about the Jbel Lakraa unit supply by underground flow of the Jbel Tissouka unit following the direction N-S.

► **Taria microtectonic station**

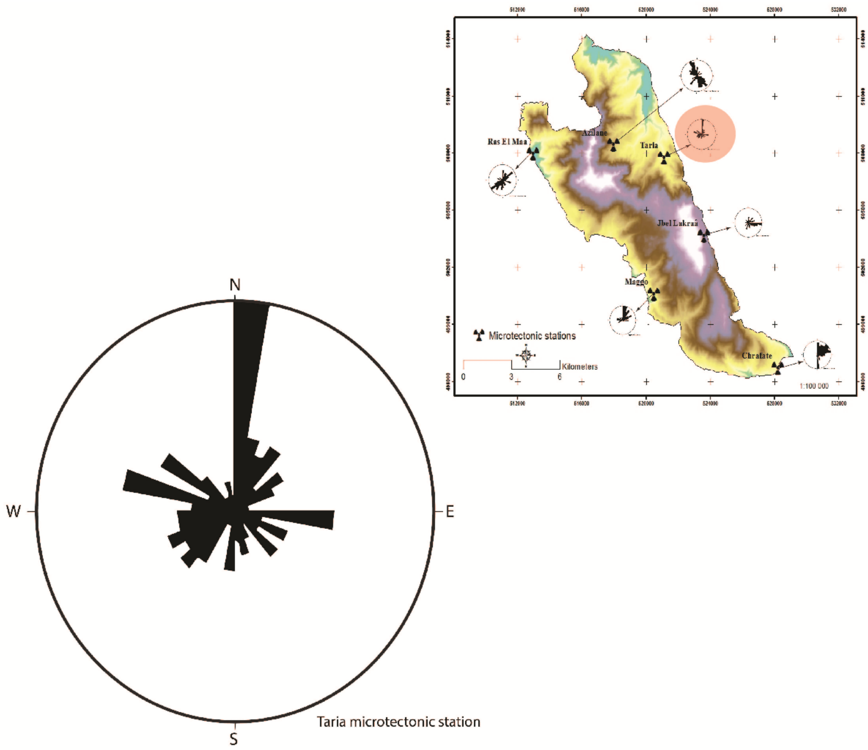

Fig. 12: Rose diagram of Taria micrtectonic station

Measures were carried out in the limestone and dolomite alternation of Rhetian age in the west of Taria village. The rose diagram of directions shows that the N-S oriented fractures are the most predominant (Fig. 12). This reassures the water recharge in Jbel Lakraâ unit from the north (Jbel Tissouka unit).

In summary, we distinguish three main directions (Fig. 13), which may explain the interconnections between the various aquifers in the study area, and a relationship with neighboring units particularly the Jbel Tazoute and Jbel Talassemtane units.

The NE-SW direction probably reflects the existence of a connection between the Jbel Tissouka and the Jbel Tazoute units. This relationship provides groundwater recharge for both units. This is marked by the sustainability of Ras El Maa spring.

The N-S fractures are responsible for the relationship between the the Jbel Tissouka and Jbel Lakraa units.

Finally, the E-W oriented fractures are responsible for water transmission between the Jbel Lakraa and Jbel Talassemtane units. The lack of water springs in the Jbel Lakraa unit suggests that groundwater flow is towards the east (Talassemtane unit). On the other hand, the sustainability of the Farda River reflects that the unit recharge of Jbel lakraâ was made by underground flow from the Jbel Talassemtane unit.

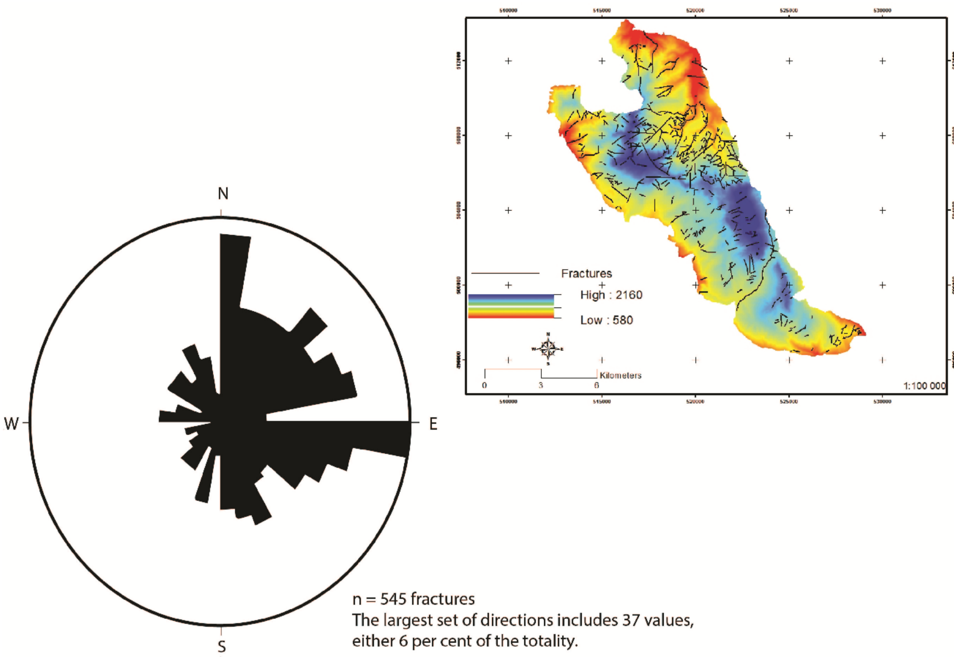

Fig. 13. Rose diagram directions of study area

4 CONCLUSION

The results of fractures analysis in the carbonate massifs in the Calcareous Dorsal in the Rif belt show the relationship of groundwater recharge in the same study area or with neighboring units. Four main directions of fractures were identified: NE-SW, NW-SE, N-S and E-W. The NE-SW oriented fractures are the most predominant and coincide with the fractures analysis of the hydrographic network, suggesting that the fracturing guides the surface streams.

With respect to the water supply, there has probably been an underground flow from Jbel Tazoute unit (NE-SW) toward Jbel Tissouka one, an interconnection between the groundwater of Jbel Lakraa and Jbel Talassemtane units (E-W) and a supply toward the south of the Jbel Lakraa unit by the groundwater flow of Jbel Tissouka unit (N-S).

REFERENCES

[1] A. Chalouan, A. Michard, K. El Kadiri, F. Negro, D. Frizon de Lamotte, J.I. Soto, and O. Saddiqi, *The Rif belt. In Continental Evolution: The Geology of Morocco, structure, stratigraphy, and tectonism of the Africa-Atlantic-Mediterranean Triple Junction*, ed. Michard, A., Saddiqi, O., Chalouan, A., and Frizon de lamotte, D., 203-302. Berlin, Springer-Verlag, 2008.

[2] L. Andrieux, *La structure du Rif central. Étude des relations entre la tectonique de compression et les nappes des glissements dans un tronçon de la chaîne alpine.* Not. Mém. Serv. Géol. Maroc, 235, 155 p, 1971.

[3] P. Olivier, *Étude géologique et structurale de la région de Jebha (Rif, Maroc). La terminaison NE de l'accident de Jebha-Chrafate*. Postgraduate thesis. University of Toulouse, 1978.

[4] M. Benmakhlouf, J. Galindo-Zaldívar, A. Chalouan, C. Sanz de Galdeano, M. Ahmamou, and A.C. López-Garrido, "Cinemática y paleoesfuerzos en la zona de falla transcurrente de Jebha-Chrafate (Rif septentrional, Marruecos)," *Geogaceta* 38, 71-74, 2005.

[5] J.G. Astruc and R. Simon-Coinçon, *Enregistrement de l'évolution climatique et tectonique par les paléokarsts (exemple du Quercy et de ses marges)*. In " Karsts et évolutions climatiques". Presses Univ. De Bordeaux édit., pp. 497-508, 1992.

[6] M. Nold, J. Uttinger and W. Wildi, *Géologie de la Dorsale calcaire entre Tétouan et Assifane (Rif interne, Maroc)*. Notes et Mém. Serv. Géol. Maroc, 300, 233p, 1981.

[7] J. Galindo-Zaldívar and F. González –Lodeiro, "Faulting phase differentiation by means of computer search on a grid pattern," *Annales Tectonicae* 2, 90-97, 1988.

[8] M.H.P. Bott, "The mecanism of oblique slip faulting," *Geological Magasine*, Paris, France, (7), XXIII, 1, 51-63, 1959.

[9] W. Wildi, "La chaîne tello-rifaine (Algérie, Maroc, Tunisie). Structure stratigraphique et évolution du Trias au Miocène," *Revue de Géologie Dynamique et Géographie Physique*, Vol. 24, n°3, p. 201-299, 1983.

[10] P. Olivier, *Évolution de la limite entre zones internes et zones externes dans l'arc de Gibraltar (Maroc, Espagne)*. PhD diss., University of Toulouse, 1984.

[11] D. Frizon De Lamotte, J. Andrieux and J.C. Guezou, "Cinématique des chevauchements néogènes dans l'Arc bético-rifain: Discussion sur les modèles géodynamiques," *Bull. Soc. Géol.* Fr., 169, 611-626, 1991.

[12] J. Tejera de Leon, *Les bassins néogènes d'avant-pays du Rif externe occidental liés à la transformante Jebha-Arbaoua (Maroc)*. PhD diss., University of Pau, 1993.

[13] R. Hlila, *Évolution tectono-sédimentaire tertiaire au front ouest du domaine d'Alboran (Ghomarides et Dorsale Calcaire, Rif septentrional, Maroc).* PhD diss., University of Abdelmalek Essaadi, 2005.

[14] A. El Gharbaoui, *La terre et l'homme dans la péninsule tingitane. Etude sur l'Homme et le milieu dans le Rif occidental*. Travaux de l'Institut Scientifique, série Géologie et Géographie Physique, Rabat, n° 15, 439 p, 1981.

[15] A. Amraoui, *Hydrogéologie de la dorsale calcaire du Rif (Maroc septentrional).* Thèse de 3ème cycle, Université J. F., Grenoble I, France, 209 p, 1988.