Recent volcanic activity and the geothermal potential of the Eastern Rif

Meryem REDOUANE[1], Faouziya HAISSEN[1], Othman SADKI[2], Mohammed RAJI[1].

[1] University Hassan II, Faculty of Sciences Ben M'sik, Casablanca, Morocco

[2] National Office of Hydrocarbons and Mines

Meryem.redouane.2015@gmail.com

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ABSTRACT

A large number of hot springs and geothermal manifestations are reported from the eastern part of the Rif belt (North of Morocco). This geothermal potential can make a significant contribution to the country's energy sector. Thus, there has been an increasing interest in prospecting this clean source to make it possible for direct use or for power generation.

Previous studies have concluded that geothermal water is hosted mainly in the Liassic sedimentary reservoir (*Barkaoui et al., 2014*). The present study aims to define the relationship (if there is any) between the recent volcanic activity in the Eastern Rif and these geothermal manifestations of the studied area.

1. INTRODUCTION

The western Mediterranean is currently the subject of many geological, geophysical and geochemical investigations. Most of geoscientists linked the zones showing geothermal gradient and heat flow exceeding 50°C/km and 100 mW/m2 respectively, to Neogene - Quaternary volcanic and neotectonic activities (*Zarhloule et al., 2007b; Barkaoui et al., 2015*).

The large geothermal anomalies occurring at depth, observed in a many boreholes in the Eastern Rif indicate that medium to high enthalpy uses are not discarded (*Rimi et al., 2010*). However, currently thermal waters in Morocco are only used for bathing, swimming and Balneotherapy purposes due to the presence of minerals.

2. GEOLOGY OF THE EASTERN RIF

The Rif belt forms the westernmost part of the alpine belt which extends along the north of Africa (with Tell and Kabylia) and continues eastward to Sicily and Calabria in southern Italy.

Three main structural domains form the Rif belt, from the North to the South: Internal zones, Flysch Zones and External Zones. Each domain is divided itself to several sub-domains.

An anomalously thinned area characterize the lithosphere and the crust (15–20 km) beneath the northeast of Morocco and extending far to the south called "Moroccan hot line" defined by *Missenard et al. 2006*. The Tertiary alkaline volcanism observed in the Rif belt, whith outcrops extending from Nador (Gourougou) to Guercif (Guilliz) and Oujda (*Hernandez, 1983 and Maury et al., 2000*) was related to this Moroccan hot line. Such volcanic activity is covering both the Atlas and the Rif domains where high magnetic anomalies were found (*Polyak et al.,1996*). Many models were proposed to discuss their origin (e.g. *Hernandez, 1983, Maury et al., 2000; Duggen et al., 2005; Missenard et al., 2006; Missenard et cadoux, 2011*), however, the relationship is still a matter of debate.

2.1 Recent volcanic activity within the area

The recent volcanism in the Eastern Morocco (Figure 1) can be divided into two groups:

- Mio-Pliocene volcanism, representing the calco-alkaline (s.s.) and shoshonitic rocks (*Hernandez, 1983*).
- Mio-Plio-Quaternary alkaline volcanism (6-0,8Ma), represented by alkaline basalts, basanites, hawaïtes and nephelinites devoided of crust contamination, extending from the Trans-Alboran zone to the Middle Atlas domain and to the Anti-Atlas. Their geochemical fingerprints are comparable to the intra-oceanic basalts suggesting the contribution of the ''so-called'' Moroccan Hot Line (*Missenard et al., 2006*), extending from the southeast of Spain to Canary Islands (*Chalouan et al., 2008*).

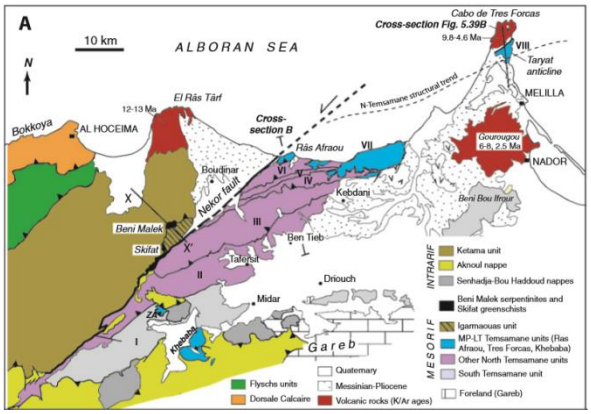

Figure 1: Structural map of the Eastern Rif (*in chalouan et al., 2008)*

Calc-alkaline magmatic activity stopped during the Serravallian in Central and Eastern Algeria. In Tunisia and Oranie/Morocco, it ended later and was accompanied by the eruption of transitional lavas, followed by Plio-Quaternary alkali basalts and basanites, the latter is actually emplaced within the African foreland and not within the Rif/Tell domains (*El azzouzi et al., 1999 & 2010; Maury et al., 2000*).

3. GOTHERMAL POTENTIAL OF THE EASTERN RIF

The northeast part of Morocco presents the highest values for both the heat flow density (80–140 mW/m^2) and the geothermal gradient (35–50 °C/km), as shows the Figure 2 and 3. The highest geothermal anomaly is located in Arekman borehole (located in Nador region). Water temperature at 650m depth reaches 93°C (*Correia et al., 2017*), the lithology is mainly volcanic (Rhyolitic and Andesitic series) (*Rimi et al., 1998 & 1999 and Bakraoui et al., 2014*).

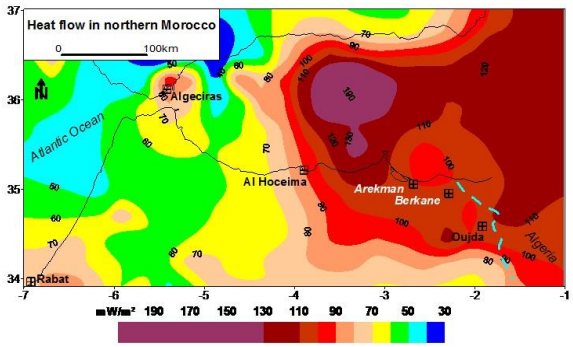

Figure 2: Detail of the heat flow density map for the northern part of Morocco (*Correia et al., 2017*)

Geodynamic studies linked the zones showing geothermal gradient and heat flow exceeding 50°C/km and 100 mW/m2 respectively, to Neogene - Quaternary volcanic and neotectonic activities. (*Barkaoui et al., 2015*)

The thermal waters are mainly hosted within sedimentary reservoirs, consisting of Liassic limestones with a thickness up to 500 m, most of them are of Na–Cl types and Ca–Mg–HCO3 types. The former results from the main influence of evaporitic rocks whereas carbonate rocks affect the latter. (*Rimi et al., 2010* and *Barkaoui et al., 2013*)

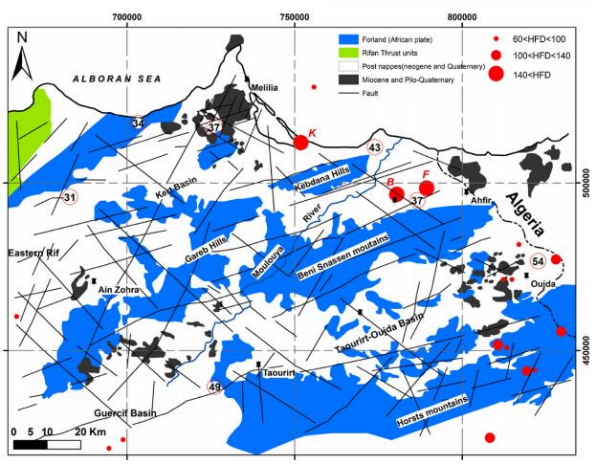

Figure 3: Simplified structural sketch map and volcanism in northeastern Morocco (after *Hernandez and Bellon, 1985; Hervouet 1985*). K: mining borehole at Kariat Arekman, B: borehole at Berkane and F: borehole at Fezouane site.

The quartz, chalcedony and Na–K geothermometers gave an average reservoir temperatures stretching from 102 °C to 122 °C, (*Rimi et al., 2012*). The silica enthalpy mixture model gave an average reservoir temperature value of about 110 °C, that value is actually higher than the average suggested from cation geothermometers, which gave a 100 °C (*Barkaoui et al., 2013*).

The geothermal energy potential of the northeastern part of Morocco is very promising: the estimated installed capacity is around 3 MW (*Rimi et al., 2012*) and it can be used in several ways other than balneotherapy and individual uses.

4. CONCLUSION

It is worth mentioning that the world's highest temperature -and perhaps most abundant- geothermal resources are associated with volcanic regions. It goes for our thoughts of what is actually happening in the Northeast of Morocco.

The future studies will help us better understanding the processes and links between the recent volcanic activity and many aspects of geothermal energy.

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