Proceedings World Geothermal Congress 2015
Melbourne, Australia, 19-25 April 2015

Progress in Understanding the Geothermal Sedimentary Basins in Northeastern Morocco

Y. Zarhloule*[1], AE. Barkaoui[1], M. Verdoya[2], V. Pasquale[2], H.Lahrach[3]

[1]Laboratory of Hydrogeology-Environment, Faculty of Sciences, University Mohamed Ist, Oujda, Morocco

[2]Dipartimento per lo Studio del Territorio e delle sue Risorse, Università di Genova, Italy

[3]Faculty of Sciences and Technology, Department of Geology, Imouzzer Street, Fes, Morocco

zarhloule@yahoo.fr

Keywords: Underground temperature, geothermal gradient, advective heat transfer, northeastern Morocco.

ABSTRACT

The aim of this paper is to contribute to the hydro-geothermal characterization of northeastern Morocco. This region is known by a large number of surface geothermal manifestations. Thermal waters are hosted within sedimentary rocks, and, in particular, the Liassic dolomitic limestones act as a reservoir. The presence of geothermal waters is closely related to important fault systems. Meteoric water infiltrates along those fractures and faults, becomes heated, and then returns to surface through hydrothermal conduits. In order to improve our knowledge about the thermal regime in northeastern Morocco, a number of thermal conductivity measurements were carried out on a set of samples representative of the local stratigraphic sequence. Temperature logs were analyzed by matching thermal data with models of vertical temperature distribution. Thermo-hydraulic parameters were calculated from the coefficients of the advective models obtained by means of the least-square fitting method. Analytical modeling of heat and water transfer involved in the deep circulation was attempted along selected hydro-geological crosssections in Oujda and Berkane region.

1. INTRODUCTION

It is well known that Morocco is an energy-deficient country. About 95.6 percent of the country's energy demand is imported. The country is heavily dependent on fossil fuel. The high price of the oil on the international market has exerted strong pressure on the country's trade balance. The government subsidies to maintain the fuel prices stability is also putting a pressure on the budget deficit. The kingdom of Morocco is producing very small volumes of oil and natural gas from Essaouira basin and small amount of natural gas from Gharb basin.

The country has a keen interest in oil shale. With resources estimated at more than 50 billion barrels, the kingdom is found in the 6th place in the top 10 global oil shale resources. However, Morocco has not yet reached the stage of industrial development, due to the characteristic of these national resources and its complexity in terms of valuation.

To face this situation, there has been an increasing interest in using renewable energy sources. In Morocco, solar energy, wind power, biomass energy, hydropower and geothermal energy are the major renewable energy resources in the future. Through its energy plan, the country aims to increase the share of its electricity installed capacity from renewables to 42% by 2020. The total renewable energy capacity is expected to be 6000 MW.

The purpose of this paper is to characterize the geothermal province of northeastern Morocco using a modeling approach. The founding results, concerning the high geothermal gradient, can act as stimulus for future deep geothermal investigation.

2. GEOTHERMAL POTENTIAL

Morocco is located at the northwestern part of the African plate. The country belongs to a key region, subject to both the shortening due to the Africa-Europe collision, and to the lithospheric processes similar to those of West African domain. In Morocco, the important number of geothermal manifestations combined with the recent volcanism, have drawn several geothermal studies (e.g., Facca 1968; Alsac et al. 1969; Rimi and Lucazeau 1987; Zarhloule 1999; Rimi et al. 2012).

Northeastern Morocco, from the eastern Rif and the Middle Atlas to the northwestern Algeria, shows a heat flow of 80 to 110 mW/m^2 [6]. This part of the country is characterized also by the highest values of the geothermal gradient reaching 50 °C km^{-1} (Zarhloule et al 2001, Rimi 1999).

In Morocco, sedimentary basins host the thermal waters. The deep circulation of the geothermal fluid is facilitated by the presence of complex fault systems (Zarhloule 1999, Rimi 1999). The Liasic aquifer, belonging to the Atlas Domain (Fig.1), is considered to be the most important geothermal reservoir in the Eastern part of the country. More than 25 hot springs with surface temperature ranging from 26 to 54 °C and flow rate equal to 40 l/s are associated with this reservoir. Figure 2 shows one of the recent borehole logging performed in the region (Barkaoui et al 2013a, Rimi et al 2012). In this well (1624/7), the measured temperature at 470 m is equal to 50 °C. The geothermal gradient begins to increase at 300 m depth from 29 to 127 °C km^{-1}. Both the upper (clay) and the lower (carbonate) section of the hole are characterized by a conductive thermal regime. The dolomitic layer in the borehole continues until 1042 m depth. The extrapolation of the thermal gradient in the lowermost section of the hole allowed the calculation of the bottom temperature which is close to 120 °C. (Barkaoui et 2013a, Rimi et al 2012).

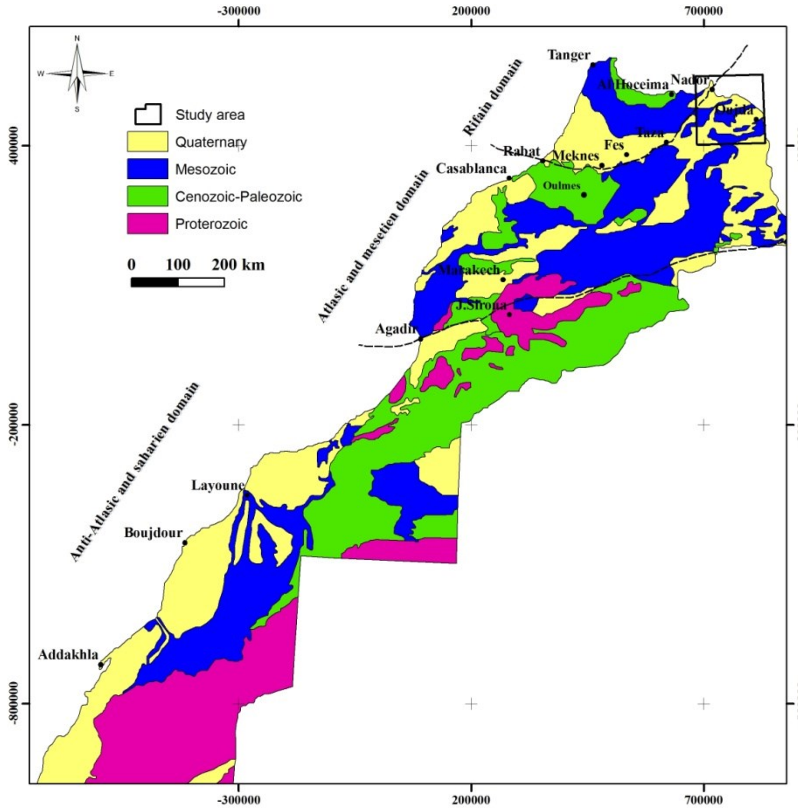

Figure 1. Main structural and geological traits of Morocco.

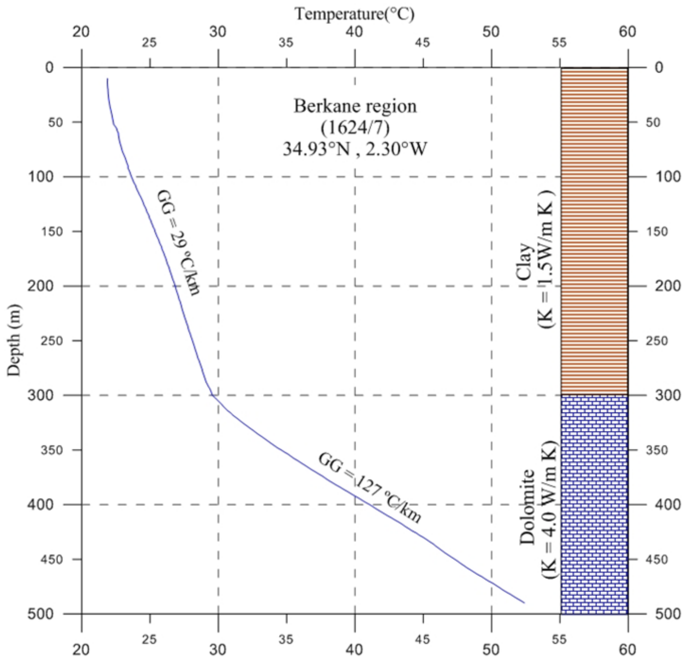

Figure 2. Temperature log of the borehole 1624/7.

3. THERMAL MODELING

The temperature distribution in flowing wells was analyzed and used in order to illustrate the high geothermal anomalies in northeastern Morocco. The information about the thermal gradient could be recovered from the temperature pattern produced by thermal loss during the fluid upwelling (Pasquale et al 2011). Besides the borehole radius *r*, the water velocity u and the thermal characteristics of the drilled formation, the pattern of the water temperature T depends on the formation thermal gradient G and a time dependent quantity f(t) that describes the response of the rock to a changing temperature in the borehole (Verdoya et al 2008, Jessop 1987).

If thermal conductivity λ is uniform and the thermal resistance between the water and the borehole walls is small, as well as the temperature difference across the boundary, the temperature of the raising flow satisfies the differential equation:

$$\frac{\partial T}{\partial z} = \frac{1}{\Phi}(G_z - T) \qquad (1)$$

where $\Phi = r^2 \mu \rho_w c_w \ f(t)/2\lambda$.

In Eq. 1, ρ_w and c_w are density and specific heat of water, respectively, and z is depth. Considering the vertical distribution of temperature to be relative to the temperature at the point z = 0, where water enters the borehole at temperature T = 0.

Solution of Eq. 1 is:

$$\Delta T = Gz - G\Phi\left[1 - e^{-Z/\Phi}\right] \qquad (2)$$

With both *z* and μ negative in the upward sense. Assuming the flow within the borehole is a constant line heat source, the factor f (t) can be expressed by means of:

$$f(t) = -0.5\mathrm{Ei}(-\varepsilon) = 0.5\left(-\ln\varepsilon - \gamma + \sum_{n=1}^{\infty} \frac{(-1)^{n+1}\varepsilon^n}{nn!}\right) \qquad (3)$$

Where $\mathrm{Ei}(-\varepsilon)$ is an exponential integral with $= r^2/4\chi\, t$, and γ is the Euler's constant, which is approximately 0.5772. In practical use, factor Φ is well approximated by:

$$\Phi = r^2 \mu \rho_w c_w \ (-\ln\varepsilon - \gamma)/4\lambda \qquad (4)$$

that applies when ε is smaller than 0.001, i.e., for conventional values of thermal diffusivity χ of the order of 10^{-6} m^2 s^{-1}, borehole radius of a few centimeters and time ***t*** of a few days since the beginning of water flow.

3.1. Thermal log analysis

The analysis procedure of temperature logs consists in matching thermal data with the foregoing models of advective heat transfer. The model that was used was derived from equation (2) and was expressed in a simplified form for curve fitting.

$$\Delta T = a_1 z - a_1 b_1\left[1 - e^{-Z/b_1}\right] \qquad (5)$$

The model coefficients a_1 and $b_1$obtained by means of the least-square method contain information about the thermal and hydraulic characteristics of the drilled formations.

Table 1 shows the result of the laboratory measurements that were carried out on a set of samples representative of the stratigraphic sequence of the northeastern Morocco (Fig. 3). All measurements were performed in the Department for the Study of the Territory and its Resources (DIPTERIS), University of Genova, in Italy. Dry and water saturated conditions were applied to samples to assess their porosity. The carbonatic lithotypes forming the deep aquifer show a relatively high thermal conductivity. Values range from 1.37-3.44 W/(m/K) in limestones to 3.5-5.01 W/(m/K) in dolomites.

The three boreholes used in the framework of this study are characterized by upward flow of hot water, coming from a deep geothermal reservoir, mixed with the cold water from the adjacent aquifers (Figs. 4a, b, c). Boreholes 159/12 and 2952/12 were drilled for water investigation while Kariat Arkman is known to be a mining hole. The three boreholes are artesian with relatively constant rates. Temperature measurements were carried out using thermistor probe connected to a cable that goes down. An ohmmeter measure the resistance of the thermistor every 2-m. To guarantee the equilibrium of the thermistor with the environment, it was left for a few minutes in each position before measuring. The thermistor have a low calorific capacity and can adapt easily to the temperature of the formation. Besides temperature profile of each artesian borehole, Fig. 4 also shows the stratigraphic details and the best fitting T–z curves obtained with the model of advective heat transfer.

For the borehole 2952/12 (Fig. 4a), the carbonatic formation at the hole bottom, below 594 m, are at the origin of water flow. The temperature calculated by means of the model of advective heat transfer fits the observed thermal profile for a formation thermal gradient of 56°C/Km.

Table 1. Results of laboratory measurements of thermal parameters (see Fig. 3 for sample locations) λ is thermal conductivity (in W m^{-1} K^{-1}), χ is thermal diffusivity (in m^2 s^{-1} x 10^{-6}), *sd* is standard deviation, *n* is the number of measurements. Subscripts *d* and *w* indicate dry and water saturated conditions, respectively.

Lithotype	Age / sampling area	Sample code	*n*	λ_d	*sd*	λ_w	*sd*	χ_d	*sd*	χ_w	*sd*
Microdiorite	Paleozoic/ A'	M1	3	1.82	0.02	2.15	0.01	0.902	0.02	0.654	0.01
	Plio-Quaternary / G'	M2	3	1.83	0.02	2.13	0.02	0.963	0.01	1.086	0.01
	/ G'	M11	4	2.53	0.01	2.37	0.03	1.176	0.01	1.131	0.01
Granite	Caroniferous / D'	M13	3	1.79	0.03	2.1	0.12	0.963	0.11	1.104	0.02
Pyroxene basalt	Plio-Quaternary / B'	M8	3	2.16	0.05	2.53	0.22	1.061	0.05	1.16	0.03
	/ B'	M12	4	1.04	0.02	2.08	0.04	0.56	0.01	0.914	0.02
Schistose basalt	Plio-Quaternary / B'	M5	3	1.73	0.32	2.19	0.4	0.897	0.02	1.118	0.02
Trachyte	Eocene / D'	M9	3	1.65	0.05	1.58	0.05	0.837	0.02	0.769	0.07
Perlite	Plio-Quaternary / G'	M4	3	1.05	0.03	1.06	0.03	0.503	0.01	0.5	0.03
Mestigmerite	Eocene / D'	M6	3	1.73	0.08	-	-	0.824	0.02	-	-
Schist	Devonian / F'	E1 (parall.)	3	2.72	0.03	-	-	1.272	-0.04	-	-
		E1 (normal)	3	1.94	0.19	-	-	0.942	-0.06	-	-
Green schist	Devonian / F'	E2	3	2.23	0.04	-	-	0.904	-0.16	-	-
Pyrite green schist	/ G'	M10	3	1.89	0.11	1.89	0.1	0.874	0.03	0.855	0.03
Slate	Devonian / F'	M14	3	2.49	0.15	2.37	0.14	1.195	0.05	1.171	0.05
Limestone	Lias / A'	S5	3	1.37	0.03	2.02	0.05	0.752	0.01	1.013	0.02
	/ A'	S7	3	2.31	0.09	2.33	0.09	1.132	0.08	1.117	0.07
	/ E'	E11	3	2.49	0.03	-	-	1.12	0.02	-	-
	/ F'	E4	3	3.03	0.05	-	-	1.347	0.02	-	-
	/ F'	E5	1	3.44	-	-	-	1.543	-	-	-
	/ F'	E6	1	2.87	-	-	-	1.289	-	-	-
Dolomite	Lias / F'	E7	1	3.5	-	-	-	1.547	-	-	-
	/ A'	E8	1	4.11	-	-	-	1.845	-	-	-
	/ D'	E9	1	5.01	-	-	-	2.193	-	-	-
	/ A'	E12	1	4.69	-	-	-	2.057	-	-	-
Conglomerate	Carboniferous / C'	S8	4	4.95	0.31	5.44	0.34	2.266	0.03	2.405	0.04
	/ F'	E3		2.27	-	-	-	1.091	-	-	-

The thermal profile of the borehole 159/12 (Fig. 4b) is explainable with two main inflows entering the hole from the fractured limestone below 485m and from layer of conglomerate at about 130 m depth with colder water. The curve matching procedure gives a volumetric flow of 2000 cm^3/s for the deepest section and 1000 cm^3/s for the 20–130 m depth interval. The corresponding formation thermal gradients in the two sections are 54 and 29C°/Km, respectively.

The borehole situated at Kariat Arkman intercepted volcanic rocks (Rhyolite) at the bottom of the well (Figure 4c). The best fitting to the T–z data available for the section (50–678 m depth) allows the inference of a thermal gradient of 90 °C/km and a volumetric flow of 2000 cm^3/s.

Table 2 summarizes the results of the curve fitting procedure for these boreholes, together with the thermal conductivity values used for calculations. It must be stressed that there may be some uncertainties in these determinations. Besides the uncertainties lying within the basic assumptions of the fitting method, the inferred formation thermal gradient may contain, in principle, also the transient signal of the recent climatic change which may distort the temperature log in northeastern Morocco (Barkaoui et al 2013b). However, this does not appear a major concern, because thermal profiles were analyzed only below 20 m depth which can reduce the recent climatic effects.

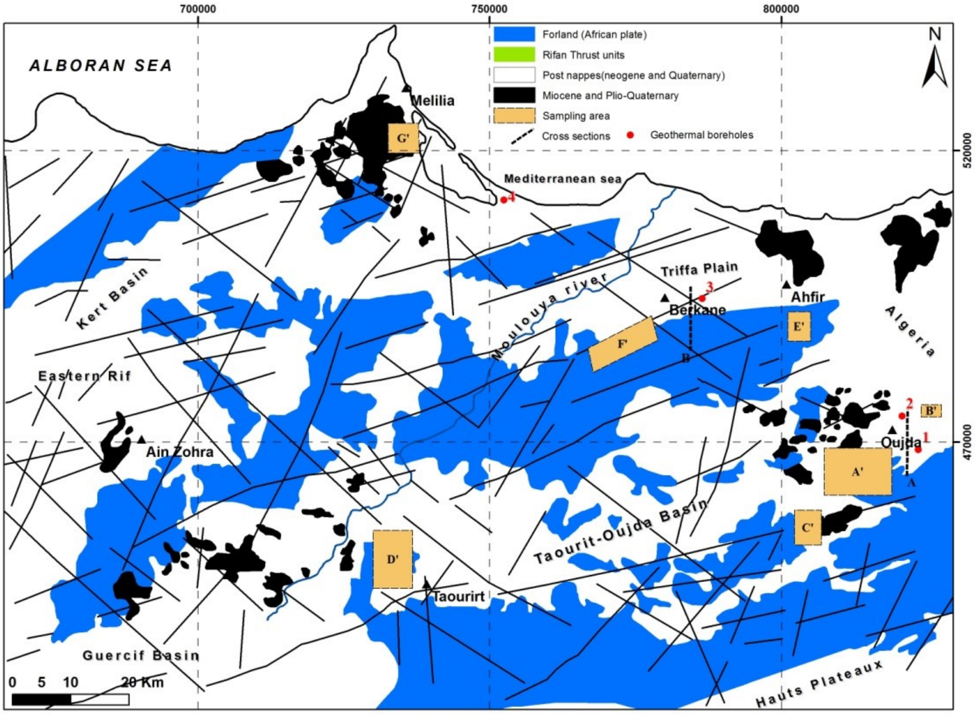

Figure 3. Simplified structural sketch map and volcanism in northeastern Morocco, (after Hernandez, 1983; Hervouet, 1985, modified). 1-2952/12 2-BenKachour(159/12) 3-Kariat Arekman.

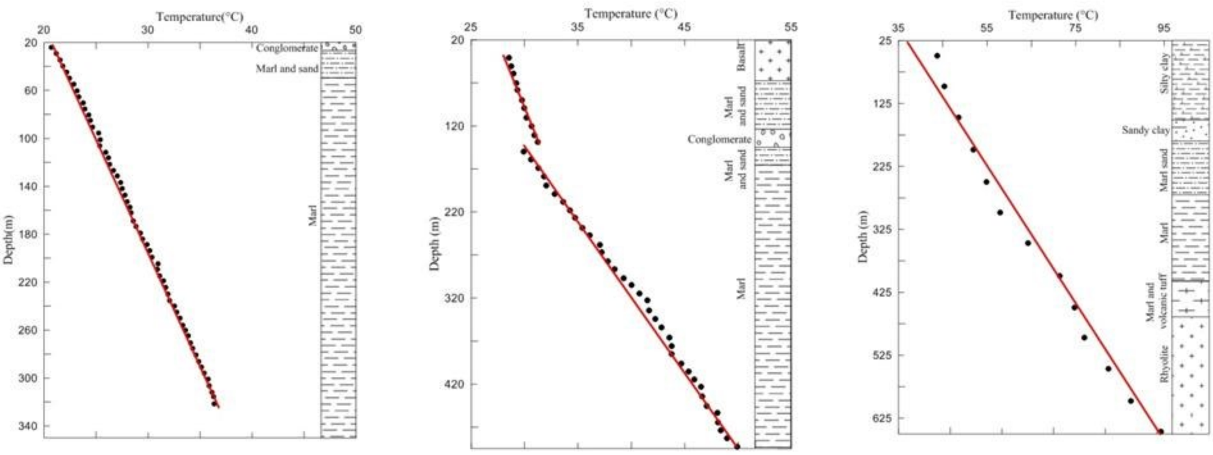

Figure 4. Temperature–depth data and stratigraphy of boreholes 2952/12 (a) Ben kachour (159/12), (b) Kariat Arkman, (c) Continuous line is the best fitting curve for the model of advectif heat flow.

Table 2. Borehole data: (*D*): Maximum depth, (*RTL*): Depth range of temperature logs, (λ): Thermal conductivity, (G): Geothermal gradient and (Q_w) is the volume flow of the upwelling water in the artesian boreholes. (see Fig. 3 for hole location).

Borehole	Code	D (m)	RTL (m)	λ (W/m K^{-1})	G (mK m^{-1})	Q_w(cm^3 s^{-1})
2952/12	1	700	20-320	2	56	800
Ben Kachour *(159/12)*	2	643	20-130	2.5	29	1000
			140-490	2	54	2000
Kariat Arekman	4	681	50-678	2.1	90	2000

3.2. Model of water circulation

Most of the information we have on the geothermal gradient and the terrestrial heat flow derives from thermal measurements in drill-holes, which are often shallower than a few hundred meters. Within this depth range, hydrogeologic and topography effects can more or less influence the temperature–depth logs, and the common assumption of a steady-state conductive thermal regime does not hold. Analytical modeling of heat and water transfer involved in the deep circulation was attempted along selected hydro-geological cross sections including the most important hot springs in northeastern Morocco (Ben kachour and Fezouane). In hydrogeological regime the water circulating through the aquifers has a longer and continuous route than the meteoric infiltrated water, and it can take a centuries compared to the seepage water. So it seems clear that the thermal exchanges between the water and surrounding land are important. In our case, many assumptions were made to fit the borehole thermal record: we considered the thermal reservoir as confined aquifer with uniform porosity σ, heated from below by the terrestrial heat flux q_0 and losing heat by conduction through the overlying cover with thermal conductivity.

Figures 5 and 6 represents the selected profiles (A and B) for thermal modeling (see the position in the Fig. 3). The reservoir thickness is constant for Ben kachour and increases in Fezouane from the south to the North area. The thermal conductivity of the liasic aquifer was measured in laboratory and the value of 2.5 W/mK was used as an average value. NorthEastern Morocco is characterized by a high geothermal regime; the heat flux q_0 used for modeling is equal to 115 mW/m^2. The values of the aquifer porosity and water velocity are respectively 10% and 1.10^{-9} m/s. The profiles A and B were divided into many sections according to the water flow direction.

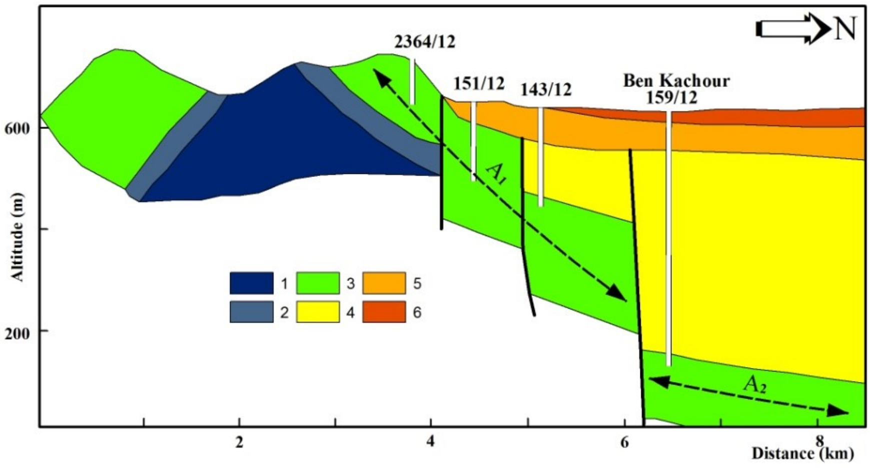

Figure 5. Geological cross-section A (see Figure. 3 for location). 1) Paleozoic schists and quartzites; 2) Permo-Triassic red marls and dolerites; 3) Liassic dolomitic limestones; 4) Miocene marls; 5) Quaternary basalts; 6) Alluvial deposits. A_1 and A_2 indicate the water flow direction.

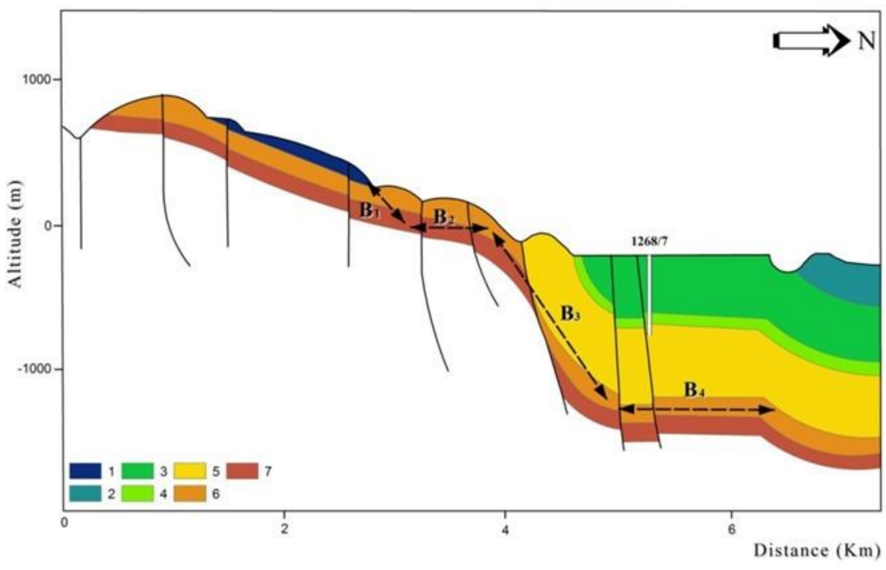

Figure 6. Geological cross-section B (see Figure. 3 for location). 1) Quaternary deposits; 2) Late Jurassic limestones; 3) Late Jurassic green marls; 4) Liassic limestones and marls; 5) Early Jurassic limestones; 6) Triassic doleritic-basalt lava flows; 7) Paleozoic schists and quartzites. B_1,B_2,B_3 and B_4 indicate the water flow direction.

In the first profile "A" situated in the region of Oujda (Fig. 5), water penetrates from the surface with an inclination α through the outcrops of the Liasic limestones in the southern part of the Angad plain at Jbel Hamra. Water continues flowing downward through the same formation that becomes deeper going to the North. Water temperature increases as a linear function but will remain colder than the ground. The temperature of the water is calculated by the following equation:

$$T(x) = T_i + \frac{x q_0 \tan\alpha}{\lambda + C_w \rho_w \sigma v h \tan\alpha} \quad (6)$$

Parameters with values are explained in Table 3.

Table 3. Parameters used for groundwater circulation modeling for Ben kachour (cross section A) and Fezouane (cross_section B).

Parameters			A_1	A_2	B_1	B_2	B_3	B_4
Surface temperature	T_0	(°C)	18	18	18	18	18	18
Horizontal Distance	x	(m)	3120	500	125	200	2175	2648
Basal heat flux	q_0	(W/m^2)	0.115	0.115	0.115	0.115	0.115	0.115
Thermal conductivity	λ	(W/mK)	2.6	2.6	2.6	2.6	2.6	2.6
Aquifer porosity	σ	(%)	0.10	0.10	0.10	0.15	0.10	0.10
Infiltration rate	υ	(m/s)	1.10^{-9}	1.10^{-9}	$0.5.10^{-9}$	$0.1.10^{-9}$	$0.1.10^{-9}$	1.10^{-9}
Aquifère thickness	h	(m)	200	200	200	250	700	1000
Water density	ρ	(Kg/m$^{3)}$	1000	1000	1000	1000	1000	1000
Specific heat of water	c	(J/Kg K)	4186	4186	4186	4186	4186	4186
	a	(m)	700	50	120	-	1750	-
	d	(m)	3120	500	125	-	2500	-
Tangent of the inclination angle	tanα = a/d		3.10^{-3}	1.10^{-3}	16.10^{-3}		12.10^{-3}	
Aquifer depth from the ground surface	Z	(m)	-	-	-	150	-	1800

Figure 7 represents the temperature evolution for the cross section A versus the horizontal distance traveled by water. The temperature obtained in the end of the profile (x=3620m) is around 50°C. This value corresponds also to the measured surface temperature in Ben kachour hot spring.

The second profile, B, was divided to 4 sections according to the water flow direction (Fig. 6). Sections B_1 and B_3 representing downward groundwater flow, the water temperature is calculated using the Eq. 6. Temperature for the two sections increases as a linear function with the traveled horizontal distance. Sections B_2 and B_4 characterize a horizontal groundwater flow, in this case, the water will absorb a certain number of calories provided by the heat flow coming from the Earth's interior, the water temperature is calculated using the following equation :

$$T(x) = T_u + (T_i - T_u)\exp\left(\frac{x\lambda}{C_w \rho_w \sigma v h z}\right) \quad (7)$$

$T_u = T_0 + q_0(z/\lambda)$ is the temperature at depth z unperturbed by water flow.

Figure 8 represents the temperature evolution for the cross section B versus the horizontal distance traveled by water. The obtained temperature in the end of the cross section (x=5148m) is around 52°C. This value is higher than the measured temperature in Fezouane Hot spring (37°C) .This result can be explained by mixing of the ascending water with colder fluids from the relatively shallower aquifer.

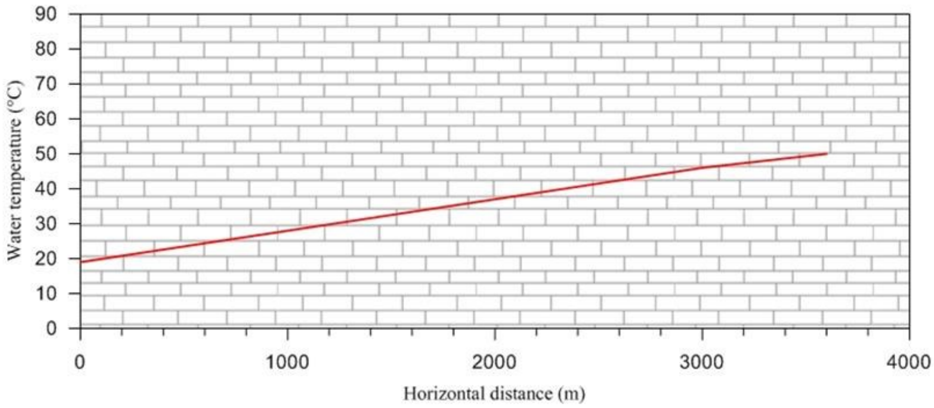

Figure 7. Temperature as a function of horizontal distance within the carbonatic aquifer (Jurassic limestone) along cross-section A. Assumed parameters are: $\lambda = 2.3$ $Wm^{-1}K^{-1}$, $\rho w = 1000 kg\ m^{-3}$, $Cw = 4186\ JKg^{-1}K^{-1}$, $\sigma = 10\%$, $v = 1.0 \times 10^{-9} ms^{-1}$.

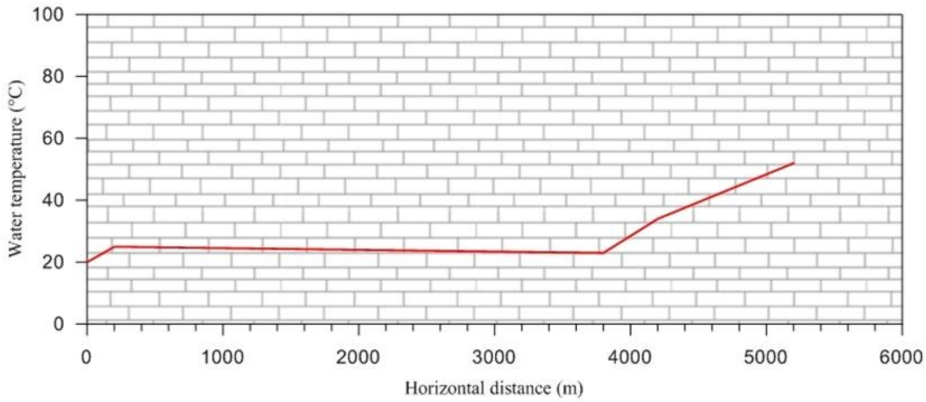

Figure 8. Temperature as a function of horizontal distance within the carbonatic aquifer (Jurassic limestone) along cross-section B. Assumed parameters are: $\lambda = 2.0\text{-}2.3$ W $m^{-1}K^{-1}$, $\rho w = 1000 kg\ m^{-3}$, $Cw = 4186\ JKg^{-1}K^{-1}$, $\sigma = 10\%$, $v = 1.0 \times 10^{-9} ms^{-1}$.

4. CONCLUSION

Northeastern Morocco is considered as a promising geothermal province. Geothermal water is hosted mainly in the Liasic sedimentary reservoir. Different authors tried to estimate the real formation temperature. In this study a number of thermal conductivity measurements were carried out on a set of samples representative of the stratigraphic sequence of the study area. The carbonatic lithotypes forming the deep aquifer show a relatively high thermal conductivity. Values range from 2.0-3.1 W/(m K) in limestones to 4.6-5.0 W/(m K) in dolomites. Temperature depth profiles from boreholes characterized by upward flow of hot water fed by the carbonatic formation are available to 350-500 m depth. Temperature logs were analyzed by matching thermal data with models of vertical temperature distribution which incorporate both heat and mass transfer. Thermo-hydraulic parameters were calculated from the coefficients of the advective models obtained by means of the least-square fitting method. The inferred temperature gradient above the advectively perturbed carbonatic formation exceeds 50 C/km, thus locally boosting the heat-flow density to values larger than 100 mW/m^2. Analytical modeling of heat and water transfer involved in the deep circulation was attempted along Fezouane and Ben kachour cross-sections. The results show that temperatures of the deep aquifer are compatible with a topographically driven flow in the carbonatic formations down to 600-1500 m depth, under conditions of enhanced geothermal gradient.

REFERENCES

Alsac, A., Cornet, G., Destombes, T.P., Hentinger, R., Lavigne, J (1969) Etude géothermique du Maroc oriental. Rapport inédit B.R.G.M, n°69, 90 p,.

Barkaoui AE., Zarhloule Y., Rimi A., Boughriba M., Verdoya M, Bouri S (2013a) Hydrogeochemical investigations of thermal waters in the northeastern part of Morocco. Journal of Environmental Earth Sciences. DOI 10.1007/s12665-013-2582-x

Barkaoui AE., Correia A., Zarhloule Y., Rimi A., Carneiro JF., Boughriba M., Verdoya M (2013b) Reconstruction of remote climate change from borehole temperature measurement in Eastern part of Morocco. Journal of climatic change. DOI 10.1007/s10584-012-0638-7.

Facca, G (1968) Les possibilités géothermiques du Maroc. Note SEGM, no. 14, inédit,.

Jessop AM (1987) Estimation of lateral water flow in an aquifer by thermal logging. Geothermics 16:117–126.

Pasquale.V, Verdoya.M, Chiozzi.P (2011) Groundwater flow analysis using different geothermal constraints: The case study of Acqui Terme area, northwestern Italy, Journal of Volcanology and Geothermal Research 199.,38–46

Rimi, A., Zarhloule, Y., Barkaoui, A.E., Correi, A., Carneiro, J., Verdoya, M., Lucazeau, F (2012) Towards a de-carbonized energy system in north-eastern Morocco: Prospective geothermal resource. Renewable and sustainable energy reviews. 16, 2207–2216.

Rimi, A (1999) Variations régionales du flux géothermique au Maroc, application. Thèse de Doctorat ès Sciences, Univ. Mohammed V, Fac Sci Rabat, 154 p.

Rimi, A., Lucazeau, F (1987) Heat flow density measurements in northern Morocco. J Afr Earth Sci 1987;6(6):835–43,

Verdoya M, Pasquale V, Chiozzi P (2008) Inferring hydro-geothermal parameters from advectively perturbed thermal logs Int J Earth Sci (Geol Rundsch) 97:333–344 DOI 10.1007/s00531-007-0217-8

Zarhloule, Y., Lahrach, A., Ben Aabidate, L., Bouri, S., Boukdir, A., Khattach, D (2001) La prospection géothermique de surface au Maroc: hydrodynamisme, anomalies géothermiques et indices de surface. J Afr Earth Sci;32:851–67.

Zarhloule, Y (1999) Potentialités géothermiques du Maroc: traitement intégré par les températures profondes et indices de surface. Doctorat d'Etat, Fac Sci Oujda, Maroc.