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Study of the thermal sources of the Bellezma mounts, eastern Algeria

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ABSTRACT/RESUME

Abstract: *The Bellezma Mounts, located in the northeast of Algeria, present cases of hydrothermalism with temperatures ranging between 30° C and 63° C. For the evaluation of the thermal potential of this dissymmetrical mountains chains (often rectified in the South, where Cretaceous and Jurassic limestones emerge), we used a multidisciplinary approach, notably geology, geophysics, hydrogeology, hydrochemistry and the isotopic tool. Hydrogeological investigations have shown that these carbonate formations can offer an important aquifer potential. From the hydrochemical point of view, the warm waters of the Bellezma mounts are characterized by the presence of three different chemical facies: the sulfated-sodium, the bicarbonate-calcium and the chloride-calcium. Evaporite terrigenous origin is attributed to sodium, chlorides and sulphates of these waters. The thermal waters circulation in this region, at great depths in the crystallophyllian formations and the carbonate ones, in contact with terrigenous salt formations, could be responsible of the salinity characterizing these waters, in some places. Geothermometry has shown that these thermal waters acquire a high temperature in their original tanks coming from a depth ranging from 1100 to 2600 m through a fault system that affects the basement. The use of the isotopic tool has shown that the thermal waters of this region are ancient and that their recharge is weak or non-existent.*

I. Introduction

From the first age of humanity, hot waters were sought by man to treat himself. Nowadays, in addition to therapeutic virtues, thermal waters provide new interest in humans and their hydrothermal systems represent a clean energy resource in perfect complicity with the environment. The Bellezma Mountains contains several thermal points and represents a geothermal set, the water temperature of which varies between 30 ° C and 63 ° C. This work is proposed, through geological, geophysical, geochemical and geothermometric tools, to make a contribution which will allow better understanding of the geochemical mechanisms responsible for this chemical categorization of these hot points.

Located at 200 km south-east of Algiers and 100 km to the southwest of Constantine (Figure 1A), the Bellezma mountains limit to the East the Hodna basin in the Saharan Atlas convergence zone extended by the Auresian the south and of the Tell Atlas extended by the North Hodna mountains. This massif looks like a vast bulge, surrounded at an altitude of 800 m by a gently undulating plain, formed of staggered and more or less extensive areas.

Several reliefs highlighted by ridges lines substantially oriented E-W rising in altitude to the East, are individualized in this massif (Figure 1B), They consist of the Djebel Bou Ari-Bou Rhioul, Kef Reched, Refaâ (highest point of the Bellezma mountains 2178 m), Kef Sefiane-Taoucherit-Ech Cheffa complex and Kef Aïssa complex, the Djebel Tabaga-Ketef Deba (1270 m).

The Bellezma Mountains are characterised by a semi-arid Mediterranean climate, with two distinct seasons: Winter, which is a cool and wet season with snowfall and sudden frosts, and summer, a hot and dry season. The intermediate seasons can more or less have some rain depending on the year and on the intensity of atmospheric disturbances.

Forming a part of the northern side of the Saharan Atlas, the Bellezma Mountains record a total annual rainfall of 400 to 600 mm; with summits receiving more than 600 mm [28]. The annual average temperature varies between 10 ° C and 15 ° C with a minimum average value corresponding to January (2 ° C) while the maximum mean value (25 ° C) coincides with the month of August

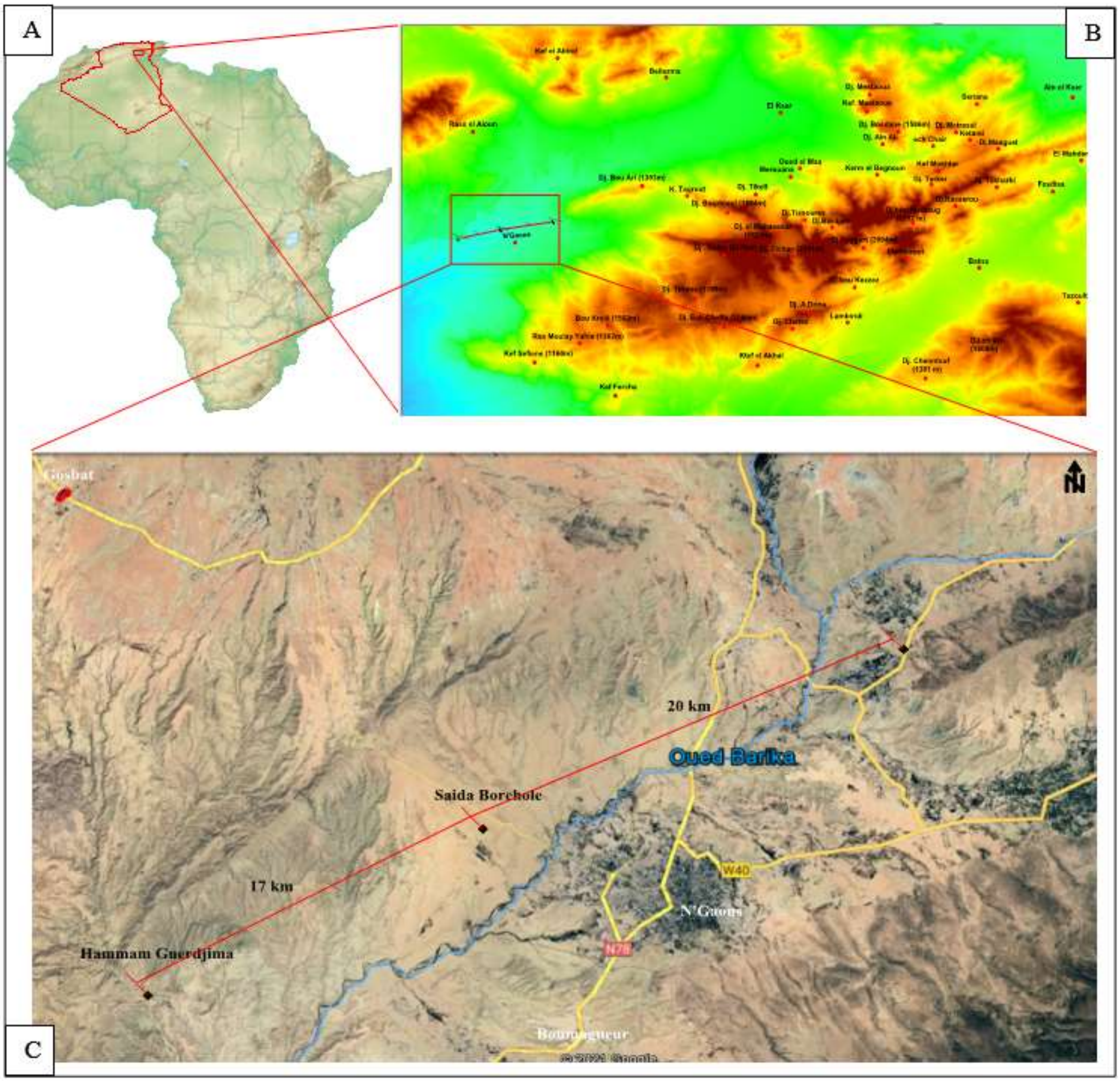

Figure 1. *Location of the study area*

*A: Whole disposition. B: Highlights of the Bellezma mountains. C: Map of location of: Saïda Borehole, Kouchbi Source and Guerdjima Hammam, emphasizing the alignment of the three sources in the direction 65**N** over 20.17 km*

II. Materials and methods

II.1. Field Expertise

The Saida borehole (B) is located in the north-west of the city of N'gaous, at the following geographical coordinates: Latitude 35 ° 34 '059 "N, longitude 005 ° 33 '792 "E, Altitude 688 m (Figure 1C). This artesian borehole with a depth of 1000 ml and which delivers 13 L s^{-1} dates back to the years 84/85 for the benefit of the agricultural services of the wilaya (region) of Batna. A large number of bathers and spa guests enjoy its hot water (63 °C) characterised by therapeutic properties.

The Kouchbi source (S1) is located in the Southeastern capital of the municipality of Ouled Si Slimane (Figure 1C) on the wilaya road N°16. Its

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geographic coordinates are Latitude 35 ° 36 '308 "N, Longitude 005 ° 40' 493" E and Altitude 850 m. This source delivers 5 l s^{-1} but can be influenced by borehole that capture the same aquifer, such as the artesian borehole Oued Chaâire of 1200 m distant from the latter with a depth of 238 m and a flow rate of 30 L s^{-1}.
The Guerdjima Hammam (S2) situated at the north-west of the municipality of Boumagueur (Fig. 1C) within a distance of about five (05) Km. Its geographical coordinates are: Latitude 35 ° 31 '991 "N, Longitude 005 ° 28 '704 "E and Altitude about 655 m. With a flow rate of 5 L s^{-1}, this Hammam is operated with an average frequency of about twenty (20) baths per day; the existing infrastructure of which is a building of two compartments and two living quarters.

II.2. Geological Setting

This region has been the subject of several geological studies, in particular those carried out by de Glaçon (1956), Bellion (1972), Guiraud (1973), Vila (1980) and Bureau (1986). The area under study belongs to the Alpine chain constituting the backbone of the mountains of all northern Algeria to the north of the Saharan flexure. At the regional level, to the East, the mountains of Bellezma limit the Hodna basin in the convergence zone of the Saharan Atlas extended by the Aures in the South and the Tell Atlas extended by the mountains of the North Hodna. This is a result of asymmetric mountains extension, often picked up in the South, where limestone of Lower Cretaceous and Jurassic outcrop. In the Bellezma mountains, with the exception of alluviums from the bottom of the valleys, there are many geological formations which stretch according to a general southwest direction, northeast in perfect concordance with the major atlas accident. These training courses mainly belong to the secondary including sandstones, marls, clays and mainly massive limestones, and dolomies. Thus, water resources are essentially located in carbonate training therefore in karst aquifers. These sometimes-hot waters emerge on the surface thanks to tectonic accidents, to give thermal baths, which are used for therapeutic purposes, by the different thermal stations. It is clear that the chemistry of groundwater depends, particularly, on the lithological composition of the layers crossed and on the contact time, consequently the elements, which are there in solution, are informative on the nature of the aquifer crossed. [9].

II.2.1 The N'gaous area

Geologically, the N'gaous region occupies the western part of the Batna Bellezma Mountains. It consists of a pleated structure of a substantially direction EW intensely fractured by accidents of ENE-WSW and NW-SE. It is formed by a large anticline EW whose heart is Turonian mostly carbonated and covered at the periphery by a marine Miocene whose base is conglomerate. This structure is a very important karstic massif by its lithological nature (limestone-dolomite-sandstone) and by its fracturing multidirectional network, hence its importance from the hydrogeological point of view. This structure is tectonically very affected by a network of sub-orthogonal accidents of an EW (N90°) ENE-WSW (N80°) and NW-SE (N110-130°) direction touching all the formations including the Miocene and indicating the posteriority of the tectonic phase responsible for this intense fracturing. This broad anticline N90° axis ends in the west, plunging into the Quaternary basin, which forms the beginning of Hodna basin. It is worth to note that these features (faults) occurred probably in different times and in different ways depending on whether the deformation regime is compressive (middle to upper Eocene - Late Miocene) or extensive (Oligocene) [8,21,15, 33].
The directional rosette of the N'gaous region lineaments (Figure 2) shows maxima representing the predominant classes. Three significant lineament direction families are highlighted. They are classified in order of importance as follows:

- EW Family (N80° -N100°) predominates;
- NS family (N170° -180°);
- Family NE-SW (N40° -N70°).

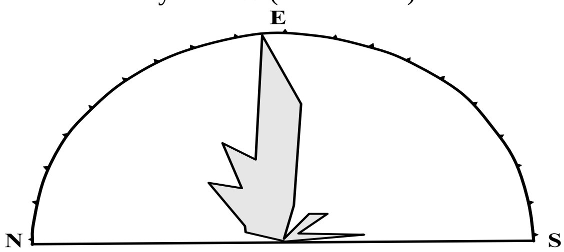

Figure 2. *Directional lineaments rosette of N'gaous region (Authors).*

II.2.2 The Gosbat region

The Gosbat is located to the northwest of N'gaous, at the limit of three paleogeographic areas belonging to different tectonic domains, namely the Batna Bellezma Mountains, the Hodna Mountains and the Constantine region Mountains. It is a chaotic with a rugged terrain area; consisting essentially of marl, clay, limestone and dolomite dating from the Jurassic-Cretaceous to the Tertiary, a fact that reflects the complexity of the geological history of the latter. It is also characterized by the presence of relatively unobstructed geological cornices formed by metric dolomite rocks banks, of a brown colour, interspersed with marly levels, highlighting combs, and by the presence of tectonic indices such as Trias formed of gypsum, dolomite and secondary gaps. These latter materialize accidents that are probably at the origin of the presence of hot springs. Thus, the Triassic Koudiat El Hammam (which highlights the major accident in NW-SE direction and continues until Khala Jebel Ain Touta) is probably responsible for the emergence of the Guerdjima hot spring in the foothills of Jebel Bou - Ari in favour of a set of accidents Northeast South west direction. [8, 21, 33].

The directional rosette lineaments of the Gosbat region (Figure 3) shows maxima representing the predominant classes. Four significant lineament direction families are highlighted. They are in order of importance as follows:

- NS Family (N0° -10°), which predominates;
- EW Family (N80° -N90°);
- Family NE-SW (N40° -N50°);
- Family NNW-SSE (N160° -170°).

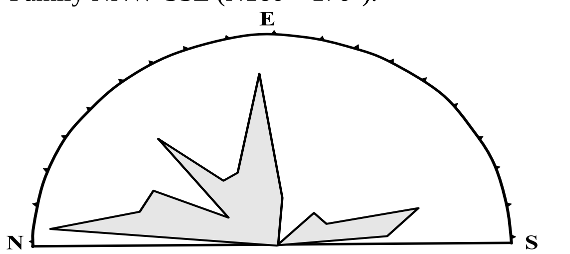

Figure 3. *Directional lineaments rosette of Gosbat region (Authors).*

II.2.3 The region of Ouled Si Slimane

This region is located to the northeast of the N'gaous sheet to the southern limit of Ras El Ayoun. It consists of an anticline whose axis is EW. The north side of the massif is characterized by rafters plunging to the north, indicating intense erosion that prevailed in the region during the Quaternary. The Kouchbi source that appears due to a faults system and the development of a karst system is located at the northern limit of this mountain in the alluvial terraces formed of Quaternary terrains. It emerges in sub-horizontal limestone benches, rich in fossils (oysters), of light colour and metrics. These limestones are affected by a diaclase network of a sub-orthogonal direction, filled with calcite. The sector shows a discontinuity in the extension of the different hills and altitude difference between the hills, highlighting the likely presence of hidden accidents that are, probably, at the origin of this source. However, this source can dry up for it depends on weather conditions. [8, 21, 33].

The directional rosette of the lineaments in the region of Ouled Si Slimane (Figure 4) shows maxima that represent the dominant classes. Three significant lineament direction families are highlighted. They are in order of importance as follows:

- Family NNW-SSE (N140° -160°), which predominates;
- EW Family (N80° -N90°);
- Family NE-SW (N40° -N60°).

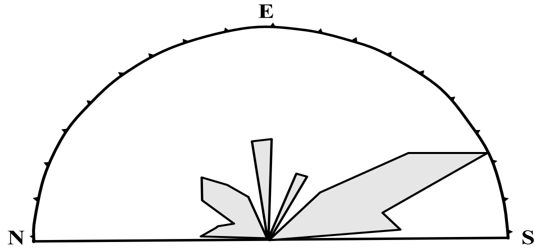

Figure 4. *Directional lineaments rosette of Ouled Si Slimane region (Authors).*

II.3 Geophysical Background

A geophysical investigation by electrical prospecting campaign conducted to reach three vertical electrical sounding (SEV) at the thermal springs in question to clarify, from measurements made from the ground surface, the permeability of the underground and deduce the indications of its constitution.

The principle of electric prospecting consists in injecting into the ground a current of intensity I continuously between two extreme electrodes A and B (transmission line) and measuring the potential difference V generated between two middle electrodes M and N (reception line). The intensity I is displayed on an ammeter and the potential difference V is measured on a potentiometer. The four electrodes are arranged in one row and symmetrically with respect to the center of the device.

Measuring the apparent resistivity is carried out by progressively separating the electrodes A and B from the center, thus increasing the depth of investigation to the vertical of the measuring station, then we report on a bi-logarithmic diagram the apparent resistivities calculated depending on the length AB / 2 which constitutes the characteristic curve of each carried electrical survey (Figure 8, 9 and 10). The interpretation of these curves allowed us to deduce the apparent resistivity of each relevant configuration, whereas the thickness of each formation, it is drawn from catalogues in the case of SEV made of low emission lines. On the contrary, we must use more complex methods (auxiliary point method) or computer programs (to optimize interpretations from data acquired) in the case of SEV made in significant emission lines.

Apparent soil resistivity ρa is obtained from the equation below:

$$\rho a = \frac{k.V}{I} \quad \textbf{(1)}$$

Or:

ρa: Apparent ground resistivity (ohm.m.);
K: coefficient geometric function of the device;
I: current intensity (Ampere);
V: potential difference (ohm);

The current injection line is 2000 m, which provides a mean depth of investigation of about 400 m. The

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implementation of various surveys helped to reach data reflecting the saliferous character of the area.

II.3.1 SEV morphological data Interpretation

Examination of these curves shown in figures 8, 9 and 10 shows a downward pace of the

endings, this allows to conclude that the salt-bearing Triassic has strongly influenced these three sources. The number of layers traversed by the SEV is three except for Saida borehole where we have passed through four layers due to the heterogeneity of the filling Mio-Pliocene. The emergence of these sources is made either at the foot of the mountains or at the center of the plain, following a system of Triassic diapir sometimes covered by sediments.

II.3.2 SEV Quantitative Data Interpretation

The SEV quantitative data interpretation was performed through the Hummel method using a two courses abacus:

The geological environment of the source Kouchbi is formed by three relatively resistant layers (table 1). The first is highly resistant (1300 ohm.m.) formed by resistant limestone and a maximum thickness of 3 m, the second more altered and cracked having a resistivity of 52 ohm.m and which extends up to 100 m deep, and finally the substrate is formed by a cracked and probably karstified layer of limestone with a resistivity of 120 ohm.m.

Table 1. *Kouchbi source crossed ground characteristics*

Characteristics	1st Layer	2nd Layer	3rd Layer
Geoelectric	1300	52	120
Depth (m)	3	100	300
lithology	Limestones	Limestones altered	Limestones karstified

The Saida area lithology (table 2) is formed by highly saline soils, with a surface layer of alluvium of 3 to 4 m thick and a resistivity of 95 ohm.m. This layer is based on gypsum marl (4 ohm.m) of up to 30 m deep. The next layer is formed by alternating sandstone and gypsummarl (10 ohm.m) and extending up to 100 m depth. The final layer is formed by a highly conductive layer (1 ohm.m) probably as gypsum marls and extending up to 800 m on the section of the borehole.

Table 2. *Saida borehole source crossed ground characteristics*

Characteristics	1st Layer	2nd Layer	3rd Layer	4th Layer
Geoelectric	95	4	10	1
Depth (m)	4	30	100	800
lithology	Alluvium	Gypsum Marl	Sandstone and Gypsum Marl	Gypsum Marl

The structure of the Hammam Guerdjima region is formed by three layers (table 3): The first and the substratum are conductors interposed by a relatively resistive layer. This is a Triassic formations assembly whose resistivity does not exceed 5 ohm.m.

Table 3. *Guerdjima Hammam crossed ground characteristics*

Characteristics	1st Layer	2nd Layer	3rd Layer
Geoelectric	3	5	3
Depth (m)	32	175	160
lithology		Triassic formation	

II.4 The hydrogeological setting

Several similar work on thermalism in Algeria has made it possible to highlight the geological and hydrogeological frame of thermal aquifers in Algeria. M. Ville in 1889 published a notice "The thermal and mineral sources in Algeria" while Pr. Hanriot published in 1911 a work "The mineral waters of Algeria". In 1940 and 1947, S. Guigue published in the service of the geological map of Algeria two volumes on the main thermal emergence. In 1985, H. DIB supported a 3rd cycle thesis entitled "The Thermalism in eastern Algeria" and in 1992, A. Issaadi supported a state doctorate entitled "Thermalism in its geostructural framework. Contributions to the knowledge of deep Algeria and its thermal resources".

Many geological formations extend in a general direction Southwest, Northeast, except the alluvium of the valley bottoms. These formations belong mainly to the Secondary comprising sandstone, marl, clays and mainly massive limestones and dolomites. The water resources of Bellezma are mainly located in the carbonated formations, consequently in karst aquifers type. These aquifers are essentially exploited by deep or very deep borehole passing sometimes through the marl and sandstone formations before reaching the limestone (N'gaous Saida borehole or others). These waters that are sometimes warm, come up to the surface due to tectonic accidents to form baths that are used for therapeutic purposes.

The scrutiny of the lithological section of the Saida drill (N'gaous) shows that the 1000 m depth work has passed through a 800 m thick gray marls, then an alternation of limestone and marl with a thickness of 200 m with (Figure 5) an estimated flow rate of 13 L s^{-1}. the marly roof makes it possible to load the groundwater which explains the artesianism of this borehole.

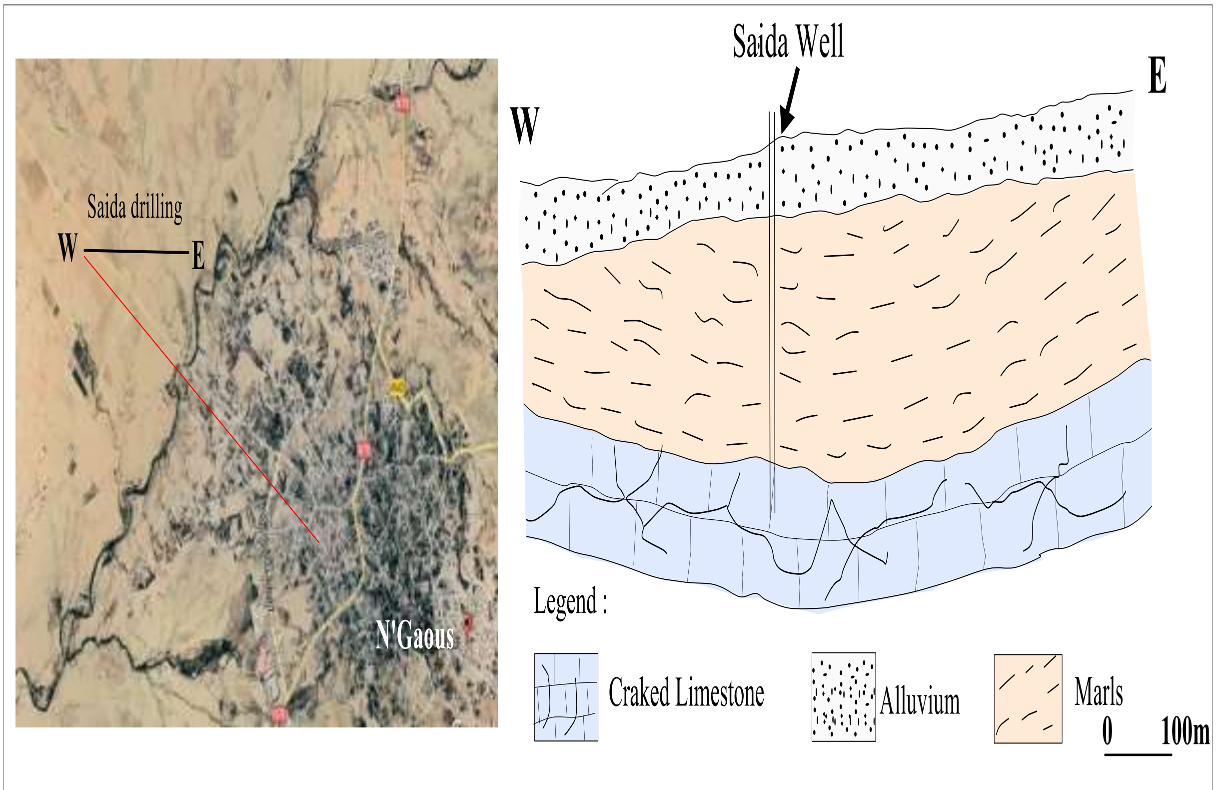

Figure 5. *Geological section of Saïda borehole, (Authors).*

The Guerdjima source (Gosbat) has also a flow rate of 5 L s^{-1}, emerges with a Triassic salty mass highly conductive, in the foothills of Jebel Bou Ari (Figure 6), thanks to a set of northeast- southwest accidents. However, recognition of 180 to 250 m is recommended to clarify the geology and detect the arrival of hot water in this region.

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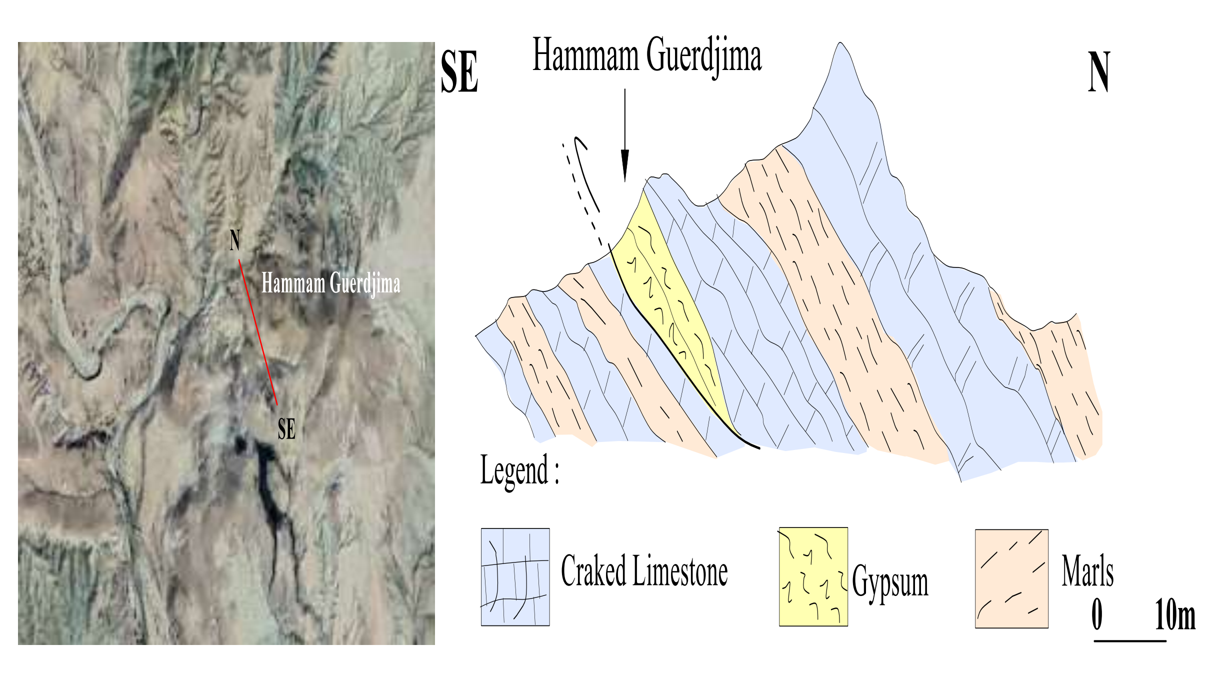

Figure 6. *Geological section of Hamam Guerdjima, (Authors).*

The Kouchbi source (Ouled Si Slimane) has a flow rate of 5 l/s, emerges with the support of an East-West direction flaw in the foothills west of Jebel Kouchbi (Figure 7). The examination of an electrical survey to the right of the source shows the existence of a cracked to karstified limestone formation starting from a depth of 110 m. This aquifer can be exploited using a minimum 170 m deep borehole.

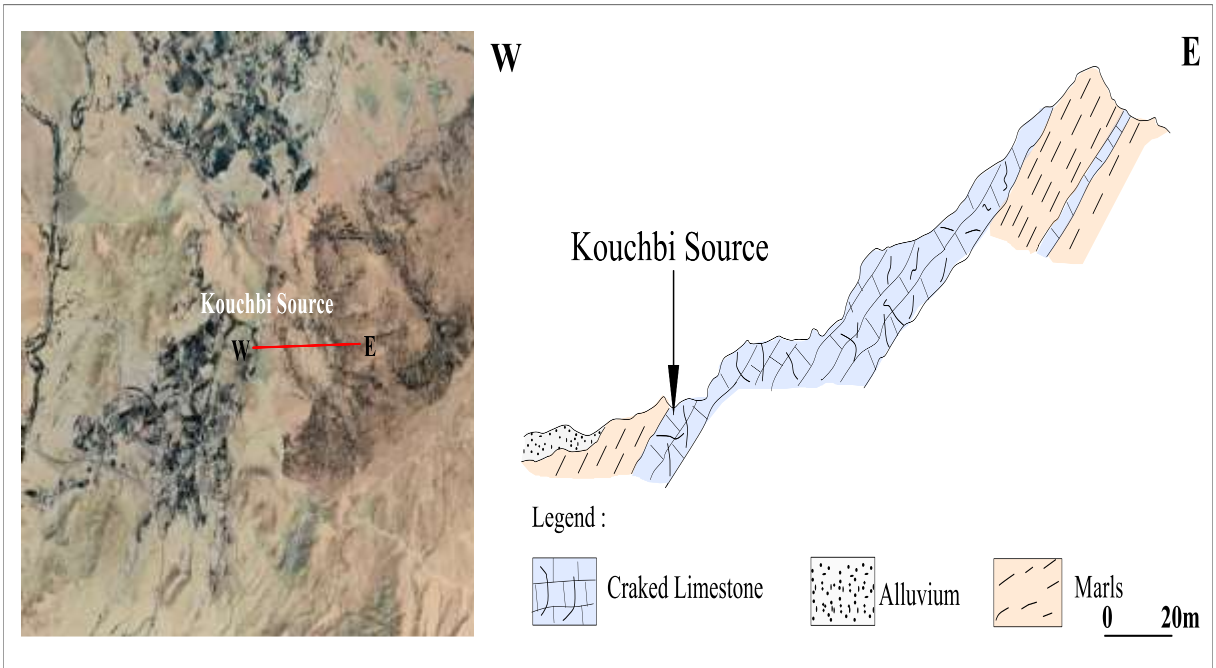

Figure 7. *Geological section of the Kouchbi spring, (Authors).*

II.5 Distribution of sources and lineaments

Generally, the interpretation of aerospace images reveals that the spatial distribution of most water sources and water points is not random and that there is a relationship between this distribution and the fracturing network. The alignment of the sources (especially those that are thermal) was used to confirm the tectonic nature of lineaments highlighted by the spatial images.

In the Bellezma Mountains, Cretaceous, Eocene and Miocene sandstone limestones are at the origin of many sources, usually located on faults or fractures and in contact with underlying marl the case of Guerdjima, N'gaous and Kouchbi.

These sources have variable bit rates. These, however, undergo seasonal variations. Linear analysis at Kouchbi, Guerdjima and N'gaous region shows a large number of lineaments crossing the Cretaceous limestones and the Miocene sandstones. It mainly includes NW-SE, E-W, NE-SW and N-S steering accidents.

The report of these sources on the lineament map (Figure 1C) makes it possible to deduce the following remarks:

These sources are either carried by lineaments or constituting the point of convergence (node) of at least two lineaments.

The source related to these lineaments and especially the one that forms the point of convergence, has a higher flow rate; probably the case of the N'gaous source.

These sources serve as a revealing index of the existence of fairly deep fissures. They would be a direct cause of the phenomenon of karstification (dissolution of limestones in depth).

II.6 Sampling and analyzes

A sampling survey conducted in September 2016, has been carried out on three warm water areas (Saida N'gaous borehole, source Kouchbi in Ouled Si Slimane and Guerdjima source of Gosbat).

The sampling is carried out at the borehole after pumping for 15 minutes (to exclude groundwater stored in the work) using polypropylene vials rinsed with acid. Filters of cellulose acetate of 0.45 µm are used to filter the samples immediately after their collection. Flasks of 250 cm^3 Polyethylene (acidified immediately after opening by adding nitric acid Merck TM ultrapure to pH <2) are used for storage of the filtrate used for the analysis of trace elements and cations. The samples thus collected were preserved at a temperature below 4° C during transport and in the laboratory.

The physico-chemical parameters (temperature, pH and conductivity) are measured in situ, immediately after taking the samples using a multi-parameter WTW (P3 Multi Line pH/ LFSET).

In order to determine the contents of the different chemical elements, three methods of analysis were used recommended by APHA (1995). First, the titration for the determination of bicarbonate and chloride, the flame atomic absorption (PERKIN ELMER 1100B). Secondly, the potentiometric titration, as recommended by [28], for the determination of cations and trace elements and finally the Quebec technical expertise centre in environmental analysis [17, 18] for the determination of nitrates.

The measurement of tritium and carbon-14 is carried out by liquid scintillation spectrometry using a liquid scintillation spectrometer with low noise background PERKIN ELMER Tricarb 2900 TR / AB, with a 300-minute counting time for each sample so as to detect events (counting) of the environment order. The vials used are those of polyethylene. The glass vials have been discarded because they contain Potassium 40, which can intervene in the process of natural radioactivity and could thus limit the sensitivity for environmental samples. The liquid used is the PERKIN ELMER's scintillating Ultima Gold LLT (Low Level of Tritium). It is a special scintillation liquid for low tritium content. The DUAL-DPM guide (isotopic double labeling) is adapted for determining both the actual radioactivity of tritium and carbon-14.

III. Results and discussion

III.1. Geochemical characterizations (major elements)

Emerging with a temperature of about 63° C, the Saida borehole (N'gaous) waters are considered to be hyperthermal, according to the classification proposed by [16]. They have a slightly acidic pH in the order of 6.73 due to the karst nature of these waters which, under the effect of temperature, dissolve much CO_2, giving it this acidity. The electrical conductivity relative to a standard temperature of 25 °C is of 1380 $\mu S.cm^{-1}$ with a dry residue of approximately 894 mg L^{-1}. This water is highly mineralized. The Redox potential of this borehole water is negative with -234.3 mv, noticeable by the release of a bad smell (hydrogen sulfide) and by a very low value (0.03 mg L^{-1}) of the dissolved oxygen. This suggests a very deep origin of this water. The Schoeller-Berkaloff diagram (Figure 11) showed that the waters of the region have a sulfated sodium feauture, indicating the influence of salt formations on their chemistry.

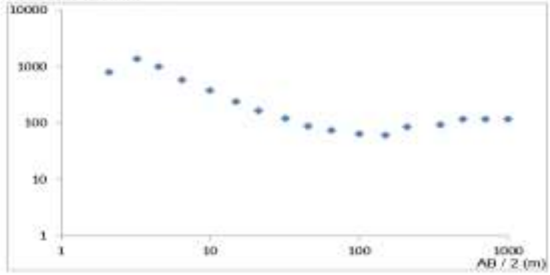

Figure 8. *SEV Curve executed at the Kouchbi source*

The waters of the Kouchbi source (Ouled Si Slimane) emerge with a temperature of about 30 °C, according to the same classification and are considered mesothermal having a slightly basic pH of 7.15. The electrical conductivity relative to a standard temperature of 25 °C is 800 µS cm^{-1} with a dry residue of approximately 470 mg L^{-1}, thus providing to this water an oligo-mineral character. The redox potential of this source water is 177.9 mv with a dissolved oxygen value of 0.30 mg L^{-1}, which leads us to presume of the shallow origin of this water. The application of Schoeller- Berkaloff diagram (Figure 11) to these waters has awarded a calcium bicarbonate feature; an indication of the interaction of thermal water with a widely carbonate environment.

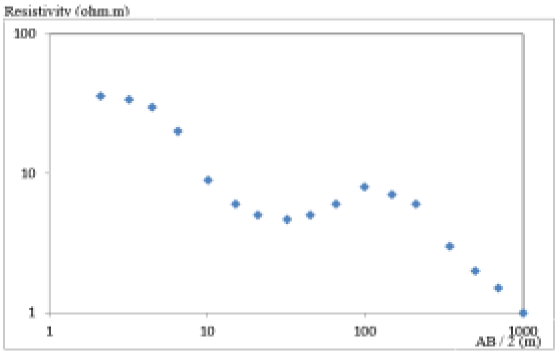

Figure 9. *SEV Curve executed at the Saida drilling*

The Guerdjima (Gosbat) source waters emerge with a temperature of about 42° C and they are mesothermal and having a slightly basic pH of about 7.25. The electrical conductivity relative to a standard temperature of 25° C is 7870 µS/cm with a dry residue of about 4904 mg/l. This high conductivity, which gives it the character of a water very rich in minerals, is probably due to the dissolution of the minerals of the Triassic formations along the way of the hot water [5].

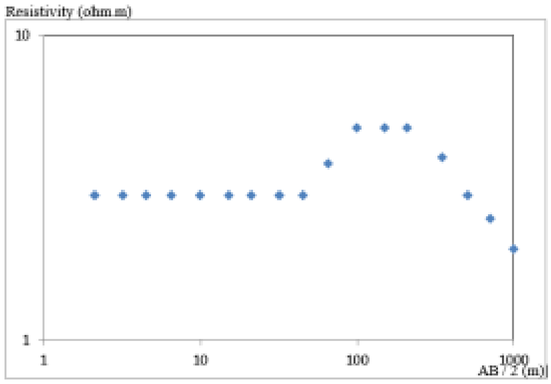

Figure 10. *SEV Curve executed at Guerdjima Hammam*

The Redox potential of this borehole water is about -198.7 mv with a dissolved oxygen value of 0.10 mg/l, which allows us to think of a very deep origin of such waters. The Schoeller- Berkaloff diagram (Fig. 11) shows that the waters of the region have a calcium chloride-feauture reflecting the influence of salt-bearing evaporite formations on their chemistry.

Table 4. *Main physico-chemical characteristics of thermal waters of Bellezma mounts.*

Designation	T (°C)	pH	Conductivity ($\mu s.cm^{-1}$)	Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	Cl^{-} (mg.L^{-1})	SO_4^{2-}	HCO_3^{-}	NO_3^{-}	SiO_2
B	63	6,73	1570	98,39	25,53	152	15	60	414	225,7	03	15
S1	30	7,15	800	81,34	30,44	18	2	20	66	341,6	11	7,20
S2	42	7,25	8100	277,78	74,81	140	19	2100	580	396,5	03	11,50

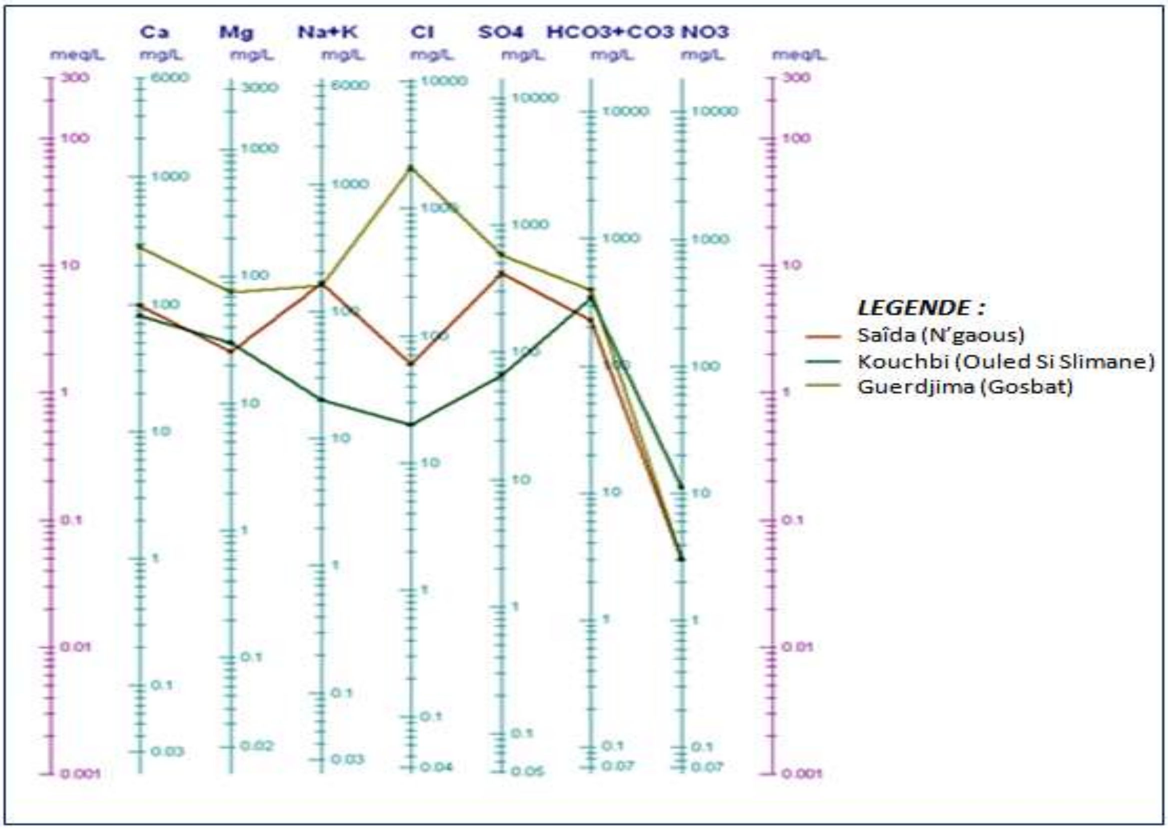

Figure 11. *Schoeller-Berkaloff diagram applied to thermal waters of Bellezma mounts.*

The postponement report of the analytical areas of the three hot springs in the Bellezma mountains diagram Na/Cl, showed a good distribution around a straight slightly steeper than the halite (R = 0.99) (Figure 12), this reflects a molar ratio Na/Cl average of these areas similar to halite (Na/Cl halite = 1.00). This approach let us assume that the salinity of these thermal waters result probably in the dissolution of salt formations [6] (it is well known that chlorides and sodium are chemical elements that can exist in water following the dissolution of halite or from a mixture with seawater. The second hypothesis is to be rejected because of the remoteness of our region from the Mediterranean Sea (over 300 km)). Moreover, it was found that there is a fair agreement sulphate-calcium (r = 0.8) and EC - $HCO_3/(Cl+SO_4)$ a fact that maintains this hypothesis (Figure 13 and 14). The dissolution of the anhydrite or pyrite according to the formula proposed by [3].

$FeS_2 + 4{,}75H_2O + 4e^- \leftrightarrow Fe(OH)_3 + 2SO_4^{2-}$ **(2)**
Undoubtedly explains the presence of sulfates in fairly large quantities in the waters of the hot springs under study (8 to 12 $mEq.L^{-1}$).

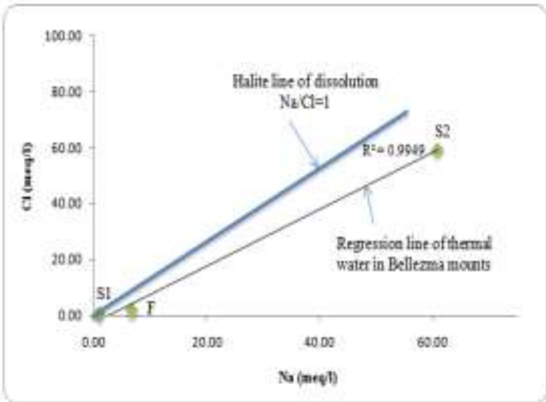

Figure 12. *Relationship Na-Cl in the thermal waters of Bellezma mounts.*

The examination of the ion ratio in molar concentration (Sr^{2+}/Ca^{2+}) contributes also to the characterization of the origin of salinity. It is characteristic of an evaporite origin if it is equal or greater than 1 ‰ [7], it is more than 5 ‰ in evaporites Alpine Triassic [29], it is greater than 7 ‰ in the waters of Turonian aquifer of the Tadla basin in Morocco [20]. In Algeria, it is more than 3 ‰ in evaporates of the Djurdjura [1], it is more than 19 ‰ in thermal waters of South Setif [4] and it is higher than 5 ‰ in the groundwater of the shallow aquifer. This ratio varies between 5 and 9 ‰ in the thermal waters of the Bellezma mountains, a fact

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characterizing a water that has circulated through lands that are in contact with terrigenous formations.
To determine the lithology of the original reservoir of thermal waters, the IIRG method (International Geothermal Research Institute) developed by [19] was applied. The principle of this method is based on the use of concentration ratios of the major elements and the sum of cations (Σ+) and anions (Σ-) expressed in meq/l. Six new parameters (A, B, C, D, E and F) are well defined and standardized between -100 and 100 whose values allow to set the rectangular patterns and compare them with reference patterns (α, β, γ and δ) established by the authors.

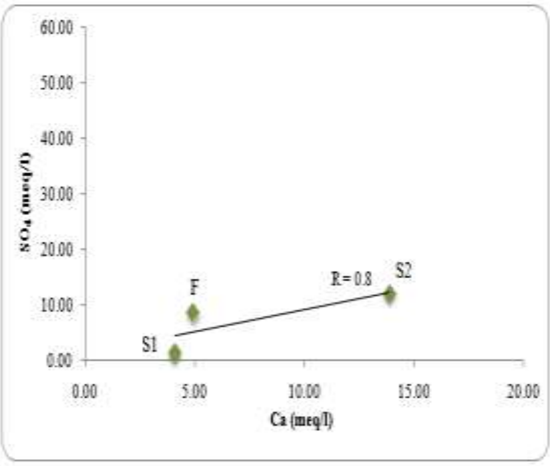

Figure 13. *Relationship Ca-SO_4 in the thermal waters of Bellezma mounts.*

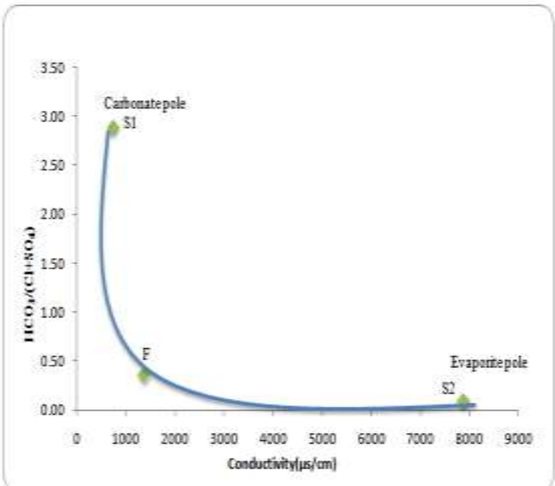

Figure 14. *Relationship CE-HCO_3/(CL+SO_4) in the thermal waters of Bellezma mounts.*

For Saida borehole waters, the resulting IIRG diagram (Fig. 15) corresponds to the type of standard diagram γ ". This standard is characteristic of a deep circulation in a crystalline basement. During ascent, the waters have gone through a carbonate formation, the parameters "A-" and "C +" are very significant.
As far as Hammam Guerdjima waters are concerned, the resulting IIRG diagram (Figure 15) corresponds to the type of standard α diagram demonstrating a flowing in an evaporate environment. Indeed, the waters have gained their mineralization in sulphate by leaching evaporites contained in the Triassic formations and oxidation of pyrite contained in the limestone reservoir.
The Kouchbi source has a similar configuration of the β- type (Figure 15) characterizing a movement in carbonate reservoirs.

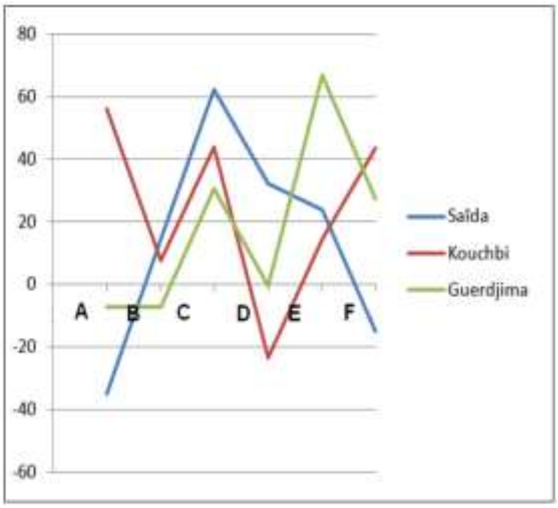

Figure 15. *Diagram of the International institute of geothermal research applied to the thermal waters of Bellezma Mounts*

III.2 Geochemical characterization (trace elements)

The review of table 5 showed that the levels of certain trace and metallic elements in the thermal waters of the Bellezma Mountains are relatively high (285<Cd<340 µg.L^{-1}, 1350<Al<93150 µg.L^{-1}, 900<Sr<4350 µg.L^{-1},). According to [24], heavy metal elements are only transported by water under very high temperature and pressure conditions. Based on this principle, we can say that the warm waters of our study area, which contain high levels of trace elements, reflect deep flows in contact with a highly mineralized magmatic and/or crystallophyllian host. The base extrusions associated with the Triassic formations that mark the region where these springs gush out are essentially magmatic and metamorphic in nature and very rich in minerals. The latter, reflecting the nature of the bedrock, are extremely associated with the various hydrothermal deposits in the Bellezma Mountains. We can then understand the interdependence between these warm waters and their richness in trace and metallic elements.

Table 5. *Concentrations of trace and metallic elements in the thermal waters of Bellezma mounts.*

Designation	Cd^{2+}	Al^{3+}	Pb^{2+}	Sr^{2+}	Fe	Cu^{2+}
			(µg/l)			
B	290	93150	0	1950	21	0
S1	285	31700	0	900	13	0
S2	340	1350	0	4350	35	12

III.3 Tritium and Carbon-14

The first applications of isotopes in Algeria were carried out under the auspices of UNESCO in the early 1970s with the ERESS project (UNESCO, 1972). To compare the results of tritium analyses of thermal waters with those of rainwater, an annual average of 50 TU (5.9 Bq.L^{-1}) was applied for the Maghreb region [21]. This author has divided Algeria's mineral and thermal waters into two groups. The first corresponds to waters with contents below 5 TU (0.59 Bq.L^{-1}). It includes the majority of thermal springs characterized by old waters without mixing with recent rainwater. The second concerns waters with concentrations ranging from 10 TU to 20 TU (1.18 Bq.L^{-1} and 2.36 Bq.L^{-1}), reflecting the influence of a recent component.

The thermal waters of the Bellezma Mountains have been found to be almost free of tritium (table 6). Consequently, they are considered old waters without mixing with recent rainwater.

Tableau 6. *Measurement of Tritium in the thermal waters of Bellezma mounts.*

Designation	Count Time (min)	CPMA TRITIUM (cpm)	DPMA TRITIUM (dpm)	BqA TRITIUM (Bq/l)	QIP (t-SIE)
BDF	300	2,45	-	-	293,47
B	300	0,00	0,00	<MDA	281,81
S1	300	0,00	0,00	<MDA	283,12
S2	300	0,00	0,00	< MDA	282,39

The measured C-14 activities (% of modern carbon) range from 0 to 6 pmc throughout the central part of the Greater Eastern Erg basin (Algeria and Tunisia) and from 50 to 80 pmc northwest of Laghouat in Algeria to 50 pmc on the Dahar mountains in [18]. These last high values correspond to recharge areas.

In the thermal waters of the Bellezma Mountains, C-14 activities vary between 0.21 and 0.75 pmc (table 7). These values further confirm the absence or weakness of a contemporary water supply to the recharge of the deep water from which the thermal waters of this region originate.

Tableau 7. *Measurement of Carbone-14 in the thermal waters of Bellezma mounts.*

Designation	Count Time (min)	CPMA CARBONE 14 (cpm)	DPMA CARBONE 14 (dpm)	BqA CARBONE 14 (Bq/l)	QIP (t-SIE)
BDF	300	12.65	-	-	293.47
B	300	0.39	0.55	0.009	281.81
S1	300	0.35	0.47	0.008	283.12
S2	300	0.61	0.81	0.013	282.39

III.4 Geothermometric analysis

In order to estimate the maximum temperature of the last chemical or isotopic equilibria before emergence, reached by the waters of the region under study in their original reservoir, from their chemical composition at emergence, we used SiO_2 geothermometers combining, on the one hand, the equilibrium equations between water and quartz, cristobalite and chalcedony and geothermometers based on alkaline elements in solution which are associated, with a balance in the reservoir between water and alumino-silicate minerals, on the other hand. Nevertheless, the use of these geothermometers assumes that there is no significant

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chemical change in the water during its ascent, despite the various possible and often remarkable colds [14]. It appears from this approach that the alkaline geothermometer Na-K-Ca is best suited to the thermal waters of the Saïda borehole and the Guerdjima spring, it gave respectively a temperature of the original reservoir of 82°C in Saîda and 92°C in Guerdjima, while at the Kouchbi spring it is the silica quartz geothermometer which seems to be the most suitable. It gave it a temperature of the original reservoir of 38°C.

This geothermal tool also makes it possible to estimate the depth of the various reservoirs. According to [10, 11, 21, 25 and 26], the Bellezma mountains belong to an area where the geothermal gradient is 35°C.km^{-1}. This allows us to estimate the depth of the geothermal reservoir in the area under study, which varies between 1100 m and 2600 m.

Tableau 8. *Table summarizing the formulas of the chemical geothermometers and their respective authors*

Désignation	**Authors**	**Formulas**
	Silica geothermometers	
T1	S. ARNORSSON .	$T1 = \frac{1309}{5{,}19 - \log SiO_2} - 273{,}15$
T2		$T2 = \frac{1522}{5{,}75 - \log SiO_2} - 273{,}15$
T3		$T3 = \frac{1032}{4{,}69 - \log SiO_2} - 273{,}15$
T4		$T4 = \frac{1000}{4{,}78 - \log SiO_2} - 273{,}15$
T5		$T5 = \frac{781}{4{,}51 - \log SiO_2} - 273{,}15$
T6		$T6 = \frac{731}{4{,}52 - \log SiO_2} - 273{,}15$
	Alkaline Geothermometers	
T7	A. J. ELLIS	$T7 = \frac{908}{0{,}700 + \log \frac{Na}{K}} - 273{,}15$
T8	R. O. FOURNIER	$T8 = \frac{1217}{1{,}483 + \log \frac{Na}{K}} - 273{,}15$
T9	A. H. TRUSDELL	$T9 = \frac{856}{0{,}857 + \log \frac{Na}{K}} - 273{,}15$
T10	S. ARNORSON	$T10 = \frac{933}{0{,}993 - \log \frac{Na}{K}} - 273{,}15$
T11	FOURNIER and TRUSDELL	$T11 = \frac{1647}{\log \frac{Na}{K} + \beta\left(\log \frac{\sqrt{Ca}}{Na} + 2{,}06\right) + 2{,}47} - 273{,}15$

III.5 Therapeutic analysis

The Saïda borehole water is sulphated sodium, the sulphate content is greater than 200 mg/l. Such water is used for its diuretic action in the treatment of diseases of the digestive tract, gastrointestinal and hepatobiliary diseases. The presence of calcium and magnesium with high levels also plays a role in the treatment of eczema, sequelae and burns scars.

The Kouchbi spring water is bicarbonated with calcium; low in sodium, it is weakly mineralized with a mineral salt content of less than 500 mg/l (470 mg/l). This water is thermo-mineral of a hard type that has a protective effect against cardiovascular diseases, unlike fresh water, which is generally aggressive and can be harmful due to its ability to solubilize so-called heavy metals. This water is also beneficial for infants, children, kidney patients and pregnant women.

Being sodium chlorinated, the Guerdjima spring water has a curative action on the mucous membranes. Generally, chlorinated water has a growth stimulating effect and is indicated in the treatment of developmental disorders, enuresis, digestive tract disorders, liver and biliary disorders. This water is also rich in magnesium over 50 mg/l (74.81 mg/l), a regulator involved in all metabolism including calcium and phosphorus. With a sulphate content of more than 200 mg/l, this water can be used for its diuretic action, in the treatment of diseases of the digestive tract, intestinal and liver diseases. In addition, the presence of calcium and magnesium are involved in the treatment of eczema, sequelae and burns scars. Its therapeutic indication is twofold (Rh-VR), i.e. for rheumatism of the musculoskeletal system (muscle, joint and bone) and for the respiratory tract (ear infections, asthma, bronchitis) and ENT, especially of allergic origin (rhinitis, rhino-pharyngitis, allergic asthma, ear infections, etc.).

IV. Conclusion

In the Bellezma Mountains, Cretaceous limestone, Eocene and Miocene sandstone are at the origin of many springs that are, sometimes, hot. In general, these springs are located on faults or fractures and in contact with the underlying marl like the Kouchbi and Guerdjima springs. A. Boudoukha and M. Athamena have demonstrated that resurgences of hotspots are made to the benefit of faults. The latter would facilitate communication between the different reservoirs and the transport of deep thermal waters to the surface [12]. These sources are a revealing indicator of the existence of developed cracks in depth and would be a direct cause of the karstification phenomenon.

Geological, hydrogeological and above all hydro-chemical surveys have shown that the thermal waters of the Bellezma Mountains acquire their original carbonate mineralization and mineralize themselves more in chlorides, sodium and sulphates in contact with saline earth formations and by basic exchange with clays. The acquisition of original chemism is engaged in the geothermal reservoir and the enrichment more in chlorides, sodium and sulfates in contact with salt terrigenous formations and by basic exchange with clays [13]. These waters have different chemical features: sodium sulphate (Saïda), calcium bicarbonate (Kouchbi) and calcium chloride (Guerdjima). Similar work on thermalism has made it possible to highlight the main types of thermal aquifers in East Algeria [22].

They also show significant concentrations of trace and metalliferous elements that indicate a deep circulation through the crystallophyllian basement. The radiometric isotopes study (tritium and carbon-14) showed that the recharge is low or absent and confirmed that these waters are of very deep origin.

Moreover, the thermal waters of the region have very good therapeutic properties, which opens the opportunity for investment in the field of curative tourism.

V. References

1. Abdesselam, M.J. ; Mania, J. ; Mudry, J.P. ; Gelard, P.; Chauve, H.; Lami et Aigoun, C. (2000). Arguments hydrogéochimiques en faveur de Trias évaporitique non affleurant dans le massif du Djurdjura (dorsale kabyle, élément des Maghrébines). *Revue science de l'eau*. 13/2 (2000) 155-166.
2. APHA. American Public Health Association; AWWA. (American Water Works Association); WPCF. (Water Pollution Control Federation). Standard methods for the examination of water and wastewater. *APHA, New York* 19th ed. (1995).
3. Appelo, C.A.J; Postma, D. Geochemistry, groundwater and pollution. *Journal of Hydrology*, vol. 155, 1-2 (1993), 295-296.
4. Athamena, M. Etude des ressources thermales de l'ensemble allochtone sud setifien. Mémoire de Magister, Univ. Batna, Algérie (2007).
5. Athamena, A.; Menani, M.R. Nitrogen flux and hydrochemical characteristics of the calcareous aquifer of the Zana plain, northeast of Algeria. *Arabian Journal of Geosciences* (2018) 11 :356.
6. Athamena, A. (2018). Flux azoté : Origine et devenir dans les eaux souterraines, cas de la région de Zana, Est algérien. Thèse de doctorat. Université Batna 2 (2018).
7. Bakalowicz, M. La formation des travertins : aspects géochimiques, essai de synthèse et discussion. Travaux de l'UA 903, *n° XVII*, rapport de l'ATP-PIREN "Édifices travertineux et histoire de l'environnement dans le Midi de la France". *In Jean Vaudour édit* (1988) p. 261-268.
8. Bellion, P.J.C. Etude géologique et hydrogéologique de la partie occidentale des monts de Bellezma (Algérie). Thèse Doctorat 3ème Cycle. Paris VI (1992).
9. Belalite, H.; Menani, M.R.; Athamena, A. Calculation of water needs of the main crops and water resources available in a semi-arid climate, case of Zana-Gadaïne plain, Northeastern. Algeria. *Algerian. Journal of Environmental Science and Technology*, 8:2 (2022) 2477-2488.
10. Bouchareb Haouchine, F.Z. Apport de la géothermométrie et des données de forage profonds à l'identification des ressources géothermiques de l'Algérie du Nord. Application à la région du Hodna.

11. Mémoire de Magister, Université Alger, Algérie (1993).
12. Bouchareb-Haouchine, F.Z. ; Issaadi, A ; Bendhia, H. Estimation and interpretation of geothermal gradient in northern Algeria. *Bulletin Service Géologique Algérie*, 5 n°1 (1994), 69-74.
13. Boudoukha, A. ; Athamena, M. Caractérisation des eaux thermales de l'ensemble Sud sétifien. Est algérien. *Revue Science de l'eau*, 25, 2, (2012),103-118.
14. Boudoukha, A. ; Athamena, M. ; Benaabidat, L. Etude du potentiel hydrothermal de Hammam Sokhna. Est Algerien. *Larhyss Journal*, (2015) 24, 161-174.
15. Bouri, S.; Gasmi, M. ; Jaouadi, M. ; Souissi, I. ; Lahlou Mimi, A. ; Ben Dhia, H. Etude intégrée des données de surface et de subsurface pour la prospection des bassins hydro-géothermiques : cas du bassin de Maknassy (Tunisie centrale). *Hydrological Sciences Journal*, 52, (2007) 1298-1315.
16. Bureau, D. Approche sédimentaire de la dynamique structurale : Evolution mésozoïque et devenir orogénique de la partie septentrionale du fossé saharien (Sud-Ouest constantinois et Aurès, Algérie). Thèse Doctorat. ès science. Univ. Pierre et Marie Curie, Paris, 2 vol., 1re partie 441 p., 1 pl. h.t., Annexe 338 p. Monts du Bellezma (Algérie). *Publication Service Carte géologique d'Algérie*, N.S., n° 45, (1986). pp. 93-98, Alger.
17. Castany, G. Traité pratique des eaux souterraines. DUNOD (Editeur), Paris, (1967) 661 p.
18. [16] Centre d'Expertise en Analyse Environnementale du Québec. Détermination des nitrates et des nitrites : méthode colorimétrique automatisée avec le sulfate d'hydrazine et le N.E.D., MA. 300 – NO3 1.0, Rév. 1, *Ministère du Développement durable, de l'Environnement et des Parcs du Québec*, (2008) 12 p.
19. Centre d'Expertise en Analyse Environnementale du Québec. Détermination du tritium dans l'eau potable, l'eau de surface et les eaux souterraines : méthode par scintillation liquide, MA. 303 – Tritium 1.0. *Ministère du Développement durable, de l'Environnement et des Parcs du Québec*, 2012, 8 p.
20. D'amore, F. ; Scandifio, G ; Panichi, C. Some observations on the chemical classification of ground waters. *Geothermics*, 12, (1983) 141-148.
21. Guendouz, A. Contribution à l'étude hydrochimique et isotopique des nappes profondes du Sahara nord-est septentrional, Algérie. Thèse Doctorat 3ème cycle, Université Paris-XI, Orsay, France (1985).
22. Guiraud, R. Evolution post-Triasique de l'avant-pays de la chaine alpine en Algérie d'après l'étude du bassin du Hodna et des régions voisines 48,60 (1975) 78p.
23. Dib, H. Guide pratique des sources thermales de l'Est algérien. *Mémoires du service géologique national* n° 15 (2008) 106 p.
24. Hsissou, Y. ; Chauve, P. ; Mania, J. ; Mangin, A. ; Bakalowicz, M ; Graiz, A. Caractérisation des eaux de l'aquifère du Turonien du bassin de Tadla (Maroc) par le rapport des concentrations molaires Sr^{2+}/Ca^{2+}. *Journal of Hydrology*, 183 (1996) 445-451.
25. Issaadi, A. Le thermalisme dans son cadre géostructural, apports à la connaissance de la structure profonde de l'Algérie et de ses ressources géothermales. Thèse de Doctorat, Université Alger, Algérie, (1992).
26. Issaadi, A. Mécanismes de fonctionnement des systèmes hydrothermaux. Application aux eaux thermominérales algériennes et aux eaux de Hammam Bou-Hadjar. *Bulletin Service Géologique d'Algérie*, 7 n°1 (1996), 71-85.
27. Issaadi, A.; Bouchareb Haouchine, F.Z. Estimation du flux de chaleur en Algérie du Nord à partir de la thermométrie silice. *Bulletin Service Géologique d'Algérie*, 8 n°1 (1997), 29-39.
28. Lakhdar, A ; Ntarmouchant, A; Ribeiro, M. L.; Beqqali, M.; Ouadeihe, K. E.; Benaabidate, L.; Dahire, M.; Driouch, Y. ; Slimane, A. Nouvelle approche géologique et géodynamique du complexe hydrothermal de Mouley Yakoub (Bordure septentrionale du sillon Sud Rifain). *Comunicaçoes Geologicas*, t. 93 (2006) 185-204.
29. Mebarki, A. Ressources en eau et aménagement en Algérie. Les bassins hydrographiques de l'Est. *Office des Publications Universitaires, Algérie*, (2009) 389 p.
30. Meybek, M. Les fleuves et le cycle géochimique des éléments. Thèse Paris VI, EN Sup. (1984).
31. Parkhurst, D.L. ; Thorstenson, D.C ; Plummer, L.N. PHREEQE- A Computer Program for Geochemical Calculations. *US Geology Survey* Water-Resources Invest. Rept. (1980) (80-96).
32. Rodier, J. L'analyse de l'eau, eaux naturelles, eaux résiduaires, eau de mer. 8e édition *Dunod*, Paris. (1996) 1365 p.
33. UNESCO. Projet ERESS, Etude des Ressources en Eau du Sahara septentrionale. (1972) 329 pages
34. Vila, J.M. La chaine alpine d'Algérie orientale et les confins algéro-tunisiens. Thèse de Doctorat, Université Pierre et Marie Curie, Paris VI, France (1980).

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