

The contribution of fracturations in the emergence of the thermal springs in Setif city, Eastern Algeria

Samir Djemmal¹ · Mouhamed Redha Menani¹ · Khemissi Chamekh² · Fethi Baali³

Accepted: 3 July 2017 / Published online: 21 July 2017
© Springer-Verlag GmbH Germany 2017

Abstract Setif city covers an area of 6550 km²; it is located about 300 km southeast of Algiers and 100 km to the south of the Mediterranean sea. The aim of our study is to know the tectonic mechanisms responsible for the emergencies and to highlight their chemical characteristics of water springs in Setif. Wherein thermalism is characterized by the presence of a number of thermal springs, the latest are usually related to recent large fractures deeply affecting the sedimentary formations and sometimes even crystallin basement. These fractures are often injected by Triassic evaporates; their directions are NNW–SSE, NW–SE, and NE–SW and limiting great structural units. Four groundwater facies were identified: the high percentage of sources, staking major accidents related to limestone mountains or to the basement, shows a calcium or sodium sulfate facies; and the sources are often hot (meso or hyperthermal). A second group, related to terrigenous saliferous formations, shows a sodium bicarbonate or sodium

chloride facies. The geothermic interpretation allows us to conclude that the reservoir supplies the two aquifer systems of the thermal complex, and is stored in fissured Jurassic limestone, where water storage and circulation is beyond 2600 m deep.

Keywords Springs · Thermalism · Reservoir · Fractures · Setif · Algeria

Introduction

Geothermal study is concerned with the exploitation of deep-water resources and their process to reach the surface. It is one of the main renewable energies in the world. There are more than 240 hot springs in Algeria. Three geothermal zones have been delimited according to certain geological and thermal considerations: the dolomites of Tlemcen in the northwestern part of Algeria, the carbonate formations in the northeastern part of Algeria, and the sandstones of the Albian reservoir in the Algerian Sahara (Saibi 2015).

The present work is based on structural and a hydro-chemical approach to provide information on the thermal context of the hot springs in the study area. This will lead to the characterization of the thermal reservoir of these sources as well as the identification of the areas of geothermal interest.

The study area is a part of the Tellian series which form a component of the external zones of the atlasic chain. Locally, the studied area is located between the Tellian series in the north and Hodna series in the south (Fig. 1). These zones form an integral part of the Alpine Maghreb chain which constitutes the framework of the reliefs of all northern Algeria to the north of the South atlasic faults (Vila 1980).

✉ Samir Djemmal
samirgeol@yahoo.fr

Mouhamed Redha Menani
redha.menani@univ-batna2.dz

Khemissi Chamekh
geologie84@gmail.com

Fethi Baali
baali_fr2000@yahoo.fr

¹ Mobilization and Management Laboratory of Water Resources, Department of Geology, El Hadj Lakhdar University Batna 2, Fesdis, Algeria

² Laboratory of Natural Hazards and Planning Territory, Department of Geology, Hadj Lakhdar University Batna, Street Ain Touta, 0500 Batna, Algeria

³ Laboratory of Water and Environment Tebessa Algeria, Department of Geology, Chiekh Larbi Tebessi University Tebessa, Street Constantine-Tebessa, 1200 Tebessa, Algeria

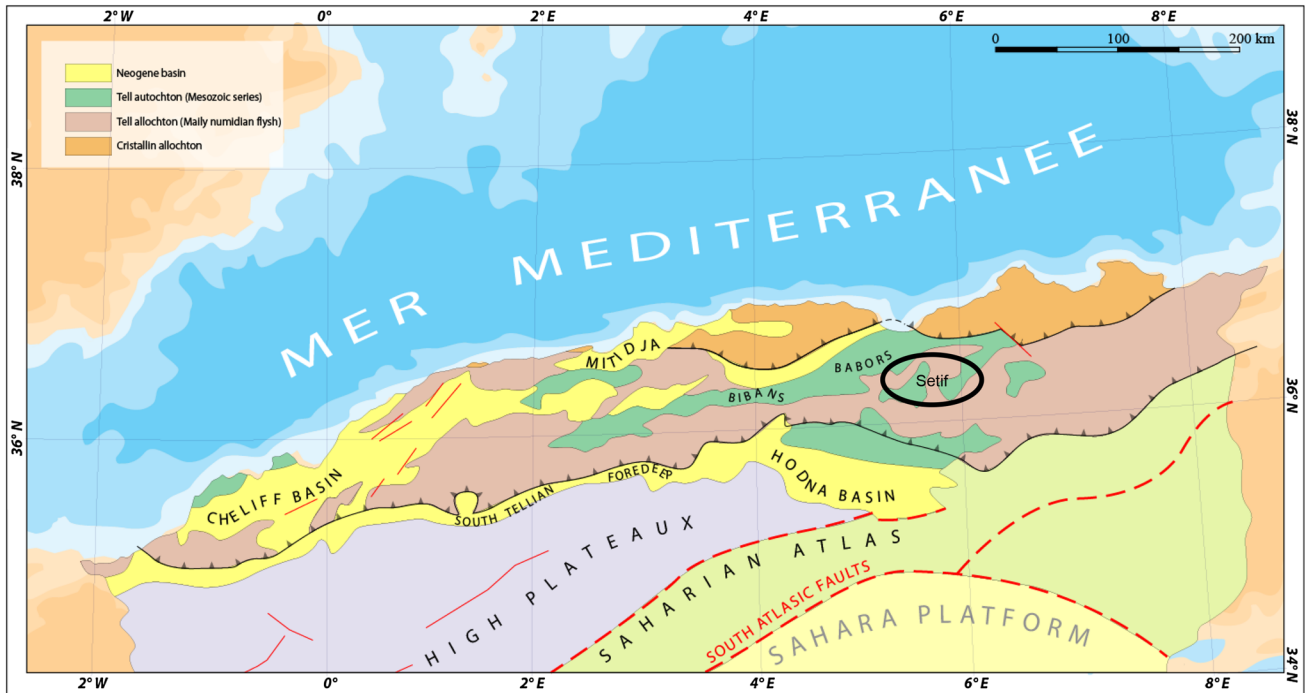


Fig. 1 Structural outline of the North of Algeria

The network of tectonic accidents affecting northern Algeria in general and particularly study area allowed the installation of a series of closed depressions, which draining the majority of surface water and groundwater in the region; this network attributes to this area a look of horst and grabens more than a shaped structure of thrust sheet (Fig. 2).

On the lithostratigraphic plan, the basal part is represented by dolomitic and sandy limestones of the lower Lias. Its upper part is represented by carbonate and sandstone formations, sometimes with thick marly layers of the Eocene. However, the middle is filled by lacustrine limestones and conglomerates surmounted by red clays sometimes gypsum and alluvial deposits, of Mio-Plio-

Quaternary age. The region also includes several triassic features, formed by a variety of sediments (gypsum cluster ground with small calcareo-dolomitic cubes), greenish sandstones, and greenstones (ophiolites), with magmatic extrusions belonging to the Paleozoic basement. The whole is packed in versicolored clays (Vila 1980).

The hydrogeological and geophysical studies (electrical method) carried out in our region lead to identify two main types of aquifers: first, superficial with porosity of interstices in the Mio-Plio-Quaternary formations; second, in karstified and sandy carbonate formations with permeability of fracture. The latter also have karstification and are drained by several sources of cold water, such as the one that located in northeast and south of El Eulma,

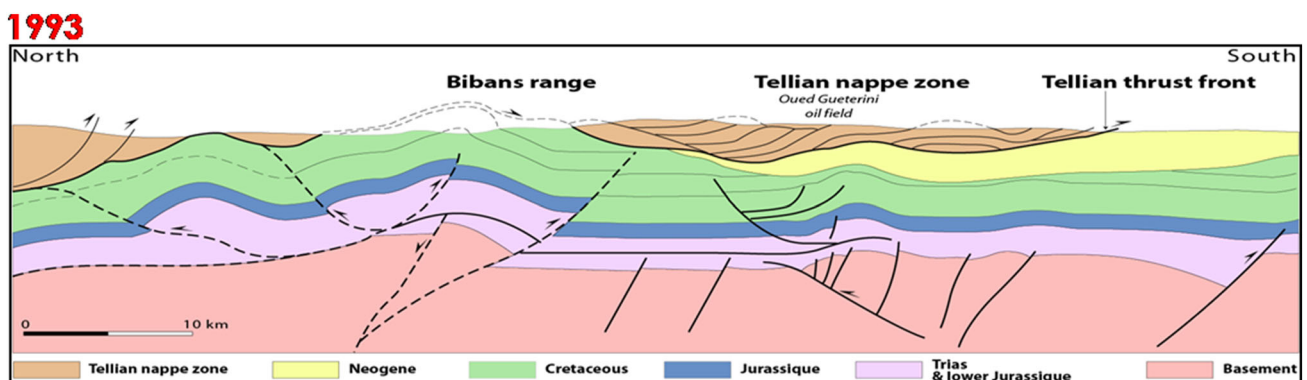


Fig. 2 Recent cross section through the Tellian nappes

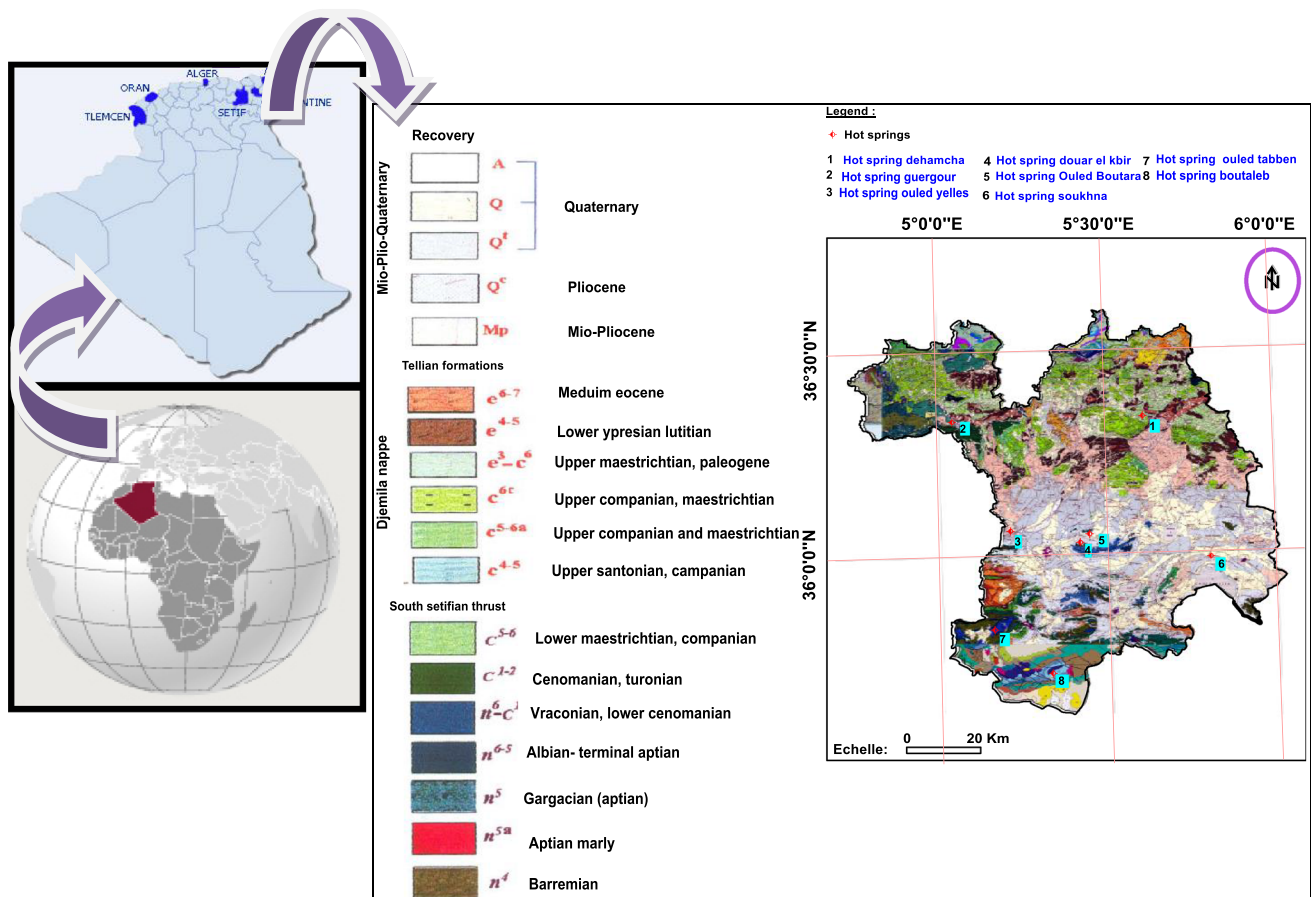


Fig. 3 Geological and geographical map of the study area

which flow out in the plains, often at the intersection of faults. The superficial aquifer is completely desaturated due to excessive pumping. Pumping by the different users (agricultural, industrial and private) is much greater than the supply represented mainly by effective infiltrations and limits to incoming flows from the boundary carbonate formations. For example, in the southern part of El Eulma, the ground water level decreased from 1.5 m in 1972 to 42 m in 1986. The substratum formed by the clays is at 45 m depth (Boudoukha 1998). This situation causes the acceleration of the piezometric level decrease and a disappearance of the springs that flow out from this aquifer. As a result of this situation, the water utilities have targeted the carbonated reservoirs to supply a large part of the population. The carbonate reservoirs are represented by the calcareo-dolomitic series of djebels Zdim, Youssef, Braou, Tnoutit, and Messaouda, which constitute a huge reservoir for the region. The boreholes that have been implanted in these series have given specific flow rates that vary between 2 and 14 L/s/m. Some of these boreholes discharge relatively hot water; their temperature varies between 25 and 43° C (Boudoukha and Belkacem 2014).

Materials and methods

Structural analysis and fracturing

Our work is based on the review of the geological map; Analysis of this map has been able to demonstrate a complex network of lineaments, which are often discontinuous.

Several thermal studies showed the close relationship between faults and thermamllis. Almost, all hot reassembled springs are facilitated by one or more significant fracture often overlapping and affecting, more or less favorable to the reliefs, sources installation (Rachid 1987). Analysis of global lineament was prepared to infer the dominant direction of fractures (Fig. 4).

Chemical analyses

The hot springs were subjected to chemical analyses; they are attached to different tectonic styles. The field campaign (December 2013) made it possible to sample the water of the various thermal sources existing in the

Fig. 4 Lineament analysis map of Setif, Extract from the geological map of Algeria, Scale 1/500,000

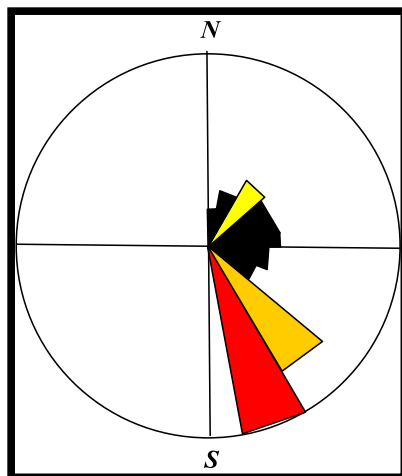
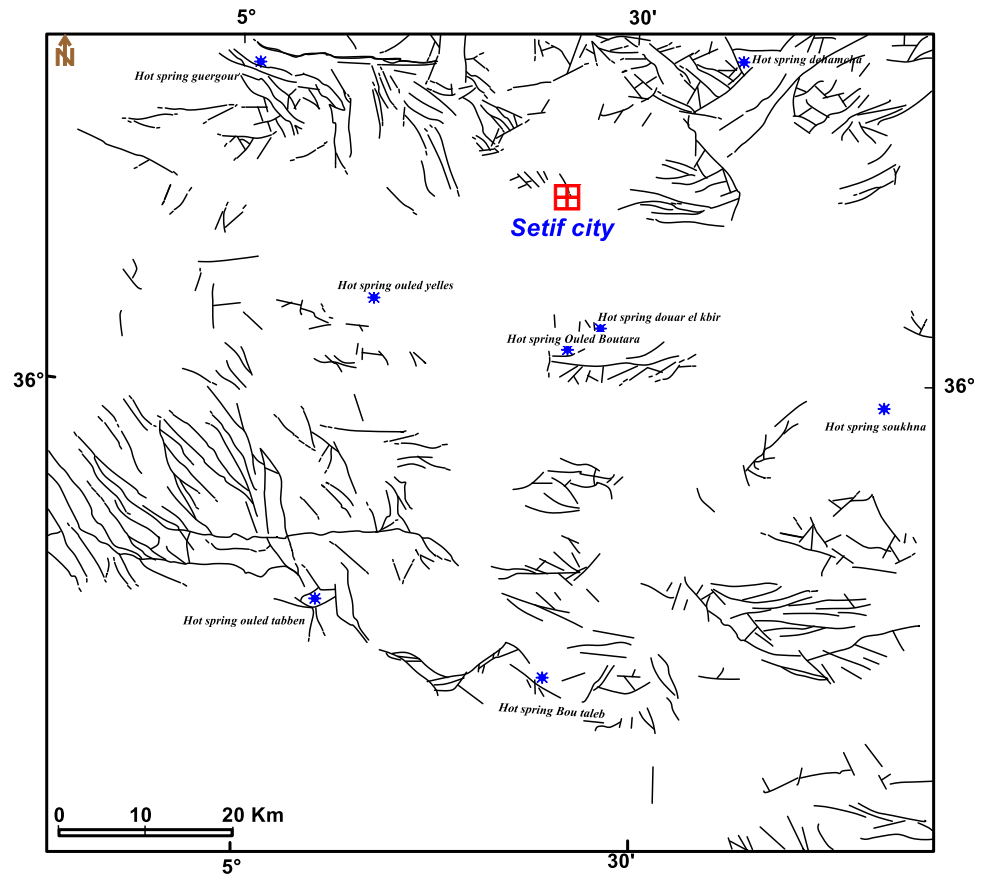


Fig. 5 Rose diagram of the global lineament

study area (Fig. 3). Analyses have been performed by plasma source mass spectrometry in the chemical laboratory of the National Office of Geological and Mining Research. Furthermore, these analyses have been specified to the major elements contents mixture.

Table 1 Summary of the major accidents in the study area

Global sector	
Orientation	Importance (%)
N–S (N40–50)	28
NE–SW (N40–50)	41
E–W (N80–90)	33
EEN–WWS (N100–110)	33
NW–SE (N130–140)	87
NNE–SSW (N20–30)	34
NE–SW (N60–70)	34
NW–SE (N120)	25
NNW–SSE (N150–170)	100

Results and discussion

Fracturing study

This method is based on the use of the geophysical data associated with geological studies which permit visualization of mega-structures of scale greater than hundreds of

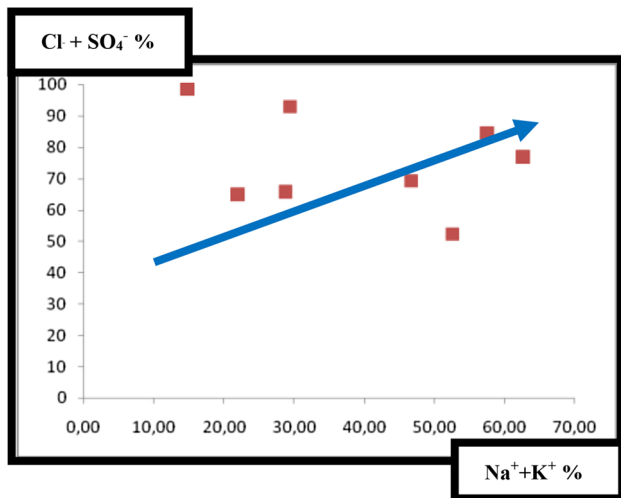


Fig. 6 Diagram of Langelier–Ludwig applied to thermal springs, relation $\text{Cl} + \text{NaSO}_4 + \text{K}$

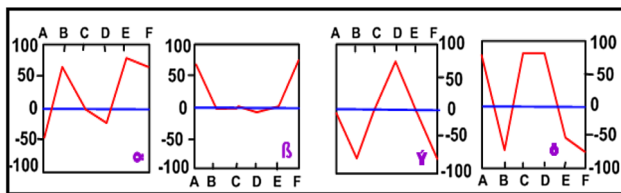


Fig. 7 Reference diagrams of the International Geothermal Research Institute; α Evaporate series; β Circulation in limestone; γ Circulation through a crystalline basement; δ Clay formation

kilometres. To bring out the major structures of the region (Fig. 4), we proceeded in three main steps:

The systematic delineation of lineaments with the development of a map and the processing of the data presented in the form of tables.

The realization of directional roses.

The description of lineaments and their distributions.

As a result of these steps, the global rose diagram (Fig. 5) allows us to conclude the existence of two fault families types: main and secondary; the families of the main type are ranked according to their importance (Table 1).

Family 1 N150-170 (NNW–SSE)

The N150-170 (NNW–SSE) is the dominant direction. This is a very important structural feature which can match the Miocene normal accidents. It is strongly related to metamorphism and Cenozoic volcanism, it is observed in the broad anticline Ain Azel (Demdoum 2010). Thus, this accident could be the thermal fracture of Boutaleb and Ouled Tabben springs.

Family 2 N130-140 (NW–SE)

This family can match the accidents related to Atlas phase of Eocene age (Eocene structure); it is dexter strike-slips; some geothermal and geochemical anomalies in the region can be justified through this accident. Thus, this accident could be the thermal fracture of Soukhna and Ouled Yelles springs.

Family N40-50 (NE–SW)

This family can match the Eocene ruptures; it is sinister strike-slips. Thus, this accident could be the thermal fracture of Guergour and Dehamcha springs.

Water Geochemistry of hot springs

The graphical representation of the major ions contents on Schoeller–Berkaloff and Piper diagrams shows that the water has four different chemical facies. First, calcium sulfate (CaSO_4) in the west. The second type is sodium sulfate (NaSO_4) in the middle. The third and the fourth types are sodium chloride (NaCl) in the southeast, and sodium bicarbonate (NaHCO_3), in the northeast.

These chemical facies reflect a movement in carbonate formation that is in contact with terrigenous salt formations. The effect of such formation on the chemistry of thermal water is also highlighted by the Langelier–Ludwig diagram (Fig. 6).

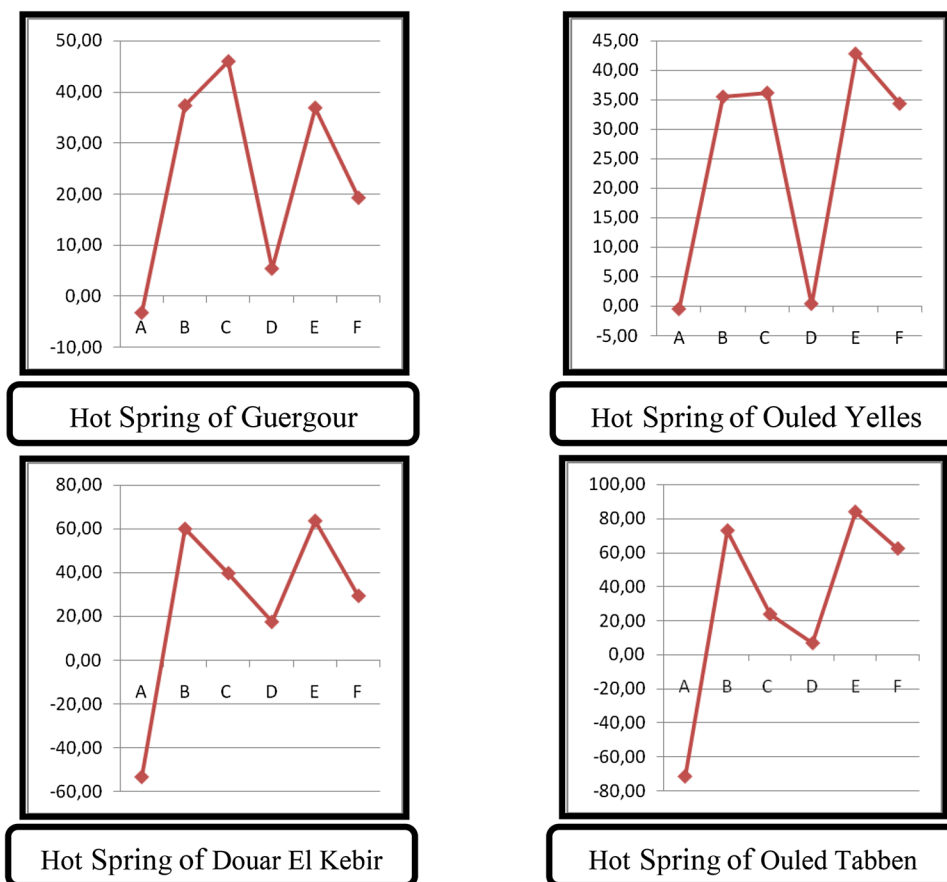
Increasing the concentration of sodium and potassium to all sources is parallel with those of the chlorides and sulfates. This concentration increase could be interpreted as result of Halite and Anhydrite dissolution (Boudoukha and Athamena 2012; Djemmal 2008).

Diagrams of the International Institute of Research Geothermal

The IIRG method (International Institute for Geothermal Research), developed by Amore et al. (1983), is the most used tool for determining the lithology of the thermal water reservoirs. The principle of this method is the use of the concentrations reports of the major elements and the sum of cations and anions expressed in Meq/L. Six settings A, B, C, D, E, and F, without unit, are well defined and standardized between -100 and $+100$ (Fig. 7). These parameters provide rectangular patterns and compare them with reference patterns (α , β , γ and δ) (Boudoukha and Athamena 2012).

The application of these diagrams allows us to conclude that the sources are of deep origin, having flowed into the crystallophyllian base (Figs. 8, 9). However, the faults

Fig. 8 Reference diagrams of the International Geothermal Research Institute applied to the thermal springs of Guergour, Ouled yelles, Douar el Kebir, and ouled tabben



effectively allowed the water to infiltrate and to acquire their initial carbonate mineralization and then ascend in contact with a terrigenous salt formation to obtain a secondary facies enriched in chloride.

Map of the isobaths of the thermal reservoir

The objective of using the chemical composition of water that arrives at the surface is to know the temperature of the sources at the thermal deposit depth; these estimations are called geothermometry methods (Table 2). The latest are tools that allow the estimation of the geothermal reservoirs depth and the temperature of the last chemical equilibrium before the emergence. Deep water and gases come to the surface and generally convey with them their geochemical history. However, during its ascent, hot water can be mixed with groundwater, which can complicate the use of chemical geothermometers. This will lead either to an overestimation or underestimation of temperatures. It should be noted that the rise of thermal waters from their original reservoirs is generally associated with a decrease in temperature and a change in total mineralization. The use of geothermometers assumes that there is no significant chemical change of water during its ascent. To estimate the

temperature of the last thermodynamic equilibrium, several geothermometers have been applied. The silica geothermometers, the most suitable in our case, gives temperatures of about 80 °C at depth characterizing a low enthalpy geothermal system. It is higher than the temperature measured at the outlets meaning an average dissipation of 48 °C. This dissipation could be due either to mixing with the ground waters or to the thermal diffusion due to the long circuit traversed by these waters to reach the surface. These geothermometry methods permit to draw up the thermal reservoir's isobaths map.

The map (Fig. 10) shows that the depth values of the thermal reservoir of the sedimentary cover are higher in the western, middle, and southern part of the region and decrease eastward and northward, the maximum values are recorded in the vicinity of hot spring of Ouled Yelles (3150 m) and hot spring of Ouled Boutara (3010 m), and the minimum value is recorded around hot spring of Dehamcha (2590 m).

Structural flow model of the thermal water springs into the surface

The thermal complex of our studied region consists of two hydrothermal systems (Fig. 11), the first one depth is over

Fig. 9 Reference diagrams of the International Geothermal Research Institute applied to the thermal springs of Dehamcha, Ouled Boutara, Soukhna, and Boutaleb

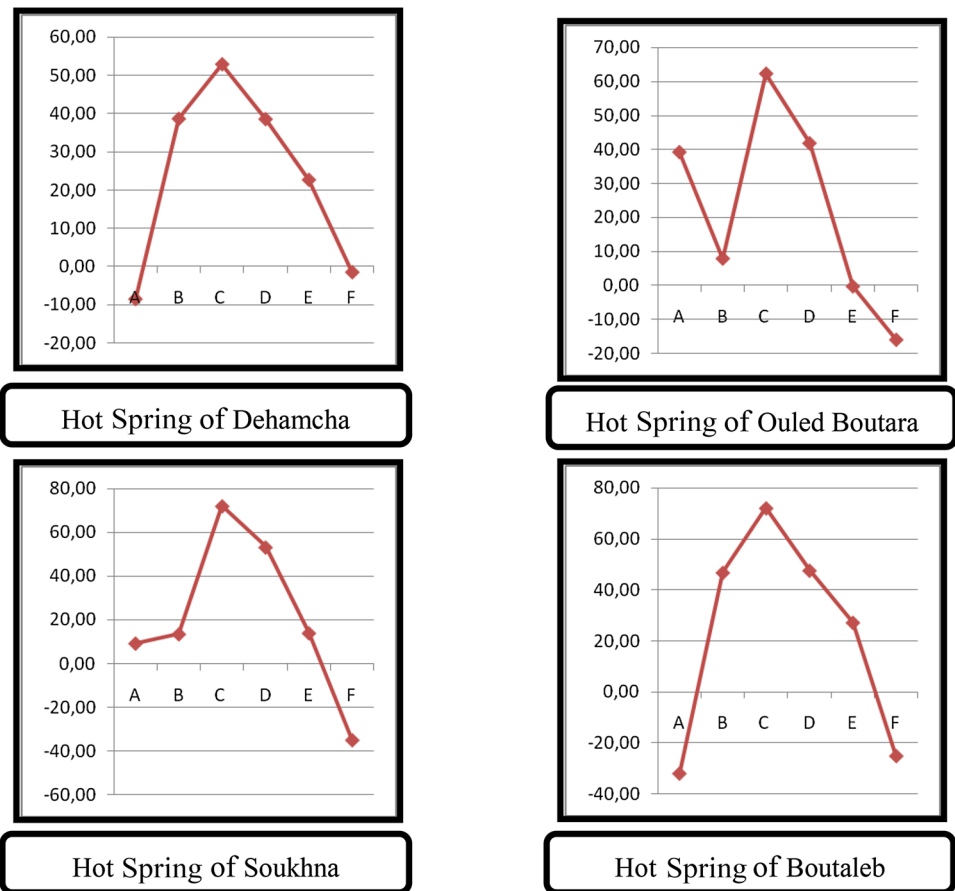


Table 2 Chemical analyses (in mg/l) and physico-chemical parameters of the thermal springs

Sources	Ca ⁺⁺	Mg ⁺⁺	Na ⁺	K ⁺	Cl ⁻	SO ₄ ⁻	HCO ₃ ⁻	pH	T °C	Conductivity
Guergour	641.28	77.76	392	8.8	739.6	15.16	268.4	7.22	48	3160
Dehamcha	124.24	21.87	218	4.51	298.2	15.12	549	7.2	30	1170
Boutaleb	380.76	70.47	820	25.5	546.4	15.96	378.2	7.6	52	3110
Ouled Tabben	769.53	48.6	180	5.09	426	14.532	38.4	6.92	48	2350
Douar El Kebir	200.4	58.32	144	5.87	284	14.763	591.7	7.03	34	1265
Boutara	180.36	19.44	226	6.54	284.1	15.435	488	7.35	37	1300
Soukhna	200.4	41.31	554	12.93	830.7	15.309	524.6	7.29	45	2800
Ouled Yelles	284.56	65.61	126	12.98	404.7	14.595	829.6	6.95	40	1500

3200 m, and the other is beyond 2600 m. According to (Issaadi 1992), the thermal complex supply is farther away. However, examination of the structural position, in association with the interpretation of geochemical analyses, shows that the only possibility of water supply is in the western part (Djebel Babor and Biban de Zemmoura).

Alpine Atlasic movements seem to be primarily responsible for the high temperatures in the western part (Dib 1985). The sources in the west are interpreted to be in contact with the volcanic formations; this interpretation supports the idea that justifies the high temperature of all sources located on the west (Verdeil 1977).

The emergence of these sources is on the edge of the outcrops which are formed by limestone, dolomite, and sandstone; it is due to the existence of a hydraulic short circuit between origin and surface in the western part, resulting from fracture related to deep accidents that affect the basement (Bouchareb and Boudoukha 2009).

As a result, the water warms and acquires their initial mineralization (carbonate and crystallophyllian) to the west, and then continues along thermal circuit in contact with another terrigenous salt formation, which consequently let it acquire a second facies saliferous in the east. Finally, hot water emerges at the surface to give the hot

Fig. 10 Thermal reservoir's isobathes map

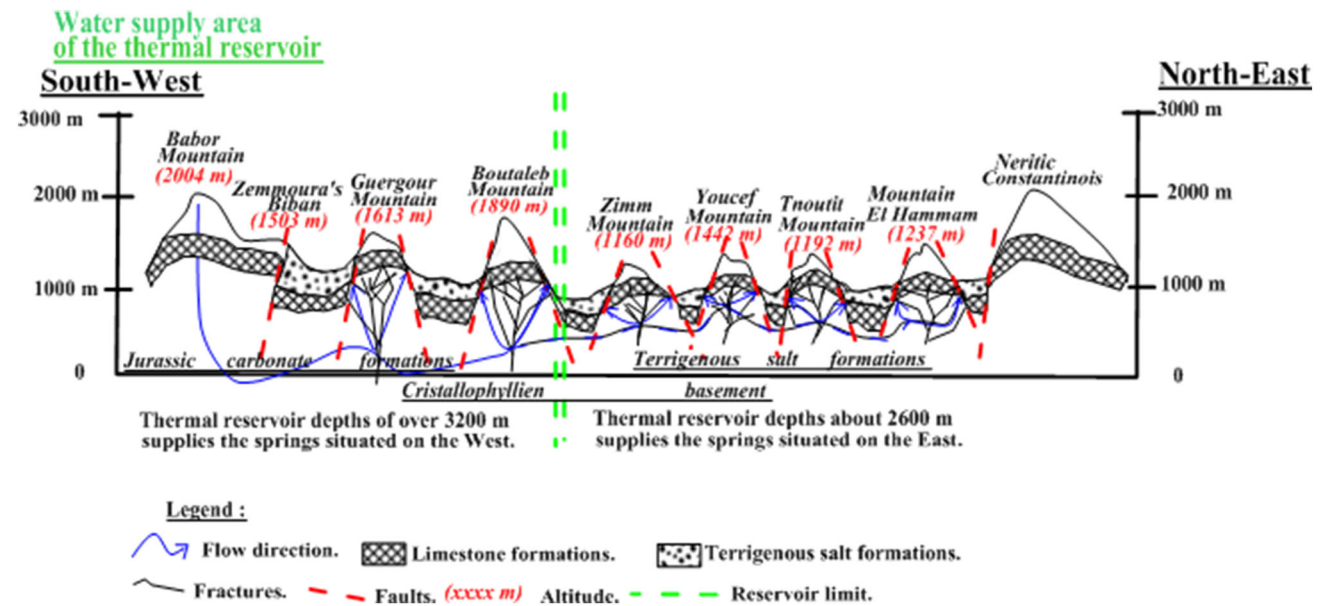
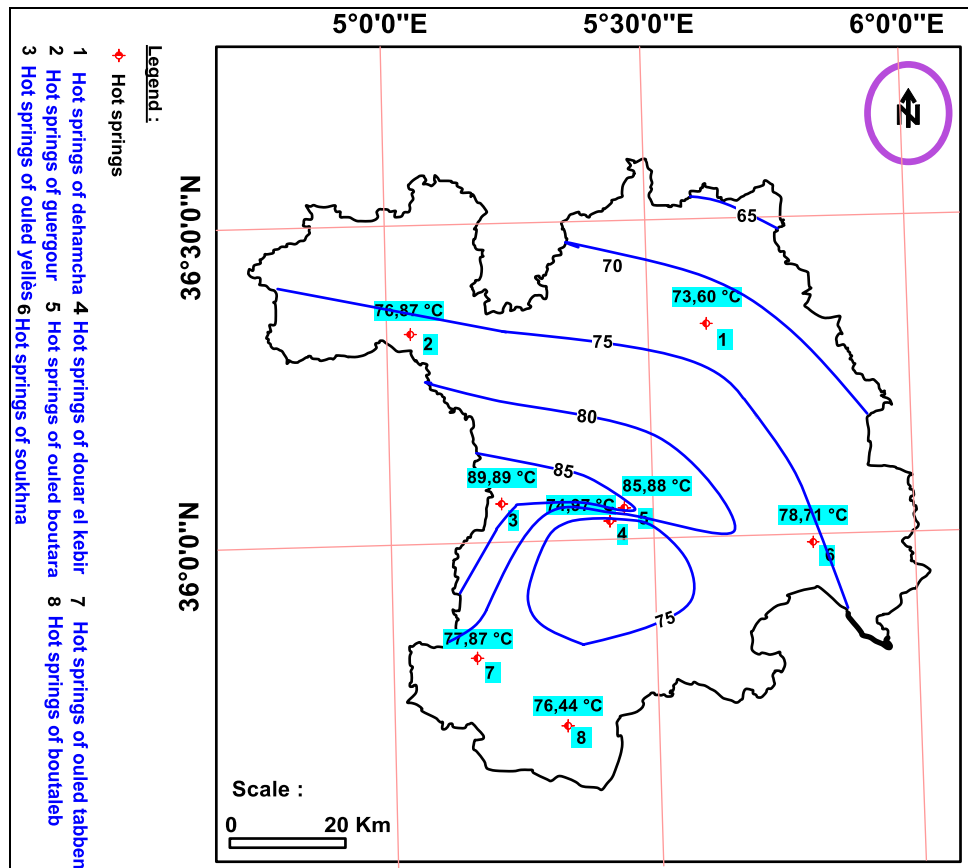


Fig. 11 Structural outline showing the flow circuit of the thermal water springs

springs of Guergour, Ouled Yelles, and Soukhna, or stay inside permeable formations to form thermal zones such as Sukhna and Zdim in the east, Boutaleb in the west, and Guerggour in the north.

According to these results, we have arrived to the conclusion of the existence of two hydrothermal systems constituting the global thermal complex. Moreover, the decrease of sources temperature and depth values,

according to the flow circuit, are interchangeably related, which confirms the existence of two deep reservoirs one in the West and the other is located in the eastern part.

Conclusion

Setif city, which is located in the northeast of Algeria, is home of many hot springs with temperatures ranging between 30 and 52 °C. All hot springs emerge due to faults in the vicinity of mountains and plains.

The overall rose set from detailed studies of lineament allows us to conclude the existence of two types of faults, a primary one whose directions are NNW–SSE, NW–SE, and NE–SW, and the other one is secondary.

Chemical analyses of the thermal spring water indicate the presence of four chemical facies; the first is calcium sulfate type (CaSO_4), the second type is sodium sulfate type (NaSO_4), and the third and fourth types are sodium chloride (NCl) and sodium bicarbonate (NaHCO_3).

The extension of fractures that affect the crystalline basement permits the emergence of deep thermal water on the surface and the release of a foremost heat flow that warms the overlying reservoir and ultimately ensures the communication between various reservoirs, and consequently dissipates much of their original energy and ensures the acquisition of a new chemical facies either carbonated or saliferous. The diagrams of the International Institute for Geothermal Research allow us to confirm that the sources are of deep origin.

The structural flow model of thermal water confirms the existence of two hydrothermal systems, one is in the carbonate and crystallophyllian formations in the west, and the other is in the terrigenous salt formations in the east.

References

- Amore F, Scandifio G, Panichi C (1983) Some observations on the chemical classification of ground waters. *Geothermics* 12:141–148
- Bouchareb FZ, Boudoukha A (2009) Hydro-geochemical and lithostructural approach of deep circulations in the mounts of Hodna, Algeria. *Eur J Sci Res* 37:12–20. ISSN: 0262-6667
- Boudoukha A (1998) Hydrogéologie des hautes plaines sétifiennes et hydrochimie des eaux souterraines. Thèse de Doctorat, Univ. Annaba, Algérie
- Boudoukha A, Athamena M (2012) Caractérisation des eaux thermales de l'ensemble Sud sétifien, Est algérien, *Revue des sciences de l'eau. J Water Sci* 25(2):103–118
- Boudoukha A, Belkacem M (2014) Caractérisation électrique des formations aquifères de l'est algérien. *Courrier du Savoir* 18:77–82
- Demdoum A (2010) Etude hydrochimique et impact de la pollution sur les eaux de la région d'el eulma
- Dib H (1985) Le thermalisme de l'Est algérien. Thèse de Doctorat, Univ. Alger, Algérie
- Djemmal S (2008) L'effet de la sebkha sur la qualité des eaux souterraines dans la partie Sud-Est de la wilaya de Sétif cas de Guidjal
- Issaadi A (1992) Le thermalisme dans son cadre géostruc-tural, apports à la connaissance de la structure profonde de l'Algérie et de ses ressources géothermales. Thèse de Doctorat, Univ. Alger, Algérie
- Rachid N (1987) Etude hydrogéologique et hydrochimique des eaux thermales du centre algérien (Nord). *Geochemistry*. Université Scientifique et Médicale de Grenoble, French
- Saibi H (2015) Geothermal resources in Algeria. In: *Proceedings world geothermal congress, Melbourne, Australia*, 19–25
- Verdeil P (1977) Le thermalisme algérien dans son cadre géostruc-turale (en coll. avec H. Gonad et J. Grevellec) 5è réunion des Sciences de la terre. Rennes
- Vila JM (1980) La chaîne alpine d'Algérie orientale et les confins algéro-tunisiens. Thèse de Doctorat, Univ. Pierre et Marie Curie, Paris VI, France