

# The main geothermal reservoirs in the south Algeria and their interest for local economic development

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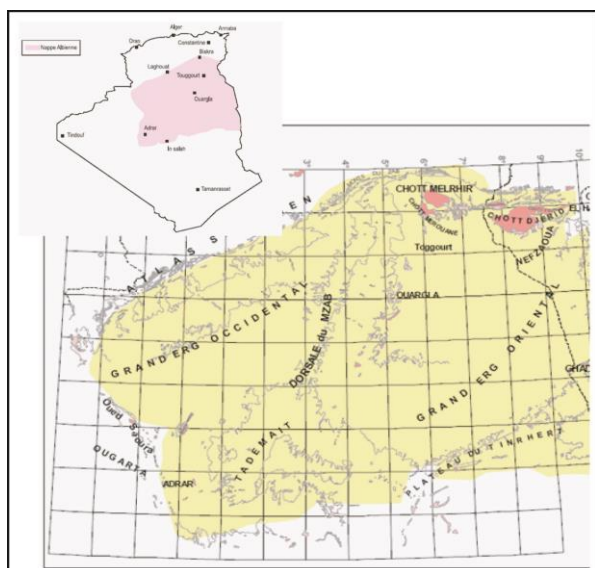
**Abstract.** The study area is one of the important geothermal provinces in south Algeria. It is characterized by a hot arid climate with intense dryness and very high evaporation rates. The Albian geothermal system is exploited by the wells mainly for domestic and agricultural purposes. The sandstone Continental Intercalary (CI) formation constitutes the reservoir for the Albian aquifer, covering an area of 600,000 km<sup>2</sup>. This reservoir is covered by calcareous formations which yield the chemical characteristics of highly mineralized Na-Cl type representing the deep thermal waters and Ca-SO<sub>4</sub> type determined the presence of evaporate lithology. For a better understanding of geothermal reservoir characteristic, a multidisciplinary approach was adopted, including hydrogeochemistry and geothermometry. More than fifty samples collected from wells recently in 2017 with a temperature average between 38 and 60° C and conductivities range from 2010 to 3460 μS/cm. Geochemical analysis of those thermal waters exhibits a certain degree of salinity with sodium-chloride type waters domination. The maximal geothermal reservoir temperature estimated using geothermometry is about 120°C.

## 1 Introduction

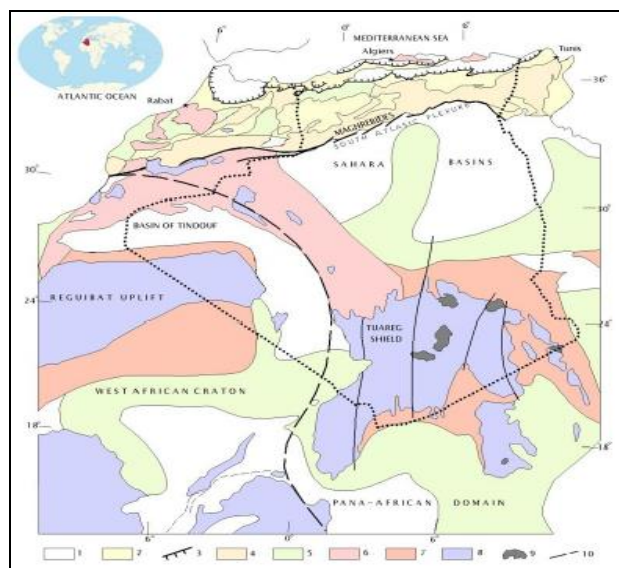
Sahara is situated in North Africa between the Atlantic Ocean and the Red Sea, it is the biggest and one of the driest deserts of the planet (Fig. 1). It's up to the big desert located in the north hemisphere, in recent years; several studies address the groundwater and geothermal potential along the south of Algeria. [1, 2, 3, 4]. The natural limits of this vast region of about 900 000 km<sup>2</sup> are the following ones:

- In North, the edge of the high plateaus of the Atlas which extends from Morocco to the gulf Gabès gulf (Tunisia). This line corresponds to a geological undulation which brutally stops.
- Towards the south mountains and high plateaus of the Atlas and mark the beginning of the Saharan platform. In the south, primary formations outcrop bordering the Tademaït and Tinrhert plates.
- In the West, the valley of Saoura which curves between the mounts of Ougarta and Large Erg Occidental and prolongs towards the south by the Messaoud Wadi whose bed is encumbered sand banks and sebkhas between Adrar and Reggane.
- At the East, the Djebel Dahar reliefs (Tunisia) relayed towards the south by the Algeria-Libyan border. In the summit there is a the multilayer aquifer of Terminal Continental constituted by Mio-Pliocene formation and the upper Cretaceous, below, the water table of Continental Intercalary which develops in the Albian and the barremiensablo-clayey lithology. The geothermal systems occur in regions of anomalously high crustal

heat flow that may be related to the presence of young igneous bodies or hot rocks located deeper in the crust [2,5]. Frequent data were presented on geothermal waters in South Algeria obtained from filed works prospection. The South Algerian geothermal fields deal an important setting of high temperature with various chemical proprieties. The distribution of sampling locations is associated with the geology structure cover the study area. The heating origin for South Algerian hydrothermal systems is the high geothermal anomaly related to the average gradient of 4.5°C/100 m [2]. Hydro chemical methods play a key role in geothermal reservoir study and are particularly widely used to determine the deep reservoir proprieties [6, 7]. The current paper focuses on the investigation of chemical properties of the principal geothermal waters located Northern Sahara provinces. Based on recent sampling campaign field work and using adapted measurement tools (WTW multi-parameter tool (2C10-0011FB ),...), various data (pH, T°, electrical conductivity (EC),...) were collected and analyzed. This work leads us to provide a reservoir temperature and the corresponding thermal power potential. All results will aid local authorities and private sector investment in various activities (residential, agricultural and tourism) to develop renewable geothermal energy for heat and electricity generation.



**Fig. 1** The huge geothermal reservoir system in the Algerian North Sahara



**Fig. 2** Major geotectonics units of West Africa modified from Fabre (1976). 1: Tertiary and Quaternary; 2: Alpine molasses; 3: Tertiary thrust sheet; 4: Secondary tabular; 5: Secondary plicative; 6: Primary plicative; 7: Primary tabular; 8: Precambrian and Precambrian of Sahara; 9: Cenozoic magma; 10: Megafault

## 2 Study area

### 2.1 Geology aspect

The geology illustrates the outcrops lithology and position in the Sahara (Fig. 2). As well as the typical provision of principal formation the Sahara aquifer system. The Final Complex formations are characterizing by less tectonics deformations. All surfaces which limit the various formations are horizontal [2]. We can subdivide the Algerian Sahara in two under-fields: the Western basin and the Eastern basin, separated by the M' Zab anticlinal from. The Western Sahara basin is the area ranging between Me Zab, the valley Saoura and the atlasique flexure. It's a punt area forms very monotonous, where one observes only one light raising of the Mio-Pliocene layers, so that the whole basin constitutes very open synclinal [1, 5]. More the half Western basin, between Me Zab and Saoura, except for the zone located immediately at the south of the Saharan flexure, we note the absence of intermediate formations between sands of Mio-Pliocene and sands of the Continental Guide. The basin of the Eastern Sahara is definitely better known than its Western counterpart, thanks to oil research [2, 8]. The Eastern Sahara, limited to the west by Me Zab and the south by the plates of Tademaït and Tinrhert, is prolonged towards the east in Tunisia and Libya. The Eastern basin is also presented in the form of vast synclinal, open towards north [9, 10].

### 2.2 Hydrological contexts

The Algerian Sahara, partly, is occupied by a vast sedimentary basin which is prolonged in Tunisia and Libya. As of the first geological investigations, one recognized that this basin was heterogeneous and contained several very wide fluvio-continental formations, separated by formations considered impermeable. Two principal systems are distinguished: Continental Guide (Ci) and the Final Complex (CT). The Continental Terminal corresponded only to sands and clays of Mio-Pliocene. Under the term of Continental Terminal, with an aim of hydrogeologic simplification from the point of view, all the series going of Cenomanien in Mio-Pliocene. Indeed, the aquifer of the Continental Terminal contained in sands of Mio-Pliocene. The Continental term is used to indicate a hydrogeologic unit and not with its usual direction. The Final Complex includes the most recent formations deposited in the Low-Sahara and limited to the west by the dorsal of Me Zab, in north by the major accident of the Saharian Atlas, in the east by Dahar, the south by a line passing to the north of the axis In Salah-Zarzaitine under Eastern Erg. S enonien, the Eocene and Mio-Plioc ene are, with the Quaternary one, the last formations deposited in the Sahara [11].

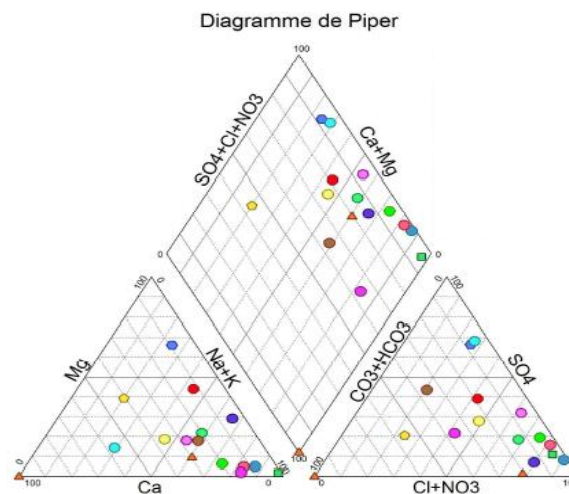
### 3 Methodology

More than fifty sampling sites were investigated with water sampling within North Sahara provinces in 2016. Thermal water samples were collected into 500-ml polyethylene bottles, cleaned with distilled water before collecting the thermal fluid. During the field works campaign, physicochemical parameters such as water temperature, pH, electrical conductivity, Total Dissolved Solids (TDS) are measured, in situ, using WTW multi-parameter tool (2C10-0011FB). During laboratory analysis, Potassium (K<sup>+</sup>), Calcium (Ca<sup>2+</sup>), sodium (Na<sup>+</sup>), Magnesium (Mg<sup>2+</sup>), Sulfat (SO<sub>4</sub><sup>2-</sup>), chloride (Cl<sup>-</sup>), were determined by ion chromatography (IC, DionexDX-120). The total silica in water was determined by a colorimetric method and alkalinity (HCO<sub>3</sub>) analyses were made using standard titration technique. Atomic absorption spectrophotometry was used for SiO<sub>2</sub> analysis. Chemical analyses of thermal waters were performed at CRD" Centre de Recherche et developement Sonatrach( national oil company).For chemical plotting, the free software "Diagramme"-copyright, provided by Avignon hydrogeology laboratory (<http://www.lha.univ-avignon.fr/LHA-Logiciels.htm>), was used. Some maps were prepared using the public domain Generic mapping Tool (GMT) software [12]. Several chemical geothermometers were used to estimate the geothermal reservoir temperature [13, 14, 15, 16,17 and 18].

### 4 Results and discussion

#### 4.1 Geothermal water chemistry

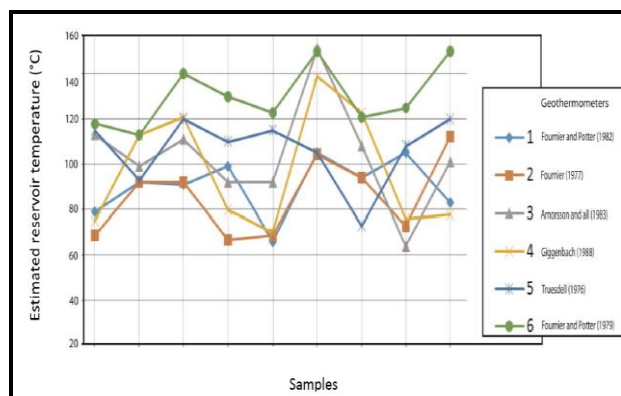
The hydro chemical features of thermal waters are connected to their underground pathway, temperature at depth, the nature of the contact rocks and the residence time. The thermal spring waters are of a variety of chemical types; this variability is due to the lithological composition of the collection sites, which overlie several different complex geological structures. The Piper diagram (Fig. 3) shows that the overall chemical character falls within the following two water types. Most waters belong to the sodium-chloride type Na-Cl. In general, all these waters are sodium-chloride waters as a result of the physical environment or of reactions with deep reservoir lithology (water-rock interaction). Allowing to the Piper diagram, the evaporates layers appear to influence the composition of the circulating shallow waters. A characteristic SO<sub>4</sub>-type composition was recognized for the study area waters, maybe due to the presence of gypsum and/or anhydrite (CaSO<sub>4</sub>) in the reservoir. Very high SO<sub>4</sub>concentrations of some samples advise a carbonate source with anhydrite. A small amount of H<sub>2</sub>S and CO<sub>2</sub> can be released during the bacterial reduction of SO<sub>4</sub> and hydrocarbons.



**Fig. 3** Piper classification diagram showing the chemistry distribution of the water study area

#### 4.2 Geothermal reservoir temperature

More than forty thermal waters samples selected to assess reservoir temperature by numerous chemical geothermometers. This technique assumes that there is a fluid-mineral equilibrium as well as an equilibration between mineral assemblages at depth in the reservoir and stabilization of dissolved chemical elements with the ascent before mixing. The outcomes of the diverse chemistry methods show that deep reservoir temperatures are quite variable. Some of the results obtained especially for the chalcedony and the Na/K geothermometers are obviously wrong since the calculated temperatures are lower than the measured discharge temperatures. This outcome may be the consequence of the interaction of thermal waters with reservoir rocks during their rising to the surface and the increase of solubility of certain elements with decreasing temperature. The estimated reservoir temperatures range from 60 to 115 °C for the quartz geothermometer, while the cation geothermometer gives the highest value around 140 °C. The wide range of the calculated values reveals that these temperatures cannot be considered reliable. This could be explained by a strong possibility of mixing between fresh and deep waters during upflow from the reservoir to the surface. Also the water composition is greatly affected by the interaction with the evaporitic rocks that are omnipresent in the region. Temperatures calculated by those geothermometers for main thermal sites in the study area given in figure 4. The outcome of the diverse geothermometers show that the deep reservoir temperatures ranged between 65°C and 155°C.



**Fig. 4** Estimated reservoir temperature based on different geothermometers

## 5 Conclusion

The study of the North Sahara geothermal reservoir was carried out in order to investigate the origin and sources of solutes and estimate the deep reservoir temperatures. It examines the hydrochemical composition of more than fifty thermal water samples from springs and wells, with various methods such as geothermometry analysis, saturation index and Piper diagram. The arrangement of major elements geochemistry has provided a comprehensive understanding of the mineralization processes that reinforce the geochemical evolution of the thermal water inside the study area. The combination of the geological and hydrogeological methods let us conclude a good relation between chemical processes and hydrothermal flow system. The main studied geothermal provinces characterized by an important outlet temperatures ranging from 40 to 62 °C (springs and wells). The chemical analyses data (recent decade field works) show us a deep flow in the Albién sandstone aquifer, influenced by Trias evaporate lithology. The data treatment let us complete that the thermal waters in the study area come from deep geothermal reservoir (1500m to 2000m). Hydrochemistry results suggest that 90 % of water samples are chloride sodic chemical types. The geothermometry applications give a deep flow path and reservoir temperature ranging between 50 °C to 120 °C.

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