

Review

Hydrogeological Characteristics of the Geothermal Transboundary Aquifer Reservoir Case Study of the Continental Intercalaire Aquifer System in North Sahara Aquifer System (NSAS) in Southern Tunisian Field

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The North Sahara Aquifer System (NSAS) shared by Algeria, Libya and Tunisia, contains very large reserves of non-renewable water. It covers an area in excess of 1,000,000km² of which 700,000km² are in Algeria, 80,000km² are in Tunisia and 250,000km² are in Libya. It is composed of sedimentary rocks that include the Continental Intercalaire (CI) aquifer, which is made of lower Cretaceous (Neocomian, Barremian, Albien) interbedded sandstones within calcareous rocks. It consists of several horizons with different hydrodynamic characteristics. The geothermal gradient ranges from 2.9 to 3.5°C/100m, the temperature ranges from 46 to 81°C, pressure from 14 to 20 bars, and TDS of 2.2-4.5g/l are of a sulphate-chloride type. Using isotopic indicators (18-O, Deuterium, 14C), radiocarbon ages, except near outcrop, area to near detection limits and the δ¹⁸O and δ²H values indicate(?). The age of geothermal water is about 25-50 thousand years old (BP). At present, estimates of annual water extraction from this basin amount to 540hm³ in Tunisia, 1,100hm³ in Algeria and 250hm³ in Libya. Tunisia holds an even bigger reserve of exploitable non-renewable groundwater than its neighbors Algeria and Libya, with estimates in the order of 1,700km³ (OSS2004). The total annual extraction from the NSAS ranges currently from 2.2 to 2.5billionm³ and this rate has been increasing. Many problems occur in the deep wells (2800m depth) such as scaling, corrosion etc. The result of this improved knowledge of the basin's hydrogeology is the refined characterization of the aquifers, which are required for mathematical modeling.

Keywords: NSAS, Continental Intercalaire, Hydrodynamic, Age, Tunisia, Isotope.

INTRODUCTION

The NSAS extends over a surface area of 1,000,000km² with 700,000km² in Algeria, 250,000km² in Libya and 80,000km² in Tunisia. This basin is located in an arid zone, with rainfall ranging from 20 to 100mm.yr⁻¹. In the southern Tunisia geothermal field, which is in the major part of the basin, rainfall does not exceed 100mm. The

structure of the latter is in fact a large depression filled by thick layers of sedimentary formations (continental and marine). This sedimentation is limited in the bottom by the basement. Detrital formations of the Continental Intercalaire (CI) constitute the main geothermal aquifer of the system.

The CI aquifer is composed of a succession of clastic sediments of Lower Cretaceous age. Its thickness and lithology shows significant lateral variation. The CI is laterally continuous over the whole basin. It is exposed around prominent mountains and plateaus such as the

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Saharan Atlas, the Tinrher Plateau, the Tassili mountains, the Dahar and Jabal Nafussa, etc. The CI is a lithologically variable formation. It is composed mainly of sandy and clayey sandstones. Towards the centre of the basin the strata forming the reservoir have entirely continental facies. Towards the basin margins, especially in the east, a transition to lacustrine and then to marine facies takes place. At its maximum, the thickness of the CI exceeds 1500 m. In its southern region, faulting has led to a compartmentalization in the CI. In the Libyan part of the basin, the CI is equivalent to the Kiklah formation, which is of Triassic age (Figure 1).

Based on isotopic techniques, the geothermal waters are about 25-50 thousand years old, corresponding to the last glacial maximum in Europe (Edmunds et al., 1997). Hydrogen and oxygen stable isotopes indicate a meteoric origin of the geothermal waters. $\delta^{18}\text{O}$ ranges from -7.5 to -9‰. This signature is characteristic of paleowaters in northwest Africa. These isotopes show that the groundwater reservoirs are non-renewable (Edmunds et al., 1997).

Exploitation of water resources of the system has seen a notable increase during the second half of the 20th century. The annual extraction was 0.6 billion m³ in 1950, then increased to 1.7Bm³ in 1970 and has since reached 2.5 Bm³. This situation is reflected by the following impacts:

- A notable decrease of artesian discharge,
- Drying of main springs,
- Generalization of pumping extraction with increasing drawdown,
- Degradation of water quality in some areas that are more vulnerable to salinisation

Climate and Hydrographie

The climate of the south of Tunisia is characterized by intense drought with low moisture content. The average annual temperature is around 25°C, with hot summers and cold winters. Extreme temperatures are above 50°C in summer. The rains are characterized by large inter-annual variability. In the northern Sahara, they are fine when they are at the center of downpours. These climatic characteristics affect the Saharan hydrography. Thus the flow of water in valleys is temporary and is lost in the closed depressions (chotts and sebkhas). When the valleys have no surface flow, they often have a sub-surface flow, which takes on a lot of importance to the scarcity of surface water.

The area is mostly located on the Saharan platform, which is a flat plateau dipping gently to the southwest, where it is overlain by the sand dunes of the Great Erg Oriental, and by very large dry salt lakes (Chott Djerid, Chott El Fedjej, Chott El Gharsa).

Hydrogeology

Piezometrie

It is considered that the water piezometry of the CI is related to sand and sandstone Kbeur El Hajj because this piezometry connects those to other areas of southern Tunisia, where this water is recognized. This piezometry shows that the flow of the water is from the edges of the basin of the great Saharan erg oriental area to chott Fejjej, which is the outlet of the water. In this zone, the flow of the water is in the direction of the fault of Gafsa-Elhamma, which creates a threshold by the tectonic force from which the water rises along fractures and discharges in the Upper Cretaceous formations (limestone and dolomite of the Turonian Senonian). The surface of chotts fedjej is the area of evaporation of water from upper levels of the nappe. The four aquifers are connected vertically by drainage phenomena that facilitate the loss of water level of the main base in the other aquifers.

Geology

In the study area, the aquifer of the Continental intercalaire is in the form of an artesian aquifer. It is the largest reserve of water in southern Tunisia. It defines the continental aquifer interlayer as the Cretaceous continental formations below, between the Neocomian and Albian, which consists of sand, sandstone with intercalations of clay, and whose depth ranges from 1000 to 2800m. The continental interlayer is overlain by the Upper Cretaceous deposits, namely the Cenomanian, Turonian and Senonian salt, which can reach a thickness of about 220m. The reservoir aquifer continental intercalaire is distinctive because of its volume, extending over 1,000,000km², and having an average thickness of several hundreds of meters. Large quantities of water were stored in Quaternary wet periods, Figure 2.

Geothermal gradient

The geothermal gradient plot is an important milestone in geothermal energy. It shows the variation of temperature with depth at each point of the study area. Figure 3 shows the distribution of the thermal gradient in the CI aquifer. Thermal gradients are measured from water temperatures at the wellhead, and the observed geothermal gradient varies widely from one place to another, sometimes it is not more than 3°C/100 m.

The geothermal gradient is calculated for each drilling through the following relationship: (Figure 4).

$$G = \Delta T \Delta Z [^{\circ}\text{C}/100\text{m}]$$

T: Temperature (°C); Z: Depth

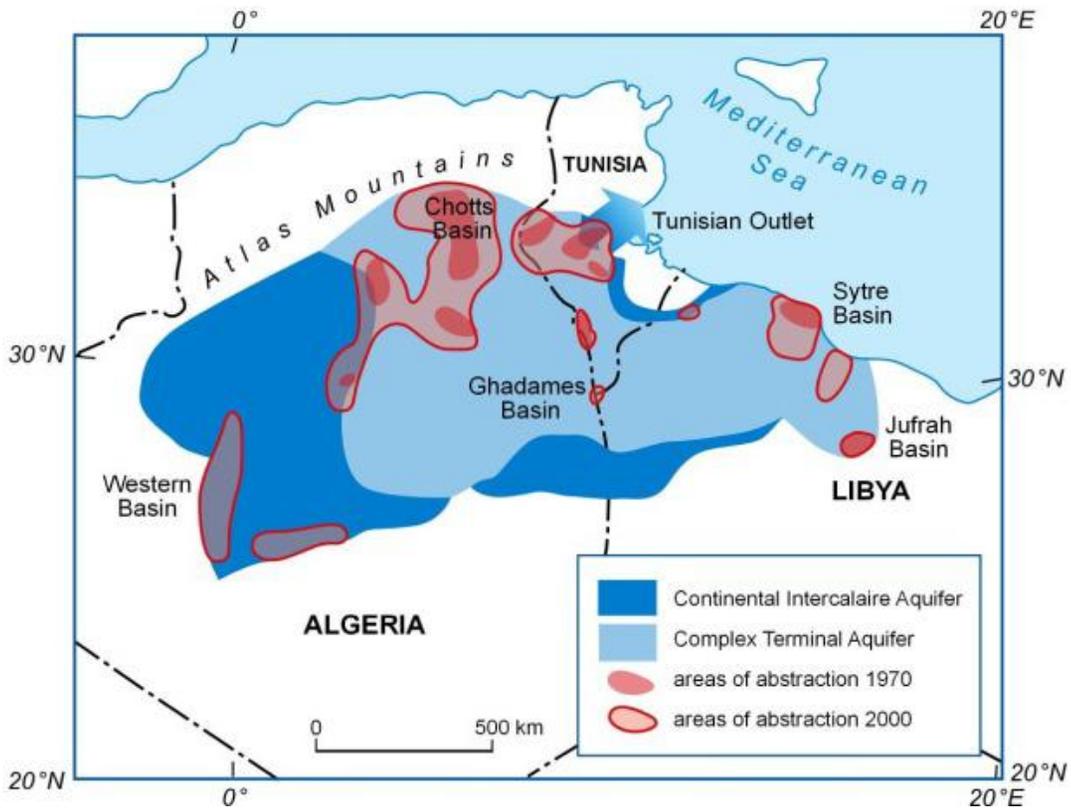


Figure 1. Hydrogeological sketch map of the extent of the C.I. aquifer in the North Sahara Aquifer System

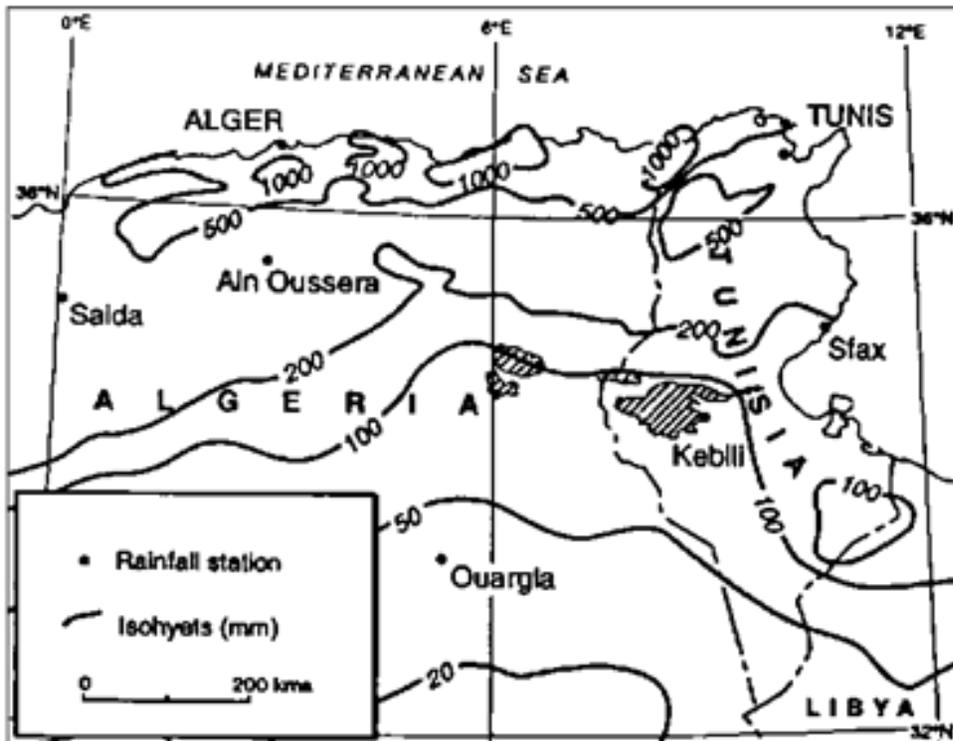


Figure 2. Rainfall over the North Sahara basin and its surroundings

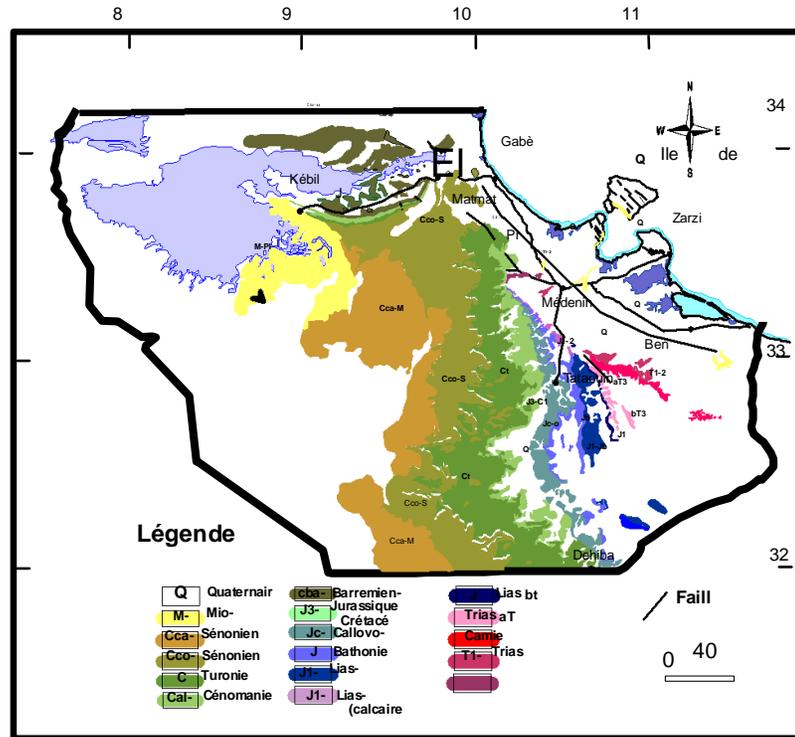


Figure 3. Simplified geologic map Southern Tunisian Field

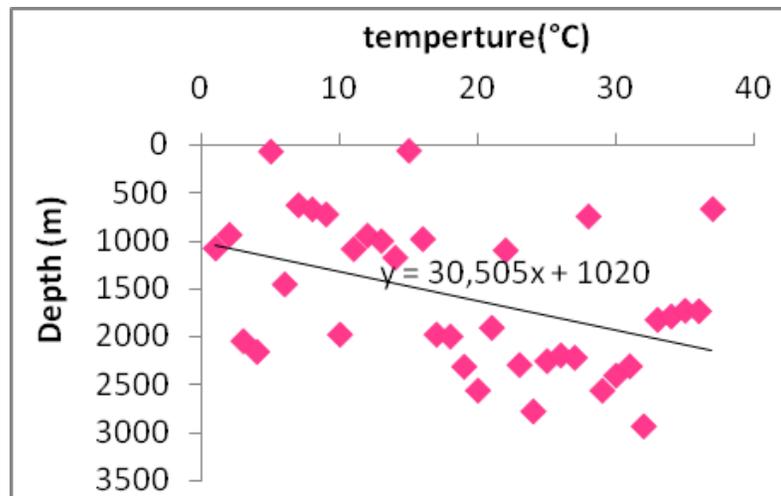


Figure 4. Plot of variations of temperature vs depth(m)

Hydrochemistry

The geochemical data acquired so far from the aquifers show clear variations from one level aquifer system to another reflecting differences in aquifer composition, recharge mechanisms, groundwater flow directions, groundwater age, groundwater mixing conditions, and hydraulic connections between aquifers.

Generally the groundwaters in all the CI aquifers are dominated by SO₄ and Cl balanced by Ca and Na

(figure 5). The chemical compositions and evolution in the aquifers are in general agreement with the general groundwater dynamics. Groundwaters from the CI aquifers have low TDS compared to groundwaters from the upper aquifers. This reflects the differences in the composition of the aquifers. Locally however, some low TDS groundwaters indicate the replenishment via upward leakage of groundwater from the CI aquifers.

Generally, groundwater TDS increases along the recognized flowline. Examples include the increase in

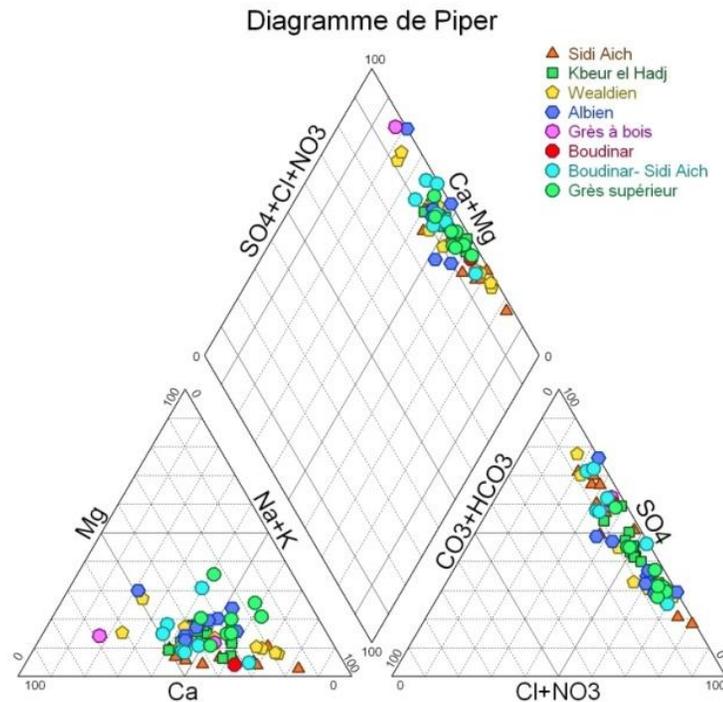


Figure 5. The plot of the waters from CI aquifers in southern Tunisian geothermal field

TDS as one goes southward from the Saharan Atlas to the discharge area located in Chotts and gafsa-El Hamma fault (~ 0.3 to ~ 1.4 g/L). The composition of the majority of the major elements increases with increases in the TDS. There is a linear 1:1 relation between Na+ and Cl- in all the aquifers indicating halite dissolution as a principal control of Na and Cl contents of the waters. Likewise Ca^{2+} is linearly related to SO_4 indicating common origin of both ions. The bicarbonate content of the groundwaters from all the aquifers is low and shows an arrow range between 2000 and 4000mg/L, irrespective of increases in the TDS.

Stable isotopes results

Comparison between the isotopic compositions of the aquifer systems with that of the present day rainfalls show major differences. Although some exceptions can be observed, groundwater in all the aquifer systems are generally isotopically more depleted than the weighted mean isotopic composition of present day rainfall (figure 6). In the Great Oriental Erg the groundwaters from the CI are the most depleted and the most isotopically homogenous. However, high variability and generally enriched waters are common in the aquifers of the CI in the Occidental Erg. Some enriched waters in CI aquifer of the Great Oriental Erg (figure 6) are observed around the Dahar Mountains where the CI aquifer becomes unconfined.

Radioactive isotopes results

Carbon 14 and Tritium activities: In the CI aquifers the carbon-14 activity is generally low. Appreciable amounts of C-14 in the CI aquifers are traceable only upto small distances from the exposure zones of the CI aquifer. The radiocarbon data indicate that a gradient in groundwater age exists in the main CI aquifer system as one goes along the groundwater flow directions. Some tritium-bearing waters containing a relatively high carbon activity are observed in shallow unconfined aquifers and in groundwater bodies around the mountainous areas, indicating the presence of modern recharge (Figure 7).

The principal areas of current or former recharge are in the South Atlas Mountains of Algeria and Tunisia, the Tinrheth Plateau of Algeria and the Dahar Mountains of Tunisia. The main discharge area is in Tunisia, in the Chotts and the Gulf of Gabes. The CI aquifer is one of the largest confined aquifers in the world.

CONCLUSION

Hydrogeological studies carried out in southern Tunisia showed that the water resources of the Sahara are located in two major geological complexes of which the water of the continental inter layer is the most important reservoir, from the point of view of resource mobilization and low enthalpy geothermal energy. It is located in the northern Sahara. The water of the continental

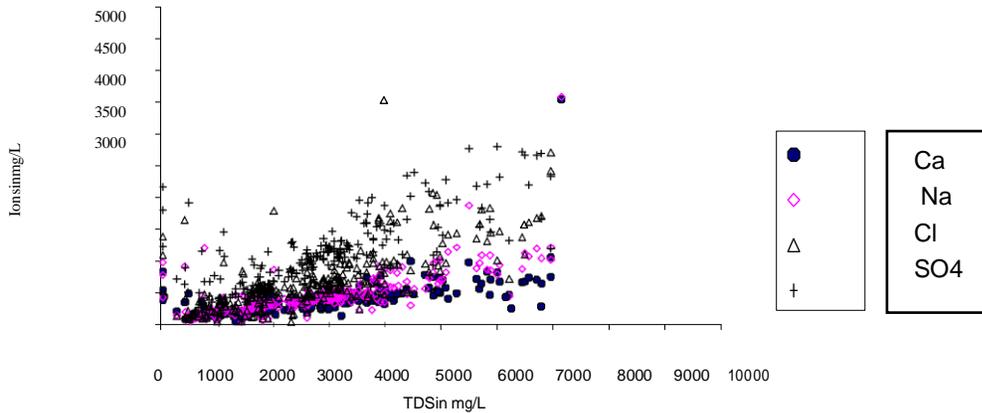


Figure 6. Variation in composition of the dominations with respect to total dissolved solids.

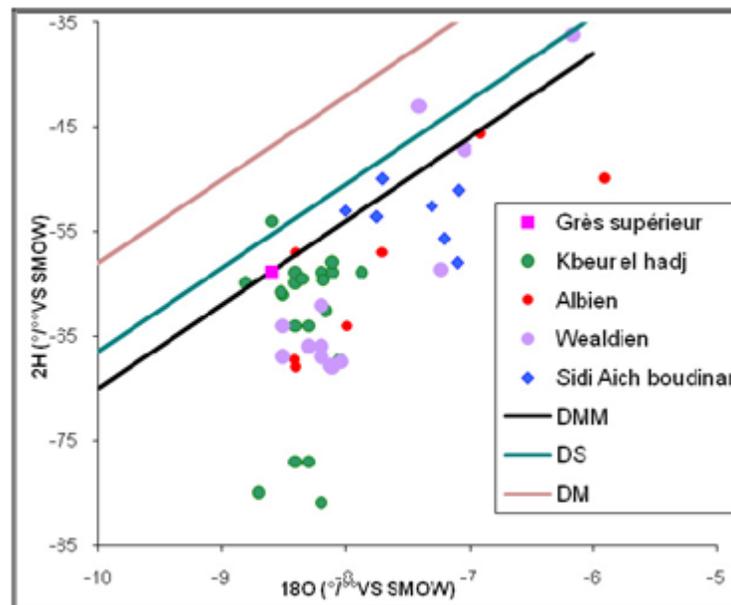


Figure7. $\delta^{18}\text{O}$ vs δD plot of all water samples from the basin with respect to the GMWL and the Weighted mean isotopic composition of rainfall

intercalaire aquifer is warm; it is most interesting as a geothermal power. According to the distribution of the geothermal gradient, the gradient is on average 3°C/100m. The northern part of southern Tunisia has two major conditions for the existence of a geothermal reservoir: a geothermal gradient and a deep aquifer. According to the previous results and to ensure best use of geothermal resources in southern Tunisia, it is suggested that low enthalpy geothermal energy in the northern part be used for heating of greenhouses, and the thermalime for curative reasons would be highly recommended in this region.

The isotopic study shows that the water is from meteoric origin. The signature of $\delta^{18}\text{O}$ (-7.5to - 9%) indicates the fossil origin of the geothermal water, of

which the age is about 25 to 50 thousand years old. The Piper diagram of water chemistry data from the wells reaching the Cl aquifer shows that the waters can be classified as sulphate-chloride waters.

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