Proceedings World Geothermal Congress 2005
Antalya, Turkey, 24-29 April 2005

The Continental Intercalaire Aquifer at the Kébili Geothermal Field, Southern Tunisia

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Keywords: CI, Kébili, wells, artesian

ABSTRACT

The C.I. "Continental Intercalaire" aquifer is an extensive horizontal sandstone reservoir (Neocomien: Lower Cretaceous: Purbecko-Wealdien). The CI is one of the largest aquifers in the world covering more than 1 million km^2 in Tunisia, Algeria and Libya. This aquifer covers 80,000 km^2 in Tunisia

In Kébili field in southern Tunisia, the geothermal water is about 25 to 50 thousand years old and of sulphate chlorite type. The depth of the reservoir ranges from 1000 to 2800 m.

The piézométric level is about 200 meters above the wellhead. The flow rate ranges from 70 to 200 l/s with a temperature that exceeds 60°C. Approximately 95% of the geothermal water is used for irrigation of oases after cooling by atmospheric towers. Partly it is used for heating greenhouses. Most problems are encountered during the hot water utilization, such as scaling in the pipes, corrosion of anchor casing and in some parts of wellheads like valves and monitoring points. Another problem is drawdown of the water level due to the the increasing water demands and salinization by intrusion of salt water from Chotts.

1. INTRODUCTION

The Continental Intercalaire (C.I.) fossil aquifer, which is composed of upper Carboniferous to Lower Cretaceous sandstone, is present beneath an area of 1 Million km^2 in Tunisia (80,000), Algeria (700,000) and Libya (250,000). It constitutes one of the largest groundwater systems in the world. The huge groundwater reservoir is mainly confined to the continental formations of the lower cretaceous (Neocomian, Barremian, Albo-aptien). In Tunisia, the reservoir covers the regions of Kébili, Tozeur, Gabes and the extreme south. The most important production takes place at the Kébili geothermal field, where the depth to the top of the reservoir varies from 600 to 2,800 m. Well pressures correspond to 200 metres above wellhead with temperature of around 70°C. The main utilization of geothermal water in Kébili geothermal field is for agriculture purposes; to help irrigate oases, to heat and irrigate greenhouses, for bathing and in some cases for animals' consumption. The hot water needs to be extracted by deep wells and cooling through a cooling tower is necessary. Offsetting the growing need for using geothermal water for irrigation, there are several problems encountered during exploitation such as scaling in the pipes, corrosion of anchor casing and some parts of wellheads like valves and monitoring points. Also drawdown of the water level has been observed due to the increasing water demands. Radiocarbon analysis has shown that radiocarbon is present at between 2 and 10 pmc which leads to the conclusion that the water is recharged during the late Pleistocene 25,000 years B.P, corresponding to the last glaciation (Edmonds et al., 1997). Water is fossil and without actual recharge, so to preserve the trans-borderers reservoir, more research must be carried out on the aquifer. Full collaboration with Algerian and Libyan organizations is necessary in order to achieve economical and sustainable future production and regional development. Long term monitoring of pressure temperature and salinity at the wellhead for each production well should be carried out. Any increase of drawdown during the next 20 years caused by increased production will lead to environmental changes.

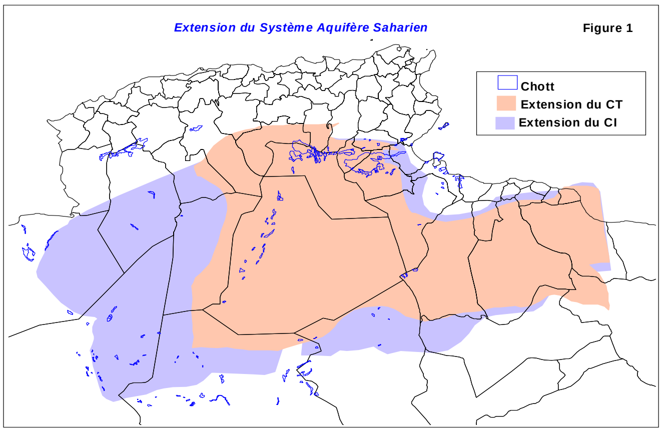

Figure 1: Extension of C.I. aquifer

2. BACKGROUND SETTING

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 very large dry salt lakes (Chott Djerid, Chott El Fedjej, Chott El Gharsa). The Kébili area has an annual mean temperature above 20°C, mainly because of the very high temperature in June, July and August. The annual mean evaporation at Kébili is as high as 8.4 mm per day, and high wind velocity is common, especially during the spring months from February to March. The climate is a semi-arid region with an annual rainfall of only 74 mm per year.

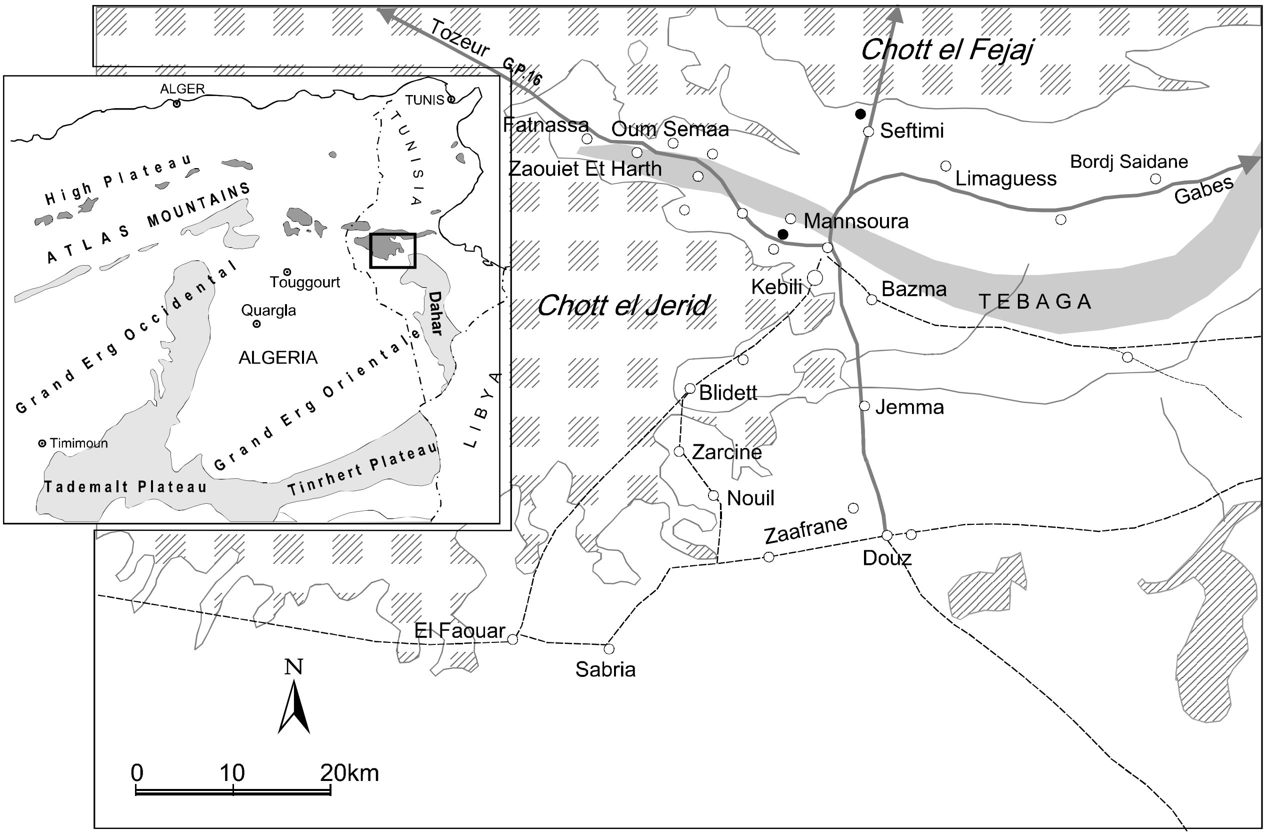

Figure 2: Location map of Kébili geothermal field

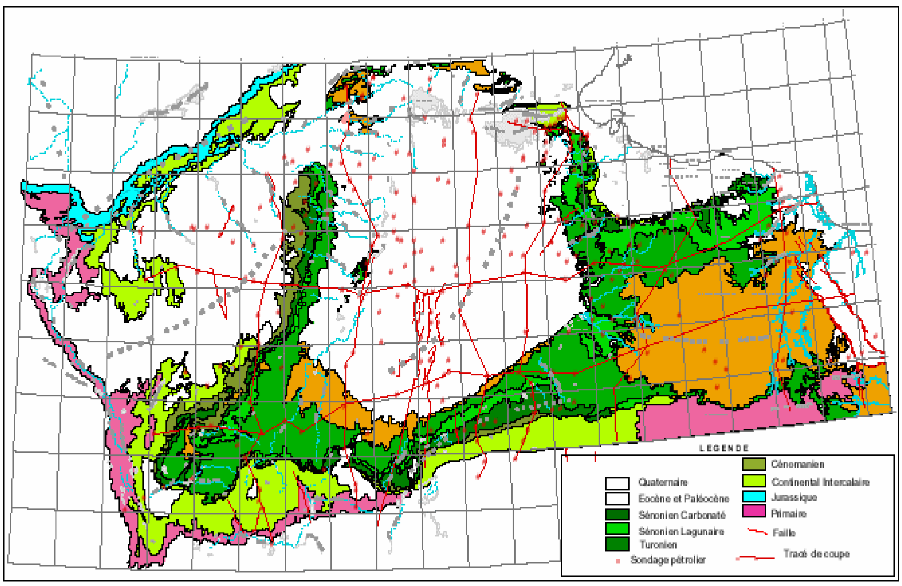

Figure 3: Geological map of aquifer system

2.1 Geological Setting

The huge groundwater reservoir of Continental Intercalaire (C.I.) aquifer is contained within the continental formations of lower Cretaceous Hautervien Valanginien (Neocomian, Barremian, Albian). It corresponds to the Asfer formation which is made up of interbedded varicolored clay or shale, sandstone, and small quantities of limestone, dolomite and evaporates, and it is marked by presence of lignite (Castany, 1982). The C.I. aquifer consists of several horizons with different permeability and different formation pressures. The main reservoir horizon is the deepest one; it is reached by the main wells.

Kébili is a very large region, but the sand of the Great Erg Oriental desert covers more than half of the area, and the lakes Chott El Djerid and Chott El Fedjej occupy considerable areas in the northwest and north. Thus, the area of human activity in this province is limited to a small zone along the eastern shore of Chott El Djerid, which is slightly hilly country forming a kind of peninsula or island in the chott.

2.2 Hydrogeology

Where the Kébili geothermal field is located, the artesian flow rate is usually higher than in the other provinces. The geothermal gradient is approximately from 29 to 35°C/km and increases from south to north. There are three main aquifers in this region, the Continental Intercalaire and secondary aquifers within the Jurassic and the Permian. The Continental Intercalaire aquifer covers the regions of Kébili, Tozeur, Gabes and the extreme south and extends to Algeria and Libya. It is characterized by temperatures ranging from 35°C to 75°C, pressures of 14 - 22 bars and salinity of 2.2 - 4.2 g/l. The geothermal resource potential in the Kébili geothermal field is estimated to be 1,000 l/s (ERESS project, 1972).

The principal areas of current or former recharge are in the South Atlas Mountains of Algeria and Tunisia, the Tinrhet Plateau of Algeria and the Dahar Mountains of Tunisia. The main discharge area is in Tunisia, in the Chotts and the Golf of Gabes. The C.I. aquifer is one of the largest confined aquifers in the world, comparable in scale to the Great Artesian Basin of Australia and covers some 600,000 km^2.

3. MAIN UTILIZATION OF CONTINENTAL INTERCALAIRE GEOTHERMAL WATER

In the Kébili region and the areas further to the south there are 24 wells reaching the different layers of the C.I. aquifer. They are used to supply the oases with water for irrigation after cooling in cooling towers. The geothermal water is also used for the heating and irrigation of greenhouses. Furthermore, in the Douz region geothermal water is used for the heating of two swimming pools and several public bathhouses. In both cases the return water is used for irrigating the surrounding oases (Ben Mohamed, 1997).

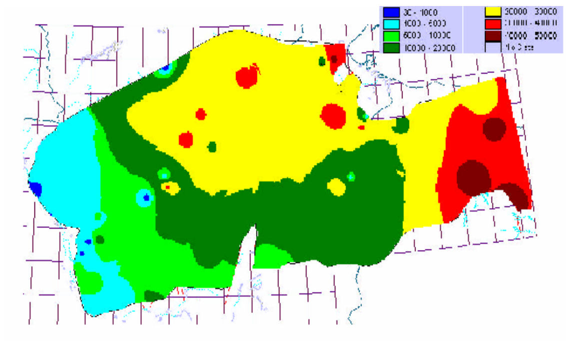

FIGURE 4: Age of water (years)

4. PREVIOUS STUDIES

Several previous studies have addressed the Continental Intercalaire aquifer. UNESCO carried out the study "Etude des Ressources des Eaux du Saha Septentrional" between 1968 and 1971 (ERESS, 1972), with financial aid from UNDP. Ten years later the project was reviewed during RAB Project (1982). The studies covered an area of 800,000 km^2 in Tunisia and Algeria. The objectives of these projects were mainly to evaluate the total water demand in these regions by the year of 2000 and 2010 to construct a mathematical model of the C.I. aquifer and predict the pressure decline in the reservoir and its economic impact.

According to these studies, the piezometric level of C.I. is predicted to have fallen by 49 to 68 m in year 2010 and to 15 - 40 m below the ground in the extreme south of Tunisia. The evaluation and management of water resources of the aquifers in Southern Tunisia was studied in a separate project in order to obtain an overview of the surface and ground water resources in the south, and forecasts of the groundwater conditions in the future. The volume of groundwater resource in the south is about 46% of all groundwater resources in Tunisia. The project "Recharge characteristics and groundwater quality of the grand Erg Oriental Basin" was started in 1994 in cooperation with the United Kingdom (British Geologic Survey), Algeria (C.D.T.N), and Tunisia (D.G.R.E. and E.N.I.S.). The main goal of this project is to define the limits of sustainable groundwater development in the aquifer system of the Grand Erg Oriental underlying eastern Algeria and southern Tunisia. This project is for all the aquifers in this area and aims at determining the modern rates of recharge and the interface between recent recharge and paleowaters. Finally, the study (S.A.S.S: Systeme aquifer du Sahara Septentrional) carried out by the "Sahara and Sahel Observatory" commenced in 1999. The main objectives of the project are to evaluate and expand previous studies of the deep aquifers (C.I. C.T. Djeffara) in eastern Algeria, southern Tunisia and, for the first time, Libya.

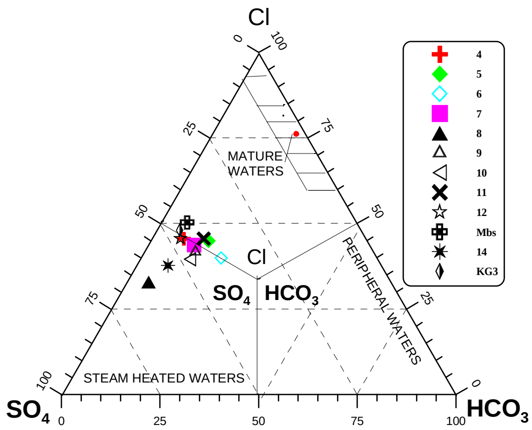

Figure 5: The Cl-SO_4-HCO_3 triangular diagram for water chemistry

5. TYPE OF WATER

5.1. Water chemistry

For the classification of thermal waters and identification of processes that have affected their composition, the triangular diagram Cl-SO_4-HCO_3 is commonly used. The plot is obtained by calculating the sum S of the concentration C (mg/l) of all the three constituents (Giggenbach, 1991), $S = C_{Cl} + C_{HCO3} + C_{SO4}$ and then calculating the %-Cl, %-HCO_3 and %-SO_4. Figure 5 shows that the data points for waters from the wells reaching the C.I. aquifer plot in the middle of the Cl and SO_4 areas, but some of these waters show relatively high concentrations of SO_4. The reservoir rocks are mainly composed of sandstone with gypsum and anhydrite intercalations and gypsum and anhydrite minerals are the likely source of SO_4. The Cl content ranges from 500 to 1,200 mg/l and is probably derives from the marine formation water. However, the concentration of I is lower than expected from the marine influence. Temperature and the chemical composition have not changed significantly with time. Evaporate dissolution and redox equilibrium processes are thought to control the water quality and the distribution of salts. The quality of irrigation water is governed mainly by four characteristics: total concentration of soluble salts, ratio of sodium to other cations, concentration of boron and other toxic elements and, the concentration of bicarbonate. The C.I. water quality is close to the limits of potability and therefore well within the limits of use for agriculture. In fact, it is well suited for agricultural uses.

The dissolved oxygen results are from on-site analysis but are not very accurate. In fact, the high concentration of oxygen can be from atmospheric origin due to the location of the sample sites. So, the solubility of oxygen in distilled water in contact with air depends on the temperature. At 70°C the water saturated with oxygen, the concentration is about 3.8 mgO_2/kg. The water from C.I. aquifer is far from atmospheric oxygen. Therefore a recommended place to take a representative sample of the water from each well is through a sampling point in the horizontal side at 1.5 m from the wellhead in order to get a way from the turbulent flow of the fluid.

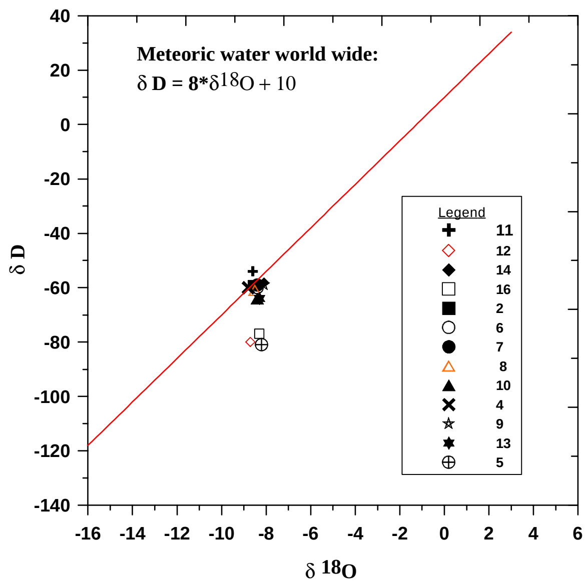

Figure 6: A δD vs $\delta^{18}O$ plot for the collected samples

5.2. Origin of water

Analysis of isotopic composition radiocarbon analysis in previous studies (Edmunds et al., 1997), shows that radiocarbon is present between 2 - 10 pmc which leads to the conclusion that the waters were recharged during the late-Pleistocene, in the period 25 kyr BP, corresponding to the last glacial maximum in Europe (Edmunds et al., 1997).

The stable isotopes of hydrogen and oxygen are used to obtain more information about the origin and the possibility of recharge of this aquifer. Figure 6 shows the relationship between δD and $\delta^{18}O$ of the geothermal water from the C.I. aquifer in the Kébili area. The data points are concentrated along the meteoric line of Craig (1961), indicating the meteoric origin of the geothermal water. $\delta^{18}O$ ranges from -7.5 to -9% and this signature is characteristic of palaeowaters in northwest of Africa. An estimate of the current recharge of the C.I. aquifer water using the isotopes shows that the groundwater reserves are non-renewable (Edmunds et al., 1997).

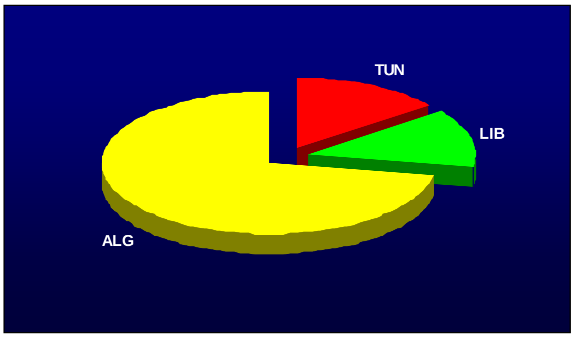

Figure 7: Exploitation of CI. Aquifer by each country

6. HISTORY OF PRODUCTION AND PRESSURE DECLINE

The production and pressure decline history of the C.I. aquifer in the Kébili area shows a general decrease in pressure with increasing production. There were three periods of production. The first was during 1982 - 1984, when about 80 l/s were extracted. Few pressure measurements are reported from this period but the draw down was small. The second period was during 1984 - 1991, when the extraction seldom rose above a 900 l/s and the drilling activity was at a maximum. In this period the drawdown was monitored and the data show a pressure drop of about 0.5 bars/year in several wells. The last period 1991-1999 shows a large pressure drop of about 2 bars/year in most of wells in response to an average mass extraction of 1,200 l/s from 29 wells operating in the region (C.R.D.A., 2003). The production was limited through the use of a water saving system under which farmers were encourage to install PVC pipelines for irrigation and to prevention water wastage due to infiltration and evaporation.

7. CONCLUSIONS

Triangular $Cl-SO_4-HCO_3$ plots of water chemistry data from wells drilled into the C.I. shows the waters to be located midway between the Cl and SO_4 corners. The fluid can therefore be classified as sulphate-chloride waters.

The isotopic study shows the data points to be concentrated along the meteoric line of Craig (1961) indicating a meteoric origin for the geothermal water. $\delta^{18}O$ ranges from -7.5 to -9% and this signature is characteristic of palaeowaters in the northwest of Africa.

Based on a plot of wellhead temperatures, the wellhead temperature plot, the thermal gradient increases from the southeast to the northwest whereas the depth to the top of the producing zone increases from the east to the west. The total concentration of dissolved salts (TDS) decreases from the southeast to the northwest

The flow path of geothermal fluid is from the southwest to the northeast. The piezometric gradient is about 6 to 10 m/km respectively in the north and in the south. The piezometric changes, due to the production, are about 1 to 3 m/year.

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