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

Geothermal Waters in Relation with Triassic Evaporitic Structures (North-Western Tunisia)

Inoubli N., Bouri S., Gouasmia M. and Ben Dhia H.

Lab. LR3E, B. P. W., E. N. I.-Sfax, 3038, TUNISIA

e-mail : nadia_inoubli@yahoo.fr

Keywords: Evaporite, Triassic diapirs, Hydrochemistry, Thermal water, North-Western Tunisia

ABSTRACT

In North-Western Tunisia; mainly in the "diapirs zone", superficial and thermal waters occur in subsurface wells, springs showing sometimes very high salinity. A geological and hydrochemical investigation has been carried out, in the studied region, to improve our understanding of the origin of saline groundwater and its evolution within the framework of the complex geological history of the region.

North-Western Tunisia has a complex geological evolution which is mainly controlled by halocinetic movements. Geological and structural studies show that thermal waters emerge through fractured limestones. It is obvious that the upcoming movement of the thermal saline and/or thermal groundwater, in North-Western Tunisia, is controlled by tectonics, mainly by the diapiric structures.

The sampled waters have discharge temperatures ranging between 21 and 71°C and total dissolved solids (TDS) between 560 and 56 000 mg/l. They show a Na-Cl type of water with enrichment in Ca and HCO3 for few samples. The warm saline waters are undersaturated with respect to gypsum but oversaturated or around equilibrium with respect to calcite. Hydrochemical data provide evidence for water-rock interaction of thermal fluids with limestone aquifers and for dissolution of evaporite deposits of Triassic outcrops, mainly the halite component.

Furthermore, several chemical diagrams were applied to have an idea about the original aquifer and the influence of the evaporitic levels on physico-chemical feature's evolution of the thermal waters.

1. INTRODUCTION

Tunisia has complex geological features especially in its North-Western part, which is the result of the succession of different tectonic phases since lower Cretaceous. This region is characterized by the abundance of Triassic evaporitic diapirs (Figure 1). The present multidisciplinary study has been carried out to improve our understanding of the thermal water's origin and evolution within the framework of the complex geological history of the region and its relation with Triassic structures.

The compilation of geological, hydrogeological and hydrochemical results, allowed us to have a clear idea about the waters flow path in depth. The water reservoirs are represented by the different cretaceous fractured limestones. The leaching of Triassic salt rocks by the waters during their ascent to the surface, gives them their high salinity and their high concentration particularly in Na and Cl.

2. GEOLOGY AND HYDROGEOLOGY

Northern Tunisia geological pattern is the result of compressive and tensional tectonic phases that have alternatively affected the country since the Mesozoïc. These tectonic movements caused the rise up of Triassic material since the Aptian (Smati, 1986; Chikhaoui, 1988 and 2002).

The main tectonic features in Northern Tunisia include the overthrust of the Numidian flysch and the diapirs zone with numerous evaporitic extrusions (Perthuisot, 1978) (Figure 1). North-Western Tunisia is characterized by broad synclines alterning with anticlines whose cores mostly consists of complexly deformed Triassic gypsum – matrix breccia containing clasts of dolomite, terrigenous clastic rocks and ophites (Burollet and Sainfeld, 1956; Perthuisot, 1978; Chikhaoui, 1988, 2002) (Figure 1). These folds generally trend NE-SW. The reservoir structuring is closely influenced by the diapirs ascent.

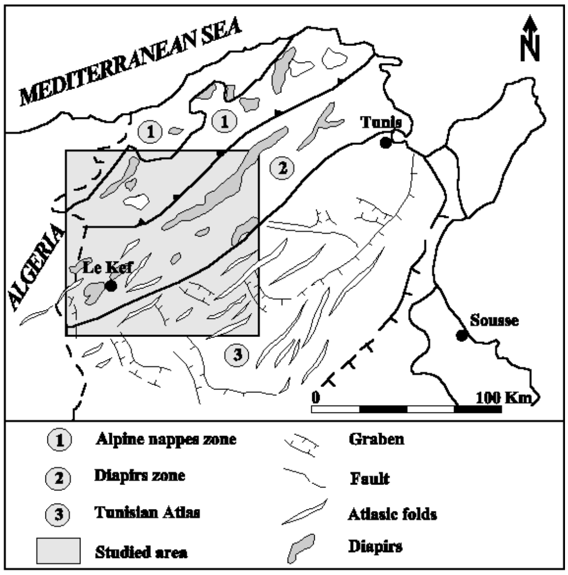

Figure 1: Geological map of North-Western Tunisia (Burollet, 1956; modified)

North-Western Tunisia shows a lithological succession from Triassic to the Quaternary. However, we note the absence of Jurassic outcrops mainly in the "diapirs zone". The hydrostratigraphical column reveals the existence of several potential reservoirs in the region. The Mesozoic carbonate units seem to constitute the most important potential reservoir aquifers (Figure 2). Their outcrops are widespread all over the entire region. The permeable Mesozoïc limestone layers are unconfined in their outcrops areas and confined where covered by relatively impermeable and thick deposits.

The regional hydrogeologic system in North Western Tunisia is that of basins with high altitude recharge areas at their margins, with a thick and an extensive aquitard overlying the regional aquifers in the centre of the basin. The Triassic structures delimitate synclines which can constitute hydrothermal basins.

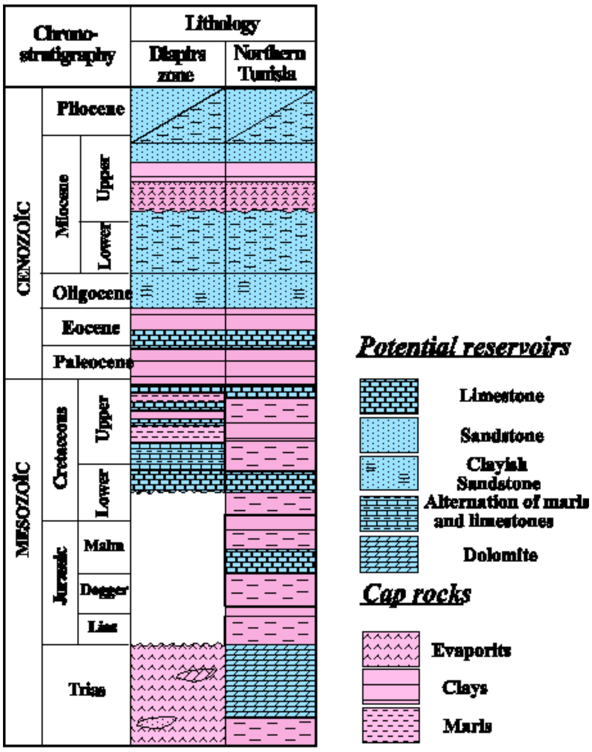

Figure 2: Hydrostratigraphic column of North-Western Tunisia (Ben Dhia, 1983; modified).

Numerous thermal springs and hydrogeological wells exist in the region. Their location is probably controlled by regional hydrology related to meteoric water recharge in the wide spread exposures of the Mesozoïc carbonate fractured units. Thermal features generally occur at topographic lows associated with areas where limestone are at shallow depths or with areas along faults bordering the numerous NE-SW trending Triassic structures.

3. HYDROCHEMICAL STUDY AND DISCUSSION

An investigation of hydrochemical composition of sample waters from North-Western Tunisia has been carried out to shed more light on its origin and evolution. In order to determine the major chemical component of studied waters (Figure 3, Table 1), sampling concerned the warm springs and shallow water drillholes in vicinity of diapirs. The temperatures range from 21 to 71°C (respectively in J. Koutif and Hammam Sollah), and the salinity between 560 and 56 000 mg Kg^{-1}. The analytical data were treated by the computer program HYDROWIN (Calmbach, 1995).

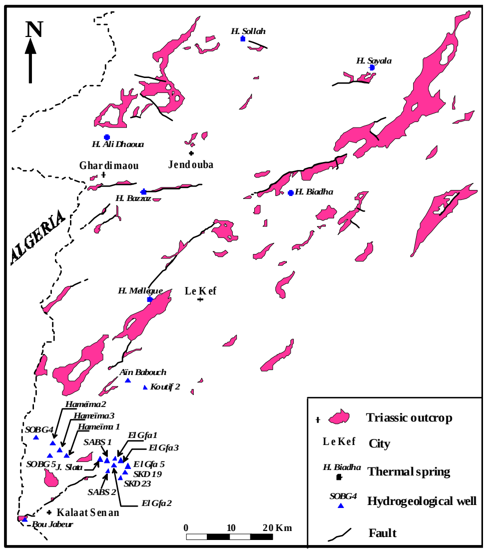

Figure 3: Location of the studied thermal springs and hydrogeological wells.

Sampled waters are mainly of Na-Cl type probably due to the Triassic halite dissolution (Figure 4). In the Hameïma region, located in the South-Western part of the studied area, some samples show a Na-(Ca)-Cl-(HCO_3) or a Ca–HCO_3 type. Their composition, together with their relatively low thermality and salinity, seem to point to a shallower circulation in chalky reservoirs in comparison with the other areas (Inoubli, 2000).

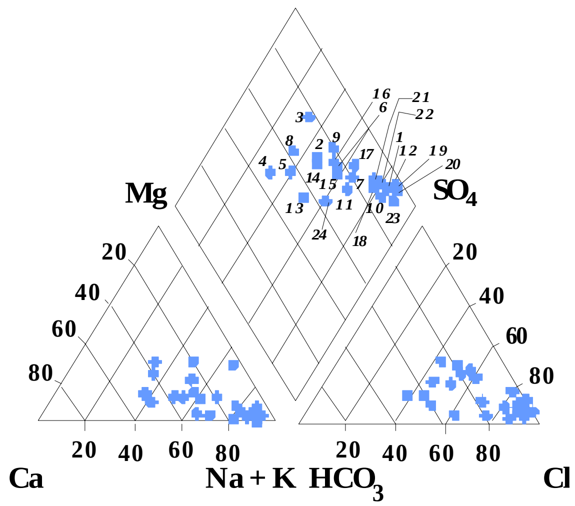

Figure 4: Distribution of hot waters from the study area in Piper diagram.

Chloride and Sodium constitute the major anion and cation in these waters. In fact, Scholler–Berkaloff semi-logarithmic diagram (Figure 5) shows waters in which Cl and Na constitute the two major elements. This diagram shows also a bicarbonate and calcium enrichment due to the dissolution of limestone that constitute the main reservoirs.

Saline formation waters can originate from dissolution of halite and/or infiltration of subaerilly evaporated seawater (Hanor, 1987; Land et al., 1988 in Iampen and Rostron, 2000). Halite dissolution as main source for the sodium and chloride in the studied groundwaters is suggested by the fact that most of the investigated waters samples have ratios close to the unity (Iundt, 1971; Sadki, 1998; Grobe et al., 2000; Grobe et Machel, 2002) (Table 1).

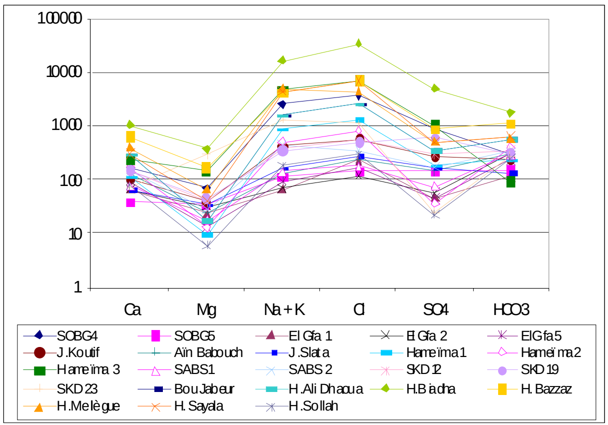

Figure 5: Distribution of waters from the study area Schoeller-Berkaloff semi logarithmic diagram.

With the exception of some samples, which correspond to the shallow hydrogeological wells of the Hameima region, the thermal waters of studied area seem to have had long circulation before rising. The evaluation of the degree of water-rock interaction reached by each sample allows us to establish whether these waters have been in equilibrium with a mineral phase (Sadki, 1998; Gemici and Filiz, 2001).

Most of studied waters are over saturated or close to the saturation with respect to calcite (Figure 6). Such saturation is acquired by waters in the presence of high p_{CO2}. By becoming progressively more aggressive towards reservoir rocks, waters rich in CO_2 favour the solubility of chalky rocks and rise their concentration in HCO_3 and Ca.

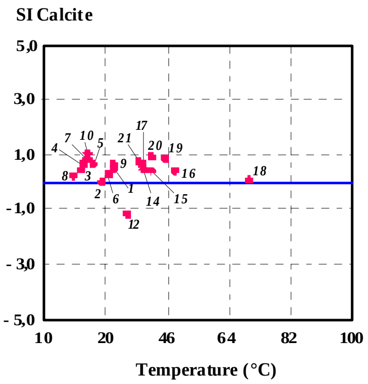

Figure 6: Calcite saturation index vs. temperature.

Furthermore, some thermal springs (Hammam Mellègue and Hammam Biadha), precipitate large quantities of travertine. The carbonate precipitation occurs as the consequence of three types of process: physico-chemical, physical and biological (Roques, 1964 in Casanova, 1986; Bakalowicz, 1988 and 1990 in Andreo et al., 1999). The first process is the more important, upon expulsion of the water at the surface, CO_2 will be released to the atmosphere and carbonate precipitation will occur by the following reaction (Ellis, 1970 and 1979, in Sadki, 1998; Minissale, 2004):

$$Ca^{2+} + 2\,HCO_3^- \longrightarrow CaCO_3 + H_2O + CO_2.$$

Most of the sampled waters lie in the undersaturtion field of the gypsum equilibrium diagram (Figure 7). In fact, water dissolves different calcium salts such us calcite and gypsum, so that the dissolution can be saturated in calcite and, at the same time, not saturated in gypsum, and therefore the water will continue dissolving this mineral.

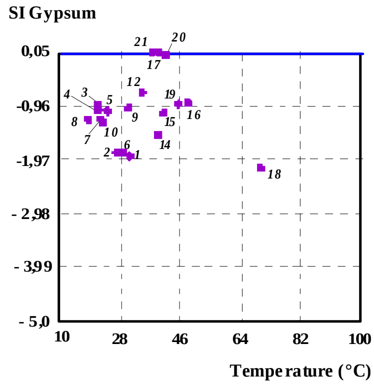

Figure 7: Calcite saturation index vs. temperature.

In the other side, the I.I.R.G. (International Institute of Geothermal Researches) diagram (Figure 8) can give an idea about the water's reservoir (D'Amore et al., 1983).

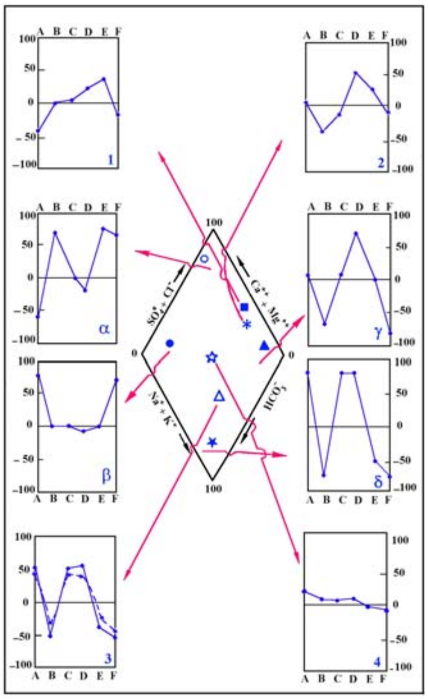

Figure 8: I.I.R.G. (International Institute of Geothermal Researches) Diagram.

In this study, almost all the samples correspond to the standard diagram γ which indicates the flowing of thermal fluids through fractured levels, mainly the cretaceous limestone (Figure 9).

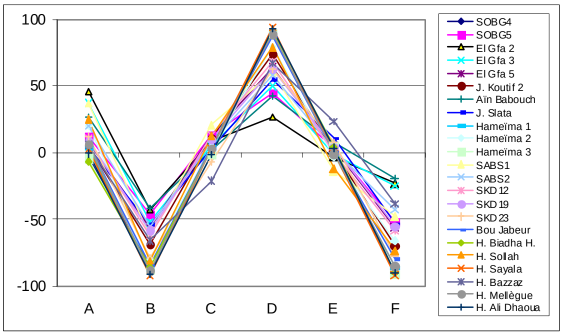

Figure 9: I.I.R.G. diagram applied to studied waters.

4. CONCLUSION

North-Western Tunisia is characterized by numerous Triassic outcrops and hydrothermal springs and drillholes. The sedimentary succession in the region is characterized by permeable formations, which can constitute regional aquifers, alternating with impermeable layers. Based on the geological features and the interpretation of hydrochemical data, it is suggested that water reservoirs are represented by the different cretaceous fractured limestones. The reservoir structuring in the region is closely influenced by the diapers ascent. In fact, the Triassic evaporitic structures constitute hydrogeological barriers which limit groundwater's circulation.

Thus, the structuration of the aquifers is closely influenced by the outcropping diapirs, while the hydrochemical nature took place during the up flowing of waters from deep reservoirs to the surface. Interpretation of chemical analyses provides evidence for the leaching of Triassic salt rocks, mainly the halite, by the waters during their ascent to the surface. Studied waters seem to have had long circulation into chalky reservoir before rising.

The compilation of geological and hydrochemical data, gives an idea about the relation between the evaporitic Triassic layers and the mineralization of studied waters in North-Western Tunisia. It seems that the reservoir structuring and the hydrochemistry of studied waters are directly related to the presence of Triassic structures.

REFERENCES

Andreo, B., Martin-Martin M., and Martin-Algarra A.: Hydrochemistry of spring water associated with travertines. Example of the Sierra de la Alfaguara (Granada, southern Spain). *C.R.Acad. Sci.* (1999) **328**, 745 – 750.

Ben Dhia H. : Les provinces géothermiques de la Tunisie méridionale. *Thèse de Doctorat ès Sciences Naturelles* (1983). Université de Bordeau I, France.

Burollet P. F., and Sainfeld P. : Notice explicative de la carte géologique de la Tunisie, Feuille du Kef n°38 (au 1/50000). *Service des Mines et de Géologie,* (1956) Tunis.

Calambach L.: HYDROWIN Computer Programme – Version 3.0. *Institut de Minéralogie BFSH 2, 1015 Lausanne* (1995).

Casanova J. : Les stromatolites continentaux : paléoécologie, paléohydrologie, paléoclimatologie. Application au rift Gregory, *Thesis Sciences* (1986), Aix-Marseille – III, 256 p.

Chikhaoui M. : Succession distension – compression dans le sillon tunisien, Secteur de Nebeur – Le Kef, Tunisie centre - nord. Rôle des extrusions triasiques précoces lors des serrages alpins. *Thèse de 3ème. Cycle,* (1988), Univ. de Nice – Sophie Antipolis, 143 p.

Chikhaoui M. : La zone des diapirs en Tunisie : Cadre structural, évolution géodynamique de la sédimentation méso-Cénosoïque et géométrie des corps triasiques. *Thèse de Doctorat d'Etat es Sciences Géologiques.* (2002) Fac. Sci. Tunis – Univ. Tunis el Manar. 323 p.

D'Amore F., Scandifi G., and Panichi C.: Some observation on the chemical classification of ground waters. *Geothermics,* (1983) **V. 12**, 2/3: 141-148.

Gemici Ü., and Filiz S.: Hydrochemistry of the Cesme geothermal area in western Turkey. *Journal of Volcanology and Geothermal Research,* (2001), **110**, pp. 171-187.

Grobe M., Machel H. G., and Heuser H.: Origin and evolution of saline groundwater in the Münsterland Cretaceous Basin, Germany: oxygen, hydrogen and strontium isotope evidence. *Journal of Geochemical Exploration,* (2000), **69 – 70**, pp. 5 – 9.

Grobe M., and Machel H. G.: Saline groundwater in the Münsterland Cretaceous Basin, Germany: clues to its origin and evolution. *Marine and Petroleum Geology, (*2000), **19**, pp. 307 –322.

Iampen H. T., and Rostron B. J.: Hydrochemistry of pre-Mississippian brines, Williston Basin, Canada – USA. *Journal of Geochemical Exploration,* (2000), 69 – 70.

Inoubli N. : Effet du diapirisme sur l'hydrodynamisme des aquifères profonds dans la partie sud de la zone des diapirs. *D.E.A.,* (2000), Fac. Sci. Tunis, Univ. Tunis II. 150 .

Iundt F. : Potentiel géothermique de la Tunisie. Etude géochimique. *Bureau de Recherches Géologiques et Minières. Service Géologique National.* (1971) Orléans. France.

Minissale A.: Origin, transport and discharge of CO_2 in central Italy. *Earth – Science Review* (2004) (under press).

Perthuisot V. : Dynamique et pétrogenèse des extrusions triasiques en Tunisie septentrionale. *Thèse Doc. és. sc.* (1978) Ecole Norm. Sup., Paris IX. 312 p.

Sadki O. : Etude des systèmes hydrothermaux du Nord de la Tunisie : Géochimie des interactions eaux- roches et circulation hydrothermale. *Thèse de Doctorat*. (1998) Fac. Sci. Tunis, Univ. Tunis II Tunisie. 246 p.

Smati A. : Les gisements de Pb- Ba et de Fe du Jebel Slata (Tunisie du centre–nord): minéralisations épigénétiques dans le Crétacé néritique de la bordure d'un diapir de Trias. Gisement de Sidi Amor Ben Salem et de Slata- Fer. *Thèse 3ème cycle.* (1986) Univ. Pierre et Marie Curie (Paris VI). 250 p.

Table 1: Chemical composition of groundwaters from North-Western Tunisia

(Values in mg Kg^{-1}, T.D.S. = Total dissolved waters, *: thermal springs, others are drill holes, nd: not determined)

N°	Sample	Depth (m)	pH	T (°C)	TDS	Ca	Mg	Na	K	Cl	SO_4	HCO_3	mNa/mCl
1	**SOBG4**	nd	7.5	nd	7800	170	68.4	2530	19.5	3585.5	892.8	292.8	1.087
2	**SOBG5**	146	nd	nd	710	40	36	108.1	3.9	149.1	144	152.5	1,117
3	**El Gfa1**	nd	nd	nd	560	64	24	64	1.4	244	48	113.6	0,404
4	**El Gfa2**	142	7.6	30.3	638	64	32.4	66.7	1.95	124.25	57.6	280.6	0.827
5	**El Gfa3**	168	7.51	27.4	650	95	13	92.5	2.8	170	45.6	238	0.838
6	**El Gfa5**	nd	7.37	21.3	2010	167	50	395	4.6	510	380	347	1.193
7	**J. Koutif 2**	218	7.3	21.1	2040	100	38.4	407.1	1.95	575.1	278.14	250.1	1.091
8	**Aïn Babouch**	61	7.97	22.8	1140	140	26	122	5.8	241	146	314	0.780
9	**J. Slata**	199	7.8	39.3	832	66.13	34.04	158.6	1.96	273.02	170.03	140.32	0.895
10	**Hameïma 1**	93	7.6	nd	2910	112	9.6	897	8.58	1366.75	192	231.8	1.011
11	**Hameïma 2**	151	7.16	nd	2100	170	12.5	497	6	844	38	402	0.907
12	**Hameïma 3**	263	6.2	34.6	14680	260	156	4554	97.5	7277.5	1 056	91.5	0.964
13	**SABS 1**	132	7.28	28.7	670	78	17.5	140	2.5	184	75	290	1.172
14	**SABS 2**	421	7.66	22.5	1300	142	29	220	3.3	355	175	320	0.955
15	**SKD 12**	nd	7.56	21.6	1950	150	40	385	4.3	527	310	348	1.1260
16	**SKD 19**	86	7.58	24.1	1900	150	48	352	4.8	495	304	314	1.096
17	**SKD 23**	204	7.3	nd	5800	72	316	1380	3.9	1118.25	25.2	274.5	1.902
18	**Bou Jabeur**	150	6.92	38	6000	286	17.5	1500	15	2600	348	567	0.889
19	**H. Ali Dhaoua***	-	6.34	38.7	50000	1 202	120	1360	164	22036	1 600	732	0.969
20	**H. Biadha***	-	6.07	41.5	56000	1 039	360	16600	273	34100	4 900	1708	1.048
21	**H. Bazzaz***	-	6.35	48.2	14000	650	175	4 150	37.6	6900	890	1104	0.927
22	**H. Mellègue***	-	6.71	41.1	8600	400	65	2 580	17.3	4400	510	607	1.205
23	**H. Sayala***	-	7.1	45.5	14400	300	42	4 390	26.7	7000	510	656	0.966
24	**H. Sollah***	-	6.69	71	850	80	6	178	5	280	23	259	1.036