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

Contribution of Geophysical Prospecting to the Assessment of Hydrothermal Potential in the Region of Hmeïma (Central -Western Tunisia)

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Keywords: Geophysical prospecting, Thermal, Aquifer, Reefal limestones, Tunisia.

ABSTRACT

By its geographical location in Central-Western Tunisia and its geology, the studied area is considered as an important geothermal province. Indeed, aptian reefal limestones, characterized by intense fracturing and important karstification, confer them the property to be a regional thermal aquifer.

This multidisciplinary study, based on geological, geochemical and especially geophysical investigation has been carried out to evaluate the hydrothermal potential of the Hmeïma's area. To better characterize the geometry of this regional thermal aquifer, we used geophysical methods.

The geophysical methods (electrical and magnetotelluric), allowed us to study the geothermal aquifer and to have an idea about its structure in depth. This is illustrated by geoelectrical and electrostratigraphical cross-sections passing by geological structures of the region. Isobaths and in isopach maps were established to delimit and to follow the lateral evolution of the reefal limestones. Furthermore, this geophysical study, enough advanced, shows all discontinuities (faults) and tectonic structures (anticlines, synclines and Triassic diapirs) that influence the hydrodynamism of the thermal water.

The synthetic approach integrating all data allowed us to delimit the favourable area for thermal water exploitation.

1. INTRODUCTION

By its position as transition between the African craton and the European plate, Tunisia has a complex geology that is far from having delivered its secrets and its potentialities for natural resources. The diapir zone that makes part of the northern Tunisia is characterized by several geothermal clues indicating the existence of an important hydrothermal potential whose assessment remains limited.

The main target of the present study was the detection of geothermal aquifer, tectonic zones and faults, by using electrical and magnetotelluric methods. Mapping of the basement relief, considered as the roof of the limestone formation, was also the aim of the present study. Furthermore, quantitative geoelectrical models of the subsurface were produced along different sections.

2. GEOLOGICAL SETTING

The studied zone is located in Central-Western Tunisia, to the Algeria-Tunisian border. It covers the area limited geographically by longitudes 6G.60' and 6G.85' and latitudes 39G.70' and 40G.03' (fig. 1). In the South-Western part, this zone is characterized by the cretaceous brachyanticlines, separated by large Eocene synclines and some Triassic alignments oriented NE-SW (Dubourdieu, 1956).

This sector shows a lithological succession from Triassic to the Quaternary, with however, the absence of the Jurassic. Lithologically, the main features are generally some marlo-carbonate alternations with the exception of the middle Albian limestones: ALLAM member (FAHDENE formation), and of the reefal limestones of middle Aptian (SERJ formation).

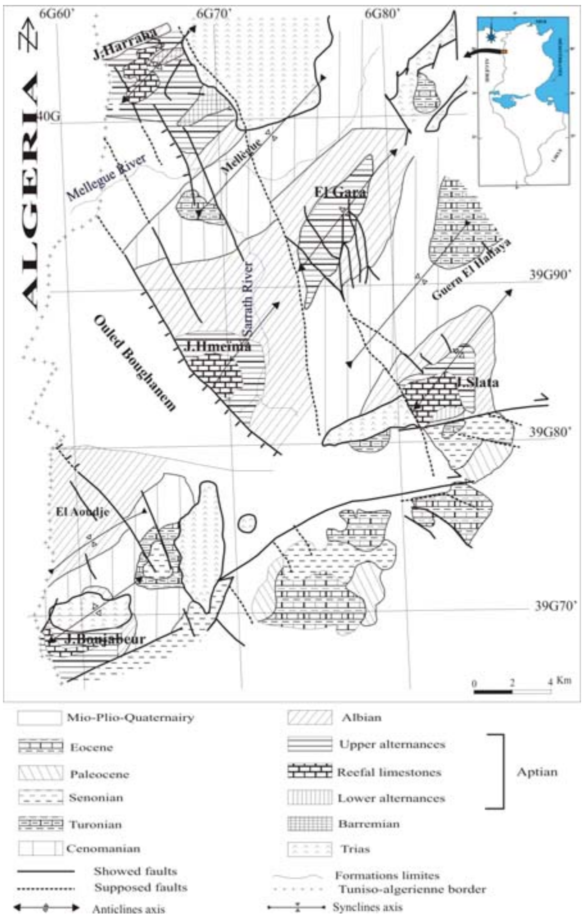

Figure 1: Location and geologic map of the survey area (Mahjoubi, 1978; modified and completed).

The structural map shows a collection of anticline and syncline structures (Dubourdieu, 1956). Among these structures we can mention: the anticlines of Harraba, Hmeïma, Slata and Boujabeur and the synclines of Mellègue, Guern El Halfaya, El Aoudje and the graben of Ouled Boughanem (Chihi, 1995). All these structures are affected by intense fracturing that we can subdivide in three families: a first of dominant direction NW-SE, a second of direction NE-SW and a third, of less importance, of E-W direction represented essentially by dextral strike-slip fault.

3. HYDROTHERMAL POTENTIALITIES

The studied zone has been considered as one of the geothermal anomalies with high gradient in Tunisia (fig. 2)

(Ben Dhia, 1983; Ben Dhia, and al., 1992; Meddeb, 1993; Bouri, 1994; PGN, 1992; Sadki, 1998; Inoubli, 2000).

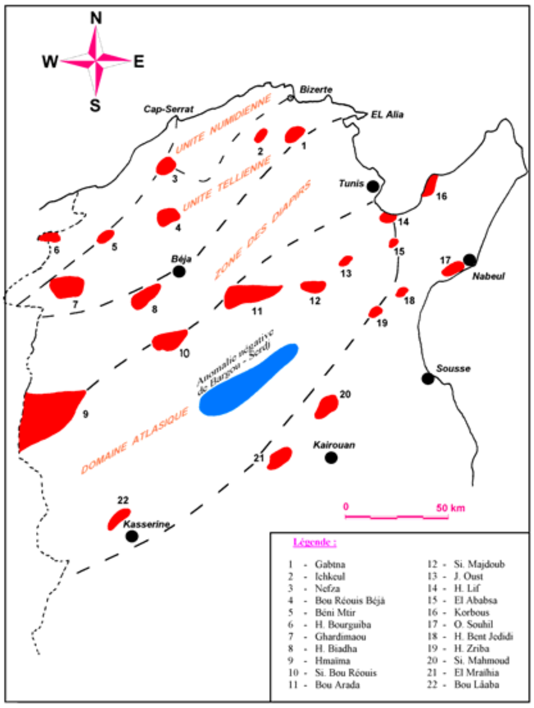

Figure 2: Main thermal anomaly site in the Center and North of Tunisia (Bouri, 1994).

Measures of temperature, taken directly in the wells, indicate values about 39°C and a positive geothermal gradient (fig. 3). On the other hand, the indirect measures, using chemical geothermometers, lead to reservoir temperature ranging between 48°C and 80°C.

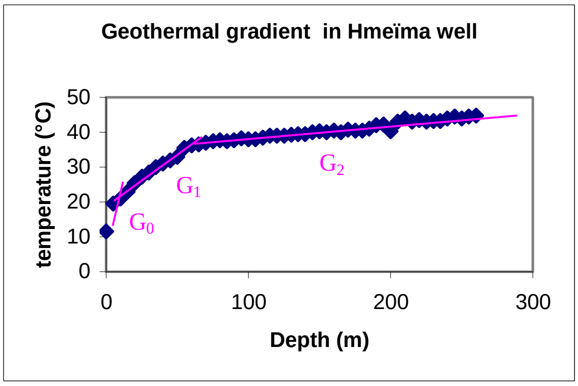

Figure 3: Thermal profile and main ruptures of slopes (PGN, 1992).

Geochemical surveys of the zone (Inoubli, 2000) showed that the geothermal aquifer is carbonated in nature, attributable to the reefal limestones of the Aptian. To better characterize this aquifer geometrically, we undertook a geophysical survey, which was the object of the present study.

4. GEOPHYSICAL SURVEY

The knowledge of the reefal limestone aquifer can be improved by a geophysical survey, permitting us to understand the structure of the basement thanks to the identification of resistivity and underground layer thickness.

To address these objectives, we used two methods: electrical sounding (ES) and magnetotelluric sounding (MTS). The first consisted of the realization of 65 electrical soundings distributed so as to cover the zone limited by Jebels Harraba, Slata and Boujabeur (fig. 4). The second has the advantage to be lighter and especially to have a more important depth of investigation. It is represented by ten magnetotelluric soundings, distributed according to three profiles (Pa, Pb and Pc) and joining Jebel Harraba, Jebel Hmeïma and Jebel Slata (fig. 4).

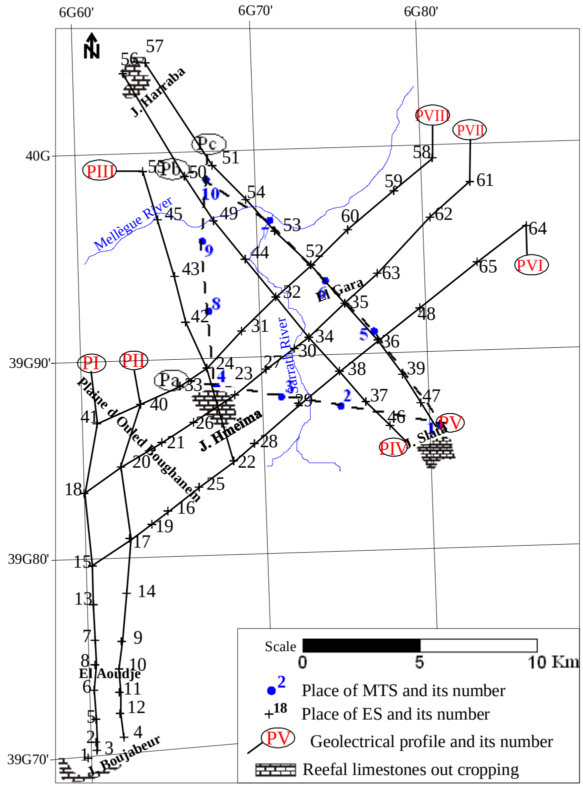

Figure 4: ES and MTS sites and profiles.

The interpretation of the ES has been achieved in two ways:

<u>- Qualitative interpretation</u>: consisted of the establishment of apparent isoresistivity maps and pseudosections (fig. 5). The resistivity map of superficial land slice shows that high resistivity values (ρ_a >100 Ohm.m) correspond to Triassic outcrops in the South and reefal limestones outcrops (middle Aptian) of Jebels Hmeïma and Harraba. The low resistivity values generally correspond to the plain of Ouled Boughanem indicating the mio-plio-quaternary cover of sandy-marly nature. In depth (map in AB = 2000 m), the apparent resistivity shows an increase, probably bound to the carbonated features that could be the continuity, in depth, of reefal aptian outcropping at the anticlines.

Pseudosections show some resistive anomalies (ρ_a >50 Ohm.m) deep-rooted in depth and that could be bound to the reefal aptian. The verticality of isoresistivity curves could be bound to the presence of faults.

However, this interpretation still shows some imprecision and does not allow us to accurately determine the geometry of the reservoir.

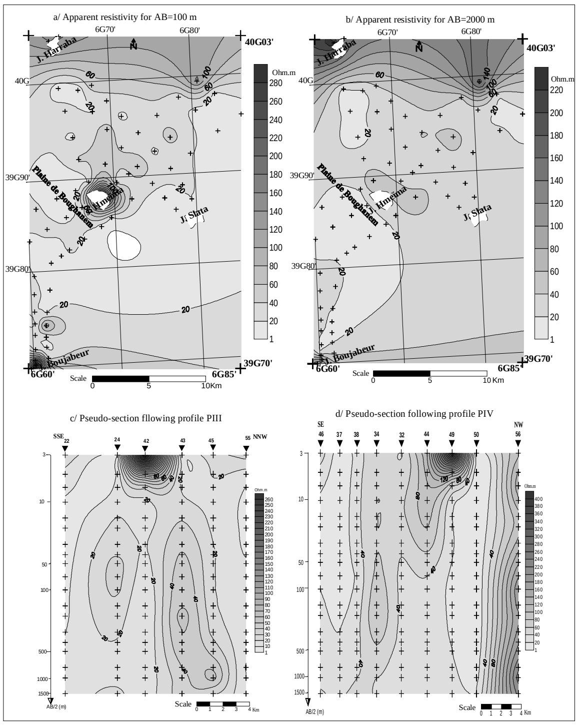

Figure 5: Qualitatively interpretation of results.

- <u>Quantitative interpretation</u>: The electrical identification of the Albian limestones (member Allam) and Aptian reefal has been possible thanks to the position of some ES on outcrops, in the absence of drill holes. We can assign values of 120 Ω.m to the aptian reefal limestones and 60 Ω.m. to Albian ones. Dominant clayish-marly layers are characterized by the lowest resistivities.

The generalization of these criteria to all the ES permitted us to establish geoelectrical and electrostratigraphical cross sections (Gasmi, 2002) and isobath maps of reefal limestones.

Geoelectrical and electrostratigraphical cross sections (fig. 6) give evidence for distinct vertical and horizontal variations of resistivity and thickness. Reefal limestones are represented as resistant levels whose resistivities range between 70 to 150 Ohm.m.

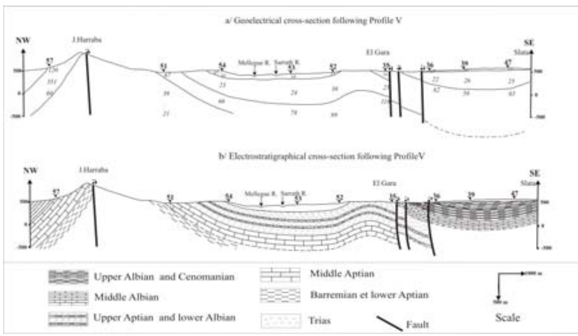

Figure 6: Geoelectrical and electrostratigraphical cross-sections following profile PV.

It is interesting to note that only the resistive level (reefal limestones) presents a hydrothermal interest in the region, for this reason we characterized it by isobath map (fig. 7) which is more precise in the North, where the ES reached the reefal limestones. The analysis of this map shows an important variation of the reefal limestones in depth. These limestones outcrop at the anticlines (Harraba, Hmeïma and Slata), deepen at the synclines (Mellègue and Guern El Halfaya) and at the collapsed zones (graben of Boughanem).

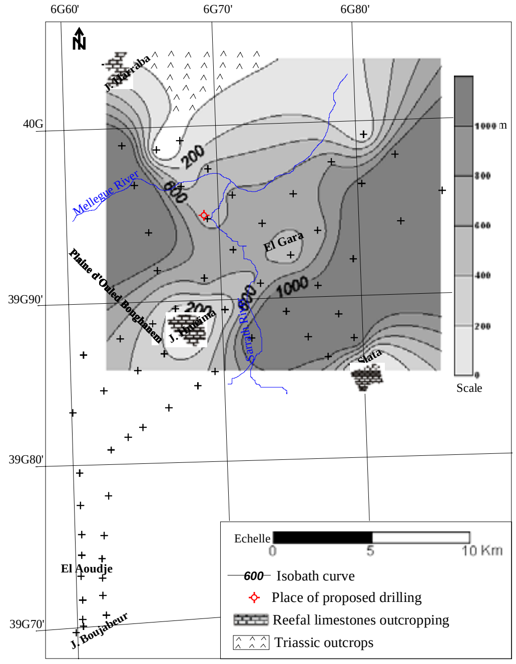

Figure 7: Isobaths map for reefal aptian.

The assessment of the reefal limestones thickness was difficult in spite of the importance of the current lines (AB = 3000 m). Despite the importance of its results, this method could not allow us to evaluate the thickness of reefal limestones. For this reason, we used the magnetotelluric method that allowed more important depth of investigating.

Although quantitative interpretation of the MT data is not easy, we tried to evaluate the real resistivities and thickness. In spite of the relatively complex geology of the region, a 1-D interpretation appears satisfactory as the two directions showed nearly the same pace. Therefore, the interpretation interested an average of resistivity of these two directions ($\rho_{xy\ (N-S)}$ and $\rho_{yx\ (E-W)}$).

Along this cross section (fig. 8), two different structures can be differentiated: a syncline on the East and a semi-anticline on the West. These structures present the succession of 3 contrasted geoelectrical levels.

The first one is a superficial conductor level (4 - 30 Ohm.m) whose thickness is about 110 m. It is represented by marly to marlo-chalky facies that could be attributable to the upper Aptian, except in the synclinal.

The second highly resistive level (> 200 Ohm.m), may correspond to the middle Aptian reefal limestones outcropping on the East (J. Slata) and on the West. In the syncline, and bearing in mind the geological context, this set could correspond to the carbonates of the middle Albian.

The third level, which constitutes a conductor substratum, may correspond to marls.

From the structural point of view, we note the presence of two faults on both sides of the MTS2 promoting the reefal limestones downfall.

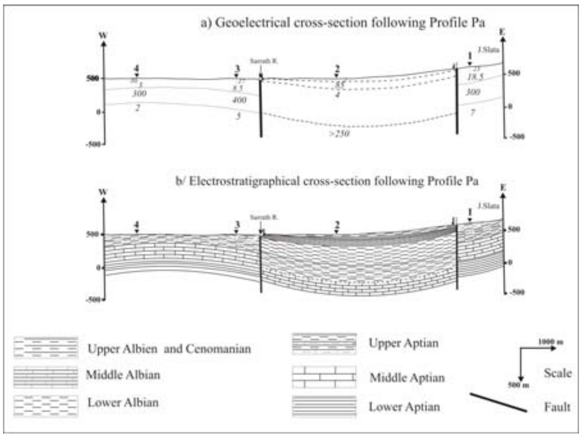

Figure 8: Geoelectrical and electrostratigraphical cross-sections following profile Pa.

An isopach map has been established (fig. 9) from the MTS that touched the reefal limestones basis (1, 3, 4, 6 and 10). For the other soundings, it has been appraised by interpolation. It ranges between 200 m, at the level of the MTS 6, and 300 m, in Jebel Slata. This variation could be explained by the reefal nature and the context of sedimentation (available space, nature of the basin, etc...).

Disruptions of curves between the MTS 5 and 6 indicate the trace of a NE-SW directional fault.

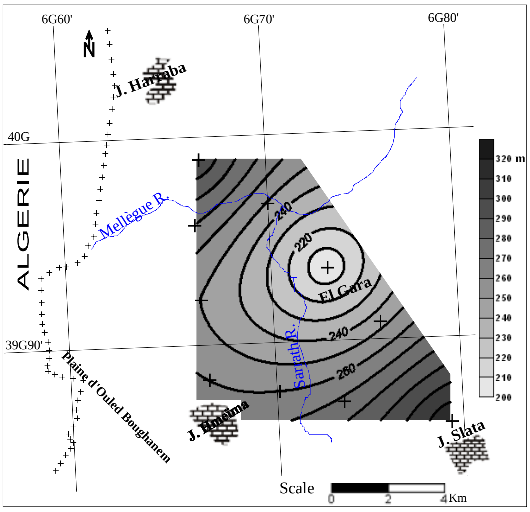

Figure 9: Isopach map for reefal aptian.

5. SYNTHESIS

The confrontation of different but complementary method results permitted us to establish a synthetic map of the studied area (fig. 10). It showed that the region is affected by an intense fracturing that we can subdivide in three groups:

- a first NW-SE direction dominant represented especially by border faults of the Ouled Boughanem graben;

- a second NE-SW direction affecting especially the structures of J. Harraba, Guern El Halfaya and J. Slata;

- a third family of less importance (E-W) represented by a dextral strike-slip fault. This last, is responsible of the downfall of the southern limit of Ouled Boughanem graben.

Otherwise, the studied region could be considered as a hydrogeological basin where deep reefal limestones are likely to constitute a good reservoir for thermal water. It also appears that the studied zone constitutes the area of discharge of these waters. It is especially confirmed by the existence of some hydrothermal indications and by a positive geothermal gradient measured in the drill holes of the Hmeïma region.

As a first stage, we identified two potential zones favourable to the exploitation of the warm waters in the reefal limestones. These zones (fig. 10) are chosen in light of the compilation of all results. A 500 m depth well could be drilled in each zone, where we think to reach the thermal water with a reasonable flow. This drillhole, could serve as "stallion point" for all complementary geophysical work.

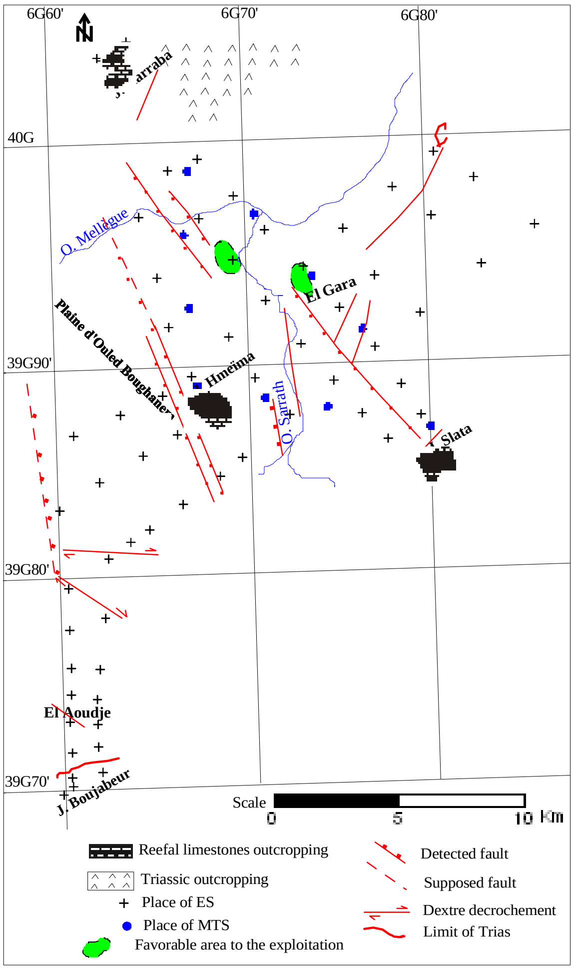

Figure 10: Synthesis map for studied area.

6. CONCLUSION

The geophysical surveys by electrical sounding (ES) and magnetotelluric sounding (MTS), undertaken in the region of Hmeïma (Central-Western Tunisia) allowed us to clarify its structure, to give an approximate image of the basement and to characterize the regional thermal aquifer. Furthermore, the studied region could be considered as a hydrogeological basin where the reefal limestones are likely to constitute a good reservoir for thermal water that could be exploited by a drill hole of 500 m depth.

From a structural point of view, this survey allowed us to follow faults that played an important role in the hydrodynamism of the geothermal water table.

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