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North-Ghoubhet Geothermal Site (Update, 2014)

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ABSTRACT

Due to a regional consideration of the whole Afar Depression, for ranking the best geothermal sites combining geodynamic and hydrogeological approach (J.Varet, Argeo meeting, 2011), the area located to the north of the Ghoubbet rift appeared as most promising for geothermal energy developments in the Djibouti Republic. This site within 10 Km long and 6 Km large, covered at the surface essentially by the recent basalts of the gulf (i.e. emitted during the early stage of penetration of the Aden ridge through the Gulf of Tadjourah, 4 to 2 My ago, O.Richard & J.Varet, 1979) benefits from unique geological conditions:

-The immediate vicinity of the Ghoubbet active spreading segment, with a shallow anomalous (partially melting, 1300°C) upper mantle at 7 Km depth, providing an important and safe (regularly renewed, hence renewable) heat source for the geothermal field.

-A tremendous fracturing of the whole block (made at the surface of recent basalts of the gulf) with at least 3 direction of open faulting with transverse components (NW-SE, NNW-SSE and NE-SW), providing a good fracture permeability of the reservoir.

This particular tectonic setting is of course due to the vicinity of the transform faulting linking Ghoubbet and Tadjourah oceanic rift segments. But it also results (as shown by Manighetti et al. 2011) from the fast rotation of this brittle block. Numerous fumaroles and hot springs, some with important silica deposits, affecting the whole block, testify of the leakage of the geothermal reservoir due to the fairly active tectonics of the site.

- Good reservoir conditions are also expected from the geology itself, as very important detrital deposits accumulated there, for the last 5My, underneath the more recent basalts, due to the up-rise and concomitant faulting and erosion of the whole area located North before and since the early stages of opening of the Gulf (up to 1000m high Dalha basaltic plateau and the famous Day mountain).

- This reservoir should also benefit from relatively low salinity fluids – certainly the best for Djibouti Republic - due to the long lasting flow of water from the Day mountain downstream towards the Gulf for the last few My. Within this specific location site, a preliminary geochemical and geophysical study were undertaken in the area by BRGM (French geological survey) and chose several high and low gravity anomalies not distributed uniformly. The CERD (Center of Research of Djibouti) has undertaken in 2011, geochemistry and geophysical surveys, to complete the early exploration studies. Reservoir model for the site have been proposed and wells site location for exploratory wells have been proposed using MT and TDEM methods. However the investigation, presently limited to the immediate surroundings of the major surface hydrothermal manifestations should be extended to the whole area down to the sea shores.

1. INTRODUCTION

The North-Ghoubhet is located on the North East of the Asal high temperature field and present different geological structures, but also very active. The interest of the zone was started earlier in 1987, when the exploration studies were done in the Asal geothermal field.

Goda Mountain and Makarassou region are found in the Northern part and the study zone is limited by the sea in the South. This field is part of Djibouti high enthalpy geothermal energy development. Located near to Asal geothermal site, it may not benefit from the same exceptional shallow heat source (i.e. the Fiale caldera, at a very shallow depth of 5 to 2 Km), but clearly benefits from both an intense multiple fracturing as well as a feeding by meteoritic waters from the nearby Day mountain drainage, an exceptional situation in this arid climate.

However, the site is located at a similar distance from Djibouti as Asal Lake, while an electric transmission line is being planned for the geothermal power plant and 60 MW of wind farm. Early stage of investigations was carried out by BRGM 1992 (French Geological Survey) and more recently by CERD in 2011 (Center for study and research of Djibouti) allowed to elaborate a first model for this geothermal field and to propose sites for exploration drillings. Although the surface exploration, presently limited to the vicinity of the major hydrothermal emergences and deposits, needs to be completed in order to cover the whole block, the North-Ghoubbet geothermal site already appears as a new objective for another geothermal project additional to Asal presently selected for drillings by a banking consortium led by the World Bank.

The development of the site should be engaged either at a successive stage in order to answer the growing needs of Djibouti town and port, or as an alternative in case of difficulties encountered in Asal, where specific risks are considered (such as crossing shallow magma body or brines difficult to manage in this environment).

This paper describes the state of knowledge of the site, and proposes successive works to be engaged in order to ascertain its quality in terms of commercial electricity production.

Figure 1: Geothermal site location; yellow circle represent the North-Ghoubhet site and red circle represent the Asal geothermal site, and the orange circle the Asal-Fiale "Worldbank site"

2. EXCEPTIONAL GEODYNAMIC ENVIRONMENT

In the context of Afar, such sites were shown to offer suitable conditions for development in areas of junction between the axial ranges and the transverse tectonic systems.

As described by Barberi et al. (1970) - like in Iceland – transform-faults are not observed in Afar. Nevertheless, Tapponier and Varet (1974) showed and Barberi and Varet (1977) more precisely confirmed that large oblique fracture systems are in many places the surface expression of a transform fault linking two distant axial ranges.

Such a tectonic structure is particularly well developed north of Asal, in the junction area with the Manda Inakir axial range.

It is also – symmetrically – well developed in the Nord-Ghoubbet block where the NW-SE trending normal faults of the northern side of the Ghoubbet ridge interfers with the transform fault ensuring the link under-sea with the Tadjoura and Aden oceanic ridge (Fig.2).

The area is situated between different zones of different tectonic pattern and therefore is affected by several tectonic trends: Asal rift NW-SE faults, Makarassou N-S trends (Tapponnier and Varet, 1974) and old trends identified in the Goda Mountain.

Tectonic activities are revealed in the area, confirmed by some faults in the recent sediments and large panels of steep cliffs formed of Dalha basalts. Along the scarped valleys of the wadis several fumaroles and one boiling spring are found at the bottom of the volcanic cliffs.Geology is marked by the Dalha basalts outcrops covered by the more recent Gulf basalts and Pleistocene sediments. The basaltic rocks from Dalha are shown in green colour in the figure and more recent basalt from Gulf is in light green. The tectonic activities of the zone are controlled by fracture networks from NW to SE (Fig 2).

Horst formation is observed in the field, resulting from the tectonic activities and rifting phenomenon (Figure 3). The horst of Moudoueoud is recovered by Gulf and Asal rift rock in the upper layer and below Dalha layer rocks are found. In the south in coastal area, the geology is composed mainly by Gulf basaltic rock.

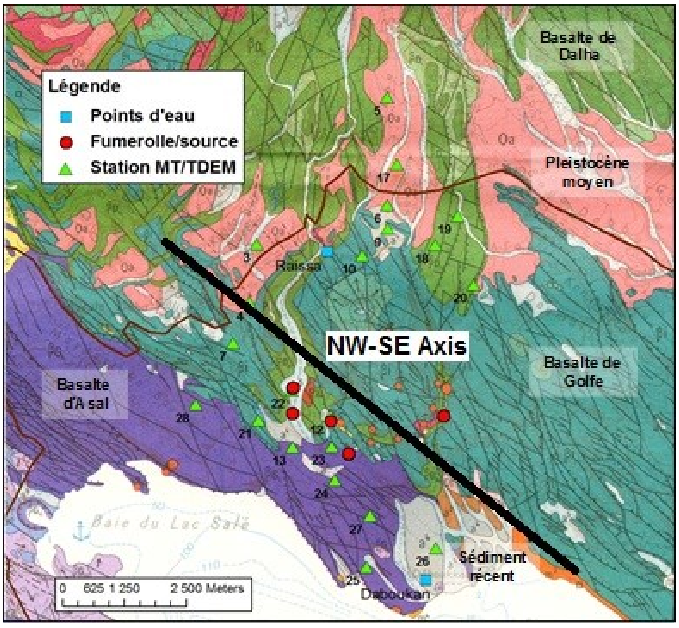

Figure2: Geological maps (CERD, 2010) made of gulf basalts (pale blue), passing to the west to Asal Rift younger basalts (deep blue and violet). The Dahla basalts (7 to 3 M y) in deep green are intensively faulted and eroded.

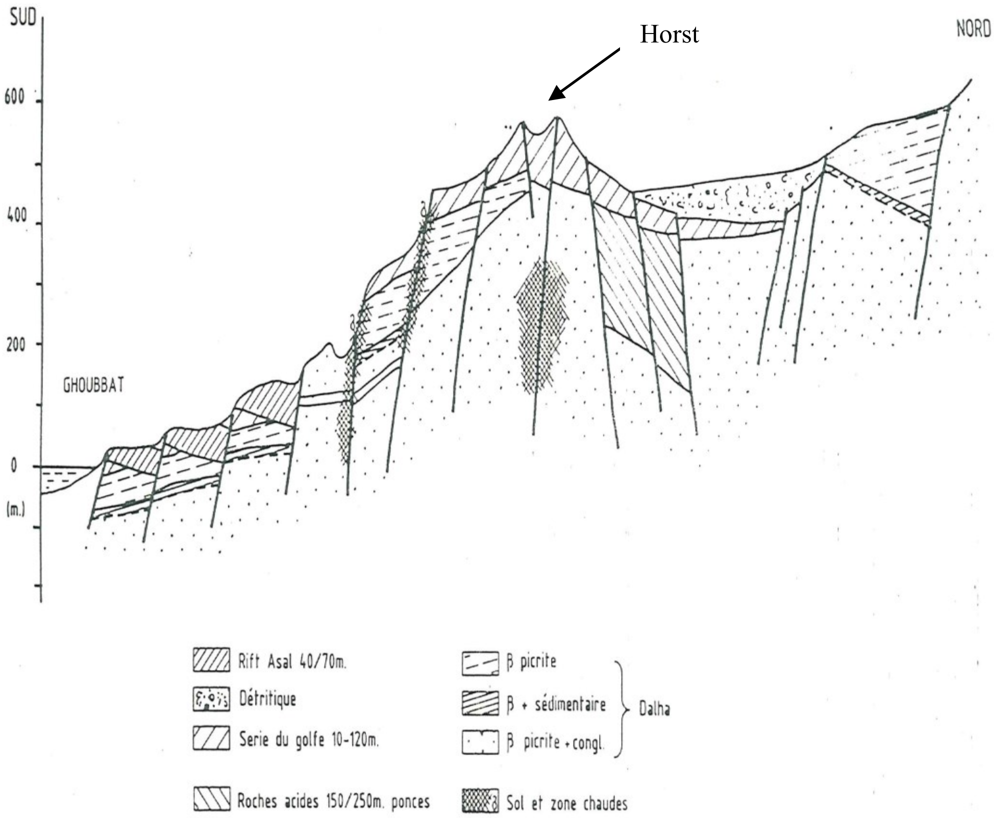

Figure 3: Geological cross section in Moudoueoud Horst (modified CFG, 1985)

3. GEOPHYSICAL SURVEYS

In the early stage of exploration, geophysical surveys were conducted in the area of North-Ghoubhet using gravimetry and AMT measurement (Audio-Magneto-Telluric) conducted by the French geological survey (BRGM) in 1983 (Puvilland, 1983).

The gravimetry results point out several high and low anomalies not distributed uniformly. However these anomalies are delimited by the different linear trends, and can be correlated to the tectonic activities of the area (Figure 4).

In the study three main zones were distinguished, in the southern Asal rift system delimits low anomalies, in the Northward, a large axis comprises a succession of high and low anomalies and in the central part, a similar axis is identified along a NNW-SSE trend. Hydrothermal activity is located along on the NNW-SSE trend (in yellow dot in figure 4).

Also the AMT survey identified conductive body in the central part of the field. It has been estimated that the bottom of the conductive zone would reach around 1000 meters.

The AMT survey has identified in the central zone of the prospect an uplifted conductive body (Figure 5).

However this previous study identified three main zones confirmed by high and low anomalies and conductive body, without any correlation between different surveys done.

To fulfill the previous work done, the CERD (Center of Research of Djibouti), has carried out an exploration study in 2010. The CERD geophysical team has carried out within 30 MT (Magneto-Telluric) soundings and 26 TDEM (Time-Domain Electromagnetic) soundings.

The geophysical measurements have shown that there is a mainly conductive body in the upper layer but in the deeper zone, at 1000 m.b.s.l and 2000m.b.s.l, a heterogonous body is found, with conductive anomalies which may be associated with hydrothermal fluids (Figure 6).

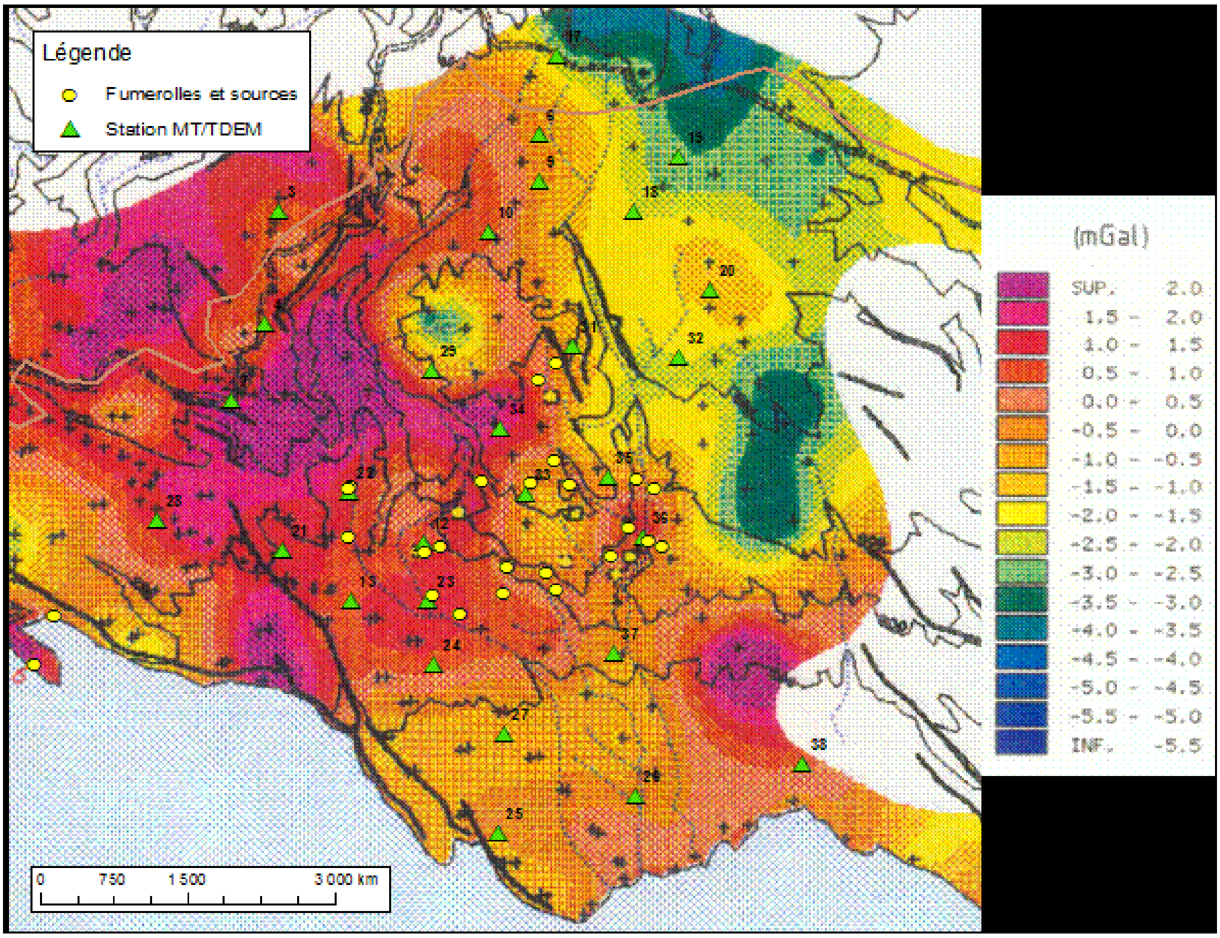

Figure 4: Gravity maps and MT//TDEM station from CERD (BRGM, 1983)

At these depths, hydrothermal circulations are probably controlled by the major tectonic structure.

Regarding TDEM, sets of models obtained by inversion under the assumption that the subsurface prospect is a tabular medium (ID) were interpolated to construct horizontal sections at different depths. Combination of different methods like gravity models, and the MT survey permit to localize the geothermal reservoir and the hydrothermal activities.

Beneath the Moudoudeoud horst (Figure 3), a negative gravity anomaly is observed, and MT revealed very low to moderate resistivity for a thickness of several hundred meters thickness throughout the area.

These can be interpreted as resulting from alteration of the Dalha basalts due to hydrothermal activity. Low to moderate resistivities encountered below this impervious zone are suggested to be possible targets for the geothermal reservoir.

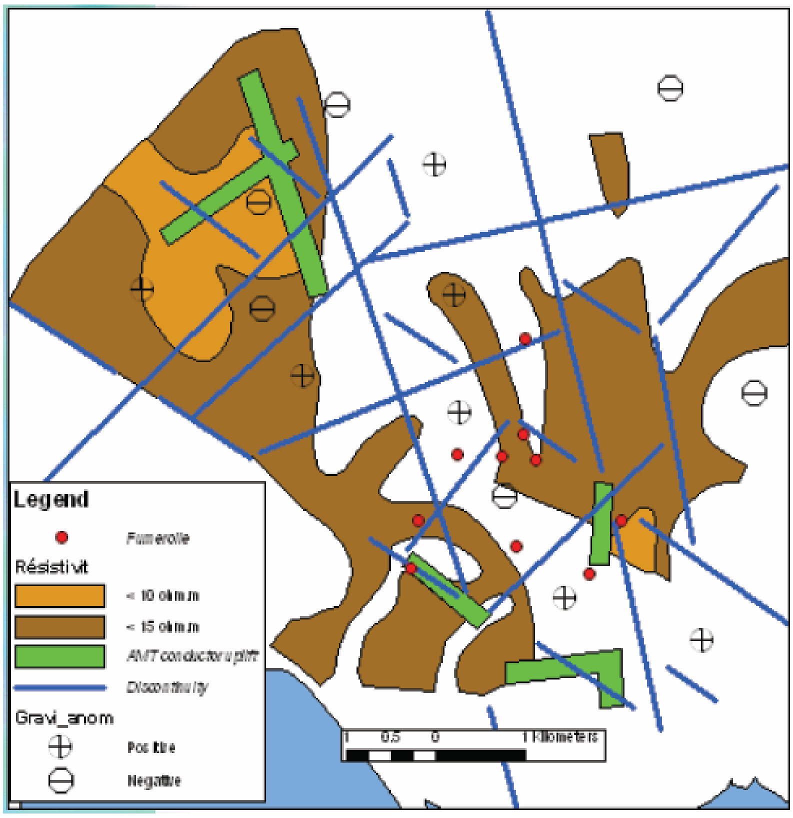

Figure 5: Resistivity Maps and gravity anomaly points done in 1983 by the BRGM

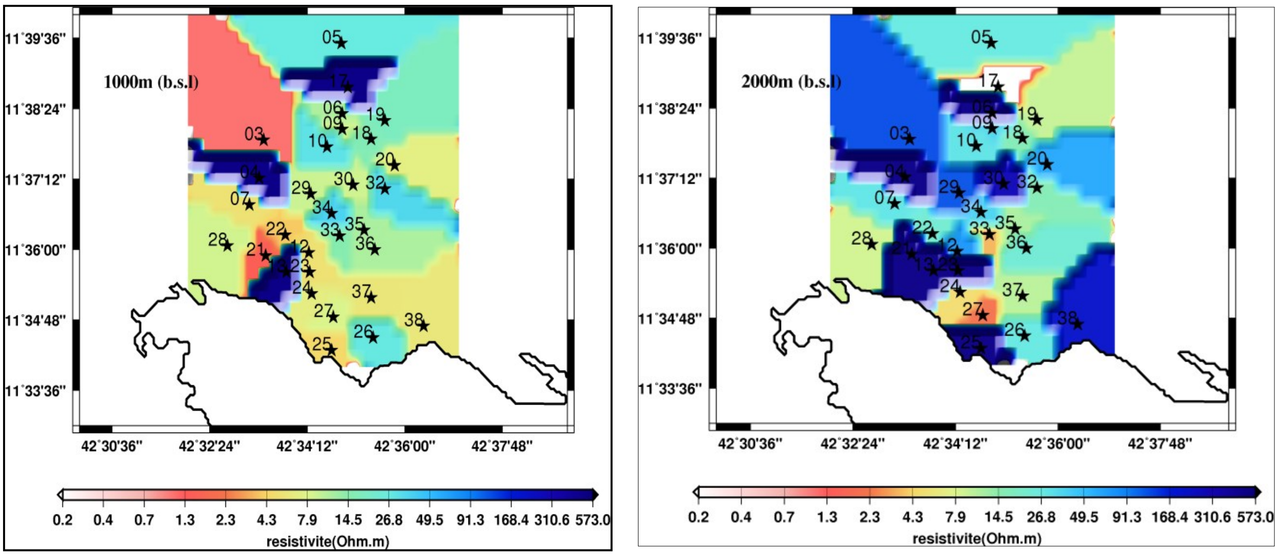

Figure 6: Resistivity Maps at 1000m and 2000 m below sea level (CERD, 2010)

4. GEOCHEMISTRY SURVEYS

A previous study, done by the Italian company Geothermica in 1987, found a fluid with different composition from the neighboring field Asal.

Less salinity content was recorded in the field. To complete this study, exploration survey engaged by the CERD in 2010 was conducted with sampling from different fumaroles around the three main zones define by the survey, and wellbore sampling. Different methods were applied to find the chemical composition of the geothermal fluids, Piper diagram, geothermometer, isotope analysis were the main methods. Primary steam was not's from undiluted or diluted deep water that exist in this zone. Fumaroles would be more likely the result of a secondary steam from previously condensed steam or boiling groundwater (Geothermica, 1987).

Also, in terms of alteration in soil, we saw a reddish alteration around the fumaroles, and assume the probable clays minerals contents in the geothermal fluids. Piper diagram shows the chemical composition of the geothermal fluid, the fluid is mainly bicarbonate-calcite and magnesium, with a same composition with the water sample from mountain Goda.

Along the scarped valleys of the wadis several fumaroles and one boiling spring are found located in the detrital terraces or along the volcanic cliffs. These fluids were sampled and analysed.

Different methods were applied to the chemical data from the water condensate of the fumaroles, and provide estimations for the possible reservoir temperature of 220°C and 170°C (Gadalia et al. 1992; Correia et al, 1983). Stable isotopes analysis of the fumaroles allowed to assess the origin of the waters. Compared to the fumaroles of the Asal rift zone, Nord-Ghoubhet fumaroles display significantly lower Deuterium and Oxygene18. It suggests that these emergences do not represent primary steam from geothermal reservoir. Fumaroles would eventually result from a secondary process from previously condensated steam or boiling groundwater (Geothermica 1987).

That gives indication on the origin of the geothermal fluid. This study set up a due a possible reservoir temperature between 100 to 170 °C due to the from silica geothermometer other geothermometers Na/K, Na/K/Ca give higher temperature (CERD, 2010).

However, to complete these measurements, more geochemistry survey is planned, using CO2 geothermometer and gradient wells sampling, to give right temperature of the geothermal reservoir.

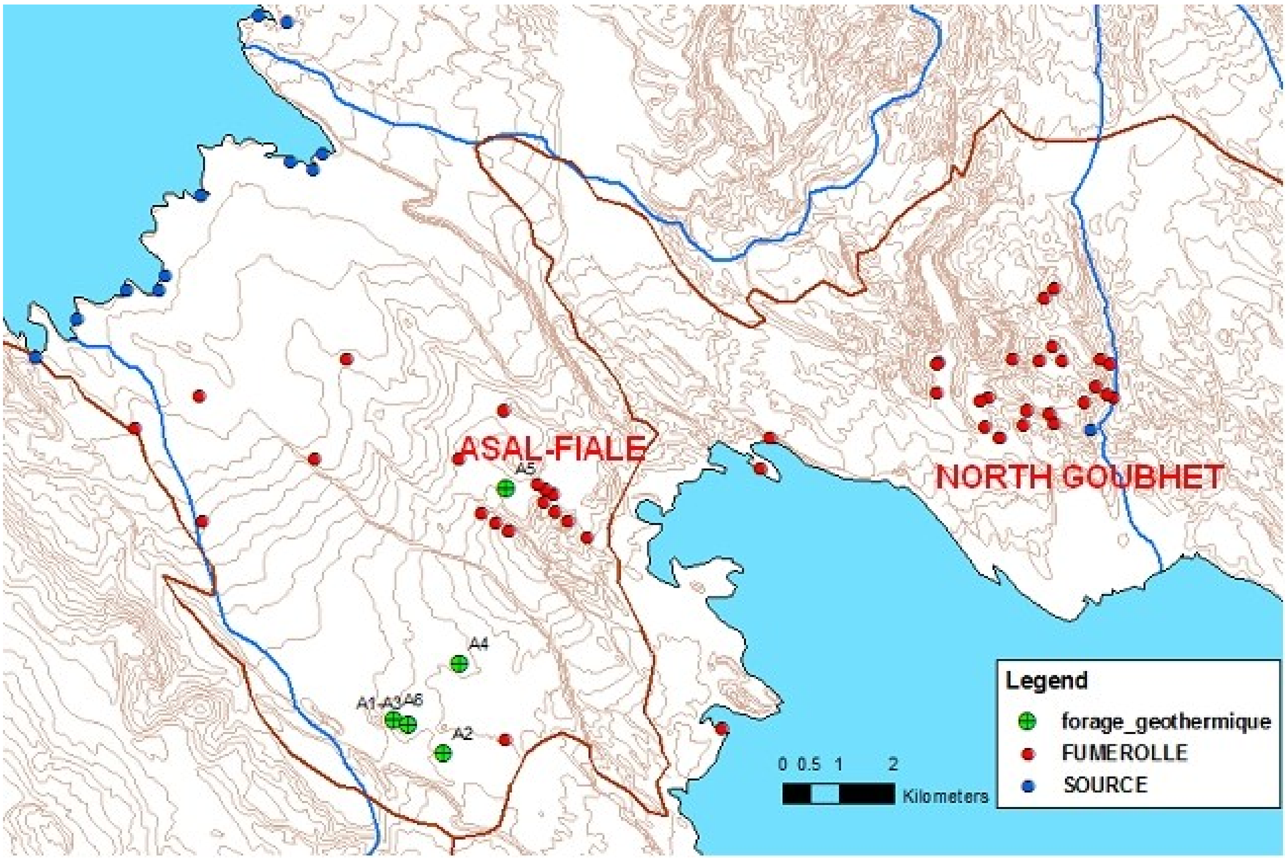

Figure 7: Hydrothermal manifestation; red dot represent the fumaroles and the blue dot the hot spring

4.1. The feeding with meteoritic water

However similar to Iceland for many geological features,Afar suffers from a major handicap: the composition of the geothermal fluids. Whereas in the North Atlantic climate, due to high rainfall, geothermal reservoirs are predominantly fed by meteoric water, Afar is characterized by a rather dry tropical climate.

Annual rainfall there being one of the world's lowest, brines predominate over fresh meteoritic water both at and below the surface (Kebede et al. 2008), notably in northern and eastern Afar. The Nord-Ghoubbet block benefits from specific hydrogeological conditions in which the highlands of the Dalha plateau – with the well-known Day forest – act as a meteoritic water source for the geothermal site (Fig. 8). Even if the annual rainfall does not exceed 200 to 300 mm, the small basin feeding the Nord-Ghoubbet site allows not only for occasional flooding, but also for recharging deep aquifers developed in the unconformity between the deeply faulted and tilted basaltic trap series of the Dalha, with additional circulation within this trap series and in the underlying unconformity with the underlying Mabla rhyolitic unit. Since these successive geological units are characterized by different tectonic regimes (Marinelli and Varet, 1972), we can infer the development of well fractured reservoirs at depth.

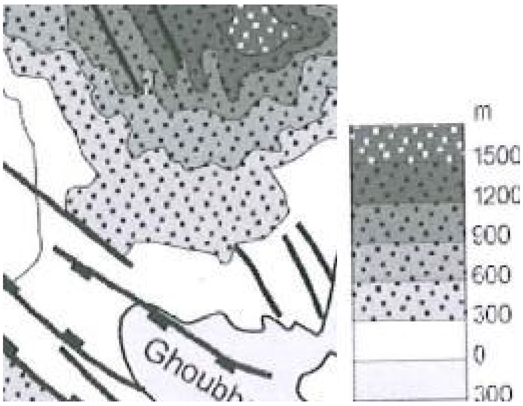

Figure 8: The North Ghoubhet site is fed by an hydrological basin with the head in the Day mountain (Dalha basaltic trapp series) (current topographic map, from J.Varet, 2011).

5. RESERVOIR MODELING AND PLANNED SURVEYS

Being convinced of the potential of the area and following this last exploratory study, it would be interesting to know and to confirm the initial results of these studies and thus allow the exploitation of this resource.

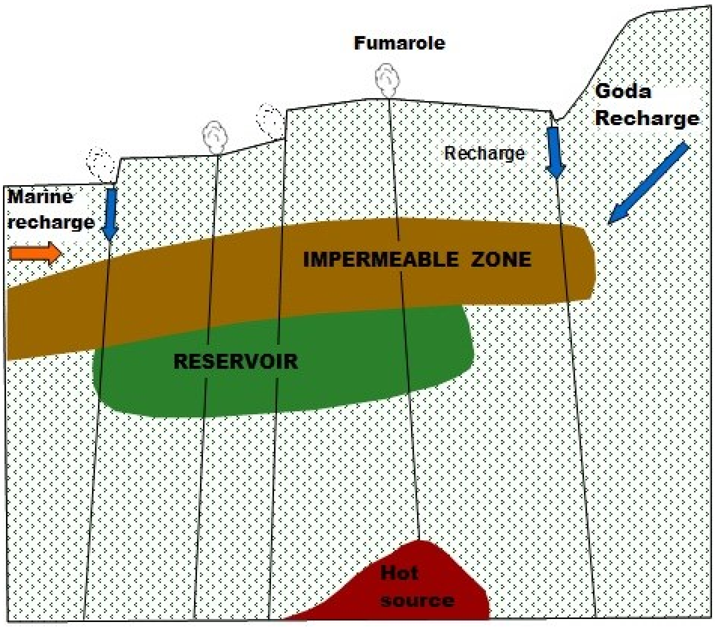

Figure 9: Conceptual models of reservoir (Modified, CERD)

This survey has enabled the creation of a reservoir model of the geothermal system (Fig.9) to delineate a prospective area for exploration drilling around the horst of Moudoueoud.

In the Figure 9, the geothermal reservoir is located below large impermeable zone and the recharge water are controlled by a fractures network displayed by the blue arrows from the Goda mountain and in orange arrows the marine intrusion.

Indeed, following the results of geophysical studies that shows the existence of a conductive anomaly in the area, revealed by MT surveys.

According to the different measurements achieve, gravimetry, TDEM, MT, sites for exploratory drilling were determined at the junction of Bouguer anomaly, and low resistivity zone to improve the chances of attain the geothermal reservoir.

Directional drilling was designed to penetrate the reservoir and target the area with more feed zones.

6. CONCLUSION: FEASABILITY AND COMPLEMENTARY STUDY

To these geological favourable parameters, the geographic location of North-Goubbet site plays in favor of proceeding with the feasibility of its industrial development:

- better road access (through the present asphalted RN1 and older tracks crossing the hydrothermal zone);

- availability of seaports for shipping of equipment with barges directly from the port of Djibouti;
- the proximity of the towns and ports of Djibouti capital and Tadjourah prefecture,
- planned electrical transmission line to be built for the Asal –Fiale World Bank geothermal project projected south of the gulf and for the 60 MW wind farm plant

However, although demonstrated as highly favorable, the site still needs further field and laboratory works, in order to propose the best location for the exploration drilling program (at least 3 wells 200m deep) and better quantify the technico-economic feasibility study. These should include:

- Geological and structural field works at 1/10.000 scales on the whole block, including the sea coasts with neo-tectonic measurements and sampling for petrographic, mineralogical analysis and age determinations;

- Hydrogeological and hydrothermal field sampling of the fluids and deposits with the aim of determining the water circulation system and its recent history based on present and fossil hydrothermal deposits ;

- Mineralogical, geochemical and isotope analysis will be carried on all liquid, gaseous and solid hydrothermal expressions;

- Detailed cartography of the heat manifestations and thermal anomalies and analysis in view of their geological and tectonic environment.

- Complementary geophysical surveys, notably gravimetric, electrical and magnetotellurics in order to cover the whole block, with interpretation.

These complementary works should allow quantifying (notably in terms of depth of the reservoirs, temperature for the geothermal fluid and optimal well location) a 3D model of the whole block. The work is to be developed with professional geothermal experts, and should allow training Djiboutian staff from CERD and MEERN. It should allow determining the precise characteristics of the drilling and testing program.

In this case, a field data collection is undergoing to cover all the geothermal site and prospects within support frem the Japan International Cooperation Agency including geochemistry study and geology survey.

In the order hand, the country is under discussion within several partners in order to finalize the surface study for the most promising site including the North-Ghoubhet site and to proceed for the drilling activities. This site is gifted with all the elements expected for a geothermal site to be developed and being productive.

REFERENCES :

CERD, (2010): Prefeasibility study for North-Ghoubhet field, Republic of Dhibouti (in French). CERD, Djibouti, unpublished report, 58 pp.

CFG, (1985) : Geothermal project Asal-Ghoubbet, updating notes on 15th May 1985 (in French). CFG, Djibouti 23 pp. AQUATER (1981).: Projet pour l'évaluation des ressources géothermiques. ISERST. 137pp
AQUATER (1989): Geothermal exploration project. Republic of Djibouti. Final Report. ISERST. 159pp. Abdou M. and al; Nord-Ghoubbet geothermal site, Djibouti Republic, Argeo C4 2012.

Barberi F., Ferrara G., Santacroce R. and Varet J. (1975). Structural evolution of th Afar triple junction. Afar Depression of Ethiopia, Bad Bergzarben, Germany, April 1-6 1974. A. Pilger and A. Rösler, vol. 1. pp 38-54.

Barberi F. & Varet J. (1977): Volcanism of Afar: small scale plate tectonics implication. Bull. Géo. Soc. Amer., v. 88, p. 1251-1266.

Battistelli A., Rivera J. and Ferragina C. (1991). Reservoir engineering studies at the Asal field: Republic of Djibouti. Geothermal Resources Council Bulletin. Nov. 1991. pp280-289.

BRGM (1970). Reconnaissance géothermique du TFAI. BRGM/70-SGN-GTM. 59p.

BRGM (1983). Reconnaissance géothermique par prospections gravimétrique-électrique, audio-magnétotellurique dans la région du Nord-Ghoubhet (République de Djibouti). BRGM/83/GPH-014. 27p.

Jalludin M. 2003. An overview of the geothermal prospections in the Republic of Djibouti. Results and perspectives. Kengen geothermal conference, Nairobi 2003.

Manighetti, I., Tapponnier, P., Gillot, Y., Jacques, E., Courtillot, V., Armijo, R., Ruegg, J.C. and King, G. (1998) Propagation of rifting along the Arabia-Somalia plate boundary Into Afar. J. Geoph. Res. Vol.103, p.4947-4974

Manighetti, I., P. Tapponnier,V. Courtillot,Y. Gallet, E. Jacques, and Y. Gillot (2001), Strain transfer between disconnected, propagating rifts in Afar, J. Geophys. Res., 106, 13,613– 13,665.

Marinelli G. et Varet J., (1973) : Structure et évolution du Sud du "horst Danakil" (TFAI et Ethiopie). C.R. Acad. Sci., (D) 276, p. 1119-1122.

Puvilland, P., Benderitter, Y., Charboneyre, P., Dore, P., Lesage, P., Madelaine, B., Reconnaisssance géothermique par prospection gravimetrique et électrique audiomagnetotellurique dans la région du Nord-Ghobbat (République de Djibouti). BRM/83-SGN-932-GTH (54p. 6 cartes).

Sanjuan B., Michard G. et Michard A. 1990. Origine des substances dissoutes dans les eaux des sources thermales et des forages de la région Asal-Ghoubhet (République de Djibouti). Journal of Volcanology and Geothermal Research, 43 (1990) 333-352

Tapponnier P. et Varet J. 1974. La zone de Makarassou en Afar: un équivalent émergé des "failles transformantes" océaniques. C.R. Acad. Sc. Paris, t. 278, Série D, p. 209-212

Varet J. (2010) - Contribution to favorable geothermal site selection in the Afar triangle, Argeo Meeting, Djibouti, 17p.

Zan L., Gianelli G., Passerini P., Troisi C. and Haga A.O. 1990. Geothermal exploration in the Republic of Djibouti: thermal and geological data of the Hanlé and Asal areas. Geothermics, vol. 19, n°: 6. p. 561-582.