Proceedings World Geothermal Congress 2015
Melbourne, Australia, 19-25 April 2015

Country Report, Geothermal Development in Djibouti Republic

Omar Ahmed MOUSSA, Hamoud SOULEIMAN

Ministry of Energy and Natural Resources, P. O. Box 10010, Djibouti, REPUBLIC OF DJIBOUTI

omarahmed61@hotmail.fr, hamoudsoulei@yahoo.fr

Keywords: Country report, Djibouti, geothermal energy

ABSTRACT

Djibouti is a small country located in East Africa in the area where the Gulf of Aden meets with the Red Sea. It is hence a strategic place between Africa and Arabia with neighbors like Ethiopia, Eritrea, Somalia and Yemen. For Ethiopia, Djibouti is presently the only access to the sea and the port of Djibouti is developing very fast, as well as the lines of communication between the two countries (roads, railways, electricity line, etc.). The current population of the Djibouti Republic is estimated to be about 850,000, of which about 600,000 live in the main town of Djibouti-Ville, 95,000 in secondary towns and the remainder, 155,000, in a rural setting, including a substantial nomadic population. The country's electrification rate is about 50 per cent. Electricité de Djibouti (EdD), the national state-owned utility under the Ministry of Energy in charge of Natural Resources (MERN), reports about 45,000 electricity connections. Demand in Djibouti-Ville area is currently supplied from two main power stations: Boulaos has an installed capacity of 100.3 MWe and comprises 15 medium speed diesel generating units operating on heavy fuel oil. The Marabout power station has an installed capacity of 18 MWe, with 6 medium speed diesel generating units operating on diesel oil is used only in summer (demand peak). The Ethiopia-Djibouti interconnector entered in operation in May 2011 and provides an additional electricity source, based on renewable (hydro), ranging from 180 to 300 GWh per year, i.e. allowing to cover nearly half and up to two-third of the demand. Forecasts of future demand have been developed; in the base case, the peak annual demand is expected to increase from 75 MWe in 2010 to 138 MWe in 2015 and 219 MWe in 2035. This provides an idea of a minimum target for geothermal energy development. The main objective of the geothermal development program of the Ministry in charge of Energy is:

1. To develop a site located in a favorable situation in order to answer the present needs of Djibouti-Ville, i.e. a target of 50 MWe

2. To explore the country's overall geothermal resource in order to answer the needs of other consumption centers and,

3. To prove commercially exportable geothermal reserves for future developments of broader interest.

The presence of geothermal resource in Djibouti has been known for more than 40 years and efforts were carried by various teams towards exploration and possible development of suitable sites, but without commercial success yet. Geothermal exploration therefore remains an important step for the Republic, towards self-dependency in the production electric power and climate change mitigation.

1. INTRODUCTION

In the actual context the government of Djibouti has accelerated the development of renewable energy in order to meet the energy challenge tomorrow. The geothermal energy has designed the first priority. Because Djibouti is geologically situated where two oceanic ridges (Gulf of Aden and Red Sea) meet with East African Rift, hence a huge quantity of energy is dissipated from the very shallow earth mantle to the surface, the only region in the world along with Iceland where an oceanic ridge is accessible off shore for geothermal exploitation, the development of the geothermal industry becomes evident with a potential estimated more than 1,000 MWe.

One of the active investigations is the Asal project. This program is financed by a public banking consortium led by the World Bank (with the OPEP fund, ADB, GEF and AFD) in order to build up a production unit of 50 MWe in the first step. The project development objectives are to finance both the exploration phase and the tendering process of the development of a 50 MWe geothermal power plant in the Lake Assal region, 80 km away from the city of Djibouti. The cost is conservatively estimated at US$31 million and will cover the design and execution of a drilling program and test protocol.

And also an exploratory campaign is being done. It is the realization of geological and geochemical studies of 13 sites with high geothermal potential spread over the whole country.

These studies will quantify and highlight the real potential possessed by the Republic of Djibouti, to promote and develop its resources so that it becomes in the near future the basic energy in the energy mix of Djibouti. These studies are conducted jointly by the government of Djibouti and Japan.

The government has laid the groundwork for the development of great scale for geothermal energy, by creating a new agency named the Djiboutian Geothermal Energy Development Office in French acronym « ODDEG ». This office will be responsible exclusively for geothermal surface studies until confirmation and sale of the geothermal resource. Its main objective is to accelerate the development of geothermal energy in order to meet the forecast demand and become the base load of the energy mix.

2. AN UNIQUE GEODYNAMIC CONTEXT

The position of Djibouti Republic is also specific in terms of geodynamics, as it is located at the eastern extremity of the Afar triangle where two oceanic ridges (Gulf of Aden and Red Sea) meet with East African Rift. Hence a huge quantity of **e**nergy is dissipated from the very shallow earth mantle to the surface, and the Afar triangle is the only region in the world along with Iceland where an oceanic ridge is accessible off shore for geothermal exploitation.

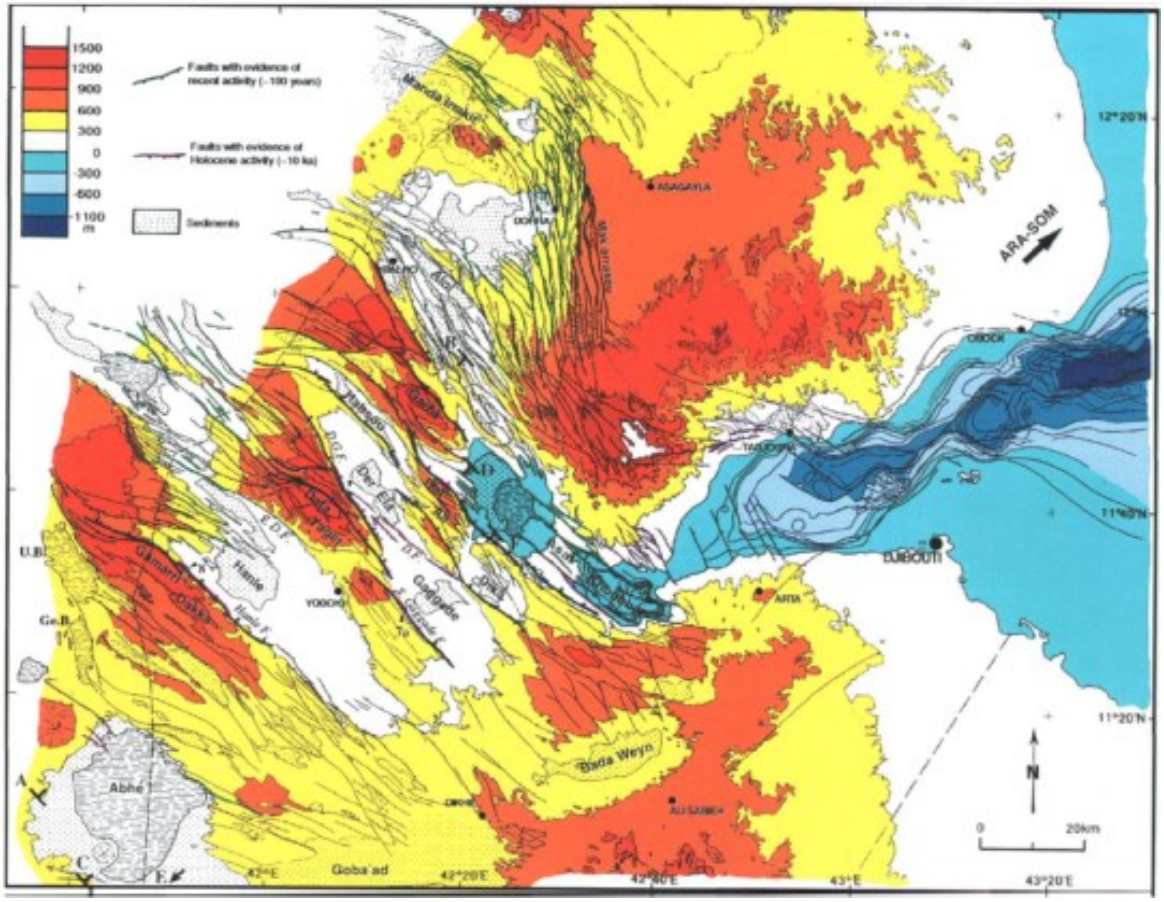

Figure 1: Topographic and bathymetric base map of Djibouti Republic. The major tectonic features are also drawn. The penetration of the Aden Mid-Oceanic Ridge into the African continent is observed in the gulf of Tadjoura, with a progressive up-rise of the ridge from east to west, the rift axis emerges in the Asal part of the Ghoubbet segment. Another active spreading segment is found north in Manda-Inakir, linked to Asal through the Makarassou (N-S) faulted zone. Location of major geothermal sites are shown.

Differing from Iceland however, the climate is rather arid, and for this reason, geothermal exploration should also pay attention to the recharge conditions of the geothermal sites. The experience resulting from the Asal site, since the years 1970's, allows considering with attention the question of hydrogeological parameters of the reservoirs, notably water recharge and quality.

3. HISTORY OF GEOTHERMAL EXPLORATION

Geothermal exploration can be divided into three main historical phases:

- First phase concerns the exploratory survey conducted by BRGM from France in 1970 which showed several possible potential geothermal areas from Lake Asal to Abhe Bad. With the two initial drillings in the Asal rift in 1975, BRGM recognized a deep reservoir at 1,100 m depth with a high mineralization fluid (120g/l) at 260^{o}C. Well Asal1 showed low production and was eventually plugged with sulphides scaling at the flash point in the well.
- Second phase, engaged in 1981 by Aquater (Italy), dealt with the exploration of Hanle Gaggade area, with the hope to find less salty fluids away from the salt-saturated site of Lake Asal. Two deep drillings in Hanle met only low temperature aquifers at depth; therefore the project continued to Asal rift with drillings of Asal3, Asal4, Asal5, and Asal6. Scaling and corrosion study has been carried out by Virkir Orkint (from October 1989 to April 1990). Second production test has been performed by flowing Asal3 well. Wellbore scaling of Asal3 well has been studied and some scale inhibition chemicals have been used in attempt to alleviate the scaling problem. But the program again failed on commercial developments due to these difficult fluid conditions.
- More recently (from October 2007 to March 2008), the Iceland company named Reykjavik Energy Invest (REI) has performed a new prefeasibility study in the Asal rift zone The results of this study were found conclusive and REI offered to proceed to the next feasibility and development phases. Due to the financial crisis in Iceland, REI did not succeed to perform the feasibility study planned initially; this situation placed the project in standby for a few years.

In the last few years, a financial consortium led by the World Bank with AFPB, OPEC fund and eventually GEF and AFD engaged a new proposal in the Asal area. This project is presently on going to drill four deviated production wells.

4. OVERALL GEOTHERMAL PROSPECTS OVERVIEW IN DJIBOUTI REPUBLIC

From general geodynamic and geologic considerations, it appears that Djibouti has a large geothermal potential which could entirely meet the country's future power demand and eventually – as in Iceland - attract foreign energy consuming industries willing to benefit from renewable non emissive energy sources located in proximity with sea transportation facilities.

There are at least seven prospect area (Fig.3), namely:

1. The Asal site
2. Nord-Ghoubbet area
3. Manda Inakir area
4. Abhe Lake area
5. Obock site
6. Roueli area (near Tadjoura)
7. Garabayis site
8. Arta site

These geothermal sites directly result from the geodynamic conditions of the Djibouti Republic. Gulf of Aden spreading centers extends as a series of an echelon rifting units separated by transform faults into the Gulf of Tadjourah and on to land at Ghoubet al Kharab and Asal. The active rift then extends north westward through Asal rift and further north to Manda Inakir rift through the Makarassou transform faults area. But some spreading also develops along the NW extension of the Asal rift through the Alol and Sak Alol grabens, also affected by numerous thermal manifestations. A series of semi parallel depressions are found extending south to the border with Ethiopia; these may be old rifts but are known to be also seismically active, while they display thermal manifestations, due to tectonic readjustments (i.e. block rotation) between the Manda-Inakir and the Manda Harraro major spreading rift segments.

Geothermal prospects can be divided into four groups on the basis of their geodynamic position. All are recognized by surface manifestations and fumaroles, hot springs, hydrothermal deposits and ground water anomalies:

- ✓ Those in an active emerged rift : Asal and Manda Inakir
- ✓ Those on site of intense deformation (transform fault and rotation) in the vicinity of active ridges: Nord Ghoubet,
- ✓ Those located nearby and allowing to reach the oceanic ridge : Obock and Rouéli (east of Tadjourah),
- ✓ Those located inland along graben (Abhe Lake, Alol-Sakalol) or on active transverse fractures: Garabbayis,

According to the energy needs of the small town centres of the country, some of the prospects have higher priority, as Obock, Rouéli (East Tadjoura), Garabbayis and Abhe Lake.

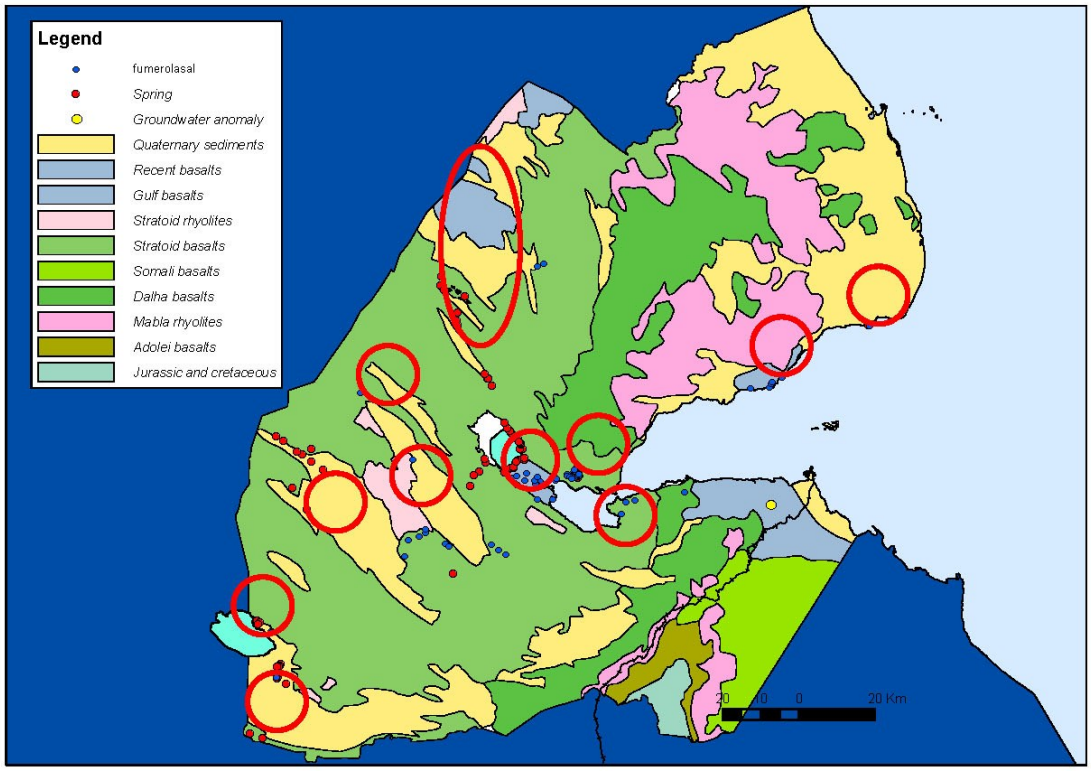

Fig. 2: simplified geologic map of Djibouti Republic, with indication of the hydrothermal manifestations: hot-springs (red), fumaroles (blue). The geothermal sites selected for further investigations and development are drawn in red circles or ovals.

5. TOWARDS A FUTURE DEVELOPMENT STRATEGY

Although not finalized yet, a development strategy is being conducted by the Ministry of Energy in charge of Natural Resources in order to answer the present needs of the population and plan future developments. The idea is to consider that the development should preferably rely upon local resources in priority.

This already allows dividing the country into two categories of areas: those in which geothermal energy development is feasible, and those where other sources should be considered. To this respect, the Republic of Djibouti is gifted with two other renewables sources of energy: solar and wind. It appears that two area should preferably rely upon wind and solar energy sources, that is the north-easternmost part of the country (along the Bab El Mandeb straight, at the southern end of the Red Sea), and the south-easternmost part of the country (the Ali Sabieh horst area). The two parts of the republic are characterized by geological formations older than 3 My, with rather stable geodynamic conditions and lack of thermal anomalies.

The rest of the country is suited for geothermal development, either through expansion of the electric distribution grid from major production units located in the central part of the country (that is Asal and Nord-Ghoubbet areas), or through development of local small to medium size power unit using ORC technologies. In this report, we will only recall the names and development perspective of these sites, as detailed papers otherwise describe in this conference the geothermal parameters of each of these areas.

6. GEOTHERMAL SITES LOCATED ALONG THE ACTIVE OCEANIC RIDGE, SUITABLE FOR CONVENTIONAL GEOTHERMAL PLANTS DEVELOPMENT

In addition to Asal, the Nord-Ghoubbet site prospect is situated on the north-east shore of the Ghoubbet oceanic rift, close to the Asal rift zone. It constitutes an interesting geothermal site and represents the alternative or complementary zone after Fiale site actually planned. The advantage of this site, located in the immediate vicinity of the active Ghoubbet rift segment, is two-fold: it deemed to find less saline fluid thanks to the water flowing from the Goda mountains, while it is affected by intense and multiple open faulting due to the rotation of this fragile block between the Asal-Ghoubbet rift segment and the more typically oceanic ridge in the Gulf of Tadjoura.

Table 1: scoring of sites for high enthalpy development located along the rift axis in Djibouti Republic

Geothermal site along the ridge	Heat source	Permeability	Water recharge quality	Potential size of the site	Geothermal knowledge	Demand size grid proximity
Asal	+++	+	-	++	+++	+++
N-Ghoubbet	++	+++	+++	+++	++	++
Rouéli	++	+	+	+	+	+
Obock	++	+	+	+	-	-
Manda-Inakir	++	++	++	++	-	-

The Obock prospect is close to the town of Obock on the northern shore of the Gulf of Tadjoura, whereas the Rouéli site is located east from Tadjoura, the most important town and port of northern Djibouti Republic. Resurgence of several hot springs and fumaroles are observed on several sites on the shores, whereas sedimentary beaches or rocky mountains, located along both normal rift (E-W to WNW-ESE) and transverse faults (NE-SW). Geochemical analyses indicate a reservoir temperature of 210^{o}C. These sites are considered in the short term for local plant developments in the range of a few MWe, and in the long range for a more innovative, ambitious approach including the study of deep-seated supercritical fluids underneath the Tadjoura oceanic ridge in the frame of the IDDP project.

The Manda-Inakir site is located north, near to the triple boundary with Ethiopia and Eritrea. This wide area includes recent quaternary volcanic activity as well as fumaroles and hot-springs sites developed along the rift as well as transverse faults. The demand is presently low, limited to answering the needs of small villages, but no doubt that providing local power would help for development, notably immediate agro-pastoral needs and future communication and transport network.

7. LOCAL OPPORTUNITIES FOR MEDIUM ENTHALPY ORC PLANTS ANSWERING LOCAL NEEDS

Outside the identified oceanic ridge, several sites are already identified as suitable for answering the local needs. In this context, ORC plants can be developed, the size of which will depend upon two factors: the quality of the site in term of geothermal potential, and the importance of the local demand. To this respect, some of the sites placed in the first category, i.e. suitable for eventually important high enthalpy development could justify the installing in a first step a small-size medium enthalpy plant only due to the limited demand at present. Note that in a few cases, the local demand may just be fed by the binary plant, due to the limitation of the resource parameters.

In the places located outside the above mentioned set, one interesting site was identified due to the demand locally, and to its limited but still attractive potential: that is Garabbayis answering the need of development axis of Dikhil-Yoboki.

The Abhé site could eventually be significant in size, but limited in terms of temperature to ORC technologies. However, due to the agro-pastoral potential of the area, other direct applications of the geothermal fluid could be developed (drying, fish farming, cooling etc.).

Besides those two places, several other sites are certainly suitable for small-size ORC medium enthalpy units exploiting local hydrothermal manifestations answering local demand. Several such sites were identified in the north-western part of the Republic, notably north-east of Asal in populated areas of Allol and Sakalol as well as around Gaggadé to the east.

There is a need for exploration work to be developed specifically for this purpose, combining precisely the village's locations and population concentrations with the fumaroles and thermal emergences related to transverse faults. It may well be that up to 10 such sites could be identified. Table 2 tries to synthetize the present views of the ministry combining all site characteristics.

Table 2: First attempt to establish a hierarchy of potential geothermal sites of Djibouti Republic for development planning according to local geothermal potential and considering present and future demand (a base for discussion with experts, to be completed)

Geothermal site	Enthalpy	Future demand type	Present needs	Potential size of the site	Geothermal knowledge	Size order (short term)
Asal	**High**	**High (grid)**	**50MW**	**Large**	**++++**	**50 MW 2016**
N-Ghoubbet	**High**	**High (grid)**	**Be prepared**	**Very large**	**++**	**50 MW 2020**
Rouéli	**High**	**Future high**	**Medium**	**Large**	**+**	**2 MW 2018**
Obock	**High**	**Future high**	**Small**	**Large**	**-**	**5 MW 2015**
Manda-Inakir	**High**	**Small**	**Small**	**Large**	**-**	**1 MW 2015**
Abhé	**Medium**	**Small**	**Small**	**Medium**	**++**	**1 MW 2015**
Garabbayis	**Medium**	**Medium**	**Medium**	**Small**	**+**	**1 MW 2015**
Karapti San	**Medium**	**Small**	**Small**	**Small**	**+**	**1 MW 2015**
Balho	**Medium**	**Small**	**Small**	**Small**	**-**	**1 MW 2015**
sites to be identified (W)	**Medium**	**Small**	**Small**	**Small**	**-**	**1 MW 2020 Up to 10**

CONCLUSION

The Ministry in charge of Energy is presently confronted with two major issues: to develop practically, in the short term, the geothermal sites with a capacity to answer the immediate needs, and in the same time to engage a sound strategy for long term geothermal development in the country. This should rely upon the improvement of the geological knowledge of the sites, as well as upon the approach of the most appropriate technologies, in order to adapt the costs of the exploration and drillings to the targeted size of the site. Moreover, the Ministry should develop a prospective view of the demand, taking into account figures already available concerning the Djibouti capital and port, but also the future development axis (for example, the two railway projected lines and induced development), taking into account the attractively of the Djibouti Republic for foreign industrial investments due to the geothermal resources located along the coasts of the Gulf of Tadjoura (as in Iceland for aluminum plant developments along the coasts of the Reykjanes peninsula).

REFERENCES

Abdourahman O Haga, Hamoud Souleiman C and J Varet, The Obock and Rouéli Geothermal Sites, Djibouti Republic, *Proceedings* of the 4th African Rift Geothermal Conference 2012 Nairobi, Kenya, 21-23 November 2012 p65-74.

Abrourahman O Haga, Said K Youssouf and J Varet,The Manda-Inakir Geothermal Prospect Area, Djibouti Republic, *Proceedings* of the 4th African Rift Geothermal Conference 2012 Nairobi, Kenya, 21-23 November 2012

Abdou Mohamed Houmed, Abrourahman Omar Haga and Jacques Varet, A Revised Approach to the Hanlé - Gaggadé (Djibouti Republic): The Garabbayis Geothermal Site, *Proceedings* of the 4th African Rift Geothermal Conference 2012 Nairobi, Kenya, 21-23 November 2012

Houmed, A. M., Haga, A. O. Abdilahi, S. & Varet, J. Proposal for new geothermal models and sites hierarchy in Djibouti Republic, *Proceedings* of the 4th African Rift Geothermal Conference 2012 Nairobi, Kenya, 21-23 November 2012

Houmed, A. M., Haga, A. O. Abdilahi, S. & Varet, J. : The Asal geothermal site, Djibouti Republic (model update, 2012) *Proceedings* of the 4th African Rift Geothermal Conference 2012 Nairobi, Kenya, 21-23 November 2012

Houmed, A. M., Haga, A. O. & Varet, J. (this volume): Nord-Ghoubbet geothermal site, Djibouti Republic. *Proceedings* of the 4th African Rift Geothermal Conference 2012 Nairobi, Kenya, 21-23 November 2012

Mohamed Jalludin **:** STATE OF KNOWLEDGE OF THE GEOTHERMAL PROVINCES OF THE REPUBLIC OF DJIBOUTI, Presented at *Short Course VIII on Exploration for Geothermal Resources,*organized by UNU-GTP, GDC and KenGen, at Lake Bogoria and Lake Naivasha, Kenya, Oct. 31 – Nov. 22, 2013.