LAKE ABHE GEOTHERMAL PROSPECT, DJIBOUTI

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ABSTRACT

The Lake Abhe geothermal prospect is located in south-western part of the Republic of Djibouti. The stratoid basalt outcrops affected by the main tectonic trends, E-W and NW-SE, delineating high plateaus and plains, control the geological setting. It is one of the thirteen geothermal fields potentials identified in Djibouti. The Lake Abhe prospect is characterized with several surface hydrothermal manifestations such as fumaroles, hot springs, altered zones, hot soils and numerous massive travertine constructions aligned upon the main faults trend. The hot spring manifestations are mainly located in the bottom of the travertine with high temperatures of more than 90°C. The chemical profiles of the hydrothermal source are alkaline-chloride in general and some bicarbonate from the previous studies. Recently surface exploration was done in this site with technical support from ISOR in collaboration with ODDEG team. This survey was undertaken between November 21th up to December 14, 2015, using all the technique of surface exploration (Geology, Geochemistry, and Geophysicist) and using different methods like MT, TEM. Several soundings was carried out using MT and TEM equipment's and all gravity sounding were carried out using Scintrex equipment's. The data quality was fine except for few soundings, located very close to Lake Abhe .The quality of the data improved in general significantly when processed with the magnetic data from the Remote Reference station. Several water samples was collected (including fumarole sample) and addition to that, stable isotopes of oxygen and hydrogen, chlorine and boron and analyzed in ISOR laboratory. The previous study done by CERD in 2012 show conductive zones from 900 m up to 1500 meters before showing higher resistivity. These deep conductive zones could identify with the heat source in this region that would lead to the geothermal resources of the Lake Abbe. However, this news exploratory campaign will allow ODDEG to model clearly the geothermal reservoir using a 2D inversion and target the well sitting for feasibility phase.

1 INTRODUCTION

The aim of this paper is to present the result of the exploration survey undertaken in Lake Abhe between November and December 2015 by ISOR and ODDEG in a project financed by the Icelandic International Development Agency (ICEIDA) and the Nordic Development Fund (NDF).

The main goals of the project were to train ODDEG experts in surface exploration methods and interpretation of exploration data. Lake Abhe geothermal prospect has been considered to have viable geothermal potential. It is located in the southwest of the country, and has geological structures related to the tectonic plates associated with the movement of the Arabian plate from 3.4 M.y and the areas was mainly composed by stratoid basalt limited by E-W faults. Surface hydrothermal manifestations are numerous around the lake along with a rich variety of fumaroles, hot springs and many travertine constructions. Studies have been conducted in the Lake Abhe previously by CERD and JICA.

The field work was focussed on geological mapping, geothermal surface manifestations, geochemistry of geothermal fluid, gravity- and resistivity surveys. Three ODDEG experts visited Iceland for three weeks in March 2016 to work on the exploration data collected at Lake Abhe. The field work and the first step of the project is described in reports by Hersir et at. (2016) and Thorbjörnsson et al. (2015). The main goals of the project were met the training was successful and the work has resulted in a conceptual model of the Lake Abhe geothermal field. However, the results of the surface exploration survey suggest that the subsurface temperature is not sufficient for electricity generation.

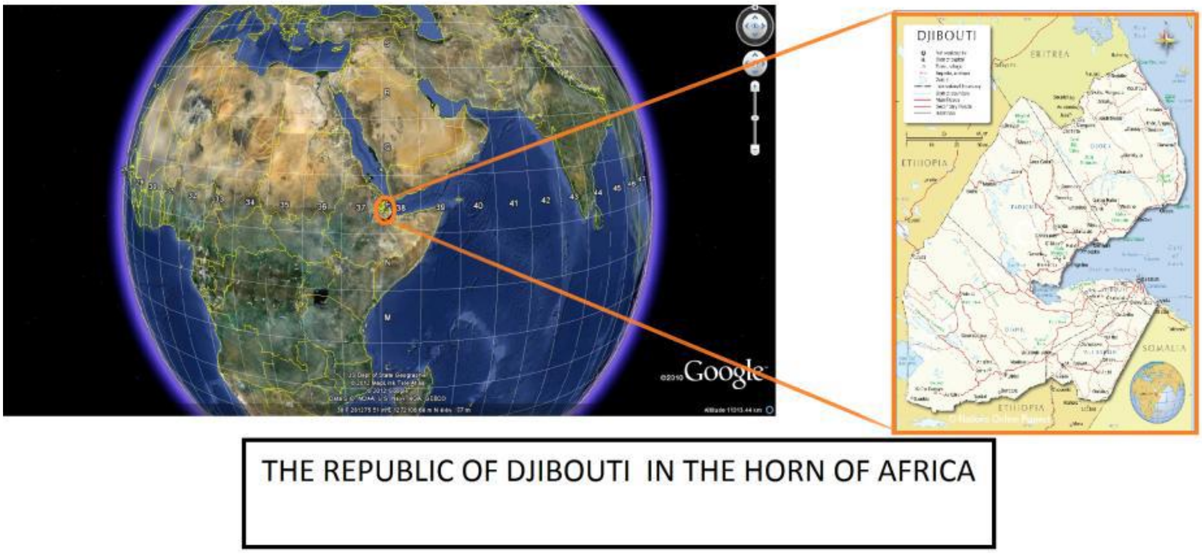

Figure 1: Location of Republic of Djibouti

2 REGIONAL GEOLOGY

2.1 Geology of the Republic of Djibouti

The Republic of Djibouti is located in the Afar depression, at the junction of three tectonic plates mentioned above. The Afar depression is of great scientific interest as it is one of the keys to understand the relationships between developments of the rift of the Red Sea, Gulf of Aden in connection with the East African rift. This relief essentially volcano tectonic originally formed by successive emissions. The whole country is covered by basaltic rocks dominance due to the various spacing movements of the earth crust.

Basalt Ali Sabieh is a marker of the first movement of Arabo-Nubian block Miocene. The rhyolite Mabla locates in the north of the country and south including Ali-Sabieh, this block-shaped ancient basement (Pre-Miocene). Somali basalt set up parallel to the basalt Dalha in the eastern part of the country oriented N160 ° to the movement of the introduction of Dalha basalt. The stratiote series and basalt Golf emitted during the opening of Tadjourah Golf. The opening of the Golf continues to earth by the recent rifting Asal first segment emerged from the ocean back to Aden Tadjourah.

Lacustrine sedimentary formations detrital and evaporitic have developed, the interior of the earth thanks to graben filled Lake diverse recently (Pleistocene to present). On the coast of marine coral formations observed well developed NE of the country (north and Obock Obock).

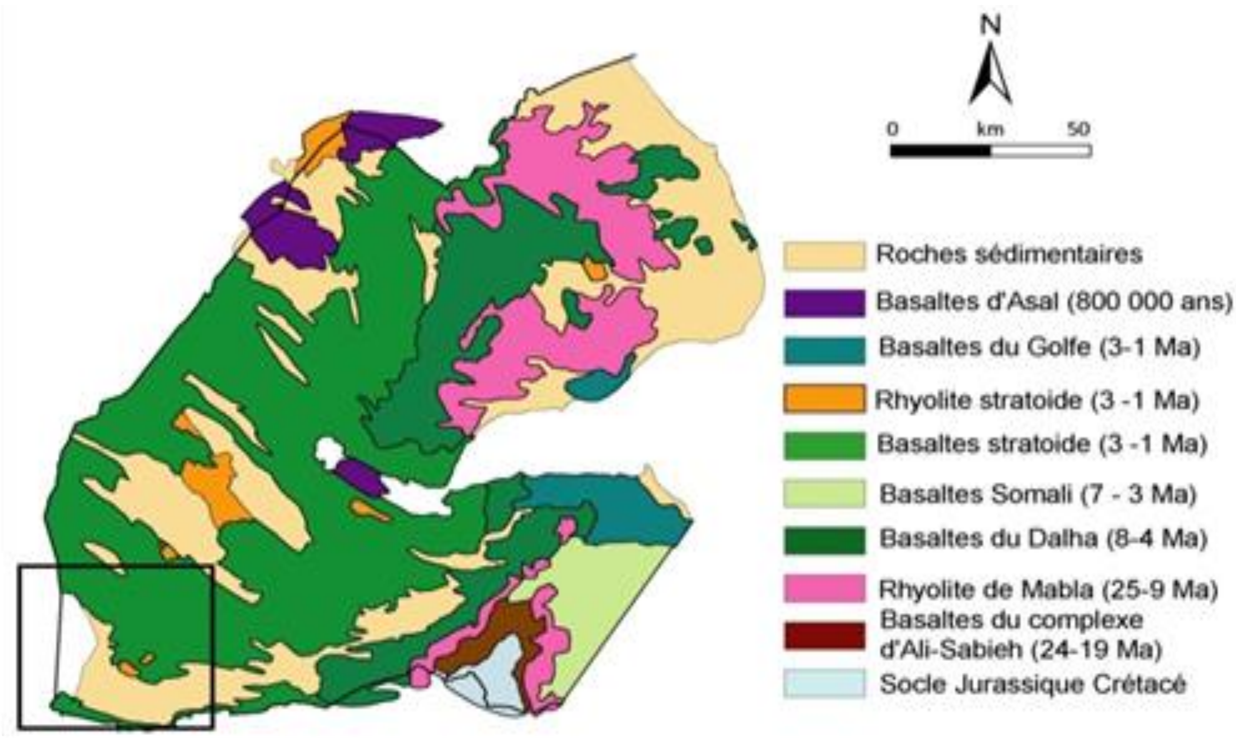

Figure 2. *Geological simplified the Republic of Djibouti Map the square indicates the study area.*

2.2 Hydrology and Hydrogeology

2.2.1 Climatic context of Djibouti

The Republic of Djibouti is located between latitudes 10 ° and 12 ° 9 7 N and longitude 41 ° and 43 ° 8 4 E. .The climate of the Republic of Djibouti is almost desert, throughout the year, n 'there is technically no rain Djibouti, according to Koppen-Geigger. Over the year, the average temperature in Djibouti is 30.1 ° C.

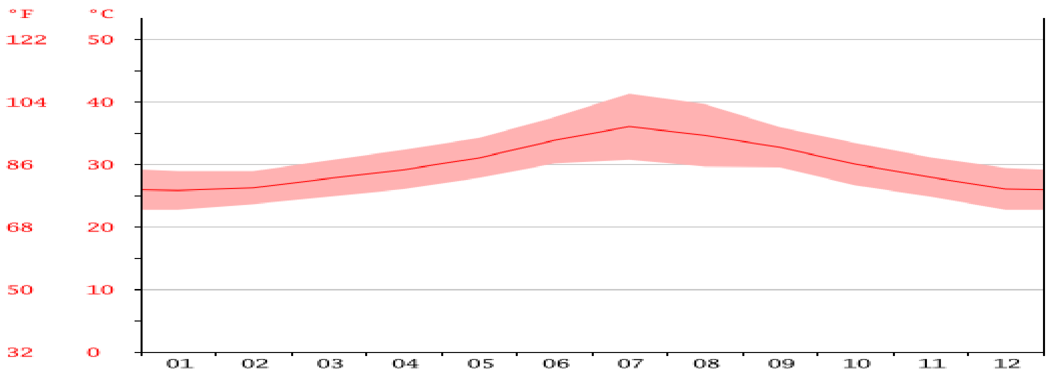

Figure 3. Temperature curve of the Republic of Djibouti

The hottest month of the year is July with an average temperature of 36.0 ° and January, the coldest month with an average temperature of 25.8 °. Climate parameters such as temperature and average monthly evaporation gave high values, the average evaporation of 959 mm and 300 mm. Over the year, the average rainfall is 150 mm with 137 mm in Yoboki village in the plain of Hanle, then the main concentration of rainwater locates in Hanle plain northeast of ABHE Lake.

2.2.2 Aquifer systems and the direction of flow of water

In the Lake Abhe we see two aquifer systems:
• Volcanic aquifer system (stratiote series).
• Sedimentary aquifer systems (including the Gobaad plain).

The volcanic aquifer system and the flow of water.
Rhyolites and basalts stratiote series outcropping south of Gobaad to the west of Lake Assal, filling almost all of Afar Depression, Djibouti to Ethopiennes trays. These two formations, basalt dominate and almost form a regional aquifer, recharge the aquifer is provided by groundwater flows from the lower valley area of the Awash River on the other side of Ethopiennes border. The flaws facilitate this flow.

The sedimentary aquifer system and the direction of flow of water.
The sedimentary formations, mainly of Pleistocene and Holocene can reach a thickness of several hundred meters and primarily the Gobaad plain tectonically collapses. Sedimentary formations are very diverse in ABHE Lake: -At the edge of volcanic formations that border the plain was coarse formations. -We Silty formations near Lake Abbe. -In The plain, river sediments and clays dominate. This sedimentary allogeneic includes a freshwater tablecloth exploited and profited by populations in irrigation fields etc. This aquifer is fed by the river Degbour the east and the Awash River descendant of Ethiopian plateau to the west.

3 GEOTHERMAL MANIFESTATIONS

3.1 The hot springs and fumaroles

For sources of hot water was 2 classifications;
In volcanic areas, the water can simply be heated by direct contact with the magma.For non-volcanic areas, the water is heated by a convection, or the rock temperature increases with depth (geothermal gradient) if water penetrates deep it will be heated by the hot rocks. In the Lake Abhe , most of the hot springs are concentrated at the feet of travertine and near the lake, their temperature varies between 70 ° C and 100 ° C. in some cases the hot springs have a slight smell of sulfur and fate with a lack of pressure, it is estimated their water flow is 0.5L / s. This hot spring is heated by geothermal boiler where their origin is a crack exists because the other side is a volcano (Dama Ali).

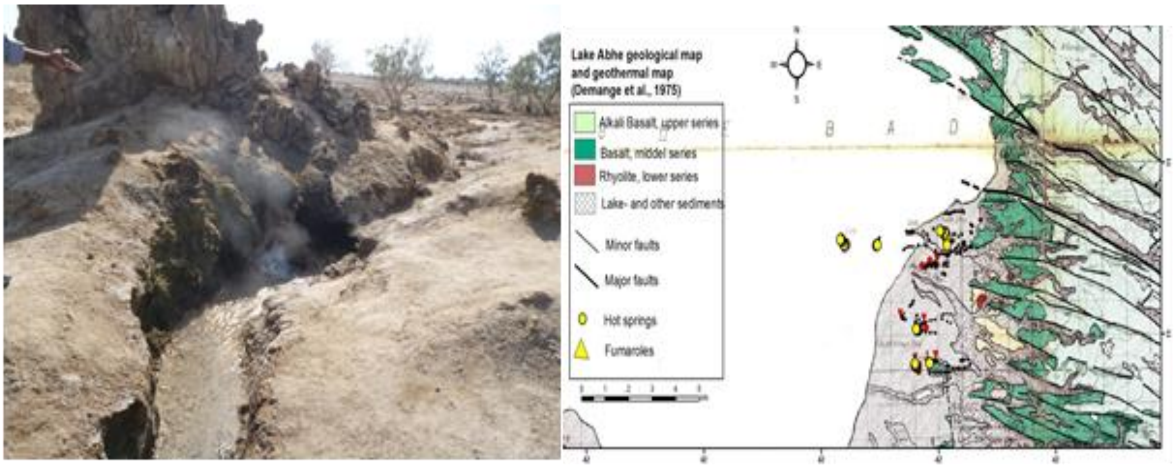

Figure 4. Source of hot water that boils with a flow rate 1 L/ s temperature is 99.8 ° C and geological map with the distribution of hot springs.

Fumaroles may occur along tiny cracks or long fissures, chaotic fields, and on the surfaces of lava flows and thick deposits flows of pyroclastic. A fumarole field is an area of thermal springs and gas vents where magma or hot igneous rocks to release gas shallow or interacting with groundwater. From the perspective of groundwater, fumaroles could be described as a hot spring that boils bubbling of its water before the water reaches the surface.
Fumaroles Gamboli (Fig 5) is connected by steering substantially E-W faults, is characterized by the presence of fumaroles. The temperature of this fumarole is 99.5 ° C in this area continues basalt clay transformed by the cast cooked following a reaction iron hydroxide (study completed after the XRD analysis). The temperature of the hot springs in the region (according to the geochemical study this hot spring is the condensate from the fumarole) is 99.1 ° C. This area presents a geological structure completely modified by tectonics; we encounter rich formations lake fossils (gastropod), then this concreted area was colonized by the lake.

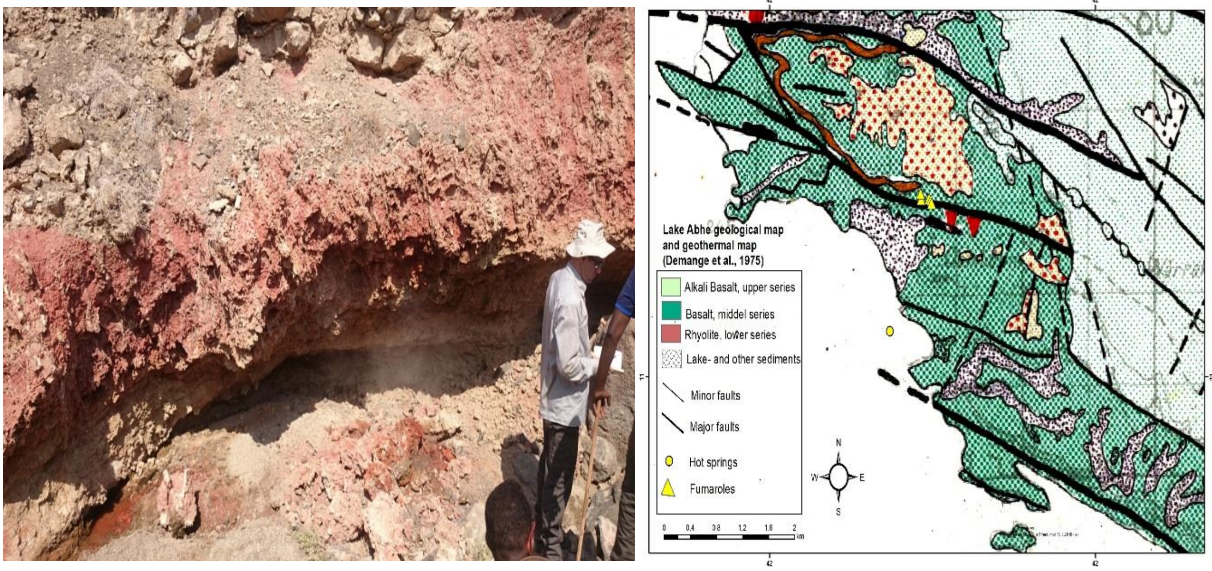

Figure 52. Fumaroles of Gambole and geological map with distributions fumaroles.

A group of 'stacks' a Gamboli without source, with two fumaroles was 99.5, can connect easily to a fault direction substantially E-W (WNW-ESE).

3.2 Travertine

Travertine limestone sedimentary rocks are white. They are formed at the time when the lake water was higher and are due to a chemical reaction caused by contact between the cold waters of the lake and underground hot springs. The implementation of reverse stalactite with lacustrine deposits gives a more complex structure. Mostly, travertine reach of 1-5m high and 5 to 15m base, named as Most bahalto (large chimney) is about 60m high and about 90m in diameter and are dispersed groups or their top off fumes. Mostly the direction of travertine is E-W but some travertine has N300 direction nearly north-south, we notice the travertine direction is similar to the fault direction (Graben) is E-W.

Figure 9. *Alignment of travertine.*

3.3 Hydrothermal Alteration

3.3.1 XRD Analysis

The samples analyzed by XRD were collected on the campaign of geological, geophysical and geochemical ABHE the lake in November 2015 with ISOR team. Analyzes were made by ISOR, Icelandic Geosurvey. Solid crystalline products have X-ray beam patterns reflected. This Crystal are used on different wavelengths, the angle of incidence produced intense peaks of radiation reflected (Bragg's Law-).

3.3.2 Results of XRD

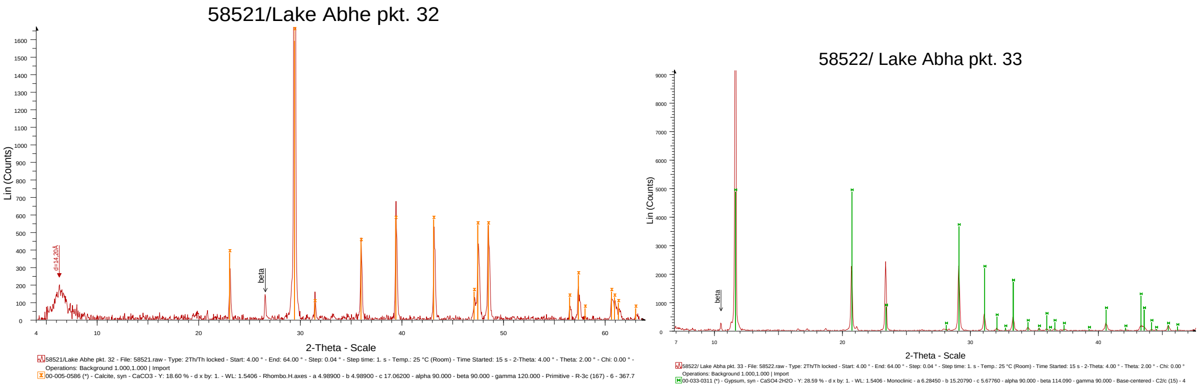

Figure 3. *XRD analysis results.*

Table 1. *Results of XRD analysis of selected samples.*

Pointes du GPS	N	E	Z	Results of Xrd
32	N11.22898	E41.85440	297 m	calcite
33	N11.22948	E41.85440	307m	gypsum
34	N11.22951	E41.85432	310 m	Montmorillonite {smectite}, heulandite, gypsum
35	N11.22951	E41.85409	301m	calcite, quartz
39	N11.21601	E41.85003	251m	calcite, gypsum, halite
65A	N11.14631	E41.84078	242m	calcite
65B	N11.14631	E41.84078	242m	calcite

3.3.3 Mineralogical Interpretation

- Modification assemblies of primary minerals.

The rocks form by primary minerals are unstable when subjected to low temperatures and pressure condition can be processed by secondary minerals stable conditions temperature / pressure. The secondary minerals formed depends on the chemistry of the primitive rock, the chemistry of the fluid and the state of permeability of the rock (Brown, 1984; Reyes, 1990).

Volcanic glass is in the pyroclastic deposits or the cooling intrusion margins. The volcanic glass is very sensitive to alteration and easily change when exposed to geothermal condition. ABHE the lake was as primary minerals volcanic glass, d after the XRD results (quartz, clay minerals montmorillonite, calcite).

Smectite were detected only in minor amounts by XRD analysis. Smectite minerals are stable at low temperature, shallow and their presence in a geothermal field indicates temperatures in the range 50-200 ° C. Quartz: in the presence of a geothermal system indicates temperatures above 180 ° C (Franzson 1998). Calcite and quartz are mainly replacing low temperature clays. Briefly, according to the hydrothermal alteration minerals, ABHE lake is a low temperature zone of 80 to 120 ° C.

4 GEOCHEMICAL STUDIES

The sampling locations can be seen on Figure 4 below. Eight samples of thermal water for chemical analyses were collected at selected locations in the Lake Abhé area (Abbe-01 – Abbe-07, Abbe-12). The springs are scattered around the area but usually formed groups with few springs at the same location. The aim was to get a good overview of the chemical composition of the water in the area, so usually one or two springs were sampled within each group. The hot-spring with the highest temperature and flow was chosen.

Collection of a sample of gas emerging from one of the springs was attempted (Abbe-13). Unfortunately, we did not have the right equipment for collection of dry gas on hand and the sample could not be used for any interpretation. For reference, one sample of cold groundwater was collected (Abbe-14), and a partial analyses of a sample from Lake Abhé itself was carried out.

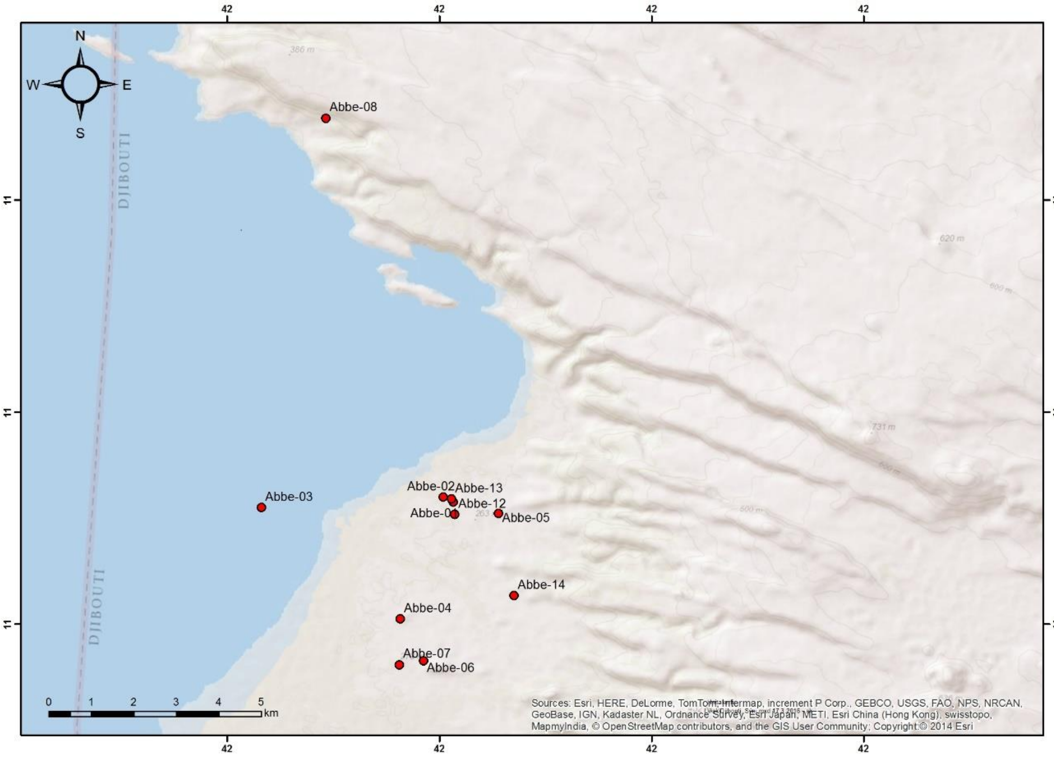

Figure 4: *Sampling locations in the Lake Abhé area. Note that the amount of water in the lake has decreased over the years and the sample Abhé 03 was collected by the lake shore.*

The results from the chemical analyses are shown in tables**Error! Reference source not found.Error! Reference source not found.**. CO_2, H_2S, pH and conductivity were measured on-site. Other components were analysed at ISOR's laboratory in Iceland, and stable isotopes of oxygen and hydrogen at The University of Iceland.

The thermal waters are slightly alkaline, with pH ranging from 8.1 – 8.7. The silica concentration is quite low, or between 97 – 125 mg/L. The salinity of the thermal waters is surprisingly low (830 – 2170 mg/L) compared to the extremely saline Lake Abhé (39200 mg/L). The salinity of the spring's increases slightly when drawing closer to the lake, but even at sampling point Abbé-03, which was under the lake surface a few years ago, the Cl concentration is only 2170 mg/L. This indicates that the reservoir feeding the springs is not connected to the lake.

Notable is also the extremely low concentrations of CO_2 in the thermal waters (16.5 – 29.2 mg/L) compared to the cold groundwater (572 mg/L). Almost no H_2S is present.

Construction of a Cl-SO_4-HCO_3 ternary diagram (Figure 5) (Giggenbach, 1991), which is commonly used for classifying waters of different origin, shows that the thermal waters are mature, and possibly slightly volcanic.

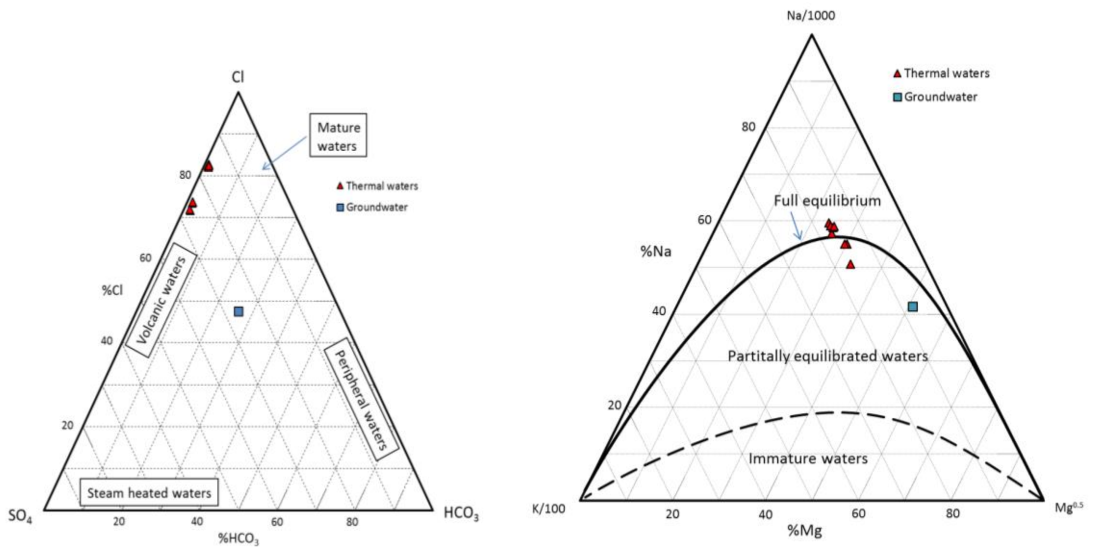

Figure 5: *Cl-SO_4-HCO_3 ternary diagram* **- :** *Na-K-Mg ternary diagram.*

Compared to the cold groundwater, Mg concentrations are extremely low which indicates that mixing between the thermal water and the cold groundwater is minimal. The Na-K-Mg ternary diagram shows that the thermal water is at equilibrium with respect to these three components.

The only fumarole activity in the Lake Abbé area is east of the lake. It was only possible to collect one steam sample in that area (Abbe-08) due to low and diffuse steam flow. The results are shown in **Error! Reference source not found.** along with analysis of gas emerging from spring Abbe-13. Of the non-condensable gases (NCG) N_2 is dominating. Low concentrations of CH_4, Ar and O_2 are also seen. Notably, no H_2 is present in the gas. If all gases are taken into account (NCG's and acid gases) the gas is comprised mostly of CO_2 (58 %V) and N_2 (39 %V), while CH_4 is about 1.6 %V and O_2 and Ar < 1 %V. Very low concentrations of H_2S were detected, or 0.03 %V, which is consistent with the fact that there was no H_2S smell in the area. It is possible that the steam mixes with atmosphere or air-saturated groundwater underground and both oxygen and H_2S are removed from the gas to form SO_2.

4.1 Geothermometry

The most commonly used geothermometers are based on silica concentrations (quartz or chalcedony) and cation concentrations. Calculated silica temperatures indicate subsurface temperatures between 107 – 145 °C, depending on which geothermometer is used . The quartz geothermometer yields higher subsurface temperatures, but is not considered applicable at temperatures below 150 °C. The chalcedony geothermometers shows a range between 107 – 125 °C. The estimated subsurface temperature in Abbe-01, Abbe-02 and Abbe-12, which are close to each other, is about 10°C higher than at other sampling locations. However, Abbe-05 which is the closest sampling point to the three mentioned above shows the lowest temperature so assuming any temperature trends is unwise. The subsurface temperatures calculated with cation geothermometers (Na/K and Na-K-Ca) are similar, or in the range of 114 – 134 °C. Some of the temperatures calculated using the Na-K-Ca geothermometer are below 100 °C, and since all the sampled springs were boiling or close to boiling temperatures, this geothermometer is probably not applicable for the Lake Abbé system.

5 GRAVIMETRIC SURVEY

The following figure shows a residual Bouguer gravity anomaly map of the Lac-Abhe prospect. On this gravity map, we can observe relative gravity high in the central part of the study area. It seems oriented SW-NE direction. The Westhern and Northern part are occuped by a negative anomaly with a relatively strong gravity light in the the North.

The relative gravity high observed in the central part can be associated at the omega-structure imaged by both 1-D joint inversion and 1-D inversion at 1500 m bsl until 3000 m bsl. This anomaly can be associated in term of geological by some less permeable stratoids basalts or some acid intrusion like rhyolitic structures.

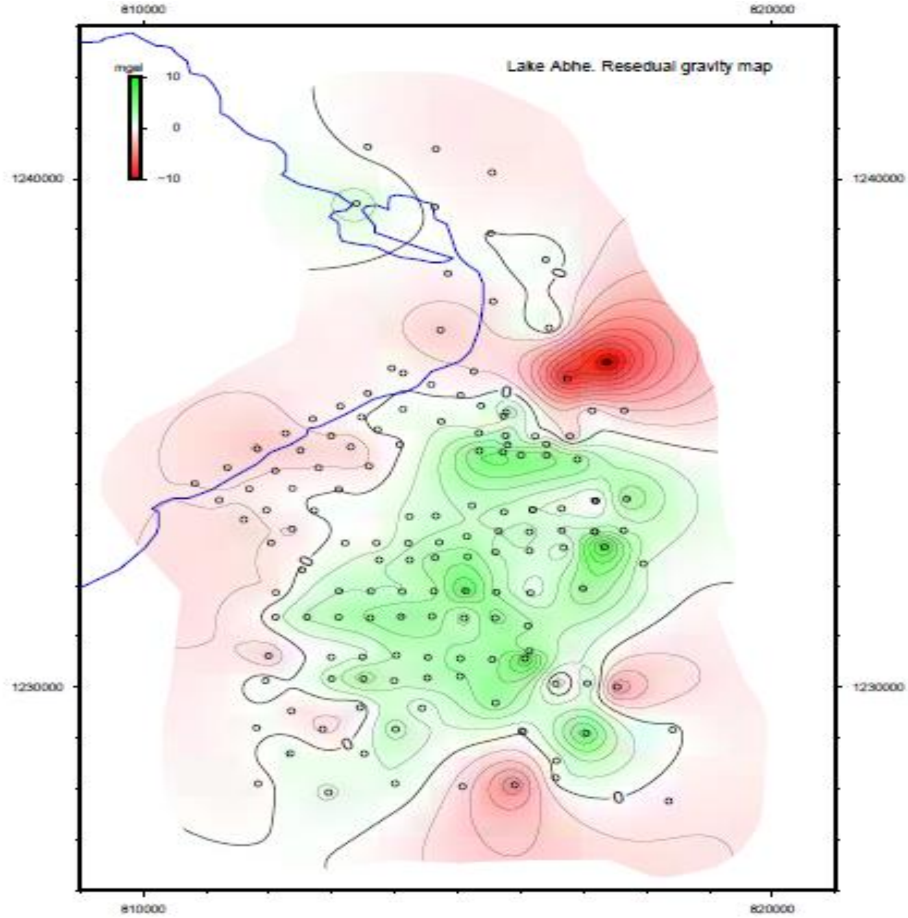

Figure 6. Residual Bouguer gravity anomaly map.

6 RESISTIVITY SURVEY

6.1 MT and TEM methods

Magneto-Telluric (MT) and Transient Electro-Magnetic (TEM) also defined by the term of TDEM (Time Domain Electro-Magnetic) are two geophysical methods exploiting the physical parameter which is electrical resistivity. There exist several methods for measuring electrical resistivity of the subsurface. These methods can be classified into two families that are galvanic (DC) or Electro-Magnetic (EM) methods. DC methods mainly the Vertical Electrical Sounding (VES) were widely used in the past for probing subsurface. Therefore, these methods presents some difficulties in the field for example in the permafrost area where it is not easier to inject the current in the ground. These methods have a weak depth of investigation and allows to describe the first few hundred meter of the ground. Nowadays, principally in geothermal exploration, the EM methods are largely used to image the area presented low resistivity.

6.2 Data acquisition

A combined Magneto telluric (MT) and Time Domain Electromagnetic (TDEM) investigations have been carried out in the Lac-Abhe prospect in the Southwest of the republic of Djibouti to determine the distribution of the electrical resistivity of the subsurface. The objective of this geophysical study was to delineate the boundaries of the geothermal reservoir. Two geophysical surveys were conducted in 2011 and 2015 on the Lac-Abbhe geothermal prospect. The first survey was carried out by the applied Geophysics laboratory of the Study and research Center of Djibouti (CERD). During this survey 34 MT soundings, 35 TDEM stations and 86 gravity points have been carried out. The MT time series have been acquired with one Metronix system. The TDEM data were collected with TerraTEM system. The second survey was conducted jointly by ISOR geophysical team and ODDEG geophysical team in 2015. For this survey two Icelandic geophysicists arrived in Djibouti on November 18. Two different acquisition systems have been used during the fieldwork for MT and TEM data collection. ISOR team have been carried out 26 new MT soundings (plus 6 repeated of the soundings from 2011) with two Phoenix systems. During the MT recording, an MT remote station was operating simultaneously at a distance of approximately 10 km from the survey area for the Phoenix systems. Isor team also have been carried out four TEM sounding before to have a trouble with Zonge intrument by using central loop configuration (135x135m for transmiter).

In same time ODDEG team has been carried out 24 MT soundings (plus 5 repeated of the soundings from 2011) with two Metronix systems. After the departure of the icelandic experts, ODDEG team performed seventeen TDEM soundings on same location as the MT stations from Phoenix systems. The confugaration for these seventheen TDEM soundings is coincident loop with 100x100m transmeter and 100x100m for receiver. A total of 84 MT soundings and 53 TDEM soundings were performed on the Lac-Abbhe site during these two fieldwork, their locations is shown on figure 1. Each MT station was kept running over night, for a total of about 18 or 20 hours. The quality of the MT data is good in the range of 800 Hz to about 300 seconds. Unfortunately, we observe a big error bar on the MT impedance tensor for the soundings from Metronix systems. But, we remark that the MT data seems smooth in the range of 800 Hz to about 300 and we think that these big error bar is due to the processing phase.

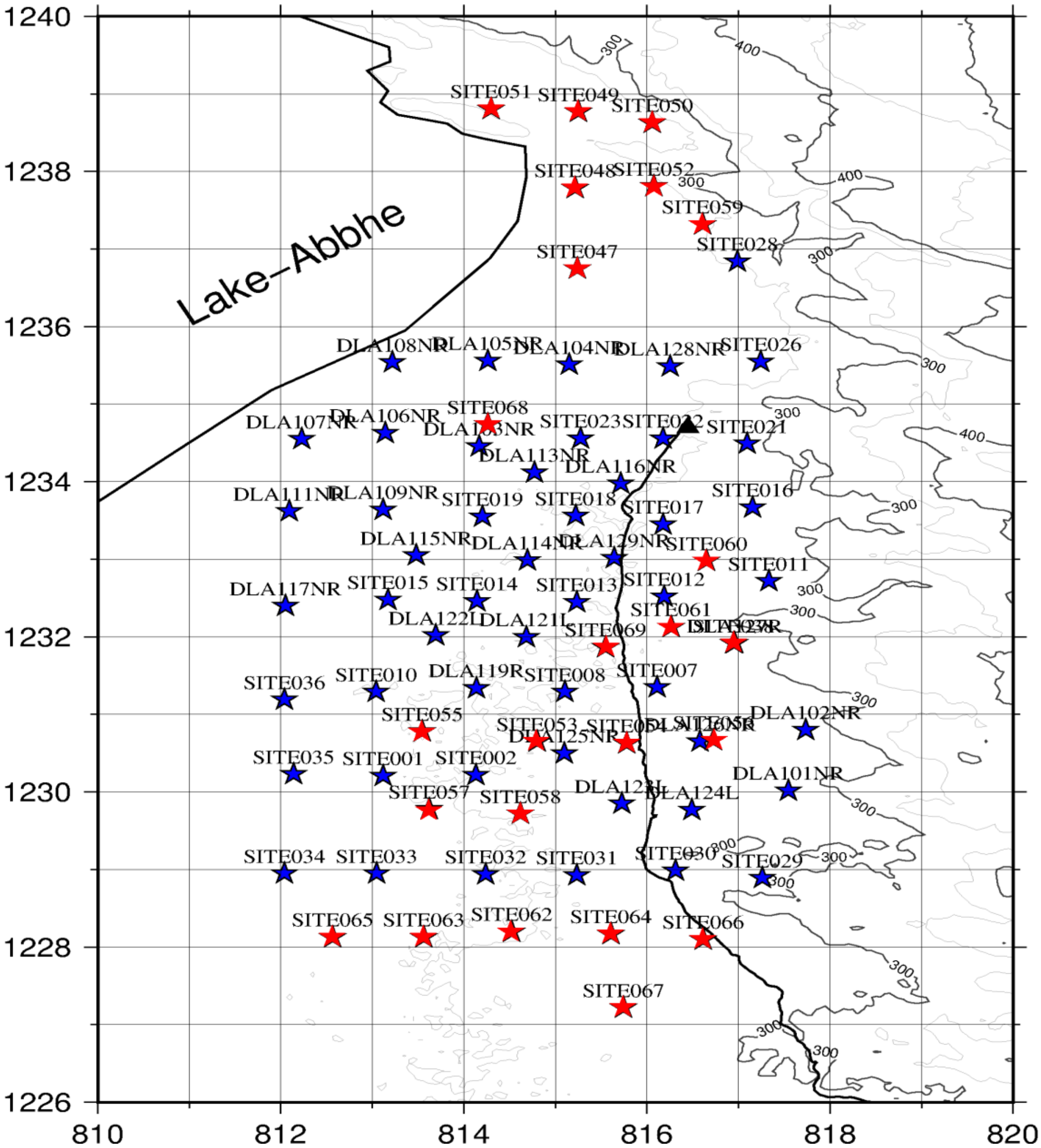

Figure 7. *Localisation map of MT soundings. The Red stars represent the MT soundings considered in the 1-D joint inversion. The blue one are the MT soundings considered in the 1-D inversion. The balck triangle is the camp and black line is road.*

6.3 Data processing and interpretation of the MT and TEM (TDEM)

The raw TDEM and TEM data from both TerraTEM and Zonge was processed by the program TemxUSF. This program calculates averages and standard deviations of repeated transient voltage measurements and calculates late time apparent resistivity as a function of time after the current turned off. The MT data from Phoenix instruments were processed by SSMT2000, MT program from Phoenix while the MT data from Metronix were processed by ProcMT, program from Metronix.

6.3.1 Cross sections WE

The resistivity models from the 1-D joint inversion and 1-D inversion of each sounding were interpolated into cross sections. The following are the distribution of the resistivity structure from each cross section in the EW directions.

a) Profile WE1

This profile WE1 which includes 5 soundings shown a high conductive structure (alpha-structure) at the shallow part. This very low resistivity layer of less than 5 Ohm.m tends to becomes thin gradually from West to East. Below this structure, at around -200m elevation to the West, there is a thick less conductive unit (beta-structure at about 30 Ohm.m). This less conductive structure seems to contain a high thick resistive body (omega-structure ~100 Ohm.m) in the eastern part of the profile. This resistive structure seems to extends westward with least resistivities. At Around -3500m elevation, it appears a very high conductive structure (sigma-structure) in the westhern part of the cross section.

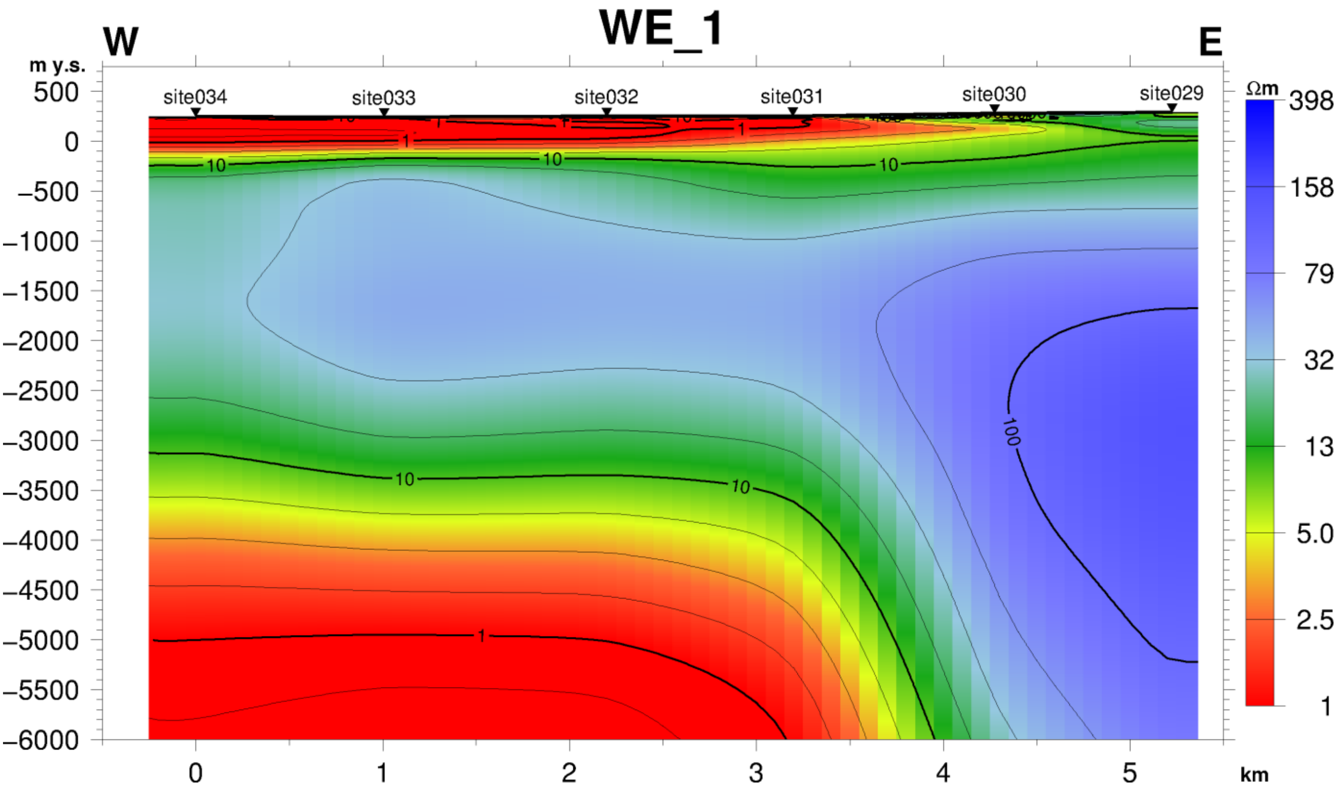

Figure 89. *Distribution of the resistivity under cross section form.*

b) Profile WE2

The cross section WE2 which includes 6 soundings shows the sames structures than the profile WE1 with a light difference of the resistivity distribution. At the shallow seems occuped in whole near surface. From center to east,the alpha-structure with some less conductive anomalous. Below the alpha-structure, we have the beta-structure. On this profile, the beta-structure seems more deeper and covers vertically the whole subsurface in the eastern part. It appears to contain the omega-structure which includes two very high resistives bodies (theta_structure). In the Western part of the profile, the beta-structure seems less thicks and underlying a very high conductive unit (sigma-structure).

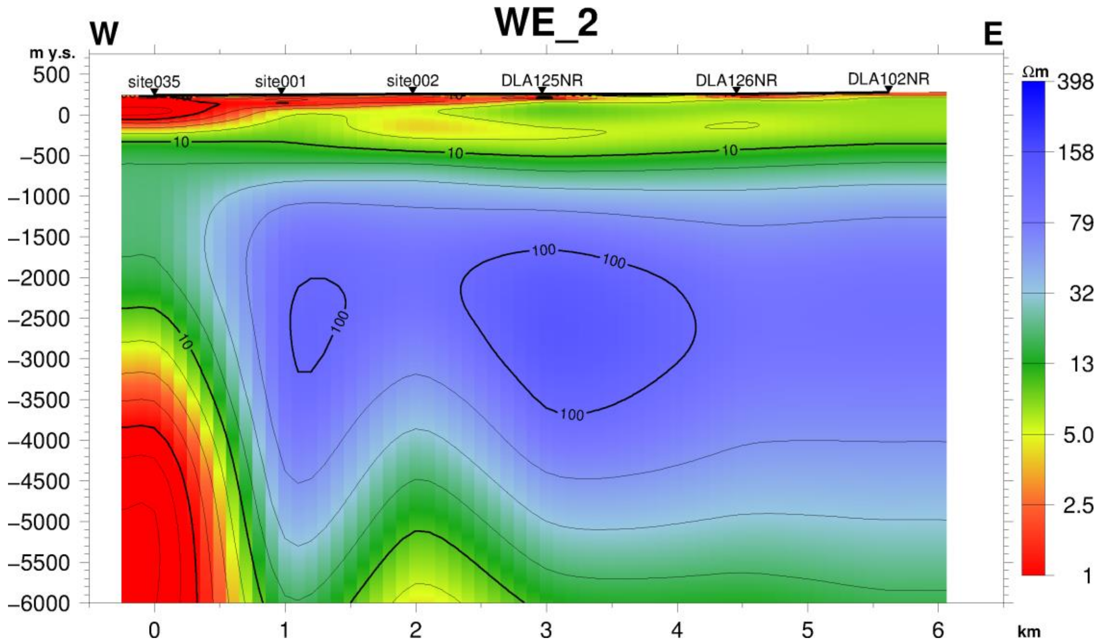

Figure 20. *Distribution of the resistivity under cross section form.*

6.3.2 Resistivity maps

The 1D joint inversion models and 1-D inversion from all MT and MT/TEM soundings are interpolated into 3D subsurface resistivity of the Lac-Abbhe prospect. The resistivity is presented here as iso-resistivity maps at different elevation above and under sea level.

Figure 21. *Resistivity 200 m above sea level (geothermal manifestations in red).*

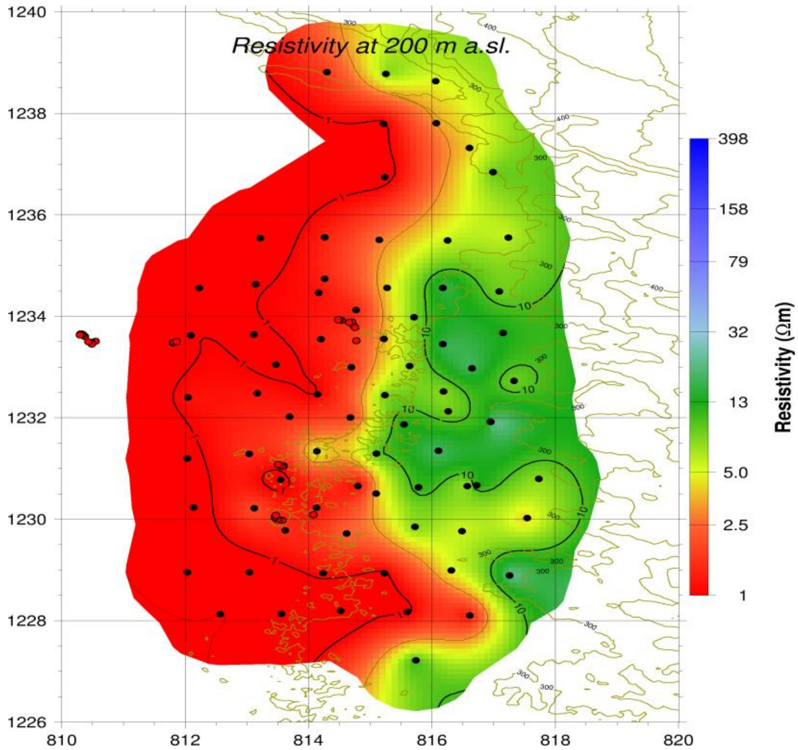

Figure 229. *Resistivity 100 m above sea level (geothermal manifestations in red).*

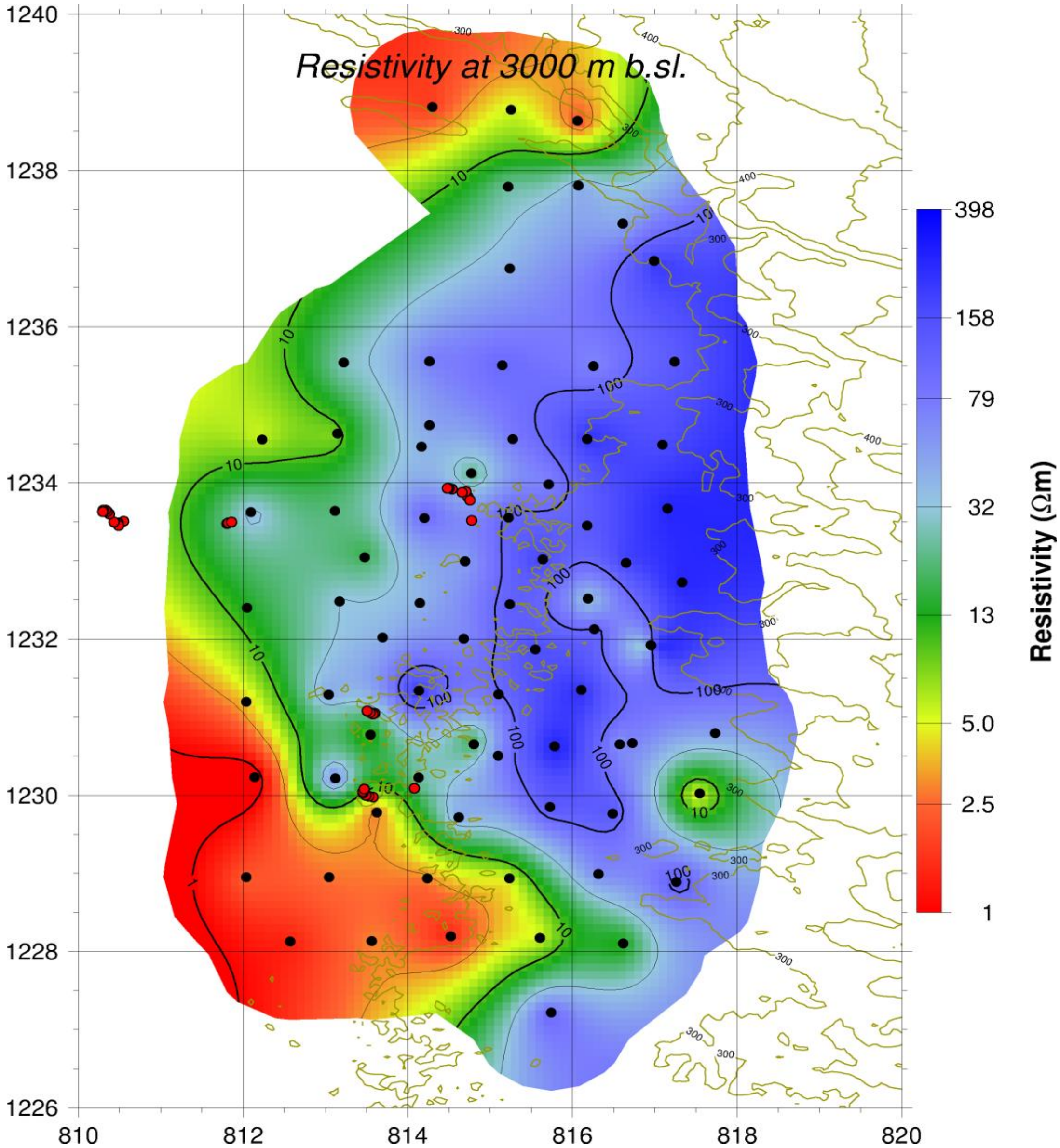

Figure 23. *Resistivity at sea level (geothermal surface manifestations in red).*

Fig 24. *Resistivity 100 m below sea level (geothermal manifestations in red).*

Figure 2310. *Resistivity 3000 m below sea level (geothermal manifestations in red).*

We can observed in the upper part of the subsurface a very conductive unit (< 5 Ohm.m) in the westhern part and resistive structure in the Easthern part. In deeper, this resistive body seems to move toward the Westhern part until to covers all study area (between 100 m bsl and 1500 m bsl). Therefore, there exist a intermediate unit with a resistivity about 5 Ohm.m betweem these two structures observed in the shallow part. In some time this intermediate structure becomes bigger and covers the all Westhern part. At 100 m bsl we can see that this structure is embbeded in the resistive anomalie. About 2000 m bsl, it appears a very conductive anomaly in the southwest part and that seems covers the all Westhern part (4000 m bsl).

7 INTEGRATED INTERPRETATION OF THE RESULTS

Size: at least the span between fumarole area and hot spring area
Temperature: According to solute geothermometers between 105-135°C. Gas geothermometers might indicate Temperatures between 150 – 250°C, but most likely below 200°C.

Water is mature, slightly volcanic of alkali chloride type.
In terem of the reservoir, there is not connection with Lake abbé or the source for cold groundwater.
Results are in accordance with report from CERD and other published papers (Houssein, 2010), (Awaleh, 2015).

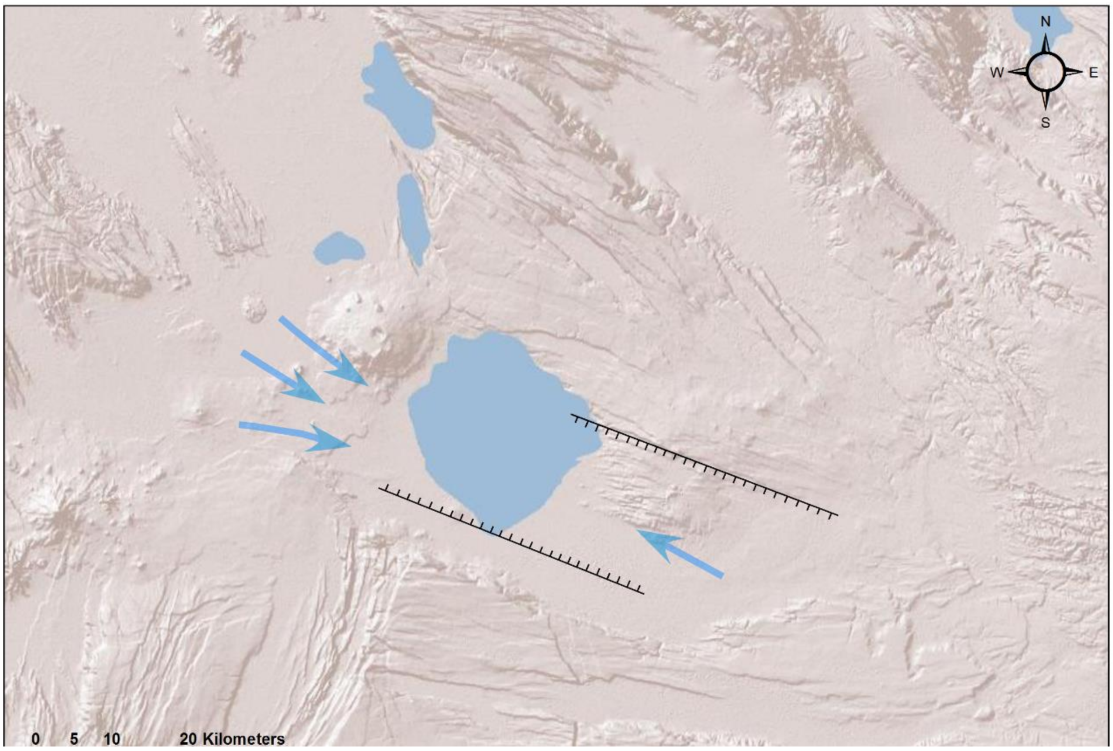

Figure 2411. *Estimated recharge of the geothermal system. The system is mainly thought to be recharged from WSW.*

In term of geological structures, the very conductive structure (alpha-structure) observed in the shallow part can be associated at a sedimentary unit observed in the major part of the site (around de lake). This sedimentary unit has a thickness about 200 m or 300 m in the westhern part. The less conductive structure (betha-structure) can correspond at the very permeable stratoid basalts outcropping in the Easthern part of the site. This betha-structure also is imaged by the residual Bouguer gravity and corresponds at the negative gravity surrounding the strong positive anomaly in the central part of the area. The resistive formation (omega-structure) can be associated at the less permeable stratoid basalts or a rhyolitic formation. In the bottom, the very conductive anomalie (sigma-structure) can be associated at pleistocene sedimentary formations. This sedimentary unit corresponds probably at oldest rocks in Djibouti republic formations which are observed in the southern part of Djibouti (Ali-Sabieh region).

To verify the existence of these deep sedimentary units, we used data from another MT study. These soundings form with 3 soundings on the Lake-abbhe site a profile oreinted SW-NE as shown in the following map:

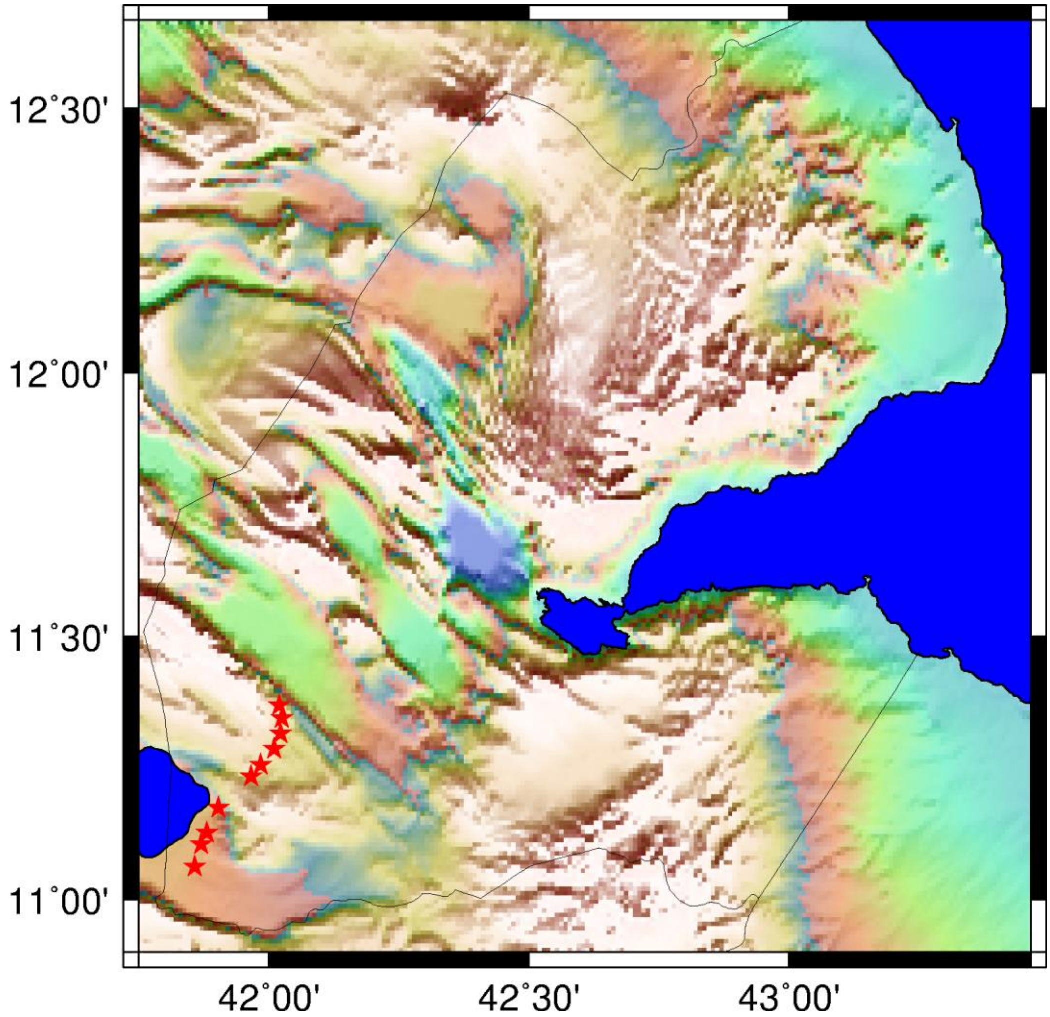

Figure 2512. *Localisation map of the MT profile accross Daka mount and Hanle plain.*

This profile has a length of 40 km and is formed at total eleven MT soundings. It passes through Daka mount and the Hanle plain.

On this profile, as we can see, the sigma-structure is not shows in the deeper part particulary in the Northeast part. If this very conductive unit was sedimentary formations under the volcanic structures Logically if this structure was under volcanic rocks sedimentary units, we should have a continuity of these formations across the study site. According of the resistivity model obtained by this profile, we can conclude that these anomalies can be associated at the hydrothermal fluids coming to the Ethiopian side (under the Lake). The existence of the volcano Damaale and presence of the surfaces activities at the other side of the lake are consistent with our hypothesis. These hydrothermal fluids rise to the surface through normal faults and are successively cooled by the regional aquifer (between 400 and 600 m deep) and the local aquifer (the first hundred meters). For this reason, at the surface, we have the thermal anomaly about 100 °C on the hot springs.