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Exploring for Geothermal Sites in Northern and Central Afar (Ethiopia)

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ABSTRACT

While geothermal exploration and development has occurred until now in Ethiopia along the Rift Valley and in Tendaho (central Afar), the northern part of the Afar Triangle was relatively neglected. The aim of this paper is to show that sites of interest for electric power production certainly exist in this area and would be worth analysing for prefeasibility and feasibility studies leading to industrial development.

Conditions for the development of high enthalpy geothermal fields were shown to be met in North-Eastern Afar when the superposition of 3 geological features was encountered (J.Varet, 2011). These include:

- The presence of active spreading segments, with important and recent volcanic activity developed in the "rift-in-rift" structures of the Erta-Ale, Alayta and Manda Harraro axial ranges, allowing for the development of significant and rather shallow heat sources;
- The development of transverse faulting crossing through the dominantly NNW-SSE normal and open faults, which frequently correspond to offsets in the scarp of the Nubian plateau as well as between axial ranges, which allow for the development of fracture permeability in geothermal reservoirs; and
- The feeding of the geothermal reservoirs from eventually wide basins developed along the intensively eroded escarpment of the Nubian Plateau, with frequent lateral grabens allowing for the infiltration of meteoritic water from the wet highlands into Mesozoic sedimentary (Jurassic limestone and cretaceous sandstone) as well as Tertiary and Quaternary detrital formations.

Due to the evaporation of a former southern branch of the Red Sea (200 to 25 ka ago), the northern part of the depression is floored with thick (at least 1000m) salt deposits - this allowing for the development of Sylvite deposits in addition to Halite. Numerous hot-springs, explosion craters and fumaroles are reported at Dallol (Chernet 2012, Frazson and Helgadóttir, 2012). Therefore, the ongoing geothermal exploration focuses on the detection of geothermal reservoir fed by less saline waters in the Mesozoic and Tertiary formations at accessible depth underneath the salt formation.

Further south, another geothermal site may have developed around Lake Afrera, where the Erta-Ale Range ends while the spreading is transferred to the two axial ranges of Alayta to the SW and Tat-Ali to the SE. Important hot-springs are interpreted as the products of the heating of superficial groundwater crossing through the Alayta Range by deeper geothermal fluids, the location of which remains to be identified by further exploration.

South of Alayta, another offset is also in correspondence with the geometry of the basement scarp, where the Mand-Harraro Range develops along 120km. In the area of transition between these two axial ranges, the Boina – Dabbahu recent silicic center developed with a fractionation sequence up to pantellerites showing the presence a shallow and active magma chamber. (Barberi and Varet, 1975). This is also the site of intense hydrothermal manifestations, with numerous hot-springs, fumaroles and silica deposits, notably along the sedimentary plains bordering the volcanic zones to the West.

Mand-Harraro, the most active axial range in Afar, displaying recent basaltic emissions, and surrounded by numerous fumaroles, hot grounds and hot-springs, was subject of an intense volcano-tectonic event with the opening in 2005 along its NNW axis of a fault 120km long and up to a few meters wide, followed by several basaltic magma injections from the mantle, 10km deep, until 2011. To the south of the range, rather intense faulting, transverse to the regional NNW direction expressing a high permeability favourable to the development of a geothermal reservoir fed by the important Awash and Mille river basins. The apex of this system is located immediately south of the lava fields, whereas the Tendaho Geothermal Prospect was developed in the graben filled by recent unconsolidated sediments of the Awash River.

1. INTRODUCTION: WHY FOCUS ON AFAR?

Our generation will have to pass from a mode of development based essentially on fossil fuels to a "Green New Deal" based on renewable energy. This is imposed on us from "both ends", by diminishing fossil fuel resources, and by the climate changes induced by CO_2 emissions that result from their combustion. Geothermal energy will play a role in this new context. Just as the world economy has moved from Europe and North America to Asia due to cheaper labour costs, a similar movement will be observed in the future to meet energy needs. The reason for this is that, previously, the abundance of fossil fuels (notably oil) enabled the cheap transport of energy throughout the world, benefiting regions far away from energy resources, whereas we will soon be constrained by local energy resources with much higher transportation costs.

In such a situation, countries and regions that have accessible, low-emission, renewable energy resources will be of interest for centralized energy-consumption activities. The time has come for regions provided with geothermal resources to develop. As geologists, we know that most of the planet's geothermal energy is dissipated along plate boundaries, with the highest heat flow located along accretion zones, that is, along mid oceanic ridges, and even more in regions affected by mantle plumes. Whereas the ARGEO programme aims at developing the entire East African Rift System, we must recognize that geodynamics offer various solutions, ranging from typical continental rift systems to typical emerged oceanic rift zones. Thirty years ago, it was shown (Tazieff et al., 1970; Barberi and Varet, 1977) that Afar is not the northern extension of the Ethiopian Rift Valley (Wonji Fault Belt, as proposed by Mohr, 1970), but rather the surface expression of the Red Sea – Gulf of Aden oceanic rift system crossing through the African continent.

The Afar Triangle covering Djibouti, Ethiopia and Eritrea should, therefore, be regarded as being of specific interest for geothermal developers and likewise be of particular interest in the ARGEO programme. Afar and Iceland are the only places on our planet where such an exceptional geothermal energy potential, combining emerged rift zones and mantle plumes, occur. Many Afar sites have been shown to be of potential geothermal interest on the basis of geological and geodynamical criteria in this so called "future Gulf region for geothermal energy" (Varet, 2006). The presence of a volcanic "axial range" (oceanic-type rift segment) combined with transverse fractures (the surface expression of transform faults) should provide both a heat source and a fractured reservoir – the two most favourable conditions for high enthalpy geothermal development (Figure 1).

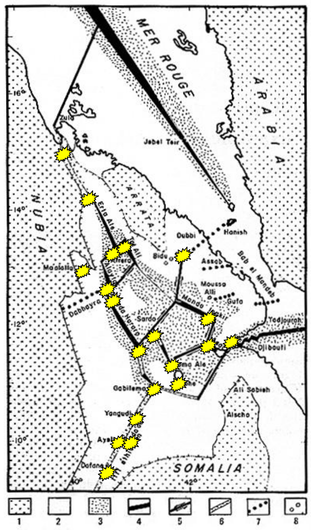

Fig.1 : Geothermal sites in Afar, revisited selection by Varet (2006, 2010) on the basis of new geodynamic considerations, based on Barberi and Varet (1977) map of micro-plate boundaries. 1. Crystalline basement and Mesozoic cover; 2. Transition zone (thinned crust); 3. Oceanic crust (stratoid series in Afar, less than 3My old); 4. Accreting plate boundaries (mid oceanic ridges & axial volcanic ranges in Afar); 5. Inferred transform faults; 6. Active Ethiopian Rift axis; 7. Transverse volcanic ranges; 8. Central volcanoe; and yellow sections are favourable geothermal sites

Ethiopia also benefits from important hydro resources and based on its energy development until now mainly upon hydropower plants. Although this energy is renewable and environmental friendly, power plant operation is affected by seasonal rainfall fluctuations, expected to increase in the future due to climate change. Furthermore, the hydropower potential is located in the western part of the country, whereas in the eastern part, the huge potential for geothermal energy has not yet been tapped. North-eastern Ethiopia is also where the population suffers from very low access to energy. Geothermal power should satisfy these local needs as a first step, and later serve the grid or local energy intensive industries - like in Iceland with aluminium plants - as it enables modular development with the great advantage of progressive investment. Moreover, this technology creates local jobs.

Studies carried out in the 1970s (Tazieff et al. 1970; UNDP, 1973) made it possible to identify several promising geothermal sites in the Ethiopian Rift Valley and Afar. The regional states of Afar and Tigré expressed their interest inr such developments, as well as industries (notably potash mines in the north). Geothermal projects would provide electricity and benefit rural communities, particularly those near the sites, and improve the socio-economic development of the entire region. The local population would benefit from enhanced water supply, transportation, health and other services fostered by the energy produced. In addition, the creation of new energy production sites and the modular development enabled by geothermal power, would attract investments in various energy-consuming sectors such as mineral extraction and processing. The energy produced from this renewable source will, in the future, be connected to the main grid, thereby benefiting the entire regional energy sector. Like Iceland, Ethiopia could become a "green state" totally relying on both hydro and geothermal power.

2. FACING A MAJOR CHALLENGE: GEOTHERMAL FLUID COMPOSITION

At the previous ARGEO conferences in Addis Ababa and Djibouti, a guide to geothermal exploration was proposed for Afar (Varet, 2006, 2010) considering that favourable sites for high enthalpy geothermal development require the simultaneous occurrence of the following parameters:

- a high heat flow, linked with either a very shallow anomalous mantle or a superficial magma chamber, notably found along axial volcanic ranges (spreading axis)
- A highly fractured area, allowing good reservoir permeability, found in fracture zones and generally in places where transverse fracture cut through the dominant "Red Sea" trend;
- The recharging of the reservoir by meteoritic water or sea water, or a combination of both; and
- The presence of a mineralised hydrothermal system.

Like in Iceland, transform faults are not clearly manifested on the surface in Afar, even if we can trace in both cases, the plate boundaries on land (Barberi and Varet, 1977). However, compared to Iceland, Afar suffers from a major handicap – the composition of the geothermal fluids. Whereas in the North Atlantic climate, due to high rain and snowfall in Iceland, geothermal reservoirs are predominantly fed by meteoric water, Afar has a dry tropical climate. Since there is much less rainfall in Afar (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. Following the initial idea of Varet (2010), we focused our attention on the hydrological basins feeding the potential geothermal sites and on related hydrogeological parameters.

3. THE ERODED, FAULTED SCARP OF THE ETHIOPIAN PLATEAU: GROUNDWATER SOURCE FOR GEOTHERMAL SITES

The Ethiopian escarpment bounding the northern Afar region displays significant hydrological systems running from the upper part of the plateau down to the Afar floor. This drainage feeds the sedimentary and volcanic aquifers along the slope and under the plains. During the rainy season, the plains frequently turn into temporary lakes. This is the case of the Great Dagad Salt Plain, where the surface salty crust recrystallizes yearly after seasonal rains. At other times, the surface flow disappears in the flat-lying plains notably developed along the western flank of the active volcanic ranges of Erta Ale, Alayta and Manda Harraro, the largest being Dodom and Teru (Figure 2).

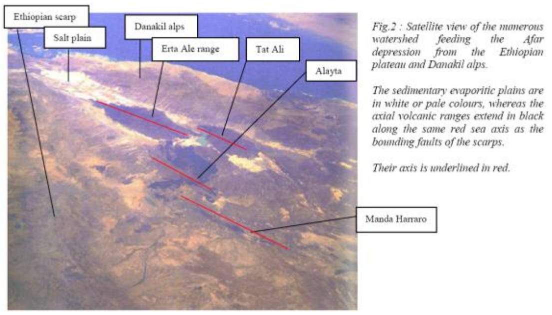

Figure 2: Satelite view of the manerous watershed feeding the Afar depression from the Ethiopian plateau and Danakil alps

Therefore, although the rainfall is very low in the depression itself (average circa 100 mm/year, 50 mm in Dallol), the western border of the Afar benefits from the much better hydrologic conditions of the Ethiopian Plateau (up to 1,300mm at an altitude of 3,000m, figure 3). As a result, a significant hydrological system developed in a complex array determined by both erosion (E-W direction, perpendicular to the scarp) and tectonics, which determines predominant NNW-SSE normally-faulted blocks with frequent marginal grabens favoring infiltration (Figure 4). The L-shaped (or rectangular drainage) river patterns, the complex lithology of the faulted material and the intense and active extensional tectonics allow for a more efficient development of groundwater systems in fractures and possibly karst aquifers.

Consequently, it is possible to select sites that meet the above mentioned criteria in terms of heat sources, transverse faulting, hydrothermal development, and that are also located in areas well fed by suitable hydrological basins crossing through the Ethiopian faulted scarp limiting the Afar depression to the West. In this paper we provide the description of three such sites located in NE Afar, in Ethiopia, i.e. Dallol, Boina and Manda Harraro South, near to Tendaho graben.

4. DALLOL GEOTHERMAL SITE

The Dallol site is located in the middle of the vast Dagad Salt Plain. It is a former potash mining site (Holwerda and Hutchinson, 1966; ELMICO, 1984) and also a tourist destination due to the multi-coloured salt concretions that have developed as a result of spectacular hydrothermal activity. Hot water and fumaroles (the temperature of which may reach 120 °C) deposit sodium, potassium and magnesium chloride as well as elemental sulfurs, creating a wide range of colors at the emission sites, from black and green under reduced conditions, to yellow, red and brown after oxidation (Figure 5). Springs and fumaroles are clearly aligned along NNW trending fissures, certainly linked to the opening of fissures on the rift axis. Vent locations change with time, as salt deposits plug old vents and new vents appear nearby along new fissures. This confirms that Dallol is also located on the active Afar rift axis. In the Black Mountain site, a $MgCl_2$ saturated brine (128°C) bubbles at the surface (Tazieff et al, 1969, Barberi et al., 1973).

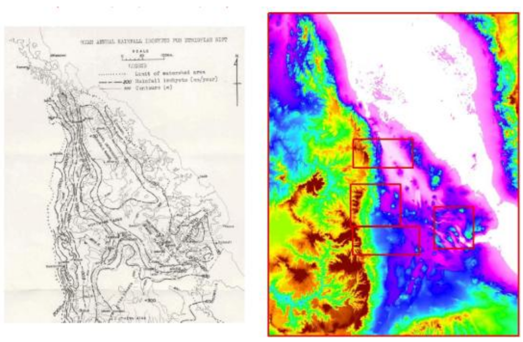

Figure 3: Relief map (A) topo from UNDP, 1973 and Kebede, 2008 and (B) from NASA/SRTM, with BRGM processing; map of isohyets correlate with altitude; the basins feeding the reservoirs of the selected geothermal sites from the Ethiopian plateau are wider from north to south.

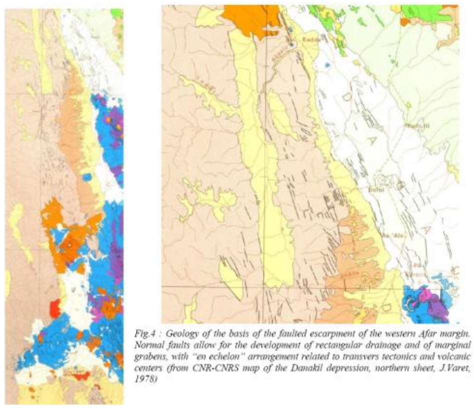

Figure 4: Geology of the basis of the faulted escarpment of the western Afar margin

Figure 5: Black smoking fumaroles in Dallol, with successive stages of oxidation of the sulphurs offering a large variety of colours from green to yellow and red (Photo J.Varet, 2010).

The Dallol "dome" extends E-W, perpendicular to the rift axis. Rather than a real salt dome, it is a vertical uplift probably initiated by a deep magmatic intrusion. The regularly horizontal strata exposed in Dallol's eroded hills confirm this hypothesis. A similar feature is observed in the northern tip of the Erta Ale range, on the western side of the Kibrit Ale volcano (Barberi and Varet, 1970).

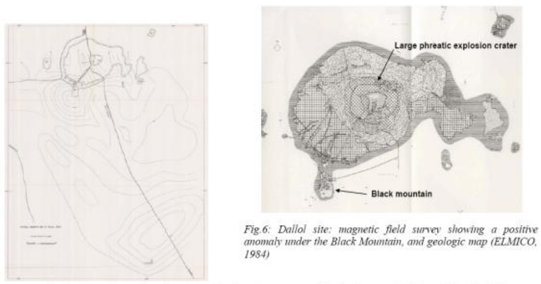

Figure 6: Dallol site: magnetic field survey showing a positive anomaly under the Black Mountain; and geologic map (ELMICO, 1984).

Geophysical data (magnetic and gravimetric) might indicate that a magmatic body (most probably basaltic), a few kilometres deep, underlies the sediments, although no volcanic products are found in Dallol. The gravity data is, however, poorly reported and inconclusive. The magnetic data show sharp positive anomaly close to Black Mountain and another somewhat broader at Mount Dallol (Figure 6). With its location in the middle of the rift, right on the NNW alignment with the Erta Ale Range, the presence of an active magmatic heat source is quite plausible. Geophysical data also show E-W anomalies that can be interpreted as being the result of transverse faults. Hence, although the existence of a well-developed and active geothermal system is obvious, we cannot be certain that suitable conditions for true geothermal development are to be found, due to the extremely salty environment, notably the saturation in salt of the geothermal fluids. The UNDP report (1973) concluded that Dallol was unsuitable for geothermal development on the basis of the geochemical content of the hot springs.

After new observations were made of the Dallol site, Barberi and Varet (in Varet, 2010) concluded that this site should be reconsidered as suitable for geothermal development for the following reasons:

a) Phreatic explosions are well-documented in the history of Dallol and its surroundings. On the top of the dome, a large crater – in which most of the active vents are located – results from a very large phreatic explosion probably a few hundred years old (Figure 7). Another phreatic explosion crater (100m large), in the Black Mountain site located SE of the Dallol dome, was observed in 1926 (Figure 8). Between the Erta Ale Range and Dallol, As Ale is also the expression of a former phreatic explosion, 55m large. New craters and pools – apparently linked to the 2005 seismic event, according to local tribesmen – are observed a few kilometres south from Dallol dome (Fig.9), showing that phreatic explosions are still occurring (Varet, 2010). This indicates the presence of a high-pressure, high-temperature (above 180 °C) geothermal reservoir currently active underneath this part of the salt plain.

Figures 7, 8 and 9: Phreatic explosion craters in Dallol

b) Considering the hydrological and hydrogeological context in the basement slope of the Ethiopian escarpment, the Adigrat sandstones and the Jurassic limestones – the latter heavily karstified – both constitute efficient aquifers that would enable the infiltration of meteoritic water, itself facilitated by the intense normal faulting (and transverse fractures) affecting the area (Figure 10).

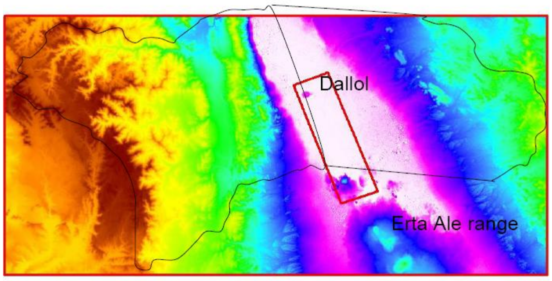

Figure 10: Hydrographic basins feeding the Dallol geothermal site, from Ethiopian plateau to Danakil alps. Observe the presence of the lateral graben developed at the bottom of the scarp.

Under such conditions, a reasonably favourable geothermal model can be developed for the Dallol site where, underlying the salt plain and hyper-saline geothermal system, there might be a deeper aquifer in the Jurassic limestone characterized by both low salinity and regular recharge by meteoritic waters descending from the plateau. The presence of a high-pressure, high-temperature reservoir is evidenced by the numerous past and present phreatic explosions, as well as by the steam vents aligned on NNW trending open fissures frequently reopened though the salt cover (Figure 11).

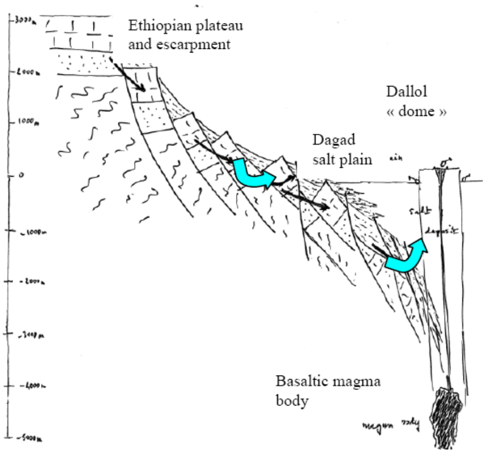

Figure 11: Geological simplified model for Dallol geothermal system. The target would be to tap a deep aquifer in the Jurassic limestone and fed by the meteoritic water flowing down from the Ethiopian plateau

Recent geological, geochemical and geophysical (MT) studies at Dallol (Franzson et.al, 2012 and Vilhjalmsson et.al. 2012) confirm the previous findings that Dallol hosts a high enthalpy (probably vapour dominated) geothermal system. The MT survey reveals distinctive resistivity anomalies thought to reflect extensive sulphite mineral deposition around the geothermal system. Exploration drilling in the vicinity of Mount Dallol has, however, shown that drilling through the salt sediments affected by the geothermal system may be very difficult. Drilling for a suitable reservoir below the salt sediments might therefore be a challenge.

In addition to meeting local needs in the surrounding Afar villages, this electrical energy production would also facilitate the re-opening of the Dallol potash mine. Instead of the costly ground mining techniques considered in previous feasibility studies (ELMICO report, PEC engineering, 1984), a less expensive solution of mining the potash deposits could be done using the geothermal fluids (either directly or through heat exchangers).

5. BOINA GEOTHERMAL SITE

Together with Erta Ale Range, the two axial ranges of Alayta and Manda-Harraro represent the extension of the Red Sea Rift System into NE Afar. These two last active basaltic ranges are offset and the central Dabbahu volcano developed on this transition zone, on a transverse fracture well expressed on the basement border, by the Dabayra transverse volcanic center (Figure 12). Dabbahu is characterized by a complete magmatic series ranging from transitional basalts to hyper-alkaline rhyolites (comendites and pantellerites, Barberi et al., 1975). The presence of a shallow magma chamber is evidenced by the series' crystal fractionation conditions. There are numerous fumaroles, locally called Boina (meaning fumaroles or steam vents in the Afar language), many of them exploited by the Afar tribesmen as a source of water with small artisanal steam-condensing units (Figure 13). Such sites are so well-developed along the western margin of the Dabbahu Volcano that it may itself be called Boina. Silica deposits are frequently observed on these hydrothermal sites, indicating high-temperature at depth.

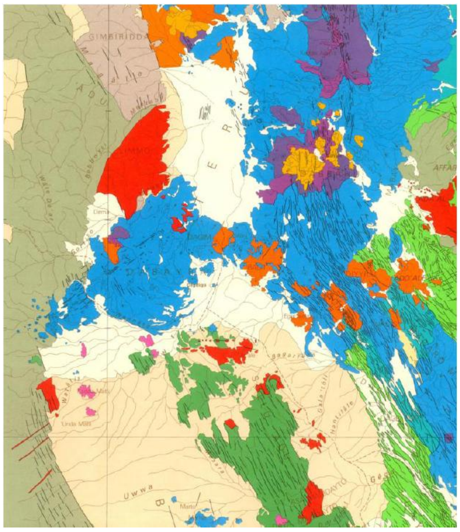

Fig. 12: Geological map of the foot of the Ethiopian escarpment and axial volcanic ranges of central Afar (CNRS-CNR, J.Varet, 1978). Dabbahu (also called Boina), located in area of junction (transverse structure) between Alayta and Manda Harraro axial ranges display a complete magmatic series from basalts to pantellerites. Numerous steam vents (locally called Boina) are observed along faults and open fissures affecting the lower part of the Dabbahu volcaniccentre along the Teru plain.

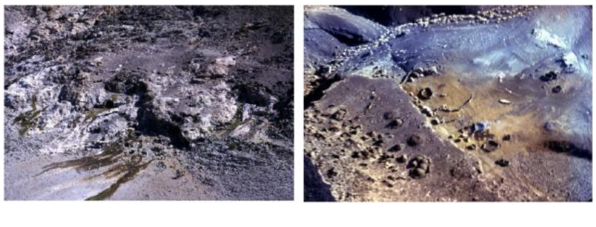

Fig. 13: Steam vents, fumaroles and hotsprings at Boina. Hydrothermal vents develop along faults and fissures affecting the basalts and the

sediments of the Teru plain. The sites are frequently exploited by Afar people for steam condensation. Silica white deposits are observed.

The magmatic, geodynamic and hydrothermal characteristics of the site appear to be favourable. The hydrological context also confirms the interest in the area for further geothermal developments. The Teru Plain - one of the most extensive and fertile plains in NW Afar - extends along the foot of the volcano and is fed by a large watershed descending from the Ethiopian Plateau with several rivers crossing through normal faults and marginal grabens (Figure 14). No Precambrian basement or Mesozoic sedimentary cover outcrop in this area, but the thick trap basalt series of the Ethiopian Plateau is heavily faulted and tilted. The rainfall is higher than in northern Afar, the surface of the basin is wider, and more water is available to recharge aquifers. This contrasts with the axial range called Tat'Ali (parallel to Alayta at the same latitude) in central Afar where saline deposits dominate.

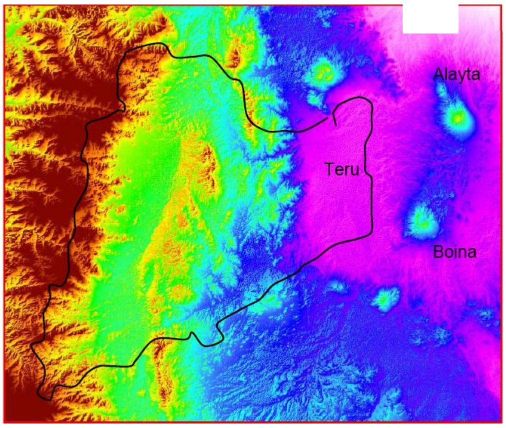

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Fig. 14: Hydrographic basins feeding the Boina geothermal site, from the Ethiopian plateau. Observe the marginal grabensalong the foot of the escarpment.(NASA/SRTM source, BRGM Processing).

Due to these favourable hydrological conditions, this area also has a higher population density. The selection of this geothermal site would be of interest for local and regional social and economic development. Furthermore, since the resource is probably of high value in terms of quantity as well as quality, geothermal units of broader interest could be further developed on the Boina site. Additional prefeasibility work should include fluid hydrochemistry and geophysics, making it possible to site exploration boreholes. A small wellhead turbine and a local electricity grid should be installed during the feasibility phase in order to convince the local population of the benefits of developing this geothermal energy resource.

6. SOUTH MANDA HARRARO GEOTHERMAL SITE

The Manda Harraro axial range was identified long ago as the most active spreading segment in Afar, according to volcanological, petrological and geochemical considerations (Barberi & Varet, 1977). This was confirmed in 2005 and in the following years by a remarkable seismo-volcanic event which lasted for 6 years (and may not have ended yet), during which a fissure did open on a total length of 85km and up to 8m wide, allowing for the injection of important volumes of basaltic magma at depth of 2 to 9km and up to the surface in 4 cases out of the 11 pulses (Wright et al., 2006, Rowland et al. 2007, Keir el al., 2009, Grandin et al, 2009, Figure 15). As a whole, a large volume of basaltic magma was injected along this 6 years period. Such phenomena are of centennial occurrence. As a result, considering that this diking process is in fact a continuous process at geological scale, a huge quantity of energy is made available at shallow depth along this range.

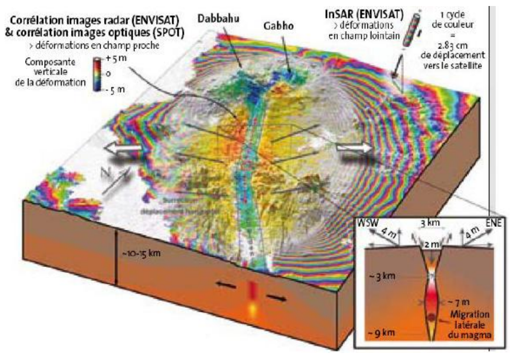

Fig. 15: Correlation of satellite radar imagery (ENVISAT) with optical (SPOT) image of Manda Harraro range movement showing vertical as well as horizontal deformation resulting from the 2005 opening event (from Grandin et al. 2009). 1 colour cycle = 2,83 cm horizontal motion in satellite direction. The resulting model implies a 7m lateral migration (magma injection) and a collapse of 2 metres along the axis rift.

In addition, considering that the area located in the southern part of the Manda Harraro Range is the place in Afar where the most important water inflow is available from both the basins of Mille River to the East and Awash River the South (Figure 16), the next question is to locate the most suitable place in terms of permeability.

The observation of the geological map led to identifying the area located immediately to the south of Manda Harraro (that is, along the prosecution of its axis), affected by intense multiple fractures in at least 3 major directions (Figure 17).

Fig. 16: The Awash rRver basin in Ethiopia (from Kebede et al. 2008) and the lowest part of the basin in the central Afar (Ethiopia and Djibouti, from CNR-CNRS geological map of central Afar).

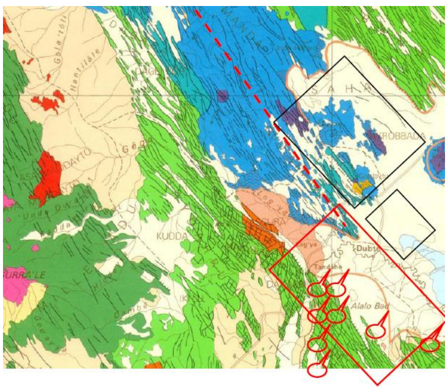

Fig. 17 : Geological map of the southern part of Manda Hararo range and surrounding regions, including the Alalo Bad geothermal site located on the southern extension of the axila range axis (in red). Bas map from J.Varet (1978).Hydrothermal emergence sites are reported in red.Black rectangles indicate the exploration area defined for the Tendahograben geothermal site under development (GSE, 2012.The new target proposed, where the axis of the MandaHararo range cross with tranverse fractures with development of thermal emergences in drawn in red quadrangle

This area also coincides with the most spectacular hydrothermal occurrences observed in Afar: hot-springs, geysers, fumaroles and steaming grounds, together with well-developed hydrothermal deposits (Figure 18), and should be considered as a key target for locating a geothermal site.

Figure 18: Satellite image of the area located immediately south from Manda Harraro range. Multiple faulting is bserved in this area where the Awash River receives the Mille River tributory.

Figure 18: Alelo Bad hot springs pools and hydrothermal deposits south Manda Harraro

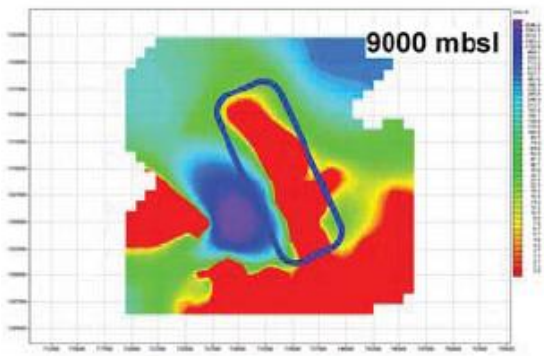

Fig. 19: Resistivity map of the S. Manda Harraro area obtained from MT survey, with values ranging from 2 (red) to 2048 Ohm*m (blue). (Source: U. Kalberkamp, 2010)

As a matter of fact, a very low resistivity zone (below 2 Ohm*m, see Figure 19), clearly elongated in a NNW-

SSE trending direction is observed at a depth of 7km, along the southern extension of the Manda Harraro axis. This traces a possible magmatic heat source by U.Kalberkamp (2010)

7. CONCLUSION

While there are major geothermal sites all along the East African Rift Valley, several of which having already seen economic industrial developments, notably in Kenya, the Afar region has not yet demonstrated its capability. Whereas a project is under development in the Tendaho Graben, central Afar, the purpose of this paper is to show that NE Afar could possess the largest geothermal potential of the African continent. Due to its exceptional character as an emerged oceanic rift segment of the southern part of the Red Sea, and a zone of accretion of the earth's crust, in addition to being affected by an active mantle plume, Afar certainly shares with Iceland the quality of having the world's highest geothermal potential.

As opposed to Iceland, however, climate conditions in Afar are not favourable for recharging the geothermal reservoir by meteoritic water. Geothermal brines with corrosive and scaling effects prevail in areas where hyper-saline lakes and salt deposits have developed, which is typically the case at the bottom of endoreic basins with high evaporation under arid climate where the axial ranges are located. Nevertheless, deep aquifers can be recharged by meteoritic waters due to the vicinity of the high and humid Ethiopian Plateau. Large water basins enable recharge of the fractured and permeable formations located on the western side of the axial ranges where transverse fracture zones offer optimal conditions for geothermal reservoir development.

There is little doubt that Afar may, in the future, become a region of major renewable energy production. The transition period will, however, be difficult due to the shortage of fossil fuels and the implementation of climate policies. The arid climate has not fostered social and economic development for the Afar population. As a first step, it is essential that the geothermal development, first of all, benefits local inhabitants. A well-adapted – probably specific mode of development that involves the local population as much as possible should be considered. Afar workers presently building the artisanal steam condensers should, for instance, be offered employment in the drilling work. This sustainable development issue is a challenge for all, including local authorities, engineering and industrial firms, researchers as well as financing agencies. The capability of these agencies to support geothermal projects adapted to these specific conditions is a real challenge that the ARGEO program should allow to master, as soon as possible.

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