

Ta'Ali geothermal site, Afdera Woreda, Northern Afar, Ethiopia

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ABSTRACT

AGAP (Afar Geothermal Development Company) is a community-based organization founded in 2015 that aims at developing geothermal sites in the Afar Regional State. After a comprehensive regional survey, in this region characterized by active volcanism and tectonics, the first-priority targets were identified in Northern Afar. The choice of this target results mainly from social considerations. Differing from Southern Afar where the Awash basin provides significant water inflow, Northern Afar is particularly dry, and droughts are significantly increased by the ongoing climate change. Geothermal is eventually the most viable solution for the pastoralist communities to continue living on their land and even ultimately provide resilience.

From the geological reconnaissance work undertaken by Géo2D for AGAP in Northern Afar, two priority targets were identified, out of which Tat'Ali located a few kilometres to the SE of the town of Afdera is one of them.

Afdera is a fast-developing centre, characterized by salt mining activity; with the salt collected from evaporation ponds surrounding the salty Afdera Lake. It is also a communication knot, where the asphalted roads linking Semara, Sardo and Addis Ababa or Djibouti's ports to Dallol Potash mines and Makalé meet. An electric line is planned to be built with the support of the African Development Bank, along the road passing a few kilometers of the geothermal site. Due to the lack of power sources in this part of the country, geothermal energy would be a good option to support the electricity production on this section of the grid and meet other local needs.

Tat'Ali site presents all the characteristics of a high-temperature geothermal system with a well identified heat source attested by a complete sequence of differentiation of the magmas from transitional basalts to peralkaline rhyolites being developed in a wide caldera elongated along the rift axis. The active nature of the heat source is proved by the recent (sub-historic) emission of basaltic flows to the north, dark trachytes to the south and pantellerites in the centre, and by recurrent seismic activity. Thermal leakages are characterized by numerous steam vents along the open fissures and faults on the South-western flank of the shield volcano and fumaroles along the caldera rims. A particularly promising area, now easily accessible by a new road under construction linking Afdera to Bidu Woreda, was identified on the SW flank where transverse faults (NNE-SSW to N-S) cross the regional NNW-SSE (Red Sea) dominant trend.

The surface exploration planned by AGAP will continue with DEM and IR drone-borne surveys, field controls, gas geochemistry and geophysical surveys (MT-TEM and gravimetry), with the objective to locate exploration wells for tapping a shallow steam reservoir for well-head production answering local needs (5MWe), followed by lateral and at depth extension of the geothermal reservoir for further development, with a target of 50 MWe to feed the regional grid crossing the SW edge of AGAP's lease. More significant developments will be possible in the future in the central part of the Tat'Ali range (caldera area), as per need.

AGAP is presently looking for financial partners to move the project to the feasibility stage and contribute to its further developments.

1. Background analysis (region, population and target group)

Northern Afar, one of the hottest region in Ethiopia and the world, with a dry climate (less than 100 mm of rainfall annually) is populated by a pastoralist, semi-nomadic population that is to be considered according to UN criteria as autochthonous people. The area is affected by climate change with – during the past few years - more frequent heavy draughts and consequent problems, particularly in the northern part of Afar located away from the permanent watershed (Awash River basin).

The region is also characterized by a scarce and particular fauna, flora (typical for deserts) and geology with active faulting and volcanism. The water table is generally very low, most frequently saline, and no permanent water manifestation is observed at the surface except for the Awash valley (Southern Afar). Due to the high geothermal heat flow, thermal manifestations under the form of fumaroles, steam vents and hot grounds are observed in many sites, along open fissures that affects the necked dominantly basaltic surface.

These surface thermal manifestations are well known by the Afar pastors, as they are sites where, whatever the climate, and even in the driest situations, some grass for the herds and eventually some water may be found. The importance of these sites in the Afar culture is reflected by the fact that specific names are given, as “Boina” for the steam vents or “Fiale” for the “geothermal grass” that has the capacity to benefit from the steam moisture for its growth.

2. Geothermal potential of Afar and related socio-economic challenge

Since the years 60' and 70' (Tazieff et al., 1969; Barberi et al., 1977, 1972), Afar was recognized as an active geodynamic area where the Red Sea and the Gulf of Aden oceanic ridges extend on land (Fig.1 & 2) and ensure the continuity of the plate boundary between Arabia and Africa (Barberi and Varet, 1977). These considerations allowed to push for the development of geothermal energy as early as 1972 (UNDP)¹. However, despite several attempts in the years 70' and 80' (Italian and German cooperation at Tendaho, BRGM and Italian cooperation at Asal and Hanle in Djibouti...) no real development occurred yet. The site of Tendaho is however at present under feasibility study with the support of several financial agencies including the French AFD. The projects directed by federal government and foreign

¹ Thanks to the interest paid to the subject by HH Lul Mengesah Seyoum, then governor of the Tigré Province who rose the interest of the Emperor Haile Selassie who introduced the request for assistance from the UNDP.

enterprises are meant to serve the electric grid with large size power plants. Aside of these large projects, small-size units should also be considered with the idea to ensure the geothermal development will benefit to the local Afar communities.

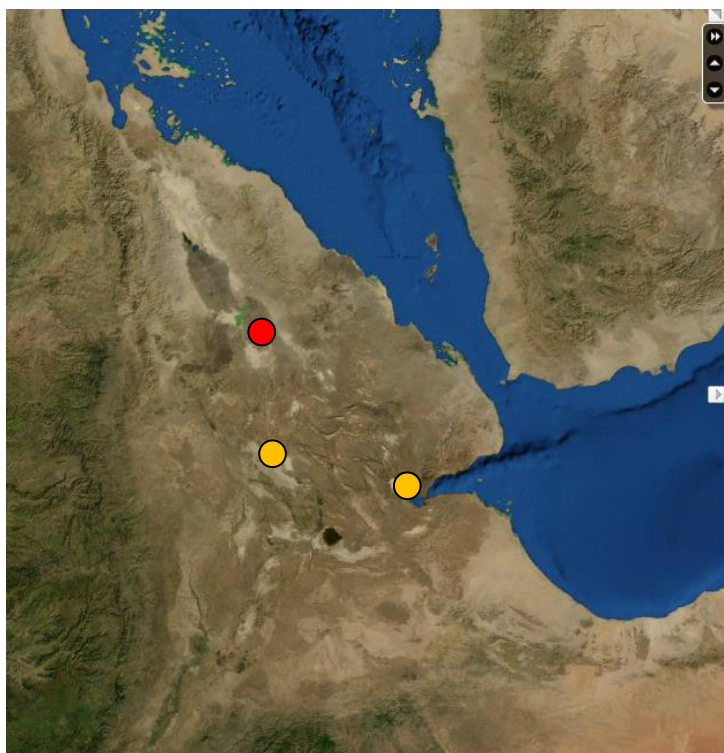


Fig.1: The « Afar triangle » (in pale colour), a large desert depression covered by recent volcanic essentially bared formations affected by active faulting, also display numerous steam vents. Red dot indicate the location of the geothermal project proposed by AGAP in Tat'Ali-Afdera area, whereas the orange dots show the location of the Tendaho projects being developed by the Ethiopian Government and of the Asal geothermal sites in the Djibouti Republic.

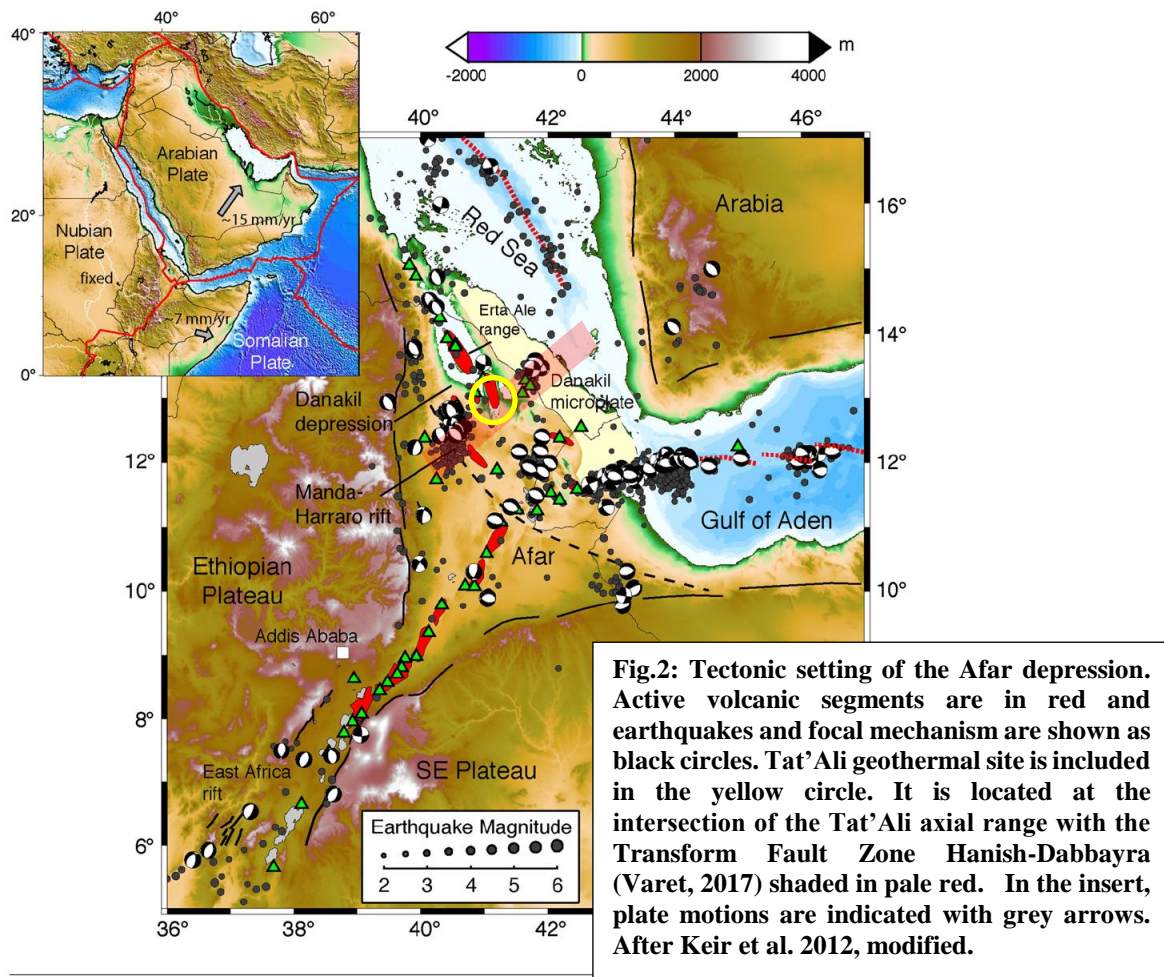
The Afar population, encountering every year more severe condition due to climate change, realized that its future survival, life and eventual development will necessitate changes with respect to the past pastoralist economy based on rain fall and subsequent temporary grazing. Therefore, the communities of northern Afar joined efforts to assemble the capital necessary to create AGAP, a company in charge of development of local natural resources, in particular geothermal energy (Nebro et al. 2016). With the help of Géo2D, several sites were identified as suitable for local geothermal developments. The approach was to identify sites where the Afar population is sufficiently concentrated and develops activities that justify the need for a small-size production system. The model of reference for these projects is the “Geothermal Village” concept exposed at Argeo Conference, Arusha (Varet et al. 2014). It aims at combining the electric power production with direct uses and the production of water either from steam condensation or pumping of groundwater or even desalinization.

3. Characteristics of the project

3.1. Constrains, needs and challenges

The project aims at promoting a better use of the naturally steaming grounds by the Afar population. The first possibility to improve the steaming of the fissures and faults by some simple diggings and to install devices for channeling and condensating the steam. This is done here and there in a very artisanal way by the Afar nomads who will dig through the clay infilling of the steam vent (the hot steam progressively alter the volcanic rock into clay) in order to increase the steam discharge, and install branches fixed with stones in order to condensate the steam into water that will fall and be collected along channels drawn in a clay surface. A more

efficient approach is to build domes in stones that allow for a more efficient condensation as developed by APDA (Afar NGO partner of AGAPI).



3.2. Objectives and of the project

The general objective of AGAP through this project is to offer sustainable energy and water production in this area deprived of other local energy or surface/groundwater resources. Through these production systems, independent from climate fluctuations, the objective is to provide resilient habitats for the Afar communities. The projects also aims at developing the appropriation of the geothermal resources by the Afar communities, as a transition from the traditional simple man-made steam condensation devices towards really engineered geothermal plants delivering both energy (electricity and heat applications) and water (thermal hot water as well as drinkable cold water).

3.3. Beneficiaries of the project

The final beneficiaries of the projects are of 6 categories:

1. Families which will be offered to live on the site, benefiting from a climate resilient habitat allowing to maintain themselves and their herds whatever the draught; they will also be trained to welcome either nomads passing through the area or tourists on their way to Afdera lake, Erta Ale volcano and Dallol.

2. Nomads that pass through the area on their way to Bidu will find there a place where they will benefit from a permanent source of water for themselves and their cattle and a community to welcome them.
3. The nearby fast-growing village of Afdera that will benefit from the electric power for replacing the presently fuel-driven devices (electricity generator, desalinization plant and numerous pumping devices for the salt extraction). The total present need is estimated at 5MWe.
4. The fast undergoing development due to the important road connection at Afdera (to Makale West, Dallol North and to Semara, Addis and Djibouti Ports South) and to the local salt industry development.
5. By duplication of the system in several other sites in Afar, develop a self-promoted resilience to climate change.
6. In the long run, the projects will prepare the Afar communities to future, more ambitious geothermal developments that AGAP will promote with foreign partners. Training programs are engaged with Semara University in this perspective.

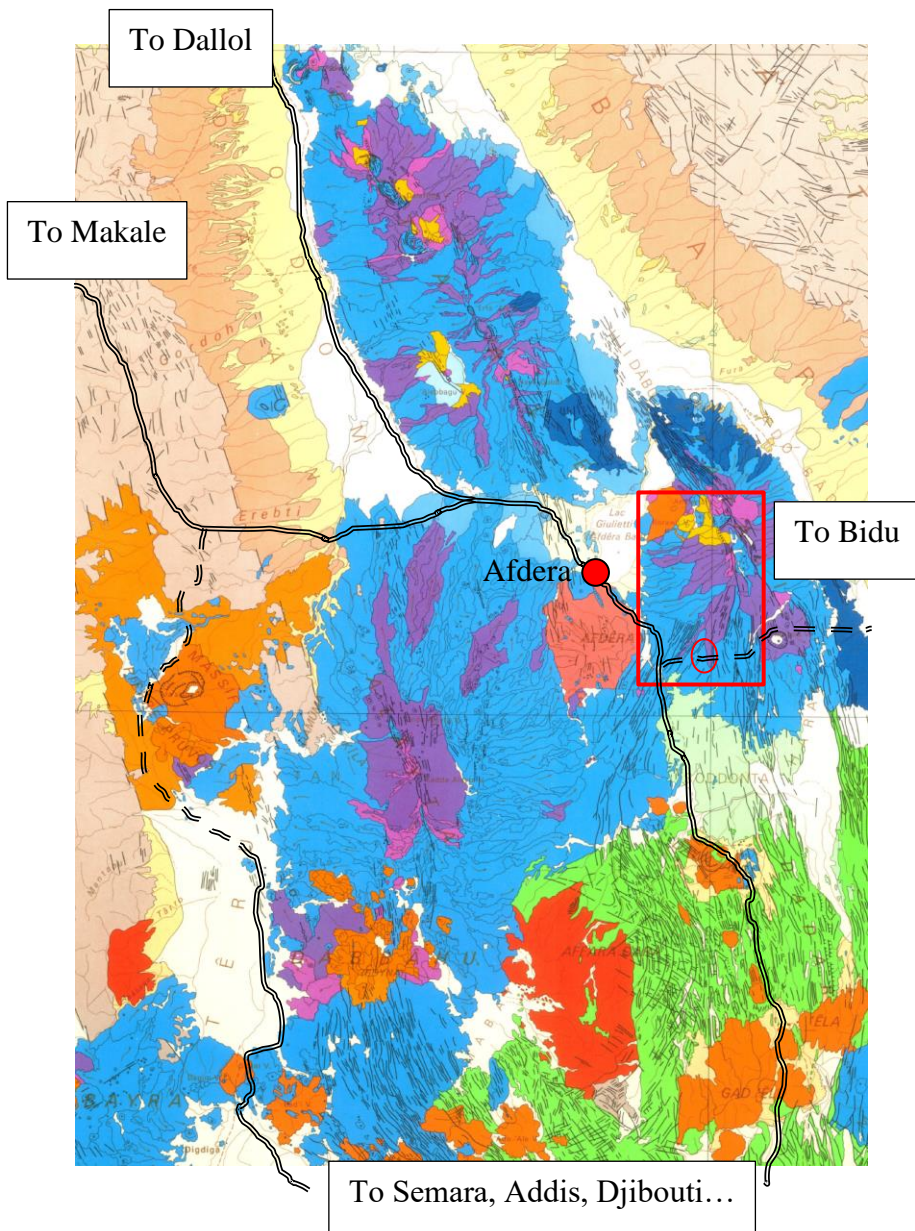


Fig.3: Localisation of the Tat'Ali geothermal project areas (red rectangle) and development site (red ovale) selected by AGAP.

It is located along a new road (black dashed line) being built to access Bidu near the Eritrean border. It is in the immediate vicinity of Afdera, a village that is becoming an important communication centre in Northern Afar, also site of important salt production.

An electric line is projected to be built along the asphalted road linking Makalé (capital of Tigray) and Dallol (Potash mines) to Semara (capital of Afar), Addis Ababa and the ports of Djibouti.

In addition to serving local needs, the production would feed the grid once the plant will be built.

4. Geology of Tat'Ali geothermal site

As shown by J.Varet (2006) at the first ArGéo conference in Addis-Ababa, the most interesting geothermal sites in Afar are located at the intersection of the axial ranges developed along the dominant NNW-SSE to NE-SW trend (Red Sea - Aden ridge) with transverse (leaky transform faults marking with axial ranges the active plate boundaries within Afar, as drawn by Barberi and Varet, 1977). Tat'Ali- Mat'Ala axial range sits on the eastern side of the Lake Afrera, at the foot of the escarpment of the Danakil Alps, on a sedimentary floor made of marine coral reefs and evaporites covered by more recent lacustrine deposits that extends also south of the range. Fed as other axial ranges by fissures emitted from a single NNW trending line, it is a quite complex structure in which several volcanic units can be distinguished (Fig.4):

- Tat'Ali fissural lava field to the north, which developed at the same latitude as the Haili Gub axis of Ertu Ale range, at a distance of 20 Km.
- This extends towards south in the Tat'Ali volcano, characterized by an elongated summit caldera built along the axial graben of this rift
- On the western flank of the Tat'Ali axis, sits the Borawli volcano that contribute to the shape of lake Afrera as it borders to the south its northern lobe.
- Further south along the NNW-SSE axis sits the slightly older Mat'Ala shield volcano at the northern extremity of the lacustrine Sodonta plain.
- The most recent (sub-historic) activity develops on the south-west side of the range, with open fissures along a graben of transverse (NNE-SSW) direction having emitted basalts and differentiated lavas up to dark trachytes.

The activity starts with submarine (to the north and east) and sub-lacustrine (to the south and west) activity with hyaloclastite cones observed to the north and the typical pavestone surface of the fissural basalts observed in early flows all around the range. The fissural flows observed to the north of the range are deeply faulted, with sometimes important fault scarps despite the fact that the affected lava flows are quite recent. One of the fault scarp marks the limit of Lake Afrera to the NE. All these lavas have been emitted along open fissures that are parallel to the faults (NNW trend) and the tectonic and volcanic activity appear to have been contemporaneous over several phases up to very recent (historic) periods. A phreato-magmatic explosion crater erupted numerous mafic and ultramafic blocks that allow to sample the earlier activity; it is also a geothermal index of interest.

The main Tat'Ali volcano is built on the southern extension of these fissures, but whereas these appear as a ridge, a well-developed axial graben, building a rectangular sink, 3 Km wide and at least 10 Km long, extends towards south in line with Mat Ala crater. If the shield volcano is dominantly made of basalts, the lavas emitted from the latest fissures bordering the sink walls on both sides are dominantly andesine ferrobasalts and dark trachytes on the eastern flank and silicic trachytes and peralkaline rhyolites (pantellerites) on the western flank. The faults bordering the sink were partly contemporaneous with the silicic eruption, showing inflation and deflation from a shallow magma chamber, also giving rise to post-caldera pantellerite domes and flows (the latest well visible to the west of the ring wall of the caldera). Postdating the caldera sequence, a recent basalt flow emitted near the southern rim of the caldera partly covers the floor of the central sink.

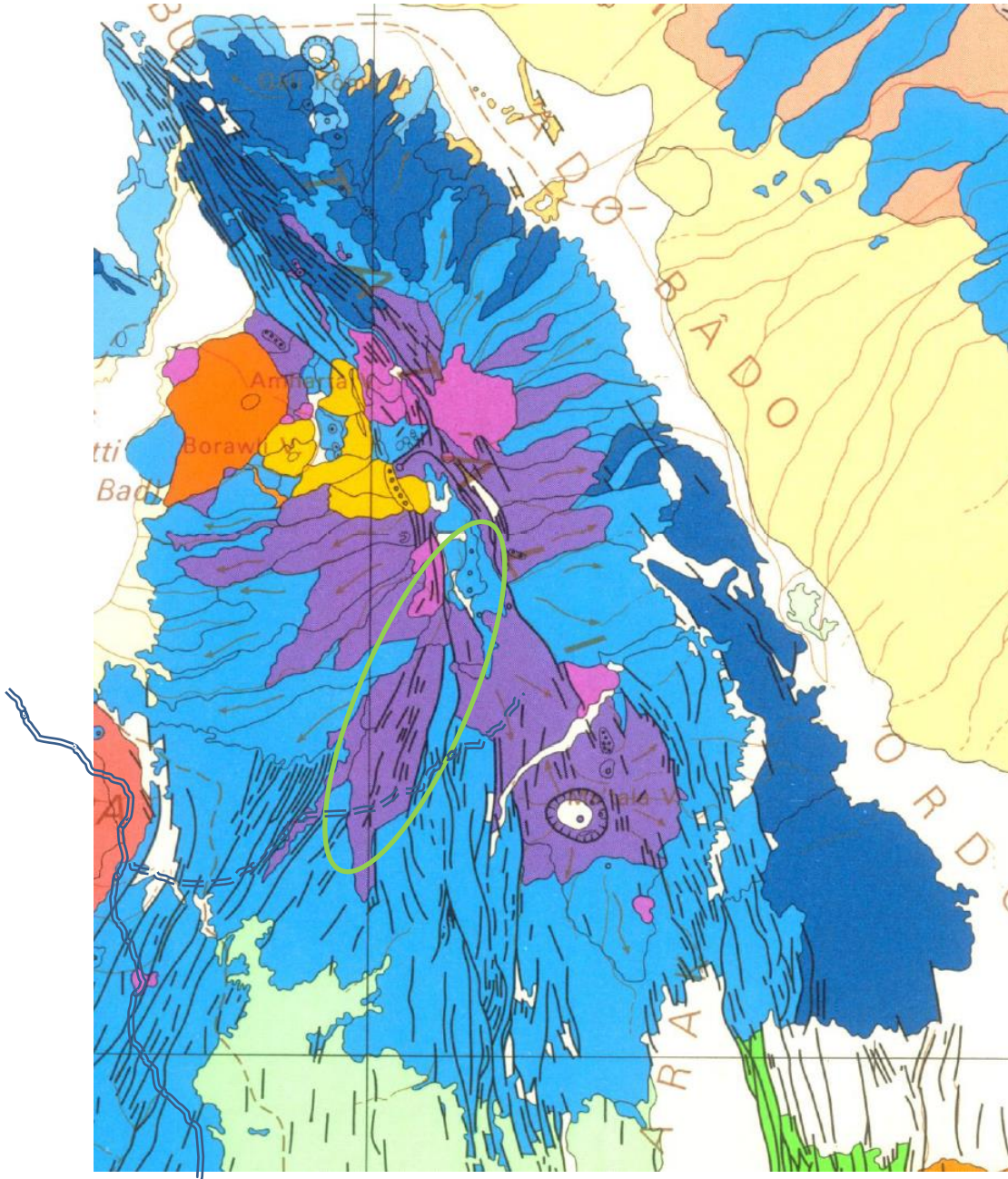


Fig.4: Geological map of the Tat Ali – Mat Ala axial range (from Barberi et al., 1971). Observe the northern, intensively faulted basaltic lava field, the complex central volcano with elongated caldera along axial rift, the southern Mat Ala shield with its large crater, and the most recent NNE-SSW emissive fissures, all hydrothermally active. Note the abundance of the differentiated products, with peralkaline rhyolites post-caldera domes and flows on the northern side and intermediate products to the south. The project area (green ovale) is located along faults and emissive fissures (transverse direction expression of a leaky transform fault).

Marking the shrinking south of the lake, Borawli is a simple cumulo-volcano of typical conical shape (Fig.5). It is made of silica saturated trachytes covering older faulted basalts. It is surrounded by a few other, rather young rhyolitic domes (probably historical), one of which emitted pantelleritic obsidian associated with pumice, probably the source of rounded pumice found all around Lake Afrera (Barberi et al. 1973).

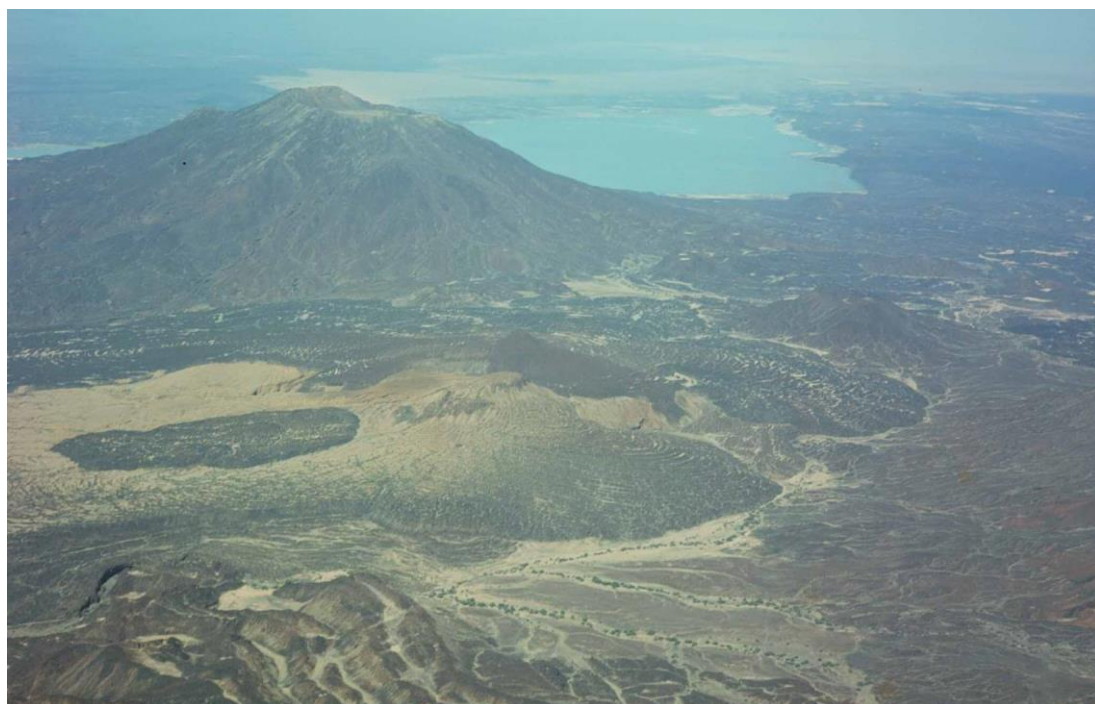


Fig.5: Oblique air photograph of the twin – rather recent - pantelleritic dome-flows erupted on the flank of Tat'Ali shield, with Borale stratovolcano dominating Lake Afrera on the back. The NNW faulted limit of the Lake is well visible at the horizon.

In the southern half of the range, Mat'ala is a flat shield volcano with a large summit crater 3.5x2.5 km diameter and an approx. 300 m deep, slightly elongated in a transverse direction. It is located along the axis of the Tat'Ali rift and close to the south.

Faults of NNE (transverse to the dominant NNW-SSE Red Sea trend) direction, well developed at the foot of Afdera volcano, are reaching the Tat'Ali Mat'Ala rift axis, and influenced both the closing of the Tat'Ali caldera to the south as well as the location of the Mat'Ala shield volcano which marks the southern end of the Tat'Ali range. Open faulting develops in a fan shape further south with all intermediate directions between NNW and NNE.

Altogether, from a magma genetic point of view, the range is characterized by a continuous series from picritic basalts to pantellerites, with all intermediate terms (Fig.6) showing that a persistent magma elongated chamber allowed for several cycles of crystal fractionation to develop until in recent, sub-actual times.

5. Geothermal conceptual model

Besides the development of an elongated shallow magma chamber, allowing for the evolution of initial basaltic magma by crystal fractionation up to the most evolved peralkaline end products underneath the caldera, the range is also affected, from its northern to its SW extremities but also along its axis, by recent tectonics and fissure emissions of basalts and differentiates showing that spreading is still active. This indicates a powerful shallow magmatic heat source all along including the SW side.

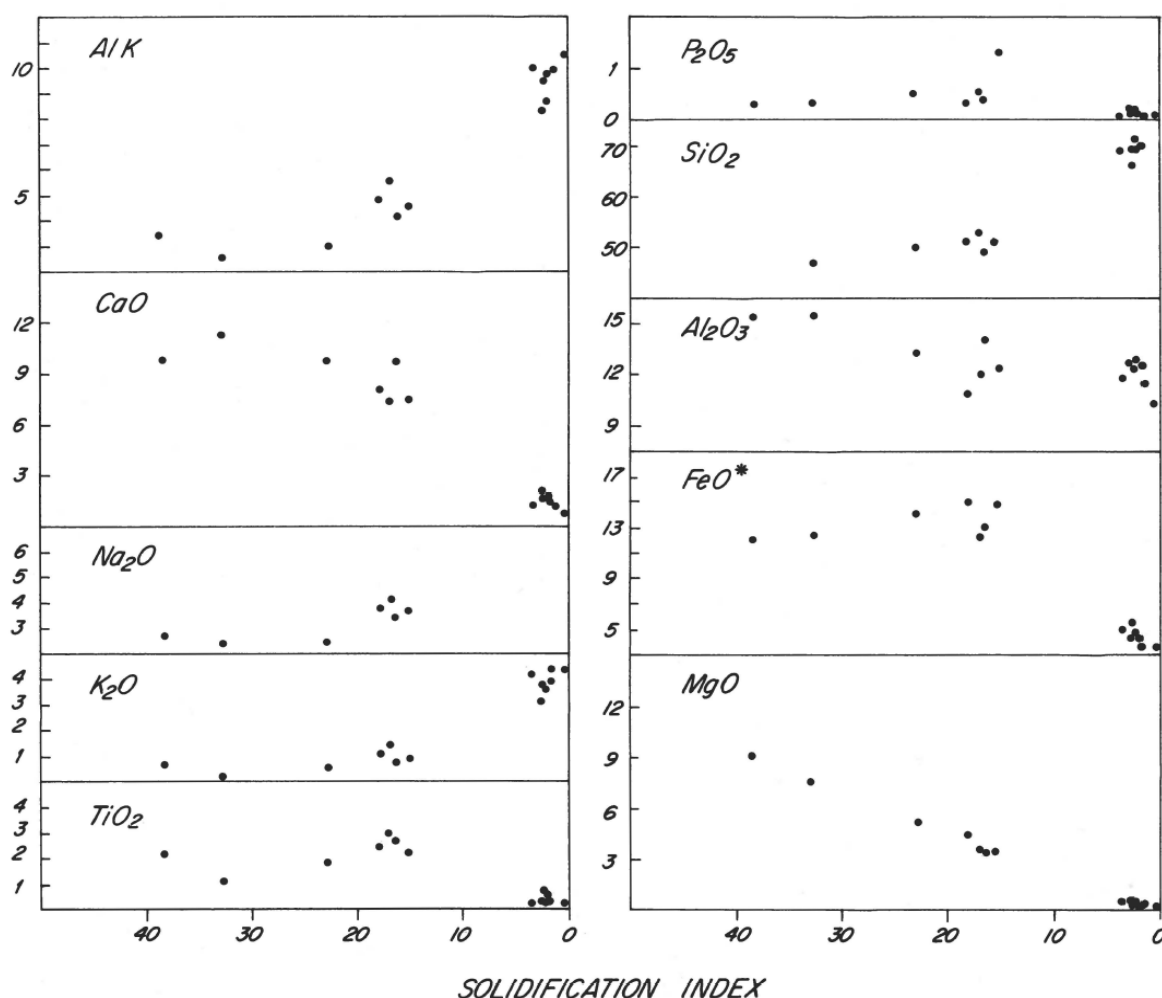


Fig.6: Magmatic evolution in the Tat Ali - Mat Ala axial range, from picritic basalts to pantellerites observed from major elements plotted against the Solidification Index (from Barberi et al. 1973).

Besides volcanic and tectonic activity, hydrothermal manifestations are well expressed in several places. Fumarolic activity is developed along the faults limiting the elongated Tat'Ali caldera as well as on the top of Borawli volcano and on the SW fissures. Together with the hot springs located at the foot of the range along the Afrera Lake shores and the phreatic activity, this allow to consider the area as a target of geothermal interest. Looking at the most recent seismic monitoring (Fig.7), the Tat Ali range also appears at one of the most active segments of northern Afar.

Particularly in areas where NNW and NNE trends intersect, this tectonic activity favours the development of geothermal reservoirs of high permeability. All these arguments – shallow heat source, high permeability, surface steam leakages - justify the choice of location of the geothermal target (Fig.8).

The area selected for the first developments is located on the southern part of the axial volcanic range of Tat'Ali (Fig.4). Several of the numerous active faults (normal faults and open fissures) that affect this area display steam vents and fumaroles with temperatures circa 60°C, some of them under pressure with temperature exceeding 100°C (Fig. 8 & 9).

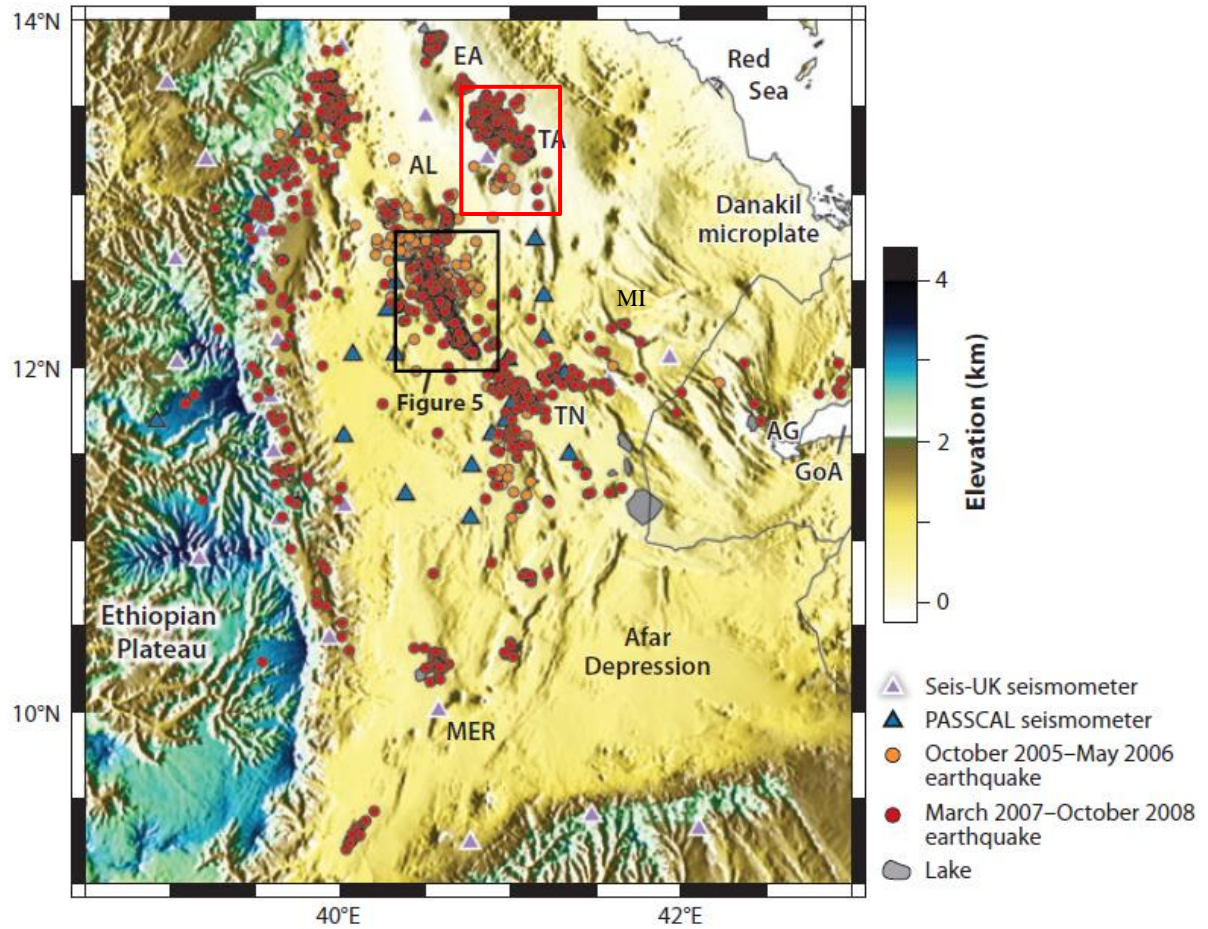


Fig.7. Regional compilation of seismicity recorded from October 19, 2005, to November 2009. Black box encloses Dabbahu-Manda Hararo segment, whereas red box encloses the Tat ali segment. Incipient seafloor spreading segments along axial ranges reported are: TA, Tat Ali; AG for Asal-Ghoubbet; EA for Erta Ale; AL for Alayta; MI for Manda Inakir (After Ebinger et al. 2010).



Fig.8 (left): Geothermally active normal and open fault at Tat'Ali SW, with alignment of steam vents, fumaroles and hot grounds and development of the “geothermal grass” (Fiale) benefiting from the condensing water and alteration of the young basalt flows. **Fig.9 (right):** detail view of a high temperature steam blowing hole along the fault seen of Fig.8 (both Photos by J.Varet, 2016).

Such manifestations are observed on several faults in the area and extend over more than one kilometre – as seen in Fig. 10 - with other indices located along the same axis towards north (Tat'Ali caldera) and south (Sodonta plain), where hot-springs are known to occur in the Sodonta plain (a remote site locally called « little Dallol »).

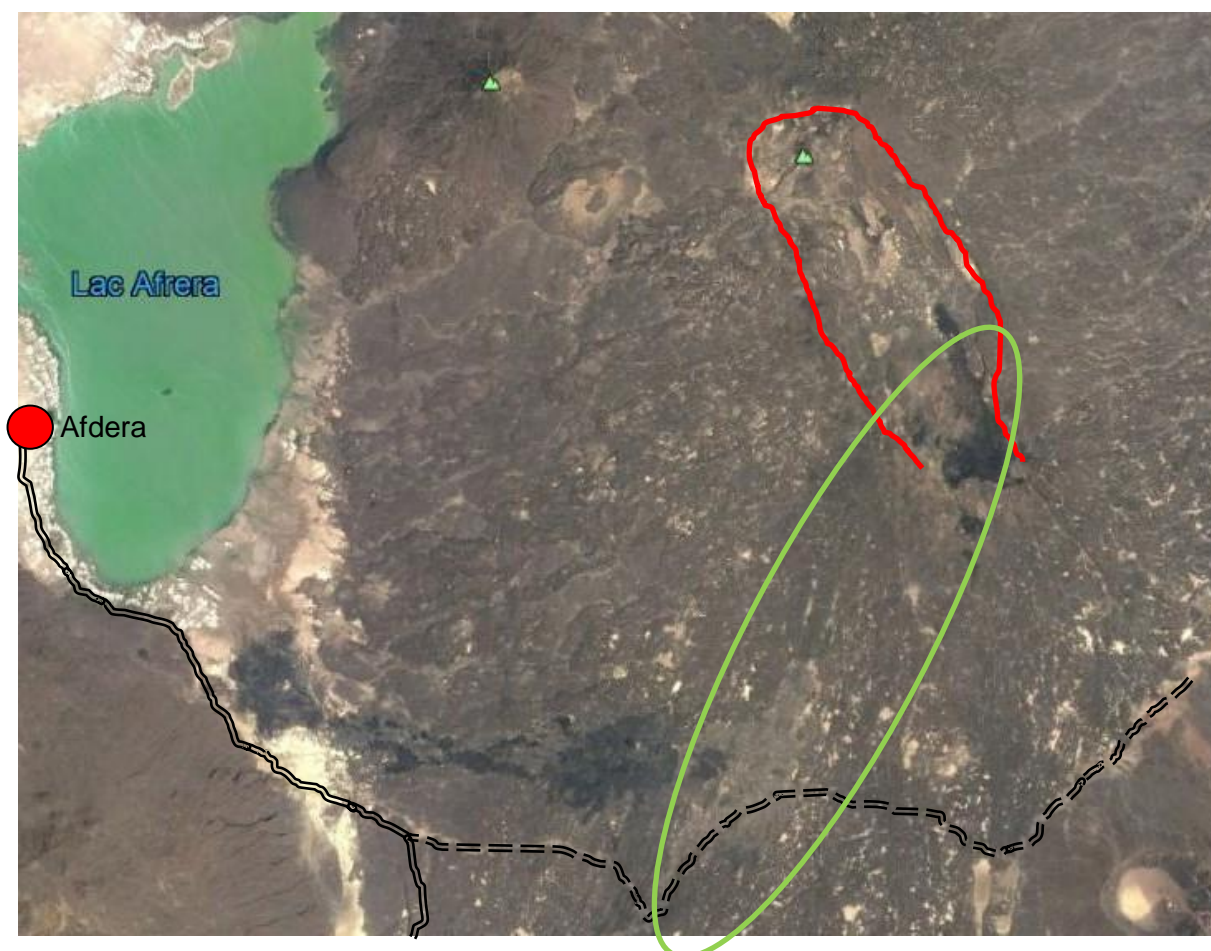


Fig.10: Google earth imagery of the site proposed, showing the location of the elongated caldera (underlined in red) and of the steam-leaking faults that borders the NNE-SSW trending rift (inside the green ellipse). The road constructed (dotted) is indicated. A very recent flow of dark trachyte composition was emitted along the graben axis.

6. Development perspective of the project

A geothermal resource of rather large extension (20 square Km in a first step) is expected there at shallow depth (circa 150°C at 500m) with a high permeability resulting from the active double faulting, allowing to initiate local developments avoiding deep and costly drilling. A binary (ORC) unit of the order of 5 MWe would largely fulfil the present needs of the Afdera community. A dry team superficial reservoir is expected to overlay a deeper highly salty brine reservoir that would not be looked for exploitation at least in a first step. To start with, the plant would replace the various Diesel power devices used at Afdera (37.000 inhabitants) for electricity generation, desalinization, and brine pumping for salt production.

Note that the site is located at less than 8 Km from the asphalted road south of Afdera, and that a large earth road is under construction (seen in Fig.10) linking this major axis to the Dubi

sultanate to the East. A request for a lease has been engaged in 2017 by AGAP with the concerned Federal Authorities and the Afar regional State mining bureau that covers the part of the Tata'Ali area to be investigated.

Given the quick development of Afdera township and Lake surroundings, and the projected electric line (with important financing recently allocated by AfBD) linking Afdera to Dallol, Makale and Semara more important production will be considered – by extension of the geothermal field north over a surface of 50 square km - in the coming years once the first production will be emplaced (hopefully 2020). AGAP engaged an action to stimulate the interest of the local population for the geothermal energy production and surface development solutions. This town will in fact become the road and railway knot between Makale, Dallol, Semara, Addis-Abeba and the port of Djibouti. In addition, local industry may develop with the valorisation of the numerous local mineral resources (gypsum, salt, pulverulent lime...). The combined production of electricity, heat and water is therefore looked for, with the idea to induce development (such as eco-tourism) in addition to the answer to the immediate communities' needs. The electricity produced will be also sold to the surrounding consumption centres and eventually to the grid as the development of the electrical network progresses. The projects will be developed in 3 phases:

- Prefeasibility study: complementary surface geology investigations, hydrogeological studies and fluids (liquid and gas) sampling and analysis, and then geophysical surveys (land MT-TEM, drone borne IR) allowing to precise the extension and characteristics of the geothermal reservoir. From these studies, a quantitative three dimensional quantitate geothermal models will be established. The cost *estimate for these works, including slim-hole drilling is of 1 M€* (these works intend to also estimate the global geothermal potential of the site for later developments).
- Feasibility: exploration-production drilling at a depth of 500 to 100m aiming to reach a superficial steam reservoir with the aim to characterize this reservoir at least for this initial geothermal development. Cost estimate : 5 M€.
- Production phase of the geothermal field and construction of the power plant (most probably with binary ORC technology) and of the various production devices (electricity, heat, water) with the corresponding networks. Cost estimate : 5 to 10 M€ *depending on associated developments*².

The support of GRMF and other donor agencies is being searched for the two first phases. Climate funds are in particular be looked for the whole project.

The following phases will be engaged with the support of banks (refundable loans) and industrial/investor partner. Training of local Afar personnel's which will work on site or on other geothermal developments undertaken in Afar by other entities is an important component. A partnership was established by AGAP with Semara University, also involving Addis Abeba and Makale Universities where Afar students are already engaged in the concerned scientific and technical fields including geosciences.

² That is an investment of 2 à 4 M€ par MWe installed for a production of 8000h/year. That is a price per kWh very competitive with Diesel units that will be replaced.

Conclusion

The project is original: it aims at implying the local African communities in the development of geothermal resource and exploitation from which they are at present essentially discarded. It aims at developing small size projects answering local needs (even for pastoral communities) which is not the case for geothermal projects engaged at present in Africa.

The project aims at demonstration and exemplarity in Eastern Africa: The Afar community has taken here an initiative that is inspired by other examples developed elsewhere, as in New Zealand by the Maori community (Onyango & Varet, 2016).

The project also intends to solve major issues like:

- *Fight against poverty* (The Afar population do not dispose of more than 1\$/per day and per inhabitant) ;
- *Community awareness* (the knowledge by the concerned population of its local resources and the undertaking of the possibly induced developments);
- *Gender issue* (taking into account the demand of the women and girls: they are the first concerned by the matter of energy and water that is presently at their charge);
- *Adaptation to climate change* (Afar was a desert for the last thousand years but the present situation is worse than ever and clearly due to a global warming to which Afar people did not contributed) ;
- *Reduction of greenhouse gas emissions* (by replacing diesel driven devices by geothermal powered units) ;
- *North-South partnership* (with the implication de scientist (geosciences and social sciences³, engineers, enterprise's⁴ (drillings, binary plants, mini-grid, local services);
- *Training of future Afar cadres, technicians and workers* (implying the Universities of Addis Abeba, Makale and Semara, mobilising the students in AGAP's projects.
- *Ecological transition* (however, in the present case, the development will drop the « fossil » stage of development to directly undergo renewable and sustainable solution):
- *Resilience* (through engagement of a sustainable development based on the exploitation of natural resources independently from climate risks).

Also note that, if aimed at serving local developments, the project will also allow for future major developments. Developing projects on this site will allow for later more classical perspectives. With the difference that the local population will be engaged in the development perspectives, instead of remaining “on the side of the road” as other communities elsewhere in eastern Africa.

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³ cf. thesis under progres by Susan Onyango at l'EHESS (gender issue & social geothermal development)

⁴ In France : Géo2D, CFG, Electerre de France, Enertime...

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