COMMUNITY-BASED GEOTHERMAL DEVELOPMENT PERSPECTIVE IN AFAR: A NEW PLAYER AFAR GEOTHERMAL DEVELOPMENT COMPANY (AGAPI)

A. Nebro[1], I.A. Gardo[1], J. Varet[2] & S.Onyango[3]
[1]colonel, AGAPI Executive Manager, Addis Abeba, Ethiopia ; [1]AGAPI President, Semera, Ethiopia; [2] AGAPI Scientific Advisor, Géo2D, France; [3] AGAPI Scientific Advisor, Géo2D, EHESS, France.
dersuma4@gmail.com; gardoali@yahoo.com ; jacques.varet@gmail.com ; sonyango1931@gmail.com

Key words: Afar, local community, geothermal energy, sustainable development, social sustainability, socio-economic needs

ABSTRACT

Afar is one of the most promising regions in the World as far as high enthalpy geothermal resource is concerned. It is the only place on the planet Earth where an oceanic rift is penetrating a continent. Fumaroles, steam vents, hot-springs and hot grounds are very common. If the arid induce rather salty geothermal fluids, the nearby basement escarpments also allow for a recharge of the geothermal reservoirs by meteoritic waters. The awareness concerning Afar geothermal resources developed in the early 70's but the local interest of the local communities for the economic development under climate change conditions is new. Several community-based economic entities have since been created, notably in the lower Awash Valley basin and in Nov 2014 the Afar Geothermal Development Company (AGAPI) was created. It was an initiative of 12 Afar communities. They share the capital (of 2 Million Ethiopian Birrs). AGAPI has selected several sites for potential development, based on a study of the geological resources and of the social demand. This approach has enabled defining priorities, and currently two sites are under investigation for the implementation of pre-feasibility and feasibility studies. AGAPI also intends to answer the energy needs of developers engaged in the region (agro-industries, mining activities, railway line, raw materials and mineral processing, etc…). In addition, AGAPI intends to facilitate geothermal investments in the Afar region and to develop partnerships with enterprises engaged in geothermal development and hope this project will benefit from the UN *SEforALL,* (sustainable energy for al initiative as it clearly answers this challenge.

1. INTRODUCTION

Afar is one of the hottest and driest places in the world. Although it is severely affected by climate change, it is an area where a population has been living since time immemorial, adapting its pastoralist activities to changing environmental conditions. The Afar triangle; a term derived from the name of the local inhabitants, extends over 3 countries (NE Ethiopia, SE Eritrea, and Djibouti Republic); the main surface and the majority of the population being found in Ethiopia. Since the Federal Democratic Republic of Ethiopia was promulgated, Afar benefits from the status of a "Regional State", with Semara at the center as its capital.

Within the EARS, Afar displays a particular geodynamic situation, as it is not only the northern extension of the EARS, but also part of the Red Sea – Gulf of Aden oceanic rift system, has exceptionally emerged there, on the African continent. Afar does not represent the "funneling out" of the MER but a specific area where the MER continental rift system hits the out-cropping Aden-Red Sea ridge (Tazieff et al., 1970, Barberi et al., 1972). The Afar floor (-120m bsl to the north and –155m bsl to the east) is surrounded by the escarpments of the Nubian plate to the West, the Somalian plate to the South and the Arabic plate to the East, with the Danakil Alps acting as a rotating microplate to the NE (Fig. 1). Totally floored by lavas less than 4 My in age, with several, still active since the last 1 My, well defined basaltic axial ranges as well as transverse ranges and central silicic volcanoes along the margins (in areas of discontinuities of the basement) similar to those along the MER northern extension (Fig. 2). This provides numerous opportunities for the development of shallow heat sources. In addition, the lithology as well as the intense and active faulting allow for the development of geothermal reservoirs.

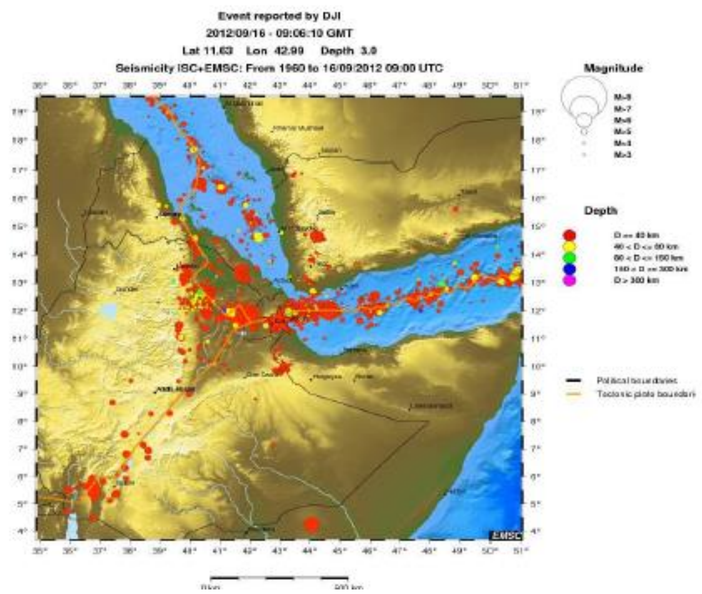

Figure 1: Map of Afar in its geographic context showing the seismic activity in the Aden, Red Sea and Afar region underlining the active plate boundary between Arabia and Africa

Besides the development of major geothermal sites of Federal interest, as in Tendaho, Afar benefits from numerous sites of local interest, suitable for development of the local population, and answering their/ immediate needs, as climate change heightens the necessity for new avenues for local development. This is the reason why the Afar Geothermal Development Company (AGAPI), a community based enterprise registered in Ethiopia and owned by 13 communities of Northern and Central Afar was founded in 2014.

2.0 GEODYNAMIC ENVIRONMENT AND UNITS OF GEOTHERMAL INTEREST IN AFAR

Conditions for the development of high enthalpy geothermal fields were shown to be met in NE Afar in Ethiopia[1] when the super-position of 3 geological features was encountered (J.Varet, 2011).

- The presence of active spreading segments, with important and recent volcanic activity developed in the “rift-in-rift” structures of the Erta-Ale, Alayta, Tat’Ali, Manda-Harraro and Manda-Inakir axial ranges, allowing for the development of significant and rather shallow magmatic heat sources.
- The development of transverse faulting crossing through the dominantly NNE-SSW 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.
- 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 faulted Proterozoic basement, its Mesozoic sedimentary cover (Jurassic limestone and cretaceous sandstone) as well as Tertiary and Quaternary detrital formations.

Due to the evaporation of the Danakil Sea, former southern branch of the Red sea (200 to 25 ky ago), the northern part of the depression is floored with thick (several 1,000m) salt deposits. This allows for the development of Sylvite deposits in addition to Halite, both of economic interest. Numerous hot-springs, explosion craters and fumaroles are reported at Dallol. Therefore, the on-going geothermal

[1] These ranges extend South and West with the Asal rift in Djibouti, which connects with the Aden-Tadjoura oceanic ridge, whereas North, Alid (in Eritrea) is also located in axial position in the Afar rift. However where the spreading rate is much lower, the place is marked by the influence of the pre-Miocene formations.

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 (Varet et al., 2012).

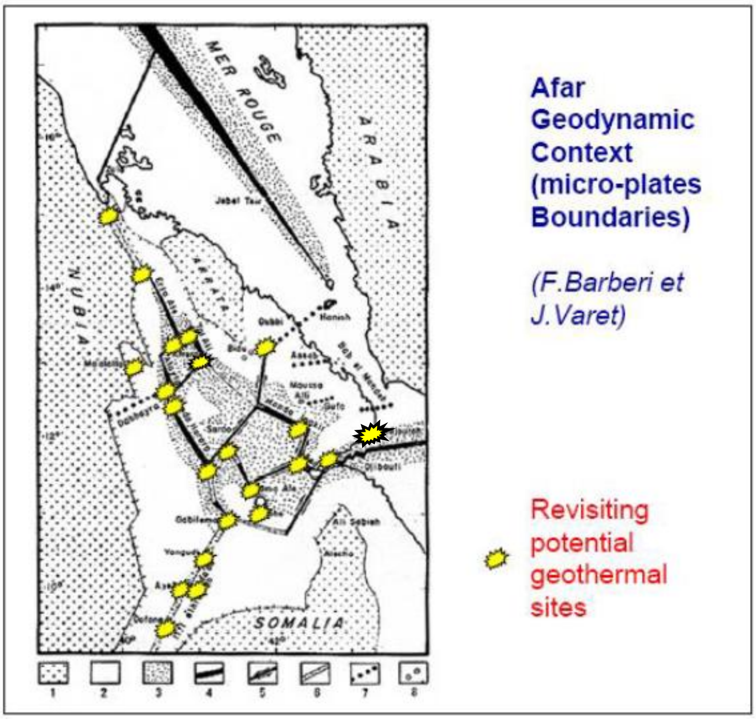

Figure 2: Schematic view of major Afar volcanic units in their geodynamic environment (from Barberi & Varet, 1977) showing potential sites of geothermal interest within Afar (from Varet, 2004). 1. Basement, 2. Pio-pleistocene Sediments, 3 Afar stratoid series (4-1 My), 4: active basaltic axial ranges (spreading segments), 5: transform fault zones, 6: continental rift (MER), 6: transverse volcanic ranges, 7, central silicic volcanoes. (4 to 7: 1My to present)

Further south, another geothermal site is found 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. High discharge hot-springs feeding the lake are interpreted as the products of the heating of superficial groundwater crossing through Alayta range by deeper geothermal fluids, the location of which remains to be identified by further exploration. However, the water discharge is carbonated, depositing travertine chimneys when the lake level was higher (10 to 6 ky). This is apparently a low enthalpy geothermal system. The South-Western part of Tat'Ali range is affected by intense volcanic and tectonic activity, with a NNE-SSW tending rift displaying numerous fumaroles and steam vents showing a high enthalpy geothermal site of interest.

South of Alayta, aong the same fracture zone[2], another offset is also in correspondence with the geometry of the basement scarp, where the Manda-Harraro range develops along 120Km. In the area of transition between these two axial ranges, the Dabbahu recent silicic center has developed with a fractionation sequence up to pantellerites showing the presence of shallow and active magma chambers (Barberi & Varet, 1975). This is also the site of intense hydrothermal manifestations, with several hot-springs, fumaroles and silica deposits, notably along the sedimentary plains bordering the volcanic zones to the West.

Manda-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 7 m 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 express a high permeability favorable to the development of a geothermal reservoir fed by the large 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.

[2] That extends from Dabbayara to Dabbahu, Bidu, Dubi and Hanish island in the Red Sea (DDBDH FZ in Fig.3)

At the previous ARGEO conferences, 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);
- highly fractured area, allowing good reservoir permeability, found in fracture zones, generally in places where transverse fracture intersect the dominant “Red Sea” trend;
- recharging of the reservoir by meteoritic water or sea water, or a combination of both;
- presence of a mineralised hydrothermal system.

The Ethiopian escarpment bordering 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 (also called Danakil sea), where the surface salty crust re-crystallizes 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 axial ranges, the largest being Dodom and Teru (Fig. 3).

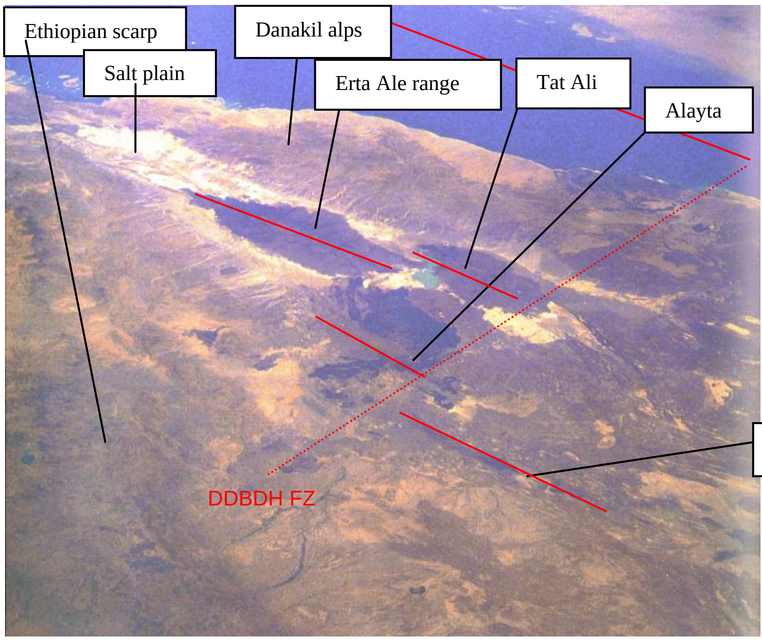

Figure 3: Oblique satellite view of the numerous watershed feeding the Afar depression from the Ethiopian plateau and Danakil alps.

The sedimentary evaporitic plains are in white or pale colours, whereas the axial volcanic ranges (Erta Ale, Alayta & Tat’Ali and Manda Harraro extend in black along the same red sea axis as the ults of the scarps.

Their axis is underlined in plain red, whereas the dotted line is the DDBDH fracture zone

Therefore, although the rainfall is very low in the depression itself (average circa 100 mm/year, 50 mm in Gagad), the western border of the Afar benefits from the much better hydrologic conditions of the Ethiopian plateau (up to 1,300 mm at an altitude of 3,000 m). 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 NNE-SSW normally-faulted blocks with frequent marginal grabens favoring infiltration. 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 detrital aquifers. As a result, 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 that are well-fed by suitable hydrological basins crossing through the Ethiopian faulted scarp limiting the Afar depression to the West.

3.0 GEOTHERMAL RESOURCE APPLICATIONS: A LONG EXPERIENCE OF LOCAL, TRADITIONAL USES

The Afar climate is so dry that the use by the Afar population of the naturally steaming grounds for water production and other uses (washing, boiling food and tea…) is quite common. The first option is to improve the steaming of the fissures and faults by some simple diggings and to install devices for channeling and condensing the steam. This is done sporadically in a very artisanal way by the Afar nomads who dig with hand instruments through the clay infilling of the steam vent (the hot steam progressively transform the volcanic rock into clay with time) in order to increase the steam discharge, and install branches fixed with stones in order to condense the steam into water which falls and is collected along channels drawn in a clay modeled surface (Fig.4A). A more efficient approach is to build domes in stones that allows for improved condensation as developed in Elidaar, central Afar (Fig.4B). These stones can be either assembled with clay found on site along the altered fissure surfaces or cemented as developed with the support of APDA[3] (Afar NGO partner of AGAPI).

Figure 4: A/ Traditional device for water condensation from fumaroles ("Boina") using branches on a well dug along an emitting fault (SE Teru, Afar). Observe the geothermal grass ("Fiale") growing around the site in this otherwise arid plateau. B/ Steam collectors built in Elidaar, an original device of climate resilience, spontaneous initiative by local pastoralists supported by APDA.

4.0 AGAPI, ORIGIN, RAISON D'ETRE AND DEVELOPMENT PERSPECTIVES

Despite several attempts in the years 70's and 80's (Italian and German cooperation at Tendaho, (BRGM and Italian Cooperation at Asal and Hanle in Djibouti…) no real geothermal development has as yet occurred in Afar. The site of Tendaho is however presently under feasibility study with the support of several financial agencies including AFD. Projects directed by the federal government and foreign enterprises are meant to serve the electric grid with large size power plants. Aside from these large projects, small-size units should also be considered with the idea to ensure geothermal through isolated grids benefits isolated communities besides cascaded direct uses of energy and water.

4.1. Raison d'être of AGAPI

The Afar population, has consistently encountered more and more severe environmental conditions due to climate change and realized that its future survival, life and eventual development will necessitate changes with respect to the past pastoralist economy based on rainfall and subsequent temporary grazing. Therefore, the communities of northern Afar joined hand and collectively contributed the capital necessary to create a company in charge of development of local natural resources, in particular geothermal energy. With the help of Géo2D, several sites were identified as

[3] APDA: Afar Pastoralists Development Association, which is also a member of the Ethiopian Pastoralists Forum.

suitable for local geothermal development. The approach was to identify sites where the Afar population is sufficiently concentrated and develops activities that justify the need for the development of a small-size off-grid production system. The model of reference for these projects is the "Geothermal Village" concept as exposed by Omenda 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.

Considering that Afar community has been able to live in desert conditions for millenniums in a sustainable way, in equilibrium with their natural environment despite very limited access to water or energy;

- Its exceptional geological situation, with its huge amount of telluric energy made available at the surface through geothermal phenomena as it is a mantle plume and triple plate boundary;
- The fact that climate change due to the over-use of fossil fuel worldwide, negatively affects, with increasing droughts, this already desertic region;
- The recently growing expression of interest for geothermal development from international, regional and bilateral agencies and institutions, as well as enterprises and NGOs;
- The knowledge of the earth geology and resources developed by scientists as well as its ancestral use and knowledge by the Afar communities;
- The increasingly on-going social awareness of the Afar communities through education, health care and population development.

4.2. Legitimacy

AGAPI was founded through the initiative of Lul Ras Mengesha Seyoum who 50 years ago played a key role in the development of geological research in Afar by backing and working closely with the researchers in Afar at the time. These research initiatives allowed for the major scientific discoveries that took place at the time, and that led to the development of applied programs. Although AGAPI benefits from the support of scientists and experts having an in-depth experience of both the Afar region and the know-how of the necessary processes and technologies, it is a community-based company, initiated and controlled by representatives of the concerned Afar communities. Combining the knowledge of the terrain and the local population's demand with the most updated approaches to sustainable development, it intends to become "The Partner of Choice" for any developer interested in enhancing the region's natural and human resources.

4.3. Vision

The vision of AGAPI is to develop access to renewable energy and water supply for Afar communities; provide opportunities for jobs to Afar people through project development; create "Positive Energy" sustainable entities in Afar (villages, enterprises, etc…); enhance community awareness regarding the local resources available for development; contribute to the general education of the population, with a gender perspective focus (Onyango & Varet, 2014) and to professional training of the Afar community regarding ground resources and related fields, in particular acilitating access to university education up to the highest level possible (PhD) for most brilliant Afar students.

4.4. Objective

Founded by the Afar communities' representatives and citizens, AGAPI's objective is to develop the local geothermal resources and associated minerals, agricultural, industrial or touristic sectors for the benefit of Afar communities and by extension; the country, the region and the world at large. It projects to promote the development of the said resources in partnership with capable like-minded institutions — through the mobilisation of local communities for goodwill support and in-kind contribution. The target geographic area is the whole Afar Regional state of Ethiopia, with an initial focus on the northern Afar (north of the Awash basin). This will with time, be expanded to include the Afar in Djibouti and Eritrea.

AGAPI envisages developing projects at the various stages: from early reconnaissance to production. This entails pre-feasibility, feasibility studies and development of both the geothermal and associated

geological resource production. It also includes all the necessary processes of transformation: electricity, heat and cold, direct use, mineral extraction and processing, etc. The power from geothermal energy should serve the needs of target local communities, as well as external entities and clients through sales and exports. Thus, the primary objective is to answer the local communities' immediate socio-economic needs, based on a social sustainability approach to geothermal projects.
AGAPI also plans to get involved in projects serving wider scopes (such as electricity production for the grid, sales and exports of commodities made from local goods that could be produced using geothermal energy).Through APDA and a sister Foundation to be created, AGAPI intends to more generally enhance the local population's awareness concerning ground resources in Afar, through information, education and communication.

4.5. **Development strategy.**

Site selection criteria.
With the help of its International Scientific and Technical Advisory Committee (ISTAC), AGAPI defines a strategy of development based on the potential sites analysis in Afar. Its strategy relies upon the early identification of sites based on preliminary reconnaissance studies. Site selection is based upon the following considerations:

- Geological characteristics of the site concerning its potential in terms of energy production (size, heat source, geothermal reservoir and groundwater quality and supply, etc…);
- Type of use of the geothermal energy and fluid requested on site (agricultural, artisanal, industrial, mineral and mining processing, touristic health or therapy applications etc…);
- Distance to the communication network and access facilities or infrastructures costs;
- Local community mobilisation to consult on the various aspects regarding concerned development, e.g. manpower, money, land access etc...;
- Availability of geothermal exploration and production rights from the concerned ministry.

Each site development will be handled as a specific project, with its own budget and management scheme, including if necessary a proper ad-hoc legal entity (daughter company or subsidiary of ISTAC involving other necessary partners.

Step considered for resources valorisation.
Based on its knowledge of Afar, which is a combination of both indigenous knowledge (from the local community) and the scientific and technological advice through ISTAC, the Company intends to cover all the necessary steps of geothermal resources valorisation, as well as of other natural resources, primarily minerals, in the frame of the more general initiative for the sustainable development of the region.

1. **At the early reconnaissance stage** of the resources, the Company will mobilize the best scientific knowledge as well as the contribution of local communities (across the various genders and generations). For instance, the knowledge of all hydrothermal manifestations in Afar, including the most subtile ones (referred to as "Boina", "Fiale", etc…) and frequently already being put into use through traditional, artisanal means, is well mastered by the local community and will be combined with the most appropriate techniques (GIS, geochemistry, etc…). This will enable the identification of all sites of geothermal interest.
2. **At the pre-feasibility stage**, the Company will deposit the necessary permits to the relevant authorities and work at advancing its own knowledge of the most promising sites. Site selection will depend upon both resource availability and local demand. This step will be undertaken with scientific and technical partners who have the required expertise around the geoscientific approaches and will seek the support of funding[4]. The aim will be to select sites for exploration drilling and production tests.

[4] [4] Agencies such as UNEP, GEF, GRMF, EU, and bilateral aid

3. **At the feasibility stage**, the Company will choose the most suitable sites for development. These could include sites already being recognized by other entities, such as Tendaho, or Asal, and open for such partnerships, as well as other sites resulting from the Company's own research efforts. The drilling and tests will be engaged in partnership with experienced geothermal engineering, with the support of GRMF and other appropriate financial partners. In this process, the Company will guarantee that the local workforce is properly mobilized and benefits from the necessary training and transfer of know-how.
4. **At the development and production stages**, the Company intends to partner with specialized power entities and will ensure a sustainable use of the geothermal fluids including electric as well as direct use applications. Even if the energy is partly sold to the national grid, local developments induced will always be emphasised, including the use of energy for water pumping, agricultural or mining developments, and other applications (agro-industry, tourism, medicinal, etc…).
5. **Besides geothermal production**, the Company will also develop **other mineral resources either directly contained in or associated** with geothermal or present in the target geographical area, Such mineral/metal resources include Silica, Carbonate, base metals, silver and gold, manganese and barium, salt and potash, diatomite, obsidian, pumice, etc. In this case, the Company will again, develop a strategy of permitting and partnership with other concerned entities and will always lay emphasis on the benefits for the local population in terms of employment, environmental care or economic development.

4.6. Challenges

AGAPI relies upon the financial support of its founding and associate members, in particular APDA with whom a Memorandum of Understanding (MOU) determines the conditions of partnership, particularly for what concerns the use of mechanical mobile equipment, including drilling rig for shallow water wells or slim holes. Challenges faced by AGAPI include its capital, means of borrowing money from the banks, and skilled staff. These challenges also tie in to the issues of necessary technical consulting, engineering and contracting entity providing the necessary skills and experience for the achievement of AGAPI's objectives.
Although its initial capital was brought by its pastoralist's members, AGAPI seeks for the support of any entity, local, national, regional, international and bilateral that may help to support its strategy and projects appraisal and development through grants and/or soft-loans, hoping for the support of *SEforALL* UN initiative, as welle as NGO's and private firms sharing the same interest

5.0 sites identified as priority for exploration and development serving local community needs

5.1. Target projects

The priority activity of AGAPI, to start with, is to sustainably produce energy and water in the Afar desert in areas where the local population is deprived of other means of accessing energy or surface/groundwater resources. Through these production systems, which would be free of the impact from climatic fluctuations, AGAPI hopes to provide resilient habitats for the Afar communities; who also happen to be one of the communities most adversely affected by climate change. The projects promoted by AGAPI are also aimed at developing the appropriation of the geothermal resources by the Afar communities, as a transition from the traditional simple man-made steam condensation devices to more engineered geothermal plants delivering both energy (electricity and heat applications) and water (thermal hot water as well as drinkable cold water).

5.2. Key beneficiaries and corresponding sites

The final beneficiaries considered as a priority for AGAPI when selecting sites are of 7 categories:

a. Families which will be offered to live on the site and would benefit from a climate resilient habitat allowing them to maintain themselves and their herds regardless of the severity of a given drought period; they will also be encouraged to welcome people passing through their territory such as: water-deprived nomads passing through the area, and ultimately, tourists on their way to Afdera lake, Erta Ale volcano and Dallol.

b. The nomads passing through the area, who will find a site with a permanent supply of water for themselves and their cattle as well as a new community to welcome them to settle down there.

c. The nearby villages (of Afdera and Teru) that will benefit from the green energy geothermal electric power, aimed at replacing the presently fuel-driven devices (electricity generator, desalinization plant and numerous pumping devices for the salt extraction). The total need on each site is in the range of of 2MWe to 5MWe.

d. The fast growing development in the concerned areas due to:
- present and future road connections(links with Makale and Dallol to the North and with Semara, Addis and Djibouti Port to the South) and to local extractive industry development
- agro-industrial development allowing for the development of exports from this otherwise resource-endowed region (ex. Dodom and Teru plains) at present too remote and deprived of energy resource

e. Other regions in the wider Eastern Africa and primarily where other Afar communities are found, as by duplication of the system in several other sites in Afar, it will ultimately result in the development of a local community -promoted resilience to climate change.

f. The larger Afar community as in the long run, the projects will prepare them for even more ambitious future geothermal developments that AGAPI will promote with foreign partners elsewhere in Afar. Training programs are being engaged with Semara University with this perspective in mind, so as to develop employment for the upcoming young Afar generation.

Taking into account the criteria for choosing a site and the key target beneficiaries, two sites were selected as a priority by AGAPI in partnership with the target local communities in Northern Afar (Fig.5): Tat'Ali near Afdera and Dabbahu near Teru.

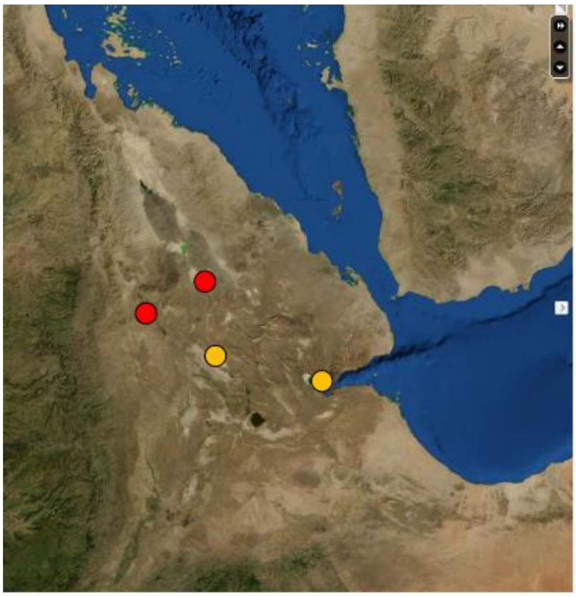

Figure 5: The Afar triangle », a large desert depression covered by recent volcanic essentially bared formations affected by active faulting, also display numerous potential geothermal sites. Red dots indicate the location of the projects proposed by AGAPI in Tat'Ali-Afdera and Teru-Dabbahu, whereas the orange dots show the location of the Tendaho project developed by the Ethiopian Government and of the Asal geothermal site in the

5.3. Tat'Ali near Afdera

The site selected is located on the southern part of the axial volcanic range of Tat'Ali (Fig. 6 & 7). This volcanic unit shows a relatively complete magmatic evolution from transitional basalts to peralkaline rhyolites (Barberi et al., 1972, 1975). The abundance of differentiated products including intermediate terms (iron-rich trachyte) and the relation between volcanic products and volcanologic evolution indicate the presence of a shallow magma chamber at a depth of less than 5 Km. The geometry of the magmatic heat source directly relates to the shape of the caldera, elongated in a N-S direction along an axial graben, with numerous post-caldera emissions of rather fluid flows of intermediate composition (well developed in the southern part) as well as more viscous domes and flow (numerous in the northern part). Several of the numerous active faults (normal faults and open fissures) that affect the axial part of the range display steam vents and fumaroles, some of them under pressure with temperature exceeding 100°C. Such manifestations are observed on several faults in the area and extend over more than one kilometre 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 salt plain (a remote site locally called « little Dallol »).

A geothermal resource of rather large extension is expected 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 about 5 MWe would largely fulfil the present needs of the Afdera community. A dry steam 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. It is worth mentioning that the site is located at less than 5Km from the asphalted road south of Afdera, and that a large earth road is under construction linking this major axis to the Dubi sultanate to the East.

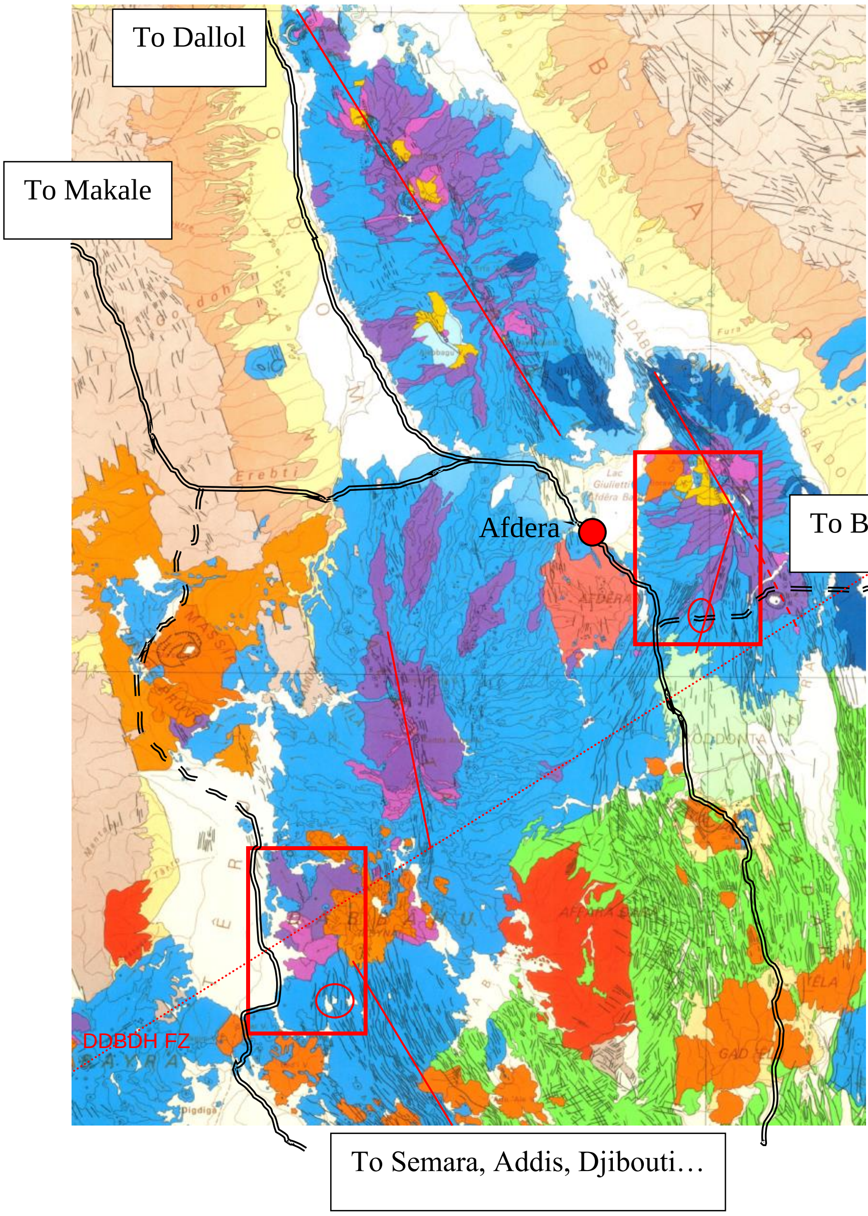

Figure 6: localisation of the two geothermal project areas (square) and development sites (round) selected by AGAPI as first priority:

- Tat'Ali near Afdera, an important communication centre in Northern Afar also site of important salt production
- Babbahu near Teru, a wide agricultural plain benefitting from the watershed from the Nubian plateau where agro-industrial developments will depend upon the presently lacking energy resource

These sites are shown on the base of geological map of Afar (CNRS-CNR) were the stratoid series (4-1My) is in green, recent quaternary basalts in blue, intermediate iron rich lavas in violet and rhyolites in yellow and orange. Active axis of axial ranges are underlined with a red line and the Dabbayra-Dabbahu-Bidu-Dubbi-Hanish fracture zone (DDBDH FZ) is shown in dotted red.

Figure 7: A/ Open fault at Tat'Ali, with alignment of steam vents, fumaroles and hot grounds with development of the "geothermal grass" (Fiale) benefiting from the condensing water and alteration of basalt flows. B/ Detail view of a high temperature steam blowing hole along the same fault (Photos J.Varet, 2016)

Given the quick development of the town and its surroundings, and the projected electric line (with large financing recently provided by AfDB) linking Afdera to Dallol, Makale and Semara larger production will be considered in the coming years once the first production will be in place (in 2020). The idea is also 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 link 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…). A request for a lease that covers the part of the Tata'Ali volcanic unit to be explored has been engaged by AGAPI to the relevant authorities.

5.4. Dabbahu in Teru

This site is also known as « Boina » (meaning fumarole in Afar) as initially called by Barberi et al. (1975) who studied this volcanic unit in great detail. It was shown to have developed along a transverse discontinuity where the spreading axis of Alayta (and Tat'Ali) axial ranges is displaced towards east and replaced by the active Manda Harraro spreading segment (DDBDH FZ). Although no caldera is observed, the presence of a shallow magma chamber was identified from the continuous differentiation sequence observed from transitional basalts to pantellerites. It recently became the focus of the international earth-scientists community due to a major volcano-tectonic activity on it in 2005. Over a length of 70Km, a normal fault opened up to 8m large and during the consecutive 7 years, several phases of magmatic injection were identified using various geophysical techniques (Microseismicity, Radar Interferometry, Global Positioning System <GPS> measurements and Digital Elevation Model <DEM> modelling) Only a few moderate surface eruptions were observed during these phases of dike injection. This means that, in terms of geothermal energy, a radiator, 70Km long, 10Km high at least and 8m large occurred complementing earlier magmatic injections.

This typical case of « accretion of oceanic crust » support the idea that a good geothermal site exists there, which should be better developed, in terms of permeability, at both extremities of the range where transverse faulting allows the development of geothermal reservoir conditions. The natural steam leakages (fumarole sites) are numerous in the area and well known by the Afar populations, who generally exploit these sites with artisanal condensing devices (see Fig. 4).

The region benefits from a favourable hydrogeological context, as the Teru plain is an endoreic basin collecting the waters from the nearby western Tigré plateau margin. Differing from Tat'Ali, this site (Dabbahu) benefits from a good natural refilling of the geothermal reservoir with meteoritic water. The Teru region is exceptionally green in Afar (comparing only with the Awash basin) with a strong agricultural development (mainly cattle breeding), a relatively large population (more than 80,000 inhabitants), and numerous villages, in addition to the small Teru Township.

A large area (over 5 Km in surface) where numerous steam manifestations occur along N-S faults was identified in the South-East flank of the Dabbahu volcanic complex during a geological exploration undertaken by AGAPI and Géo2D in 2015. These are not the only manifestations in the area, but they are well developed and located in a specific location along normal faults and open fissures tending in a N-S direction, that results from the interference with NNE-SSE faults (surface expression of transform faults) with the main NNW-SSE trend of spreading. This is interpreted as a "leaking" of the main geothermal reservoir located in the Dabbahu volcanic centre. This "outflow" is however large enough to constitute an interesting target for the small size geothermal project AGAPI is looking for.

A first unit of up to 5MWe fed by shallow geothermal wells (500m to 1,000m deep) should answer the socio-economic needs of the local population, implying the development of a local grid. This should help for local agro-industrial development (eg. food processing abattoirs, milk industry) and exports which would create additional incomes for the target Afar community. This could be a first step before larger development allows for a connection to the Federal electric grid which lacks base load production in this north-eastern part of the country.

6. AGAPI'S PROJECTS FOLLOW UP

These two first AGAPI's projects target an electric production answering the local needs (that is power units of a few (2 to 5 MW) in a 3 years period. In both cases, the combined production of electricity, heat and water is 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 surrounding consumption centres and eventually to the grid as the development of the electrical network progresses (see AfDB project in Afdera). The projects will be developed in 3 phases:

- Prefeasibility study: complementary surface geology, hydrogeology with fluids sampling and analysis, and geophysical (MT-TEM) surveys allowing to precise the extension and characteristics in depth of the reservoir, and establish geothermal models on both sites.
- Feasibility: exploration-production drilling at a depth of 500 to 100m aiming to reach a superficial steam reservoir and characterize its initial geothermal development.
- Production of the geothermal field and construction of the power plant (probably with binary ORC technology) and other devices (electricity, heat, water) with the corresponding networks[5].

The two first phase will hopefully be engaged with the support of GRMF and other donor agencies. Climate fund will in particular be looked for. The next phase will be engaged with the support of banks (refundable loans). Both projects are conceived in the objective of training local afar personnel's which will later work either on the sites or on other geothermal projects in Afar. A partnership was established by AGAPI with Semara University, also involving Addis Abeba and Makale Universities.

7. CONCLUSION

AGAPI's approach to projects is innovative: It aims at involving the local African communities in the development of geothermal resources and exploitations, the situation being that they are at presently essentially disregarded from such processes. It aims at developing small size projects answering local rural needs (even for pastoral communities) which is also not the case for geothermal energy at present in Africa.

AGAPI's projects aim at being pilot projects that can be replicated in other parts of Eastern Africa: The Afar community has with their proposed projects, taken up an approach that originates from themselves and that could then be, in the true sense of the word, considered to be community-initiated, led and managed. Interestingly, there are similarities to be drawn from the Afar community's approach with the Maori, an indigenous community of New Zealand, despite the fact that when AGAPI was set up, the Afar had no knowledge of the Maori example, who presently directly benefit from geothermal projects they own as a community (see Onyango & Varet, this volume).

AGAPI's projects also intend to address some key developmental issues like:

- *The fight against poverty*: The Afar population lives on not more than 1$/per day and per inhabitant;

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

- *Enhance the local community's awareness:* The increased knowledge of the target community regarding its local resources and the anticipated resulting undertaking of community-based development initiatives. ;
- *Gender:* Taking into account the perspectives of women, men, boys; and girls and particularly in view of the fact that among the Afar, as in most African communities, women and girls are the ones primarily in charge of provision of energy and water.;
- *Adaptation to climate change*: The Afar region has always been a desert and with global warming (primarily resulting from carbon emissions), the situation has worsened, despite the fact that the Afar population has had little if no contribution to this situation.
- *Reduction of greenhouse gas emissions*: By replacing diesel-driven devices with the green energy geothermal powered units;
- *Enhanced North-South partnership:* With the involvement of scientists (geosciences and social sciences[6], engineers, enterprise's (drillings, binary plants, mini-grid, local community services);
- *Training of future Afar geothermal professionals, technicians and workers:* With the participation of the Universities of Addis Abeba, Makale and Semara, by training interested local students in studies related to AGAPI's projects.
- *Ecological transition:* In the proposed approach, the development will move directly to renewable and sustainable energy solutions, skipping the « fossil » stage.
- *Enhanced community resilience:* Through the promotion of sustainable development based on the utilization of natural resources, which provides stability regardless of climatic variations.

It is expected that developing the proposed projects will open up avenue for major potential future development initiatives. This is because having the activities proposed by the project around the geothermal sites has the potential to open up future larger developmental opportunities; the innovation here being that local communities will meaningfully participate in decision-making processes that affect them and the ensuing management of their natural resources, instead of remaining on the periphery of decision-making processes as is currently the case of all the other pastoralist communities in Eastern Africa.

AKNOWLEDGMENTS

The authors thank Ras Mengesha Seyoum for his constant support, for the last 50 years, for geothermal development in Afar and Peter Omenda for his in depth review of this manuscript.

REFERENCES

Ayele, A. & all. (2009). September 2005 mega-dike emplacement in the Manda-Harraro nascent oceanic rift (Afar depression). *Geophysical Research Letters*, vol. 36.

Barberi, F., Borsi, S., Ferrara, G., Marinelli, G. & Varet, J., (1970). Relations between tectonics and magmatology in the northern Danakil Depression (Ethiopia). Philosophical *Trans. Royal Soc. London*, A267, 293 - 311.

Barberi F., Giglia G., Marrinelia G., Santacroce R. et Tazieff H., Varet J. (1971) - Carte géologique du Nord de l'Afar, CNRS-CNR à 1/500 000e. *Géotechnip*. La Celle-Saint-Cloud.

Barberi, F., Tazieff, H. & Varet, J., (1972). Volcanism in the Afar depression: its tectonic and magmatic significance, *Tectonophysics*, 15, 19–29.

[6] cf. Thesis under progress by Susan Onyango at l'EHESS, Paris (Community-based Geothermal Development from a Gender Perspective)

Barberi, F., G. Ferrara, R. Santacroce, M. Treuil & J. Varet, (1975). A transitional basalt-pantellerite sequence of fractional crystallisation, the Boina centre (Afar rift, Ethiopia), *J. Petrol.* 16, pp. 22–56.
Barberi, F. & Varet, J., (1977). Volcanism in Afar: small-scale plate tectonic implications, *Bull. Geol. Soc. Amer.*, 88, 1251–1266.

Kendall, J.-M., Stuart, G., Ebinger, C., Bastow, I. & Keir, D., (2005). Magma-assisted rifting in Ethiopia, *Nature*, 433, 146–148.

Omenda' P., Achieng, J., Onyango, S.Varet' J., (2014): The "Geothermal Village" Concept: A new approach to geothermal development in rural Africa. *Proc.5th Afr.Rift geoth. Conf.Arusha, 29-31 Oct.*

Onyango, S. & Varet, J. (2014). For a new social gender-based approach to geothermal development. *Proceedings 5th African Rift geothermal Conference, Arusha, Tanzania, 29-31 October 2014*

Varet J. (2006). The Afar triangle: a future "gulf region" for world geothermal energy? - *ARGeo-C1 - First East African Rift Geothermal conference -Addis Abeba - Ethiopia - 24/11-02/12/2006*