A Geothermal Civilization in the Afar Region: Era Boru
(Teru woreda, Ethiopia)

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ABSTRACT

Extensive field surveys in Afar show that the geothermal resource has extensively been used by the local population for a long time, at least few thousand years, since the climate changed from wet to dry (4,800 years BP). With the noticeable exception of southern Afar, where the Awash river always provided water, and the marginal grabens along the Nubian faulted western Afar margin, the use of geothermal resource appears as generalized (most fumaroles are equipped) in northern and eastern Afar. The fumaroles are numerous along the active volcanic ranges and centres as well as along active faults and open fissures affecting the basalts and rhyolites of the stratoid series (3.5 to 1 My). Most (if not all!) of them appear to have been engineered by the local population in order to recover water from the condensation of the steam. The device includes digging in the steam vent, removing rocks and clay that result from the alteration of the volcanic lava, allowing the steam to rise along the upper wall which is most frequently the fault plane. Then building a dry-stone wall that will allow to place branches of acacias over the steam vent. This will form a wet well, where steam will condensate along the branches and liquid water will fall in the impermeable basin that will have been shaped with the clay in the lower part of the system. Depending on the topography the basin may be directly accessible (in case of steep slope) or will be accessed with a bucket and a short rope. Water is used for all kinds of human consumption, but mainly for herds of livestock in this pastoralist society.

In some areas where seasonal pastures and water points are temporarily available these devices are only used by nomads when passing through these places – called “Boina” in Afar language and well known as such, or as refuge in case of drought. But there are places where these devices are the only current source of water, throughout the year, with Afar people having settled there permanently. This is notably the case in north-eastern Afar, at a place called Boina during the first exploration, a name that was retained by the Geological Survey of Ethiopia. It was later called “Dabbahu” from the name of the silicic peralkaline centre that form the nearby summit. Dabbahu meaning “high mountain” in Afar, it is the appropriate name for this volcanic centre (1,440m high) but not for the geothermal field, that is named “Era’Boru” (meaning “steaming crater”) by the local population that have over the years developed this historical geothermal civilisation.

These systems extend at an average altitude of 700m over several hundreds of square kilometres, in which hundreds, if not thousands of steam wells have been engineered and are still operating currently. This paper describes these artisanal devices (built and maintained by skilled specialized Afar community members), their geographic extension, geological environment and the geothermal conceptual model supporting this exceptional field. It also recommends for further interdisciplinary research to be engaged on this historical geothermal civilization.
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 immemorial times, 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 (over one million) 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 centre as its capital.

Within the EARS, Afar displays a particular geodynamic situation, as it is not just the northern extension of the East African Rift System (EARS), but in fact part of the Red Sea – Gulf of Aden oceanic rift system, 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 Arrata block (earlier called Danakil Alps) acting – for the NE part - as a microplate rotating anticlockwise in-between the Southern Red Sea and the former Danakil sea, whereas the SE part acts as an accretion of the Arabia plate (Varet, 20018 ; Figure 1).

Figure 1: The Afar triangle and surrounding region (modified from Keir et al., 2012). The anticlockwise rotation Arrata Block is shown in pale color whereas the Arabia accretion is in yellow. The orange triangles show Holocene volcanoes. The grey circles show large (>ML 3) earthquakes. The black earthquake focal mechanisms are from the Global Centroid Moment Tensor catalogue, the red earthquake from Illsley-Kemp et al. (2018).

Bottom right inset: Plate motions relative to a fixed Nubian plate (ArRajehi et al., 2010).

The violet rectangle limits the studied area where geothermal steam appear as the regular source of water for the local pastoralist population.
The floor of the Afar triangle is covered by dominantly basaltic lava piles, called the Afar Stratoid series, ranging in age from 4 to 1 My. This unit is extensively faulted (active normal faults and open fissures). From North (Gulf of Zula in Eritrea) to South-East (Gulf of Tadjourah in Djibouti), several well-defined spreading segments expressed at the surface by basaltic axial ranges developed in the last 1 My and are still active (Figure 2). All are oriented in a NNW-SSE (in the NW part) to NW-SE direction (in the Eastern part including the link with the Gulf of Tadjourah at Ghoubbet-Asal), coherent with the Red Sea and Gulf of Aden Mid-Oceanic Ridges (MOR). Along both sides, transverse ranges and central silicic volcanoes – equally recent and active – are observed in areas of discontinuities of the basement. They eventually mark transverse fracture zones (TFZ). These central volcanoes show similitude with those found in South-West Afar along the MER northern extension.

Figure 2: Geological sketch map of Afar (after CNR-CNRS, 1973; Varet, 1975; Beyene & Abdelsalam, 2005, modified) showing the location of Era Boru (violet rectangle) and the volcanic units of Afar (from Miocene to present). Miocene units (earlier continental rift type) are located along both sides of the now stabilized margins of eastern and western Afar. Most of the Afar floor is covered by the dominantly basaltic stratoid series (rose). During the last million year, all along the Afar floor, the activity concentrated in Axial ranges, oriented NNW-SSE and NW-SE, as well as in marginal centres and transverse units. Similarly, along the Main Ethiopian Rift (observed here in SW Afar), the recent activity concentrated in basaltic fissural lava fields and central silicic volcanoes along NNE-SSW faults and dikes.
Both active faulting of the stratoid series and these various active volcanic units provide numerous opportunities for the development of surface heat release, under various forms, dominantly as fumaroles, steam vents and hot-wet grounds.

As a result, with the exception of its stabilized margins, the whole Afar floor benefits from this particular form of groundwater, despite generally deep water tables, thanks to convective systems emerging at the surface through open faults. All sites are known – and named as such – by the local pastoralist population, which will use them for water production by condensation and also as graze-lands thanks to specific vegetation developed on these wet environments in which sand and dust brought by the wind will contribute to the development of soils, together with the red clays produced by hydrothermal alteration of the volcanic rocks.

In many places these sites are used temporarily in the most arid periods, which tend to become more frequent due to climate change. But in Era Boru, a place meaning “steaming crater” located in central-western Afar, an important population settled in a wide area which benefits from important steam manifestations in a specific geological environment. The aim of this paper is to provide a first description of this “geothermal civilisation” which deserves a specific geo-anthropological study that should be engaged by an interdisciplinary team.

2. The Era Boru geothermal civilisation

Until now, the Era Boru area has been of rather difficult access. The only route was from Teru, a wide, flat-lying sedimentary plain located at the foot of the Nubian escarpment. Over a width of 15 to 20 Km and a length of 45 Km, this plain at an average altitude of 300 metres developed a rather large green-grass-land as it forms an endoreic basin closed East by the Alayta and Dabbahu lava fields and north by the Ma’Alalta central stratovolcano, fed by short temporary river beds benefitting from the wet climate of the Nubian plateau border (Figure 3). Teru can be reached in 3 hours’ drive along a well-maintained earth road from Semara, capital of the Afar Regional State.

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**Fig.3:** Hydrographic basin feeding the Dabbahu geothermal site from the Nubian plateau.
Observe the marginal graben;
Along the foot of the escarpment.
NASA/SRTM source, BRGM Processing (Varet et al., 2012).
From the south-eastern end of the plain, a difficult track allows to reach the southern bottom of Dabbahu volcano, where the first sets of steam wells can be visited, with a few dozen of Afar families settled there where both green plain provide vegetation for the livestock and the condensation of the steam provide water answering human and herds (goats, sheeps, cows, donkeys and camels) needs (Figure 4).

![Figure 4](image1.jpg)

**Figure 4:** Traditional device for water condensation from fumaroles (“Boina”) using acacia branches on a well dug along an emitting fault South of Dabbahu (Photo: J.Varet, 2016).

Similar habitats are found all over the southern flank of Dabbahu (Figure 5), where the same steam well design is used for water production, whereas active N-S faulting provide linear sets of vegetation which benefits from the humidity released by the open faults (steam release progressively cooling towards the surface along the fault walls).

![Figure 5](image2.jpg)

**Figure 5:** Circular constructions seen from satellite imagery South of Dabbahu several of them used for steam condensation
As a whole, on this southern flank of Dabbahu volcanic centre, two wide areas totalizing 100 Km² are observed where condensing devices engineered by families using the grazing lands in the numerous grabens and open faults affecting the foot of the volcanic massif. The southernmost is in fact the northern extremity of the Manda Harraro axial range where numerous N-S trending faults are leaking steam feeding a rather abundant vegetation developed along the fault planes (Figure 6).

![Figure 6: Satellite image of vegetation developed along faults, South Dabbahu (North Manda Harraro axial range)](image)

The solution of reference for the population is to condensate the naturally steaming grounds for liquid water production and other uses (washing, boiling food and tea…). The technique is to improve the steaming of the fissures and faults by diggings with a short hoe to enlarge the vent, removing stones and clay produced by alteration of the lava, and to install devices for channelling and condensing the steam. This is done building a dry-stone wall, 2 to 5 metres wide, allowing to fix horizontally acacias branches in order to collect the liquid water by condensation. The drops then fall in a basin made of the red clay resulting from the hydrothermal alteration of the volcanic rocks earlier extracted from the well through diggings. The water is then drawn out with a bucket and a rope (Figure 7 & 8).

![Figure 7: schematic cross section through a traditional geothermal steam condensing device as observed at Era Boru. Steam leaking from faults is channelled through a circular (2 to 5 m diameter) dry-stone wall and condensate through acacias branches. Liquid water is collected in a clay basin accessible through removeable opening in the dry-stone wall.](image)
The widest zone, where hundreds of water-condensing devices are installed and currently used by an important population (several thousand people) is located on the East and North-Eastern sides of Dabbahu, on a plateau averaging 700m high over a surface of circa 200 Km² (Figure 9). The place is dominantly covered at the surface by silicic pyroclastic layers, some welded, allowing easier digging and construction of the steam wells. We find here, in a rather remote area (a full day walk through rugged terrain from Teru) a real autochthonous population which settled there, probably for centuries if not millenniums, using geothermal as a source for water and other needs, cooking and washing in particular. In addition to serving the needs of the herds (Figures 10 to 12). The numerous obsidian tools found in the area results of course from the vicinity of the obsidian domes and flow in the surroundings, but also testify a long-lasting human occupation of the plateau, linked with the use of the geothermal resource.
Figure 10: The numerous steam wells are well visible on this satellite image detailed from south centre of image above.

Figure 11: steam wells used by pastoralists to provide water for the herds (oats here), installed on a fault scarp. The slope allows for a direct access for the herds to the clay basin. Observe the fabrics drying on a wall after having been washed.

Fig. 12: Satellite view of numerous steam wells along the side of a fault scarp a few Km north of Fig. 7 (same site as Fig.9)
Figure 13: further north, at the foot of a recent obsidian dome, numerous steam wells are observed along a N-S and NE-SW faults. (satellite image)

Figure 14: Over most of the Era Boru plateau, a detailed observation of the satellite imagery reveals the ubiquitous presence of steam wells

At present, an East-West road is being built that will link the N-S Sardo-Afrera asphalted road to the N-S Semera-Teru road (Fig.15). The road will eventually cross through Era Buru, inducing social changes. It is therefore highly time to engage an interdisciplinary research on this genuine geothermal civilisation that will not survive the changes.

Most probably, the construction of the new road will induce interests for development projects in the area, like livestock products, agroforestry, mining, and of course industrial geothermal units of electricity production. The challenge being for the population on site to be part of these projects, allowing them to continue benefitting from the ancestral use of these geothermal resource that allowed them to live for centuries in a sustainable way with a low dependence from the outside world. A challenge for Ffar Pastoralist Development Association (APDA) and Afar Geothermal Alternative Power Company (AGAP) now looking for technical and financial partners to develop these resources for the benefit of the population on land. Meaning to invent a modern way to maintain on site a continued original geothermal civilisation.
3. Geological characteristics of the Era Boru geothermal site

The site is located at a place where two spreading segments trending NNW-SSE are “en-échelon” with Alayta north and Manda Harraro south, a shift that is also observed in the Nubian escarpment. It is therefore considered (Varet, 2018) as resulting from pre-existing lines of weakness in the basement which induced a transverse fracture zone (FZ) that resulted in the occurrence of a transform fault (TZ) between the two spreading segments, as shown in Figure 16.

However no clear transform fault is observed at the surface between the two spreading segments, but a set of silicic peralkaline domes and flows, with a few pyroclastites (pumices and welded tuffs), emitted along feeding dikes of sub-N-S direction, as seen of Figure 17. The transform fault zone, 25 Km x 25 Km i.e. circa 600 Km2 wide acts as a set of short slow -spreading segments, favouring the development of crystal fractionation in shallow magma chambers (Barberi et al., 1975; Gardo & Varet, 2018).
Figure 17: Satellite image showing - underlined in red - the termination of the basaltic spreading segments of Alayta (north) and of Manda Harraro (south), and – underlined in yellow - the emissive axis of the silicic domes that developed in the Era Boru area.

The high elevation of the Dabbahu volcanic centre (reaching 1400m high asl; its name meaning “the large mountain”) results from the accumulation of thick silicic obsidian flows on the top of a basaltic shield (also made of lavas of intermediate composition), but may also be a consequence of inflation of the whole volcanic edifice by underlying feeding dikes and magma chambers. InSAR modelling of interferograms obtained since the 2005 event allowed to
identify an uplift signal of 50 cm, that could be interpreted as a point source at a depth of 3 Km inflated by 0.022 Km$^3$, but a better fit was obtained from multiple stacked sills at depth of 3 to 4.5 Km.

The aseismic zone observed from the 2005-2006 earthquake data allowed to locate the magma storage region at a depth of 2 to 6 Km, whereas abundant earthquakes above 2 Km suggest a fractured roof – and eventually the site of the geothermal reservoir - above the magma chamber. Using geothermometry and geobarometry models from the phenocrysts composition, Field et al. (2013) précised the temperature (1200-680°C) and depth (10-15 Km) ranges where this crystal fractionation process occurred. If the crystal fractionation initiated for the basalts at depth or 15 Km in the feeding dikes, the final steps of differentiation therefore apparently essentially occurred at shallow depth (in the 6 to 2 Km range) in small size bodies, such as stacked sills or closely spaced dykes. Ages were measured 44 to 10 ka by Barberi et al., (1972) for two obsidians; and Field et al. (2013) provided ages of 64 ka for andesine basalts from the shield volcano, whereas younger andesine basalts were dated 33 ka, comendites 30 ka and pantelleritic obsidians younger than 7.8 ka. As whole, these still incomplete set of dates show a recurrent activity from for the last 100 ky, until present day (the last silicic eruption occurred in 2005 during the earliest seismic events).

As a whole we can deduce that an efficient magma storage system has maintained a rather stable geometry within this 600Km2 area over the past few ten thousand years. Therefore, huge and powerful shallow magmatic heat source characterize the area, and a geothermal gradient up to 34°C per 100 m (that is 10 times a normal continental gradient) can be expected at Era Boru steam field. As shallower depth (up to 2 Km deep) multiple and recurrent faulting and facturing favour the permeability in the brittle rocks overlying the magma chamber(s), hence the development of geothermal reservoirs. Surface leakages (steam vents) are abundant due to the recurrent distensive faulting affecting the area.

Two MT profiles were undertaken in the Dabbahu massif by Johnson et al. (2016). The results indicate the characteristic resistivity profiles that are expected in a geothermal system, with a very low superficial resistivity zone that can be interpreted as the clay cap covering the geothermal reservoir, displaying high resistivities down to 2-3 Km depths, whereas a deeper (8 to 3 Km deep) low resistivity zone indicate the magma chamber. Note that these characteristics extends over a width of 20 Km along an E-W line across the area. The wide hydrographic basin pictured in Fig3, which developed along the normally faulted and intensively eroded escarpment of the Nubian plateau provide a natural refilling of these geothermal reservoirs. In addition to active normal faulting, lateral grabens facilitate the infiltration of meteoritic water from the wet highlands into faulted Proterozoic basement, its Mesozoic sedimentary and Miocene basaltic cover granite intrusions and detrital formations.

**CONCLUSION**

Era Boru area appears as a place, eventually unique in the world, where a complete social organization emerged, based on a direct relation of a human community with an exceptional geothermal resource with steam abundantly available at a surface of a wide plateau, isolated from the rest of the region given the difficult access conditions. For millennium, a sustained development demonstrated its efficiency. Now that a new road is being build, which will open
this society to outside world, the opportunity arise for these geothermal resource to be used more efficiently for both energy and water production.

With:
- an exceptionally large magmatic heat source,
- an abundant water recharge,
- active complex fracturation determining high permeability for the reservoir
- magmatic heat source, geothermal steam reservoir and clay cap confirmed by geophysics

Era Boru appear as a highly promising geothermal resource of major interest at national and regional levels.

At the Argeo C7 conference in Kigali in 2018 the authors expressed the call of AGAP, looking for partners to confirm the resource through complementary surface studies and exploration drilling. However, given the importance of the geothermal civilisation that live in the area thanks to the ancestral use of the geothermal steam gathered at the surface with artisanal devices, the authors who met the people now consider that such a development requires an in depth socio-anthropological study in order to better document the characteristics of this specific population. People at Era Boru lived for centuries in a rather autonomous, self-sufficient economy with a pastoralism based on direct use of this high temperature geothermal resource available at the surface. This plateau separated from the surrounding Afar lowlands where communications by roads developed in the recent years, will in the coming month be made accessible by a road now under construction. This will induce changes in this society that need to be properly anticipated and accompanied.

Geothermal development will not be responsible for the social consequences of this new communication axis, but should obviously play a role in a local development which must be appropriated by the people concerned. It is therefore a priority for AGAP and APDA to identify the partners that would accept to partner for such a social approach.

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REFERENCES


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