THE GEOTHERMAL VILLAGE (GV1) LEAP PROJECT 11 THE ERABORU SITE (AFAR REGIONAL STATED TERU WOREDA, ETHIOPIA)

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Long-Term Joint EU-AU Research and Innovation Partnership on Renewable Energy

The LEAP-RE project has received funding from the European Union's Horizon 2020 Research and Innovation Program under Grant Agreement 963530.

Introduction

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- Context & Relevance of the study

A site of exception, with steam at the surface

Among the 4 sites selected for the Geothermal Village (GV1) project supported by the EU under the LEAP-RE (WP11), the northernmost (Fig.1) named “Era’Boru (meaning “steaming crater”) is located at the northern extremity of the active Manda Harraro range, at the Eastern foot of “Dabbahu” silicic peralkaline volcano (1440m high).

- In terms of geodynamics, this can be considered as a “leaky” transform fault zone, itself part of a major fracture zone crossing through the whole Afar triangle (Fig.2).
- Such volcano-structural environment, similar to Olkaria in Kenya, indicate a “Giant” geothermal system (Omenda & Varet, 2020).
- As most of Afar, this is an arid site where a rather important Afar Pastoralist Community lives, based here on the use of water condensation from geothermal steam.

Off-grid and off-communications, the site is ideal for a resilient solution answering the needs for energy and water

Geodynamic context favors geothermal solutions

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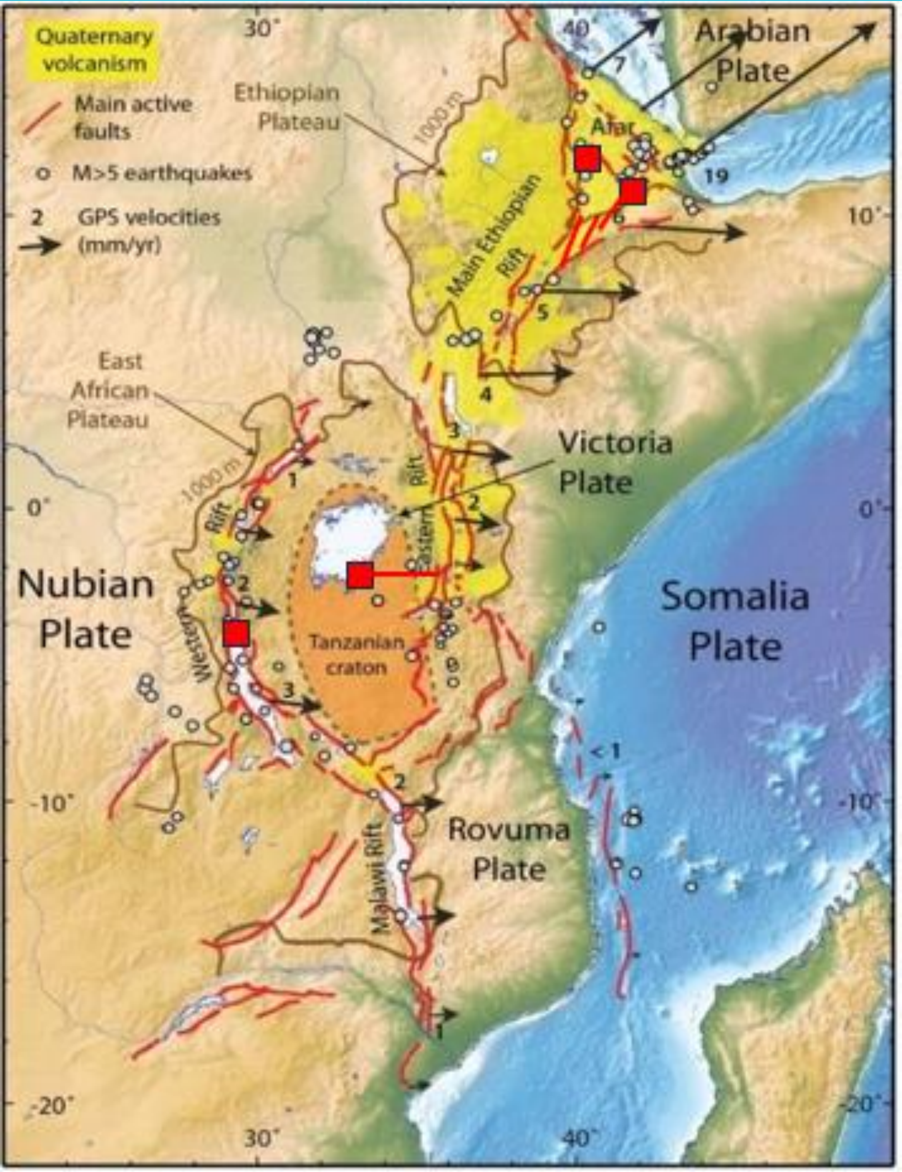


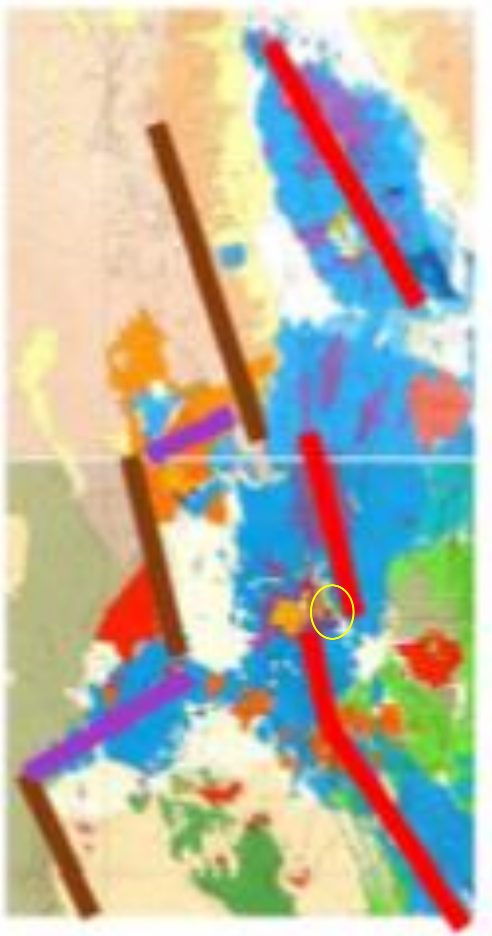
Figure1: The East African Rift System (EARS), extending from Mozambique (S) to Eritrea (N), with

- *major fault systems (in red),*
- *main earthquake location (white dots for M> 5),*
- *manifestations of Quaternary volcanism (in yellow) and*
- *plate-motion vectors with GPS velocities (black arrows, with numbers in mm/y).*

Observe the progressive increase of the spreading rate from South to North along the EARS (from 2mm/y in the KRV, 5 to 7 mm/y along the MER and up to 2 cm/y in Afar).

Among the 4 sites studied under LEAP-RE WP11, pictured with red square, The northernmost is Era Boru (EB) in Ethiopia with plate motion of 20 mm/y.

The base map is modified from Calais (2016)



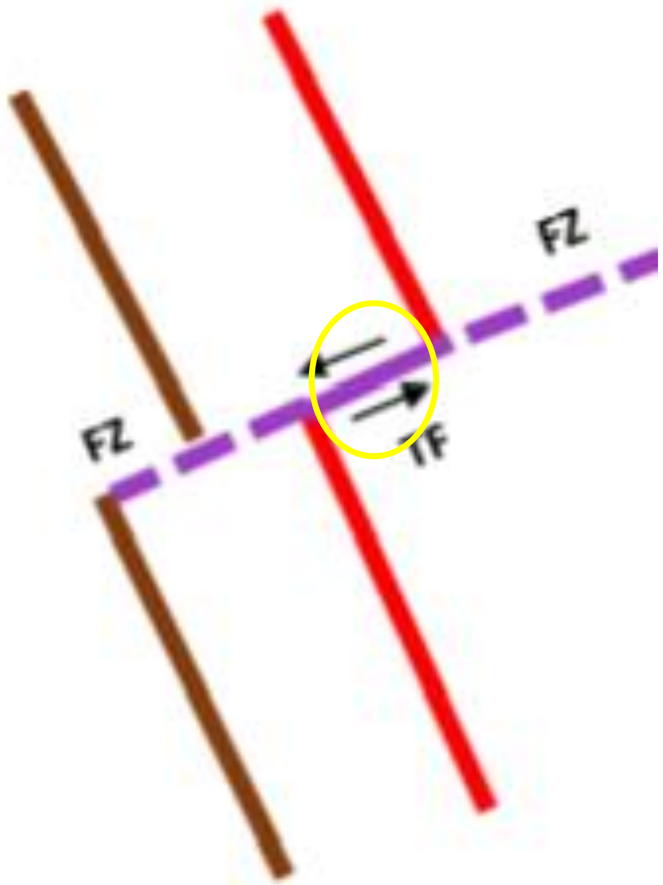


Fig.2: Left: A Extract from the geological map of Afar (CNR-CNRS, 1971 & J.Varet, 1975).

- *Basement discontinuities (bottom of faulted escarpment) are underlined in dark brown.*
- *The spreading axis of axial ranges (Erta Ale, Alayta and Manda Harraro) are underlined in red.*

The shift between these two active segments appears as directly linked with – and resulting from - a similar shift observed along the faulted margin of the Escarpment. Transverse volcano-tectonic structures are in violet.

The scheme provides a plate tectonic interpretation with Fracture Zone (FZ) and Transform Fault (TF);

Eraboru site is underlined in yellow

from Varet (2018); Omenda & Varet (2020).

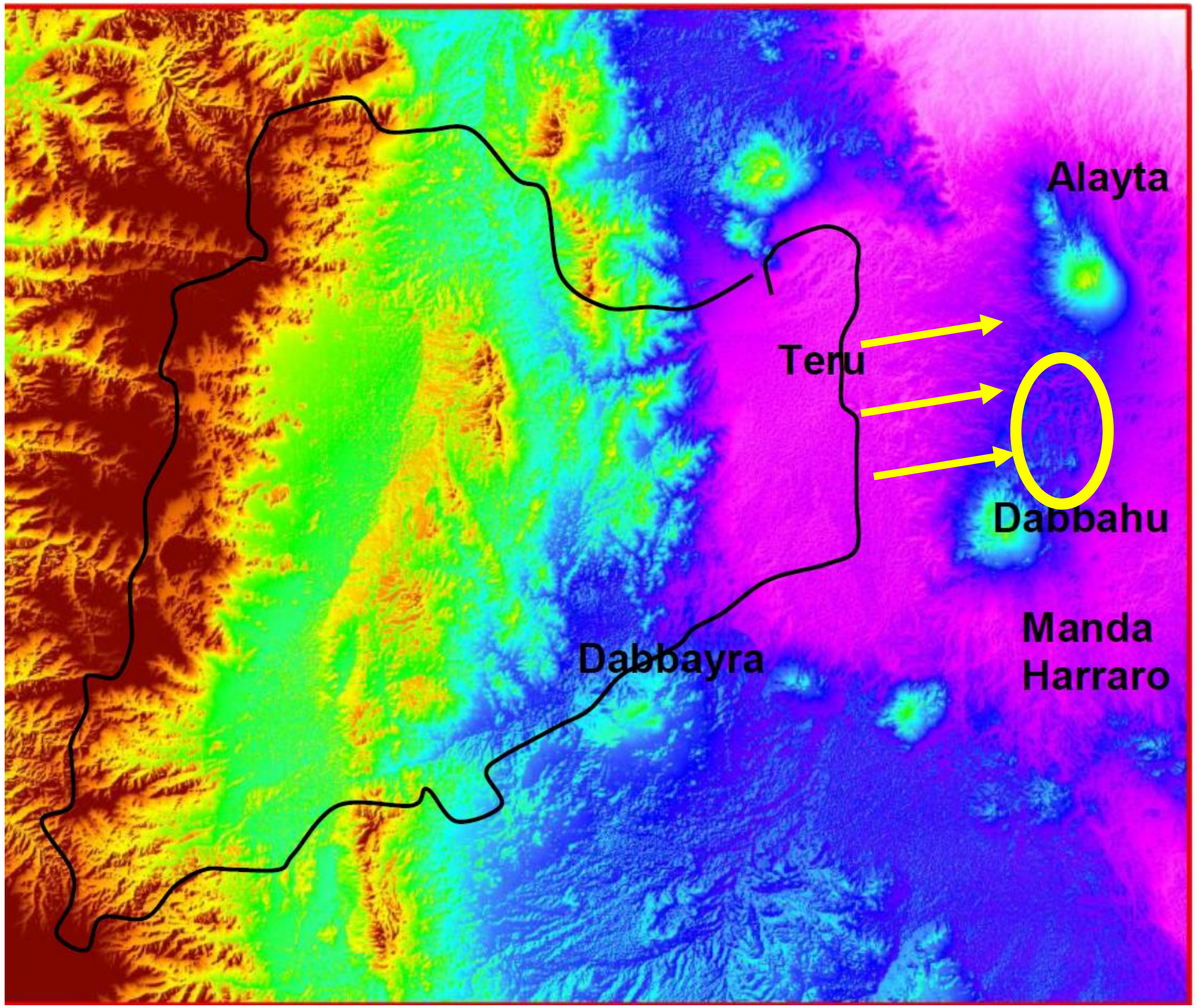


Fig.3 Elevation map showing the extension of the hydrographic basin feeding the Teru sedimentary plain and ensuring a meteoritic water ensuring the refilling of the geothermal system by underground flow (yellow arrows) and feeding surface steam vents at Eraboru;

Eraboru geothermal site is pictured in yellow ovale

From Varet (2006).

NB: A limited outflow of the endoreic Teru plain is possible north, towards the Dodom plain along the western foot of the Erta Ale range

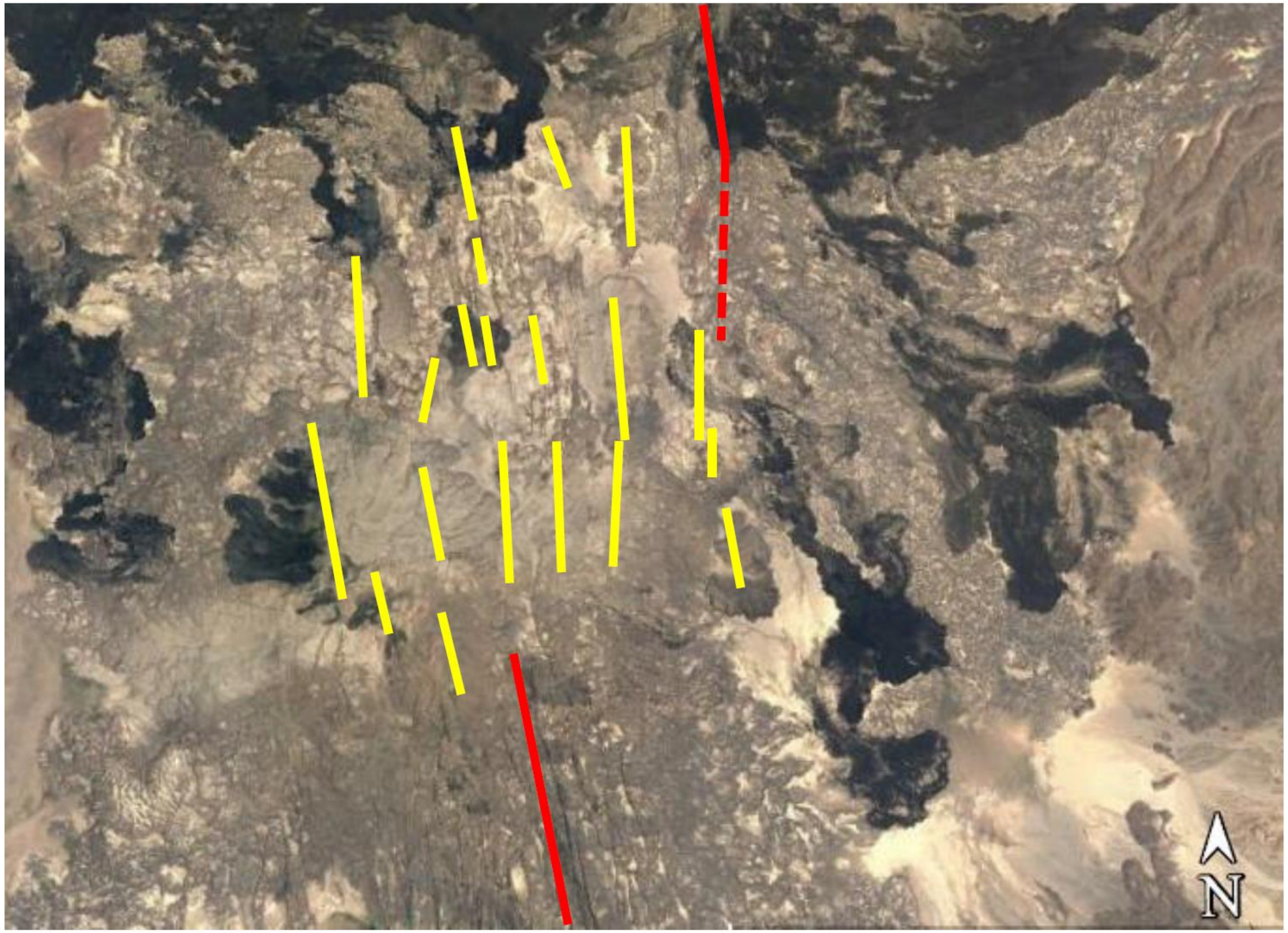


Fig.4 : Satellite imagery of the Eraboru geothermal site with the spreading axis (axial volcanic ranges) of Manda Harraro (South) and Alayta (North) underlined in red.

The open fissures, emissive of rhyolite domes and steam vents are underlined in yellow, covering a surface of 25x25 Km, i.e. over circa 600km^2.

From Varet et al. (2020)

Context Analysis: previous studies

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The site was first studied by Barberi et al. (1977) who did show that le Dababhu volcano (meaning ‘high mountain”), called Boina by mistake, (Boina meaning steaming engineered site in Afar language) is the site of a magmatic differentiation from transitional basalts to pantellerite through crystal fractionation)

Since then, first neglected by the UNDP geothermal survey of Ethipia (1972) it was identified as a geothermal site by the Ethiopian Geological Survey (under the name of Boina)

The site was then studied following the 2015 Volcano-tectonic Event affecting the whole Mand harraro Range called Dabbahu (Ayele, 2015; Ebinger et al. 2010)

It was considered as a priority geothermal target for the newly created Afar Geothermal Alternative Power company (AGAP) as reported by Gardo & Varet (2016), and as a «Giant» by Varet et al. (2020).

The extension of the use of the geothermal steam in the Eraboru plateau allowed to describe this indigenous population as a «geothermal civilisation» (Gardo & varet, 2020).

It was then selected as one of the 4 geothermal Village for LEAP-RE WP11 (GV1 project)

Methodology

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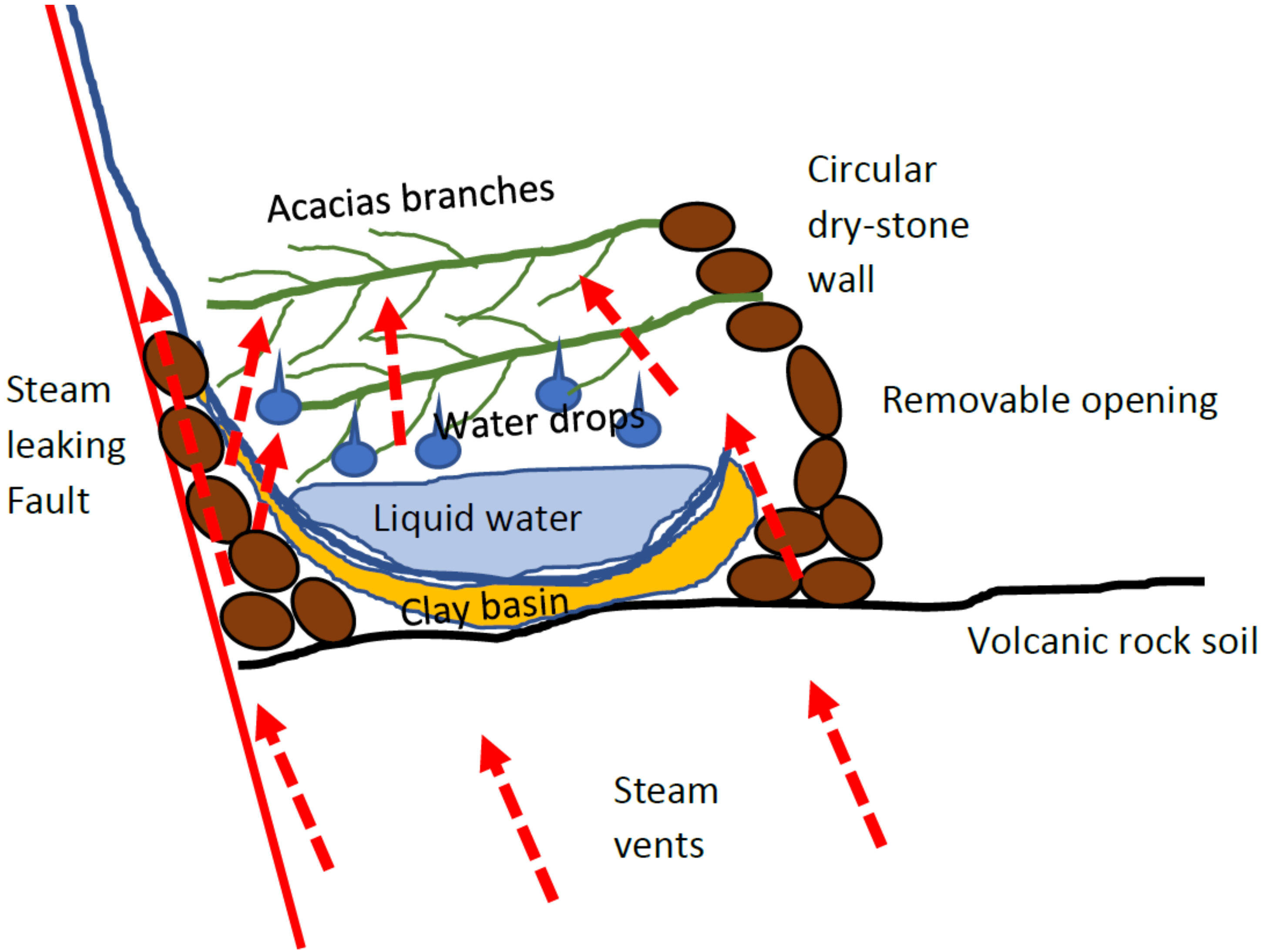
1. **A geothermal resource traditionally captured for water production by steam condensation**

Eraboru is a plateau, 700m high, where a wide geothermal field extends over several tens of square kilometres (Fig.4), in which hundreds of steam wells have been engineered by local pastors to recover liquid water from the condensation of the steam (Fig.5).

The device includes digging with simple tools 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. Branches of acacias, placed over the steam vent and maintained by a circular dry-stone wall allow the steam to condensate along the branches, and liquid water will fall in the impermeable basin shaped with the clay. Water is used for all kind of human and herds consumption (Fig.6).

Such adaptation of the indigenous population to extreme arid conditions (no surface water is available) can be regarded as an early “geothermal civilization” (Gardo & Varet, 2020).

Fig.5: One of the typical steam-well engineered by local Afar people at Eraboru, allowing to condensate the steam and provide liquid water for the herds (cows, goats, sheep, donkeys and camels) and circa 100 pastoralist families.



Interpretative section across these artisanal devices (Gardo & Varet, 2020).

After digging with simple tools 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.

Branches of acacias, placed over the steam vent and maintained by a circular dry-stone wall allow the steam to condensate along the branches, and liquid water will fall in the impermeable basin shaped with the clay.

It is then extracted using a baquet

Results (1)

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- Scientific Methodology Adopted in the Study

1. A wide, shallow (6 to 2 Km deep) magmatic heat source

Dabbahu volcano and Eraboru (EB) steam fields are located at the northern extremity of the Manda Harraro range, the most active spreading segment in Afar, with a spreading rate of 2cm/y, confirmed by the recent event (2005-2010), when this rift axis did open 8 m wide over 75 Km long, with basaltic magma injection and scarce eruptions, including a silicic pyroclastic eruption at EB (Ayele, 2015; Kendall at al. 2005; Ebinger et al., 2010). This vertical radiator in itself provides a significant heat source!

Besides this, the magmatic evolution at EB studied by Barberi et al (1975) using petrology, geochemistry, and microprobe mineralogical analysis, show a complete set of crystal fractionation from transitional basalts to pantellerites, and compositional variations within the rhyolite domes showing distinct magma chambers. Geothermometry and geobarometry models from phenocrysts composition, précised the temperature (1200-680°C) and depth ranges where this crystal fractionation process occurred (Field et al. 2013). It initiated at depth or 15 Km in the basaltic feeding dikes, with the final steps in the 6 to 2 Km range in stacked sills or closely spaced dykes.

K/Ar ages are ranging from 64 ka for the shield volcano, with pantelleritic obsidians less than 7.8 ka. A recurrent activity occurred from for at least 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 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 Era Boru steam field.

The aseismic zone observed from the 2005-2006 earthquake data confirmed the location of magma storage at a depth of 2 to 6 Km, whereas abundant earthquakes above 2 Km suggest a fractured roof – eventually the site of the deep geothermal reservoir - above the magma chamber (Ebinger at al., 2010).

Results (2)

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A fractured steam geothermal reservoir, a few hundred meters deep, refilled by meteoritic water

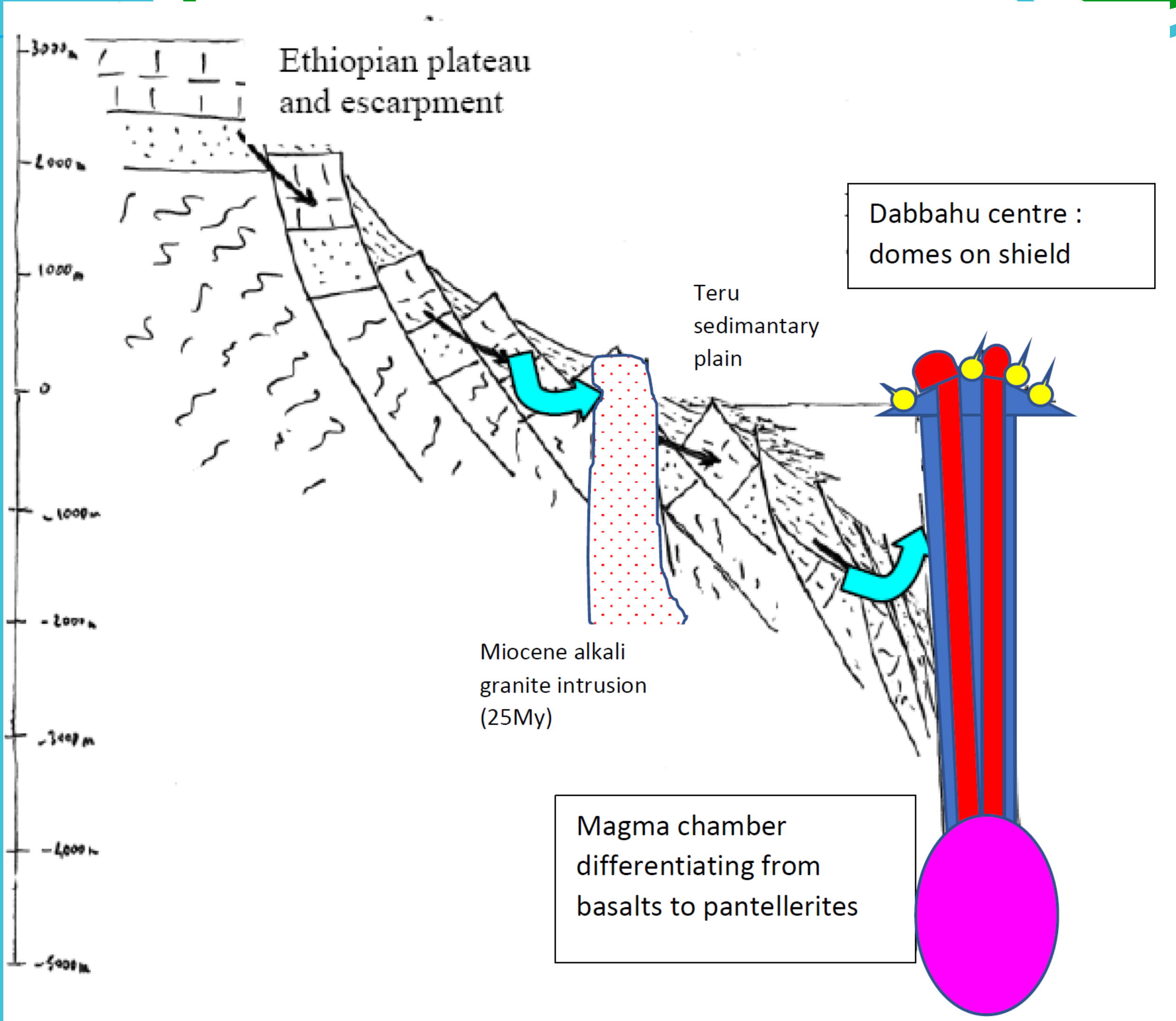
Surface observations show numerous open fissures, most of them displaying steam vents: an intensively fractured substratum, i.e. a leaking shallow geothermal reservoir. The geological environment of this volcanic system, located at the foot of the deeply faulted Nubian escarpment allows for a refilling of the geothermal reservoir from important surface and groundwater inflow in the nearby Teru sub-endoreic sedimentary plain (see Fig.3).

This allows to sustain important steam leakages made of relatively pure water of meteoritic origin, captured by the traditional steam wells described in Fig.5&6.

Two MT profiles indicate characteristic resistivity profiles expected in geothermal systems, with a very low superficial resistivity zone interpreted as a clay cap covering the geothermal reservoir, with high resistivities down to 2-3 Km depths, whereas a deeper low resistivity zone indicate the magma chamber (8 to 3 Km). Such characteristics extending over an E-W width of a least 20 Km. (Johnson et al., 2016)

2. A powerful heat source and large fractured geothermal reservoir

Preliminary geothermal conceptual model for Eraboru.
Important magma chambers developed at shallow depth (6 to 2 Km) underneath Dabbahu volcano and in the leaky TF Zone East.
Water inflow if provided from the Nubian plateau through the Teru plain and sedimentary basin.
Important steam upflows occur along the numerous open fissures in the Eraboru plateau, at an average altitude of 700m, in the leaky Transform Fault zone linking Manda Harraro and Alayta axial ranges



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Conclusions

Conclusion:

These elements allow to elaborate a first geothermal conceptual model supporting this exceptional field, which now needs to be better documented in its shallowest part.

Delayed due to the political unrest (Tigray war), further interdisciplinary research is now being engaged in the frame of the LEAP-Re project with the support of the community-based entity AGAP (Afar geothermal Alternative Power Cy).

The geothermal conceptual model will be refined and complementary social sciences investigations will allow to precise the best demonstration site.

This will allow for designing engineering devices for production and distribution of both energy and water answering local population needs.

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