THE AFAR TRIANGLE: A FUTURE "GULF REGION" FOR WORLD GEOTHERMAL ENERGY?

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ABSTRACT

The highest amount of energy dissipated by the earth system is located along the mid oceanic ridges system. There are only two places on the planet earth where these spreading axes occur above sea level: Afar and Iceland.

The double fossil fuel crisis (resources limitation for oil and climate change induced by greenhouse gas emissions) obliges the humanity to develop alternative renewable energy sources when available. Globalisation of the economy will facilitate the development of energy intensive economic activity at any site where renewable energy sources will be available at a competitive price. Especially if such sites are located near to the sea (shipment facilities).

Like in Iceland, many sites in the Afar region (found in Ethiopia, Eritrea & Djibouti) display favourable conditions for geothermal energy development:

- shallow energy sources due to thin lithosphere, anomalous shallow hot mantle and superficial magma chambers;
- fractured aquifers due to tectonically active zones where several faulting systems occur;
- Hydrothermal reservoir developed thanks to favourable alterations sequences ("wet" minerals in the cover, "dry" minerals in the geothermal aquifer.

In addition to scientific and technological knowledge, to be developed by transfer of know-how, the major need is for education of local population in order to allow them to benefit from economic development and take part to this huge challenge.

1. INTRODUCTION

Oil and gas resources are limited, and we will have to face the "peak oil". Besides this, the climate change issue obliges the humanity to revise drastically its development model based on rapid extraction of fossil energy resources. There are not so many alternative energy sources, and geothermal is among the most convincing solutions.

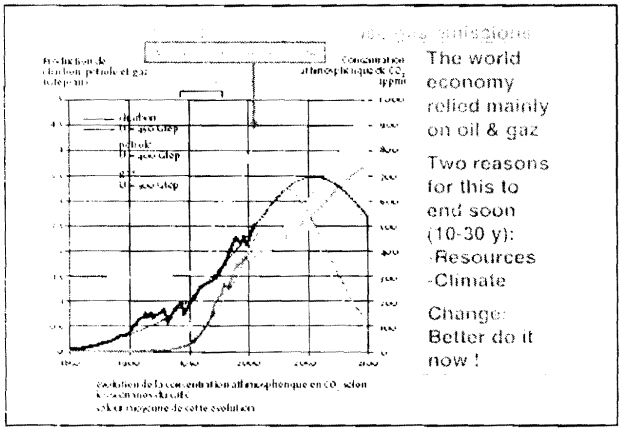

Figure 1: the two parameters governing the world energy issue: the fossil fuel depletion (peak oil) and the climate change issue (J.Varet, 2005).

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Under the pressure of oil & gas prices and related risks, as well as an answer to the CO2 issue (Climate Change Convention and further steps to the Kyoto Protocol) the world economy will relocate all energy intensive activities in areas of production of clean and renewable energies at a competitive price.

2. GEOTHERMAL ENERGY: A PRIVILEGED SOLUTION

High enthalpy geothermal energy is one of the solutions. The major limitation to its development is that only favourable sites can be developed in economic conditions. In fact, the economy of geothermal energy relies upon two major parameters:

- the earth heat flow, controlled by geodynamic location, which determines the geothermal gradient and hence the depth of the target, i.e. a major cost constraint;

- The permeability of the reservoir, which can be obtained by rock permeability and/or by fracture systems. In volcanic contexts, besides fractures, permeability is mainly controlled by hydrothermal alteration sequences.

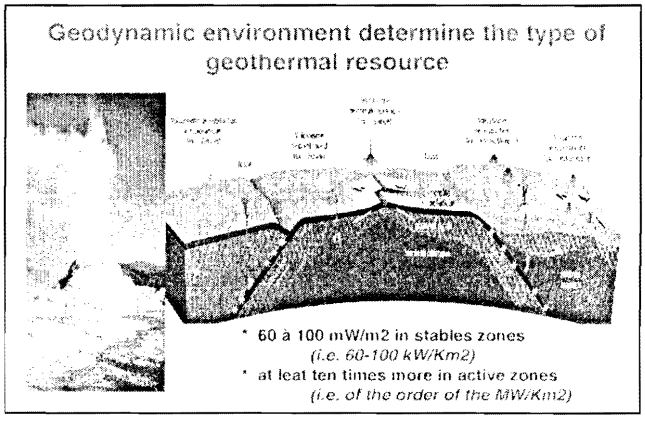


Figure 2: plate boundaries are the areas where both active magma tic and tectonic systems develop favouring the occurrence of geothermal sites.

Such conditions are found along plate boundaries. In areas located along sub ducting plates, geothermal sites are found in specific spots where central volcanic activity developed for a sufficient time. Along diverging plate boundaries (rift systems) the amount of heat dissipated is much higher and hence geothermal sites more frequent.

It is a fact that, at the Earth surface, rift systems, and more specifically oceanic type rift systems allows the development of both these characteristics in extremely favourable conditions. It is a pity that most oceanic rift systems are found in the deep ocean, with the noteworthy exception of two areas in the world: Iceland and Afar. This is a chance which has to be met.

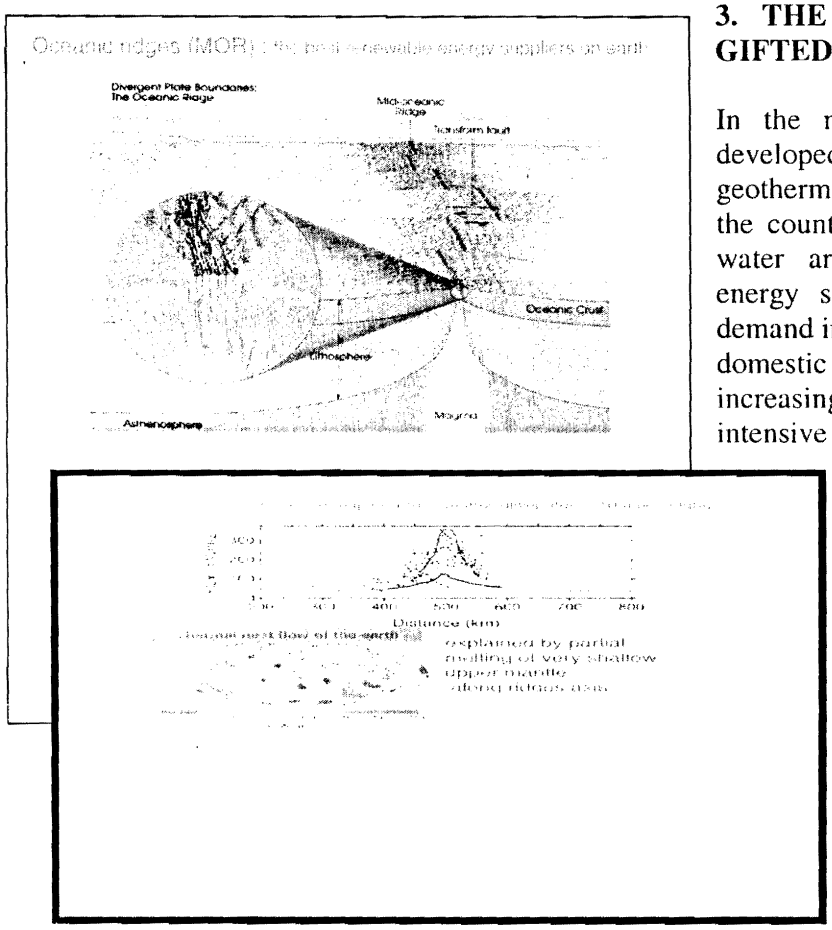


Figure 3. Mid oceanic ridges are the places where the highest thermal heat flow (10 times higher than average) is dissipated on earth

3. THE TWO WORLD MOST GIFTED AREAS

In the north, Iceland has already developed an economy based on geothermal energy uses: the needs of the country in heat and sanitary hot water are covered by geothermal energy sources, and the electricity demand in the country not only serves domestic needs but also allows the increasing implementation of energy intensive industries, such as aluminium smelting. There is no reason why, in the south, the Afar region (i.e. the lowlands of Ethiopia, Eritrea & Djibouti) could not encounter a similar development in the coming decades. It is notably just as well located in terms of proximity to sea transports and ports facilities, and if the climate is at the other extreme, this may be balanced.

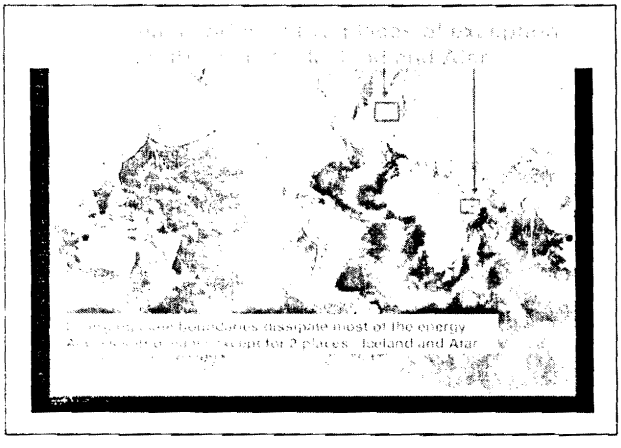


Figure 4: the two emerging segments of the mid Oceanic ridge system: Iceland and Afar

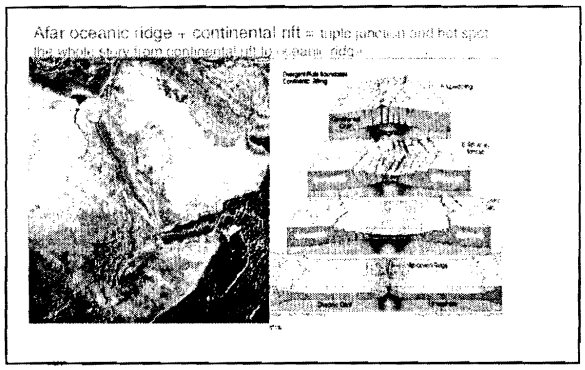
4. AFAR COMPARED TO ICELAND

Compared to Iceland, Afar display a few specific geological differences that need to be taken into account:

- Afar is at an earlier stage of oceanic rifting. If basaltic axial ranges similar to MOR are found in central Afar (South Erta Ale, Manda Harraro) and in Djibouti (Asal), as shown by F.Barberi & J.Varet (1977, 1978), all stages of geological evolution from continental doming to oceanic splitting are observed (Barberi & all., 1970, 1972).

- Afar is an area of triple junction, between continental rifts (the east African rift) and an oceanic ridge (The Red Sea – Gulf of Aden MOR).
- the scarcity of meteoritic water in Afar, restricting the re-filling of the natural geothermal systems;

- the composition of fluids, more salty and hence corrosive and depositing secondary minerals;



Nevertheless, Afar displays volcano-tectonic features characteristics of mid oceanic rift systems. This was shown in the years 1970 on the basis of geological observations as well as petrological and geochemical analysis and interpretations. Since then several tectonic events, with opening of large fissures along axial rift axis measured in the field or by satellite, have confirmed the reality of this geometry of the spreading system.

Figure 5: Afar display all stages of rifting from Continental doming to Oceanic splitting

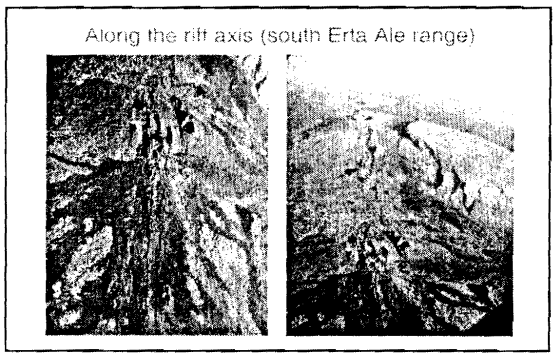


Figure 6. A typical Oceanic ridge structure: south Afar, Erta- Ale Axis range (Barberi & Varet,1970)

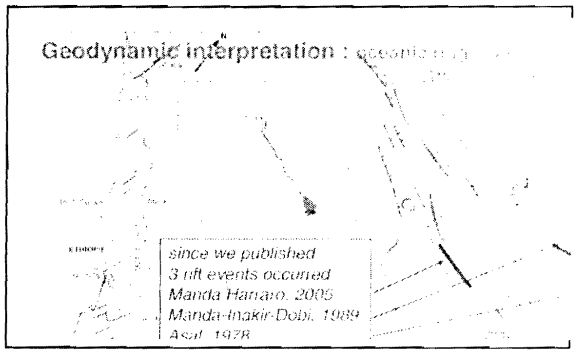
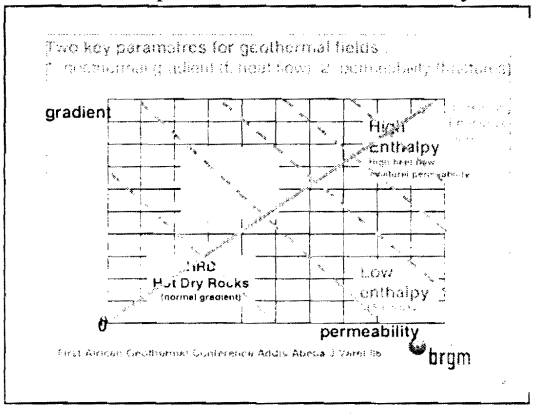


Figure 7. Three major rifting events occurred in with the opening of several meters large rift with length of tens of kilometers

5. PROPOSAL FOR A GUIDE TO GEOTHERMAL EXPLORATION

Favourable sites for high enthalpy geothermal development need the simultaneous occurrence of the following parameters:

- a high heat flow, linked with either a very shallow anomalous mantle or to a superficial magma chamber;
- a highly fractured area, allowing a good permeability of the reservoir;
- the refilling of the reservoir by meteoritic water or sea water, or the combination of both;
- the development of a mineralised hydrothermal system.



In the context of Afar, such sites will develop in areas of junction between the axial ranges and the transverse tectonic systems. As described by Barberi & al. (1970), transform faults are not observed in Afar, but one observe "en échelon" emissive fissure systems as described in Iceland. Nevertheless, as shown by Tapponier & Varet (1974) and précised by Barberi & Varet (1977), large oblique fracture systems, frequently define the surface expression of a transform fault linking two

Figure 8: Two of the key parameters for the development of a high enthalpy geothermal site (J.varet, BRGM, 1980).

distant axial ranges. This allows the interpretation of focal mechanisms of earthquakes, such as the Sardo event.

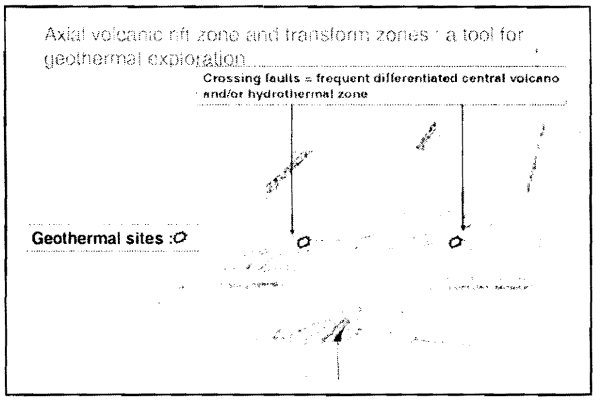


Figure 9: Near to the termination of axial ranges, A transverse faulting is frequently observed, as a Surface expression of the transform fault.

6. IDENTIFICATION OF POTENTIAL SITES FOR GEOTHERMAL DEVELOPMENT

Applied to Afar, this guide for geothermal exploration allows defining the following sites (in Ethiopia, except if mentioned otherwise):

Alid (Eritrea), Dallol, Afrera, Boina, Tendaho, Abbhe, Asal (Djibouti) and North Ghoubbet (Djibouti)

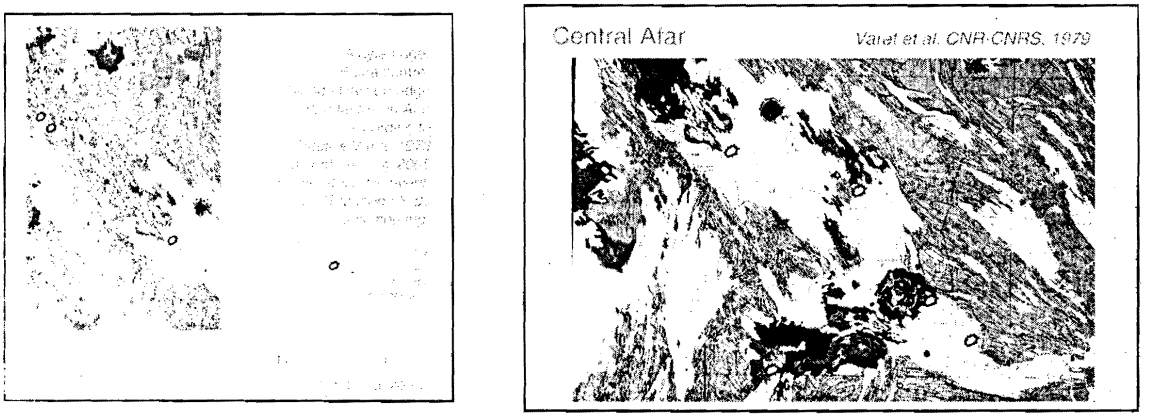


Figure 10: Geological map of central Afar (Varet at al., 1978), with potential geothermal sites. Tendaho is at present the only confirmed commercial geothermal site in Afar.

Among these sites, the two sites located at the two extremities of Manda Harraro Axial Range, which is the most "oceanic like" in terms of volcanology, petrology and geochemistry, i.e. Boina and Tendaho are certainly the most promising geothermal sites in Afar, as they not only display the most efficient heat source and fractured reservoirs, but also the most efficient feeding from meteoritic water from the Awash and Mille basins fed by streaming waters from the Ethiopian plateau.

Fig. 10: Boina (meaning "fumaroles" in Afar language) is a geothermal site located near to a per alkaline silisic volcanic centre, itself developed along the transverse structure linking Alayta and Manda Harraro axial ranges

7. ADDITIONAL OPPORTUNITIES

In addition to these sites located in typical "oceanic ridge" conditions, there are also sites located within or near to central volcanic systems developed locally either in continental rifting systems (South Afar) or along transverse structures. This is notably

the case of Pierre Provost massif (Ma'alalta, at the foot of the Tigrinian scarp in Ethiopia) and of the Dobbi-Bidu volcanic system (south of the "Danakil alps" in Eritrea).

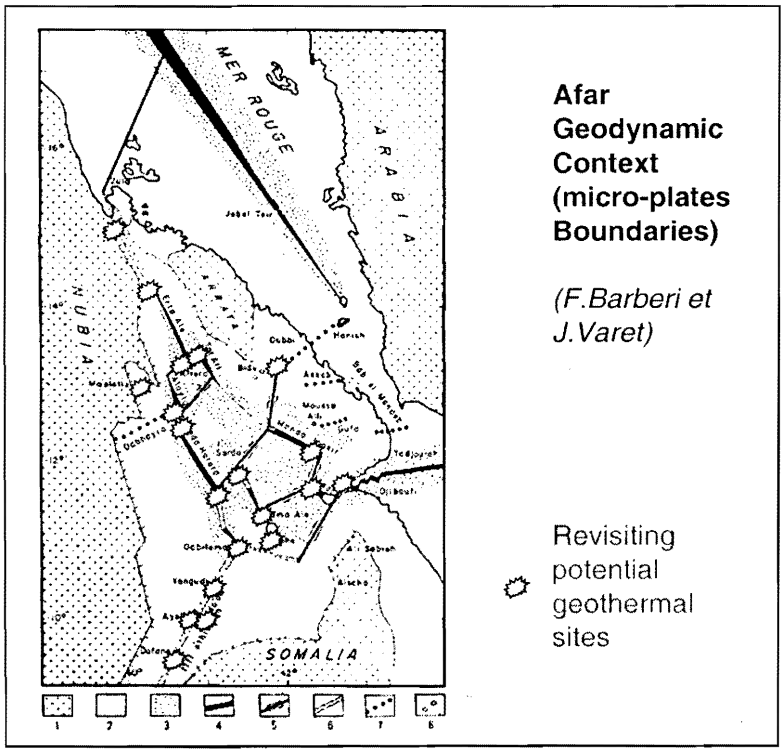


Figure 11: Potential sites suitable for high enthalpy geothermal development in Afar, located in their geodynamic context (defined by Barberi & Varet, 1977, 1978)

8. CONCLUSION

Of course, the Afar region suffers from a few constrains, quite different from Iceland:

- the cultural context, with a lack of Earth science specialists, and an insufficient concern of the population and the decision-makers for renewable energy;
- a less favourable economic context, with a lack of communication, industrial, and financial infrastructures.

But such apparent difficulties can be solved with appropriate technical measures, local cultural changes, and favourable regional and international decisions. In the future, the world economy will rely upon the most favourable renewable energy sources, and as it has to be used on the site of production, the industry will relocate on the best spots. On the basis of geological exploration work carried out years ago, we will show that the Afar region – just like Iceland – can offer several tens of sites suitable for the development of very significant geothermal power plants.

This is a subject for a wide and long-lasting joint European and African action, including education, R&D, new exploration works, feasibility studies, transfer of know-how and industrial & financial investments. The Humanity was born in Afar, and it could also be there that, after having exhausted oil and gas reserves, she will find new energy resources for her future.

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