Second International Conference on the Geothermal Resources of the East African Rift Region

Entebbe,

November 24-28, 2008

A New View on the Distribution of High Enthalpy Geothermal Areas in Ethiopia

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Why discuss the topic

1. Advancing knowledge during recent decades has provided a better understanding of the nature of the Ethiopian Rift System (ERS) leading to a better understanding of the nature of its geothermal resources
2. The opening of the Northern Afar rift to economic development + overall infrastructure development has promoted geothermal prospect areas there from status of “remote” interest to one of “near term” interest
3. As a rule, the continuous updating of thoughts is called for in such a trade as geothermal resource study and development

OUTLINE

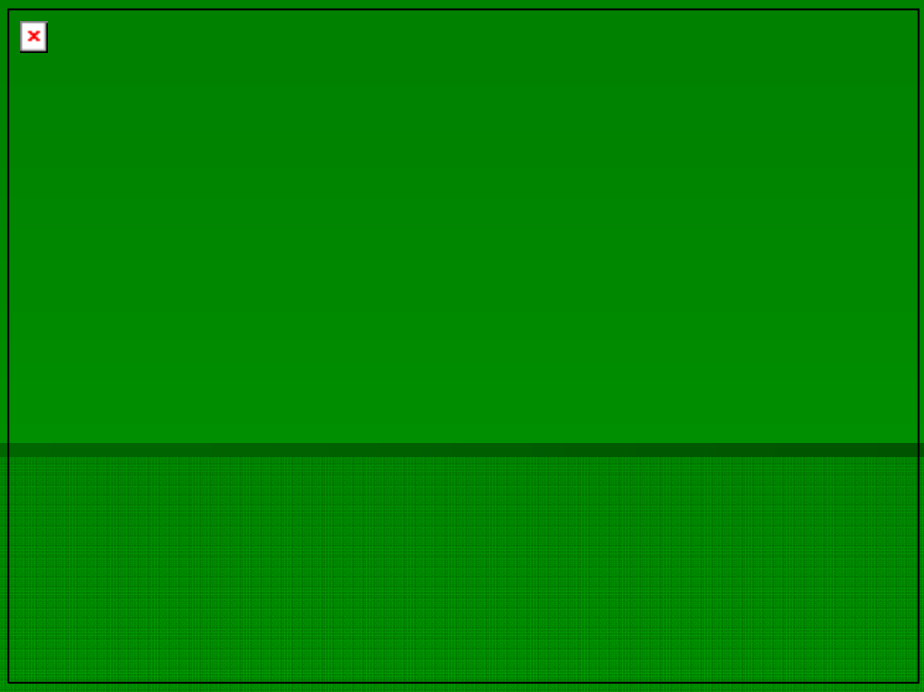
1. The Natural Condition underlying resource occurrence
2. Reflection in hydrothermal activity
3. Rift Development & Associated Magmatism

   Component parts & characteristics
4. What do they mean in terms of geothermal resource occurrence
5. High enthalpy prospect areas

Sources:

Geological survey of Ethiopia, incl. own experience,

A rich bank of academic research output



1. The natural condition as reflected in Seismic shear wave velocity anomaly under Africa (Ritsema et al 2004)

Interpreted as:

A. Large scale positive thermal anomaly in asthenosphere under Africa

Hotter than normal asthenosphere deepest under Southern Africa (left) rises to northeast to reach highest elevation under Afar (right)

B. Red area= asthenosphere upwelling causing oceanic lithosphere heating at the mid-Atlantic Ridge, cross-section

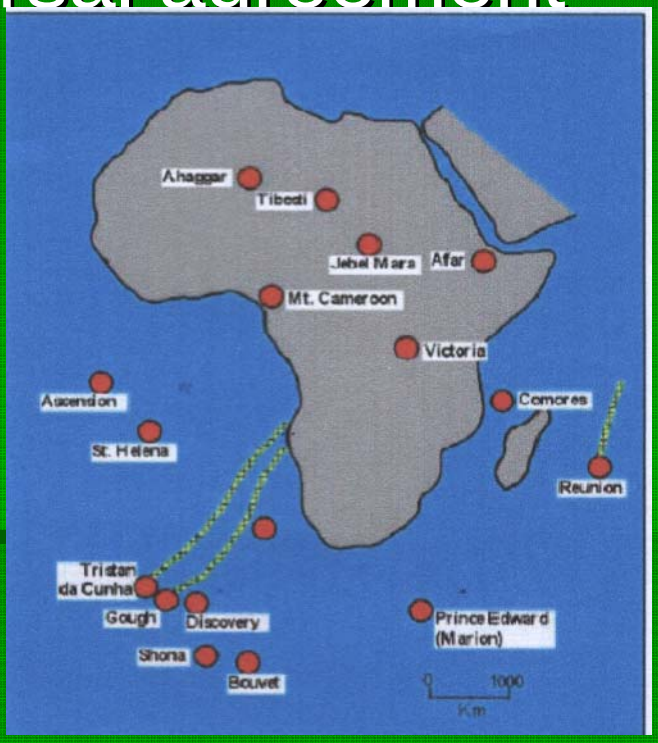
C. Longitudinal thermal anomaly along the mid=Atlantic ridge.

Vertical thermal structure under Iceland (far right) thought similar to that under Afar

- Afar plume the most energetic in Africa

PLUMES ROSE FROM THE ASTHENOSPHERIC THERMAL ANOMALY STRUCTURE

A view of mantle plume (hot spot) distribution, from the Geological Society of South Africa. No universal agreement



African plate is fertile;

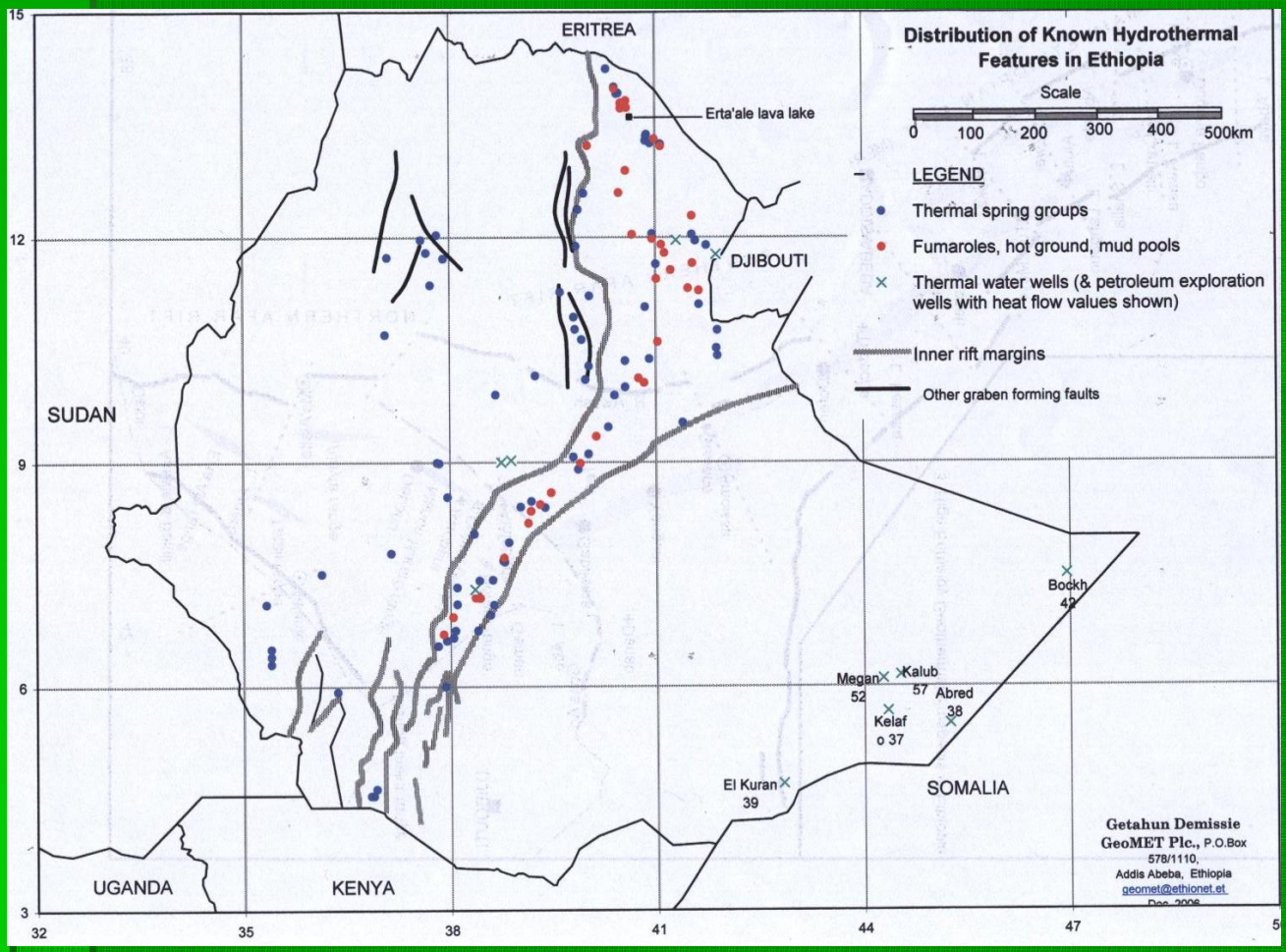
Which plumes may create and sustain exploitable geothermal systems can be determined from volcanic rock petrology

2. Reflection of Afar Plume hydrothermal activity

Note: high concentration in Rift System & marginal grabens

Note: contrasting NW plateau (hot) & SE plateau (cold)

Note: ERS “horse-tails” in South



3. Rift Development & Associated Magmatism

Rifting took place in Oligocene flood basalt terrain: The Ethiopian Large Igneous Province (LIP), the youngest of the Worlds LIPs (31-29Mya)

ERS has two component parts

-Afar & Main Ethiopian rifts

Border faults were initiated during the mid-Miocene,

A little earlier in Afar than in the MER

Episodic rift-bound magmatism in-tandem with advancing rift development during

By Pliocene times (5.6-1.2 Mya) rifting and magmatism became concentrated along rift axial zones.

This phase of tectonic and magmatic development entailed the overlap of the two rifts in the Southern Afar rift zone;

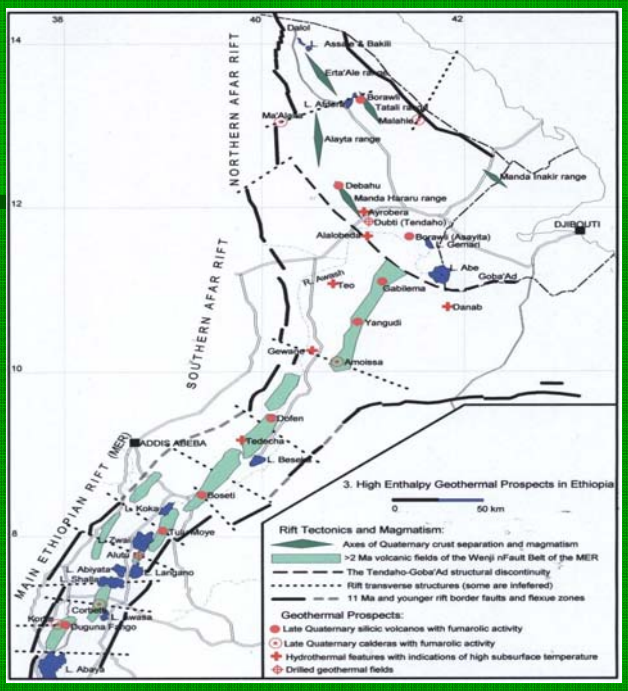
It also defined the home of the high enthalpy geothermal prospect areas

Characteristics of the Component Parts

Afar Rifting:

Border faults: Miocene, NW-SE: Red Sea trend

Axial faults: Late Pliocene - Holocene: N-S to NW-SE in North & Central Afar



Afar magmatism:

- Main rift floor basement: Afar Stratoid Series, Late Pliocene, Main basaltic sequence followed by silicics, commonly candidate reservoir rock
- Axial ranges: initiated earliest, Erta'ale 1.2 Mya; latest, Manda Hararu 40Kya
- Axial ranges mostly produced basaltic lava. An exception is Manda-Hararu which hosts Debahu, a large silicic center
- Transverse structures also host young volcanoes, some silcic.

Illustrating Afar tectonism and magmatism

- Fissure opened on Debahu volcano flank during the seismic episode of September 2004. Dyke injection predicted based on GPS survey.

- Such tectonics enhance reservoir permeability. Directional drilling exploits this opportunity.

Dyke injected & Fissure lava extruded during August 2007: Red line & star

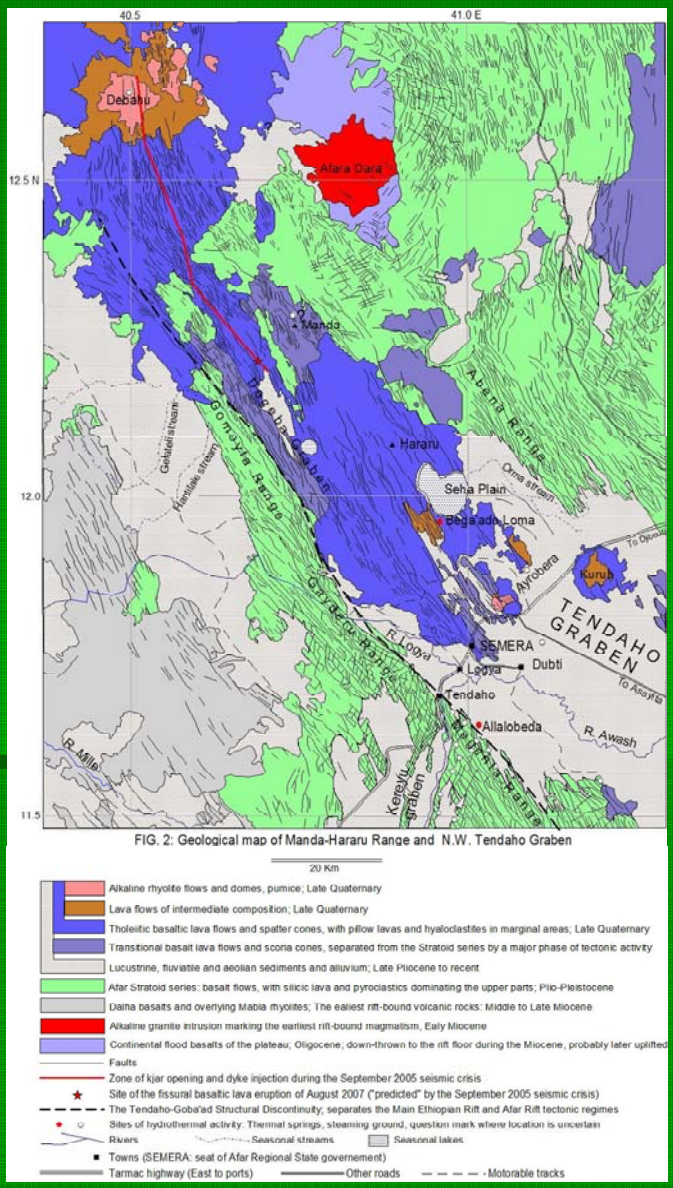
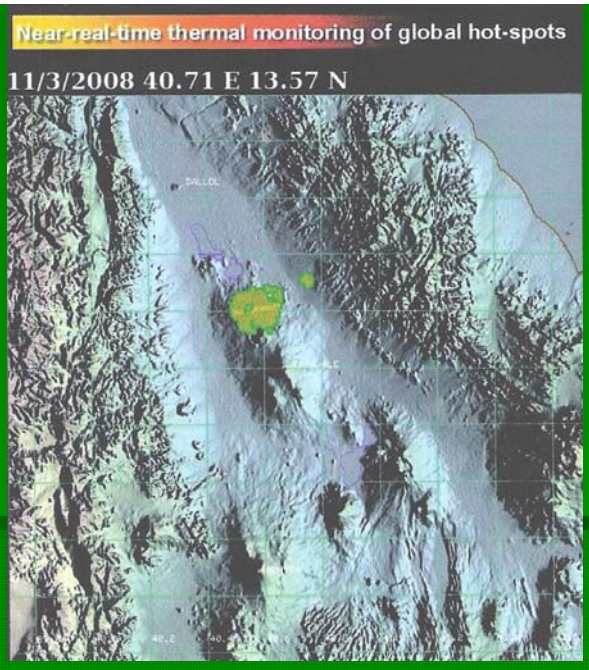
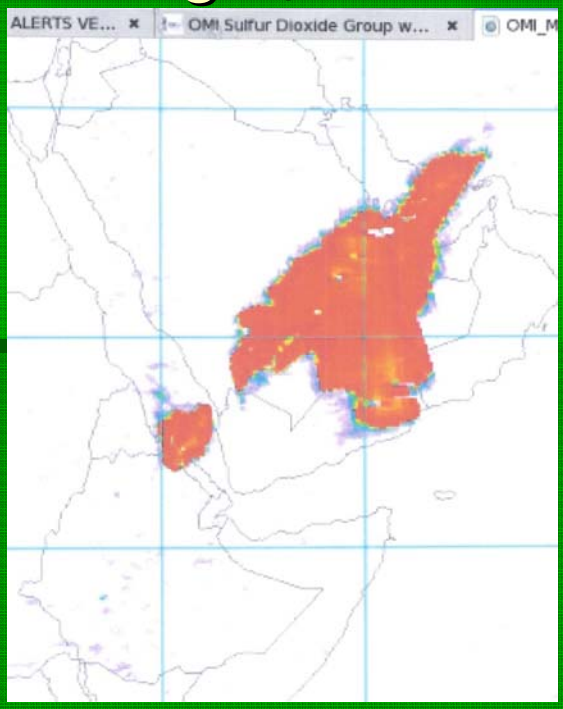


FIG. 2: Geological map of Manda-Hararu Range and N.W. Tendaho Graben

Normal lava lake activity in one of the two Erta'Ale pit craters



MODIS Satellite image of eruption from Dalafila volcano on Erta'ale range, Nov 3, 2008



SO_2 in volcanic gases migrating across Arabia

The MER during the Quaternary

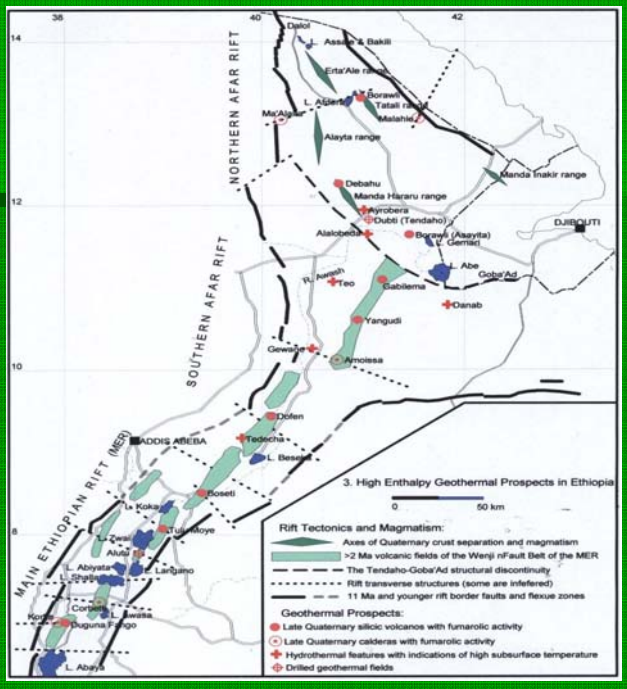
- Rifting:

Evolution of the Wenji Fault Belt: (WFB) a discontinuous chain of rift axial structures which extend from L. Abaya in the south to Gabilema volcano in the northeast

The WFB is the medium of structural overlap between MER and Afar Rift in Southern Afar

MER Magmatism

- WFB became site of segmented volcanic fields during the Quaternary: Volcanic products are: co-genetic typically bimodal basic and silicic lavas and pyroclastics



4. Meaning in terms of geothermal resource occurrence

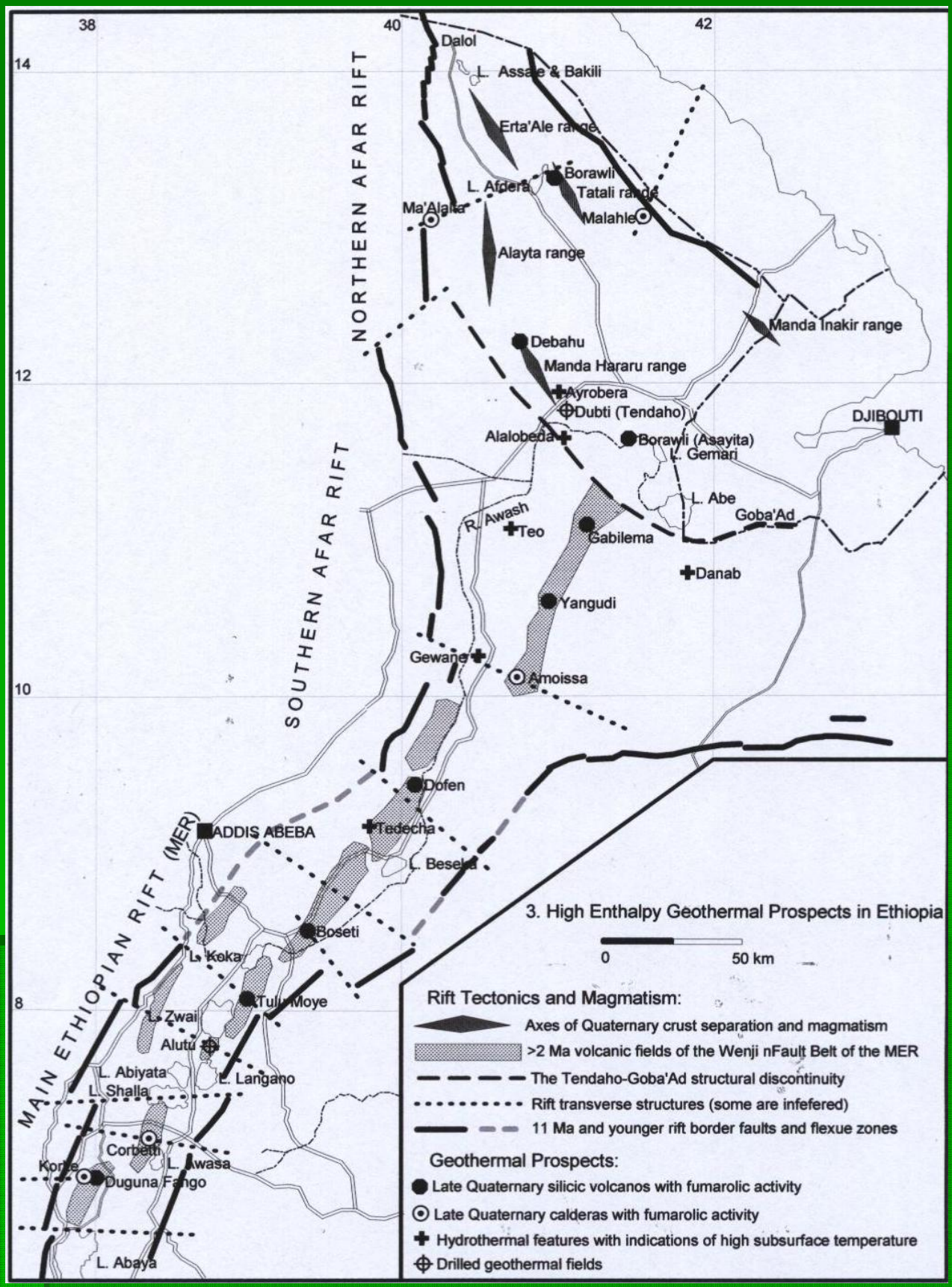
A. Hydrothermal feature occurrences related to spatially and temporally proximate bimodal rock suite occurrences illustrate the existence of magma chambers which support geothermal systems

B. Where the silicic eruptive centers have calderal structures, high degrees of focusing of heat and convecting hydrothermal fluids is expected to provide easy exploration targets and good resource development objectives

C. Dyke injection is thought to be a viable means of transporting heat to the near surface for transfer to circulating ground waters

D. Deep circulation of meteoric waters in actively faulting thinned lithosphere areas is thought to be responsible for the occurrence of near-boiling temperature hydrothermal fluids with high interpreted subsurface temperatures

These thoughts lead to the view that there are good prospects as shown below


38
40
42
14
12
10
8
NORTHERN AFAR RIFT
SOUTHERN AFAR RIFT
MAIN ETHIOPIAN RIFT (MER)
Dalol
L. Assale & Bakili
Erta'Ale range
Borawli
L. Afdera
Tatali range
Ma'Alalta
Malahle
Alayta range
Manda Inakir range
Debahu
Manda Hararu range
Ayrobera
Dubti (Tendaho)
DJIBOUTI
Alalobeda
Borawli (Asayita)
L. Gemari
L. Abe
Goba'Ad
R. Awash
Teo
Gabilema
Danab
Yangudi
Gewane
Amoissa
Dofen
ADDIS ABEBA
Tedecha
L. Beseka
Boseti
L. Koka
Tulu Moye
L. Zwai
Alutu
L. Abiyata
L. Shalla
L. Langano
Corbetti
Kone
L. Awasa
Duguna Fango
L. Abaya
3. High Enthalpy Geothermal Prospects in Ethiopia
0
50 km
Rift Tectonics and Magmatism:
Axes of Quaternary crust separation and magmatism
>2 Ma volcanic fields of the Wenji nFault Belt of the MER
The Tendaho-Goba'Ad structural discontinuity
Rift transverse structures (some are infefered)
11 Ma and younger rift border faults and flexue zones
Geothermal Prospects:
Late Quaternary silicic volcanos with fumarolic activity
Late Quaternary calderas with fumarolic activity
Hydrothermal features with indications of high subsurface temperature
Drilled geothermal fields

- Thank you for you attention
- Thank you Uganda for hosting such a useful conference