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EAST-AFRICAN RIFT SYSTEM GEOLOGICAL SETTINGS OF GEOTHERMAL RESOURCES AND THEIR PROSPECTS

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1. INTRODUCTION

The geothermal areas of the East-African Rift System are not all of the same type. Even though related to the Rift the geological settings are different. Some are volcanic, and the volcanoes are different. Others are not volcanic. Parts of the rift zones are highly volcanic but large segments of them are sediment or lake filled grabens. Cases are also found where rift-related fractures produce permeability in basement rocks. In retrospect it may be useful to point out the differences and likely resource characteristics.

Below, the different types are described, and in which countries they occur as the dominant type. Most of those are genuine high temperature geothermal areas and they are accessible to a different degree. Others are high stratovolcanoes, difficult of access except in the off flow zone of the high temperature geothermal systems. Sedimentary basin type of low to medium temperature occur, and one of the low temperature type is related to fractured basement rock.

2. OFF MAIN RIFT VOLCANOES

Eritrea (Alid), Yemen (Al Lisi):

- Volcanic HT-systems probably over 260°C.
- Main resource at relatively high ground (Eritrea)
- Off flow to south? Perhaps suitable for binary.
- In case of off flow, temperature inversion likely.

Alid rather unique: uplifted ellipical block probably due to a silicic shallow intrusion. Later rhyolite flow(s) occur. The Alid dome is part of a larger volcanic centre. There are Alid type domes in Iceland. One has been described in detail (Sandfell in East Iceland).

Al Lisi: classical in structure; central volcano cut across by a fissure swarm; geothermal area within a collapse structure.
Research methods: Geology/volcanology, hydrology, geochemistry, TEM/MT, airborne magnetics, seismicity, gravity.

3. OCEANIC RIFT VOLCANOES (analog to black smokers)

Djibouti (Asal):

- Volcanic HT-system about 300°C.
- Recharge from sea water
- Probably a rather closed reservoir
- Steam zone likely
- Production from liquid-dominated reservoir may cause rapid drawdown and thickening of steam zone
- Utilization of steam zone and brine fluid.
- Close analogy: Reykjanes in Iceland.

Research methods: Geology/volcanology, hydrology, geochemistry, TEM/MT, airborne magnetics, seismicity, gravity

4. OCEANIC TO CONTINENTAL RIFT VOLCANOES

Ethiopia (several), Kenya (several), Eritrea (Dubbi):

- Volcanic HT-systems. Many good prospects
- Some of the volcanoes in this category possess a volcanic shadow zone. This is a positive sign as regards a geothermal reservoir.
- Off flow possibly suitable for binary
- Sometimes at a fairly high relative altitude and hence great depth to water reservoir
- Question there about exploitation of steam on top of main reservoir?

Olkaria is the only one of its type among the volcanoes in Kenya. It is a rhyolite volcano with an extensive geothermal area. It has erupted rhyolite only, since far back in time. Basalts occur north of its volcanic shadow zone. Volcanic centres of this type host geothermal reservoirs of high potential. Other volcanic geothermal areas in the Kenya rift are not likely to equal Olkaria in power. Iceland has one example among its active volcanic centres. This is Torfajökull which has been estimated by far the most powerful of the Icelandic geothermal areas (1000 MW for 50 years).

Ethiopia may have a centre of this type, most likely in southern Afar near centre of domal uplift.

Research methods: Geology/volcanology, hydrology, geochemistry, TEM/MT, seismicity, gravity

5. MAINLY SEDIMENT FILLED RIFTS

Kenya (Magadi, Turkana), Uganda (central and north), Burundi.

- Possibility of medium-temperature geothermal systems, in faulted sedimentary rocks of variable permeability.
- Subordinate volcanism. Some dyking likely

Research methods: Geology, hydrology, geochemistry, deep gradient wells (300-500 m), explosion seismology

6. DISTAL OFF FLOW FROM HIGH-TEMPERATURE SYSTEMS

Uganda (south), Burundi:

- Low- to medium-temperature (up to 160°C?) geothermal systems
- Bicarbonate waters likely.
- Dyking from distal volcanic centres probably not massive enough to constitute a heat source.

Research methods: Geology, hydrology, geochemistry, resistivity, shallow depth (800-1000 m) exploration wells

7. PROXIMAL OFF FLOW FROM HIGH-TEMPERATURE SYSTEMS

Tanzania (Rungwe), Congo, Rwanda (Virunga mtns):

- HT-resource present but difficult to access
- Only off flow with perhaps up to 150-200°C accessible
- Travertine sinters indicate bicarbonate water
- Suitable for binary from temperature, but high carbonate content poses a problem due to scaling
- Temperature inversion likely

Research methods: Geology/volcanology, hydrology, geochemistry, resistivity, shallow depth (800-1000 m) exploration wells

8. FAULT CONTROLLED LOW-TEMPERATURE SYSTEMS

Zambia, Tanzania:

- Mostly low-temperature (<<150°C?) geothermal systems
- Suitable for binary if hot enough
- Other uses of low-temperature geothermal waters possible (Lindal diagram)

Research methods: Geology, geochemistry, shallow gradient wells, ground temperature survey, magnetics.

9. OCEANIC VOLCANOES, FRACTURE ZONE OR HOT SPOT RELATED

Comoros

- High stratovolcano inaccessible for drilling at reasonably low level.
- Rock alkalibasalt? Are there silicic rocks too?
- Possibly warm or hot off flow towards north (La Grotta)
- Heat source at 1000-1700 m depth under La Grotta doubtful.
- Consider other interpretation: Perhaps low resistivity anomaly caused by reduction in permeability and alteration of glass (rich in submarine part of volcano) to smectite??

Don´t take all of the above for granted.
Make your own assessment with regard to possible flaws or ill founded statements.

10. CONCLUSIONS

10.1 A few general recommendations for geologists working in surface exploration of high-temperature geothermal prospects

Make a *hydrological study* of the field and its wider surroundings preferably a whole catchment. This should cover cold springs, streams, rainfall pattern, water levels in wells and any information about ground water movements. Define area of fumarolic activity where a boiling reservoir would exist underneath. Deep water hydrology will be reserved for reservoir people at later stages when deep wells are drilled.

Define the *volcanic system* (if there is one), its main volcanic centre and the fissure swarm which transects it. A high temperature geothermal reservoir if present is usually located in the area of highest volcanic production, the greatest rock variety and caldera if such has formed. Ring structures may extend far beyond caldera. Direct the exploration towards such volcanotectonic features. Locate secondary high volcanic production foci on the volcanic system. They may be of interest if the volcanics there are young and concentrated within a limited area.

In rift zone regime, take into account how the volcanic system which hosts the geothermal system developed with time. Try to find out the relative age pattern of the volcanics and follow this up by radiometric dating. There may be a focussed zone of intrusion (more or less stationary) which will cool off marginally in the direction of extension (minimum compression) with time.

9.2 Other issues

Western Rift is less endowed with geothermal than the *Eastern Rift.* This is evident from the less volcanic production of the Western Rift. Sediments form a larger part of the graben fill there and lakes occupy large segments of it. The rate of opening is probably also less. The Kenya rift is at the apex of a domal uplift (centred upon plume head) whereas the Western Rift follows its western margin.

The feeders of *explosion craters* may be good targets to drill into at depth. Recognize such as occur at low level of the ground (often with water in them). They are probably phreatic, i.e. conversion of cold ground water to steam upon contact with hot magma caused the explosivity. Hydrothermal explosion craters result from boiling of geothermal reservoir water if it finds access to a volcanic vent following an eruption. A distinction can be made by carefully searching the ejecta for hydrothermally altered rock fragments and thermal alteration in the surroundings would also be an indication that they are generated from geothermal steam.

An intensely fractured rift segment of a geothermal field may not be a good target because of high secondary permeability. This may provide a pathway for percolation of cooler ground water, i.e. a sort of drain leading away from the main reservoir. However, the temperaure of the water (if about 200°C) may be well suited for binary.

Hazard assessment was touched upon in lectures and discussions during the course. This may become an issue in future developments. As geology is concerned the hazards are volcanic (lava flows, ash flows, ash falls, mud flows), tectonic (fault movement) mass wasting (debris slides, mud flows), or flooding. In a highly volcanic area the geologist will be asked about the frequency and type of eruptions. For this it is necessary to study the most recent ashes and lavas, find suitable sections and material for dating. This is being done in Iceland and the Azores, probably also in SE-Asia. Don‘t forget, however, the time scale. It is very different for human live span on the one hand and geological processes of catastrophic nature on the other.

As regards choice of geothermal prospect the intensity, areal extent of thermal manifestations and chemistry of fumarole gases will always weigh heavily in exploration and decision. Hot spring areas may not be a good choice unless where silica sinter occurs and the water has high silica content. Therefore give due regard to *sinter deposits* if such occur. Avoid CO2 rich hot spring areas depositing travertine unless you are looking for intermediate (possibly of use for binary?) or low temperature fields.