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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, others are not. Parts of the rift zones are highly volcanic but large segments of them are sediment or lake filled grabens. Extreme 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 seven types are described, and in which countries they occur as the dominant type. Three of those types are genuine high-temperature geothermal resources. Two may be accessible only in the off flow zone of high-temperature geothermal fields. One is of the sedimentary basin type resource of low to medium temperature, and one other of the low-temperature type is related to fractured basement rock.

2. OFF RIFT VOLCANOES

Eritrea (Alid), Yemen (Al Lisi):

- Volcanic HT-systems suitable for back pressure turbines
- Main resource at rather high ground (Eritrea)
- Off flow probably present, perhaps suitable for binary
- In case of off flow temperature inversion likely

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

3. OCEANIC RIFT VOLCANOES

Djibouti (Asal):

- Volcanic HT-system
- 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.

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

4. OCEANIC TO CONTINENTAL RIFT VOLCANOES

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

- Volcanic HT-systems. Many good prospects
- Off flow possibly suitable for binary
- Sometimes at a fairly high relative altitude and hence great depth to water reservoir
- Question about exploitation of steam on top of main reservoir?

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 180°C?) geothermal systems
- Bicarbonate waters likely.
- Dyking from distal volcanic centres

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
- Suitable for binary from temperature, but TDS ($CaCO_3$) may pose a problem

- Travertine sinters indicate bicarbonate water
- 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. CONCLUSIONS

9.1 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.

After locating a thermal manifestations. Role of geologist:

- Define type: Fumarole, steaming ground, spring, seepage, CO2 vent, alteration, type of surface clay (kaolinite or smectite). Type of efflorescence minerals. Temperature. Flow rate. Type of sinter if present.
- Define local geological control.
- Correlate with ground temperature survey and soil gas survey if such is made.

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 they 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 steam generated.

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 temperature of the water (if about 200°C) may be well suited for binary.

Hazard assessment was only briefly 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. Hotspring areas may not be a good choice unless where silica sinter occurs and the water has a 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.