Conceptual Models of the Kenyan Geothermal Fields: Case of Olkaria and Menengai Geothermal fields

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Geothermal Fields in Kenya

- Olkaria – 690 MWe (158+70 MW under construction)
- Eburru – 2.52 MWe
- Menengai -105 MWe (Under construction)
Geology

- No central volcano but a series of arcuate aligned domes forming a ring structure and effusive fissures.
- Volcanics characterised by alkali rhyolites (comendite) lava flows & pyroclastics (ash and pumice).
- Ololbutot comendite dated ~ 180 ± 50 yrs is the latest episode.
  - The heat source at Olkaria is associated with
    - discrete magma chambers that underlie the volcanic centres
    - When aspect ratio is considered then the magma sources form one large heat source at depth
Young lava flow

- Ololbutot lava flow dated at 180+/-50 yrs occur within Olkaria field
Olkaria Domes

- Ring of domes that form an arcuate structure
- Drilling under the domes intersected granitic/syenitic intrusions
Rock Types

Major element analysis of Olkaria Domes rocks show compositions similar to those of Olkaria East & Olkaria Northeast, plotting in the basalt, trachyte and rhyolite portions of the TAS diagram.
- Old structures oriented NW in line with rift geometry
- Youngest faults have NNE-SSW trend
- Reactivated faults trend NNW-SSE and show strike slip fault movement
- Resistivity anomaly trend NW-SE
- The most productive geothermal reservoirs at Olkaria trend NW indicating that these structures are “open”.

Structural Setting of Olkaria Geothermal field
Microearthquake study

- Location of micro-earthquakes in the Olkaria geothermal system
- Seismicity is intense at the intersection of structures. These events are associated with fluid movements along these structures.
Seismic attenuation depths

- Shallow attenuating bodies occur in the Olkaria NE, west, and Domes fields
Olkaria Geothermal System

- Resistivity anomaly/geothermal reservoir at Olkaria is controlled to a large extent by the NW-SE accommodation structures
Resistivity structure
- High temperature zone is oriented NW in trend with the old rejuvenated structural trend (accommodation zone)
Geochemistry classification

- Cl-SO4-HCO3 ternary diagram for water types in the Greater Olkaria Geothermal Area (Giggenbach).
- Fluids in Olkaria west and Domes are mature bicarbonate waters. Olkaria NE and East fields are Chloride waters.
Olkaria Conceptual model

- Olkaria geothermal is hosted within the plateau trachyte series composed of rhyolite, basalt, trachyte, and tuffs
- West field reservoir is within Mau tuff formation
- N-S, NNE-SSW, ENE-WSW, and NW-SE structures occur
A model of the reservoir in Olkaria
The Model

- Three upflow zones (ONEF, OWF, ODF)
- OCF – a mixing zone
- Oloobutot fault & Olkaria fault zone control fluid movement
- Recharge mainly from Rift flanks (East & West) and also from the north
- Outflow zones not clearly defined but could be southwards
The Model

- Heat source shallow magmatic body (4-6 km)
- Differentiated magma – provide deep heat source
- Magmatic intrusions – define shallow heat source
- Fractures, dykes – control permeability
Conceptual Model of Olkaria

- Recharge from east and west escarpments
- Outflow dominantly to the south
- N-S structures are common and conduct cold fluids also
- Upflow is from a reservoir of more than 398°C
- West reservoir has contribution of deep mantle CO₂
- Reservoir is dominantly two-phase liquid dominated
MENENGAI GEOTHERMAL FIELD
Menengai Geothermal Field

- Caldera built of trachyte lavas
- Resurgent activity within the caldera floor
- Rocks predominantly trachyte (<1400 BP)
- Latest post-caldera activity occurred within caldera floor
Structural Features of Menengai

- Pseudo focal mechanism solution for fault kinematics for the Menengai area show strike slip movement in NW of the caldera
- Accommodation structures result in enhanced permeability and “bigger” wells
- Seismics show high velocity body under the caldera
- Common feature of all volcanoes in EARS rift axis
Gravity

- Caldera structure has imposed a low gravity anomaly on a high axial anomaly
- However, local highs exist within the caldera with NNW trend.
Micro-seismics

- Concentration of seismic events along Molo TVA, Solai graben and inside the caldera.

- Hypocentral depths show a decrease in seismicity at depths elsewhere.
Resistivity Structure

- Resistivity structure at sea level shows moderate resistivity within the caldera floor and which extends to the north.
- East of caldera shows highly conductive bodies.
Ground temperature values at 1m depth shows high temperature anomaly within the caldera floor.

Temperature distribution at 1m depth

- Temperature (°C)
  - 90
  - 85
  - 80
  - 75
  - 70
  - 65
  - 60
  - 55
  - 50
  - 45
  - 40
  - 35
  - 30
  - 25
  - 20
  - 15

LEGEND
- Data points
- Railway line
- Roads
- Rivers
- Lake, Pond
- Shopping center
- Pyroclastic issue craters
- Lava eruption center
- Major (rift scarp) fault
- Rift floor fault
- Inferred fault

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High soil CO₂ values are associated with fault/fracture zones.
High radon values correspond to structural patterns in the wider Menengai geothermal area.
Fluid Type

- Fluids plot within the HCO₃ corner
- High CO₂ is contributed to by degassing magma under the volcano
- Scaling potential is therefore very high for most of the wells
Well Discharge test

- 30 MWe single well under discharge test at Menengai
- Well drilled directionally into a strike slip structure
  - Temperatures of > 400°C measured
  - Shallow magma bodies ~2.3km
Downhole Temperature profile

- Reservoir below 1800 masl is supercritical fluid and is at very high temperatures
- Vapor dominated flow from bottom of several wells
- Reservoir is supersaturated with respect to HCO3
Menengai Stratigraphy

- Stratigraphy dominated by trachytes and pyroclastics
- Magma body at ~2.3km and drilled into be several wells
- Syenitic cap intersected by several wells
- Tmax >400°C
- Supercritical fluid encountered by several wells
Menengai stratigraphic Model

- Tuff layers
- Trachyte
- Syenite
- Magma

Lithology:
- Basalt
- Dike
- Glass
- Fine grained
- Phenocrysts
- Pyroclastic
- Syenite
- Trachyte
- Tuff
Menengai Model

- Model developed using Leapfrog software
- A large liquid magma body exists at about 2.3km under Menengai
The geothermal system at Menengai is better modelled by “supercritical” model.
Conceptual Model

- Heat source under the caldera and further in the NE
- Upflow under the caldera with supercritical fluids in some areas
- Recharge dominantly from the east
Conceptual model

- Heat source for the system is a shallow magma chamber

- Two separate steam zones identified at 1000 – 1500 masl and 400 – 700 masl

- Resistivity shows reservoir extends from the centre of the caldera towards the NW as far as the Olrongai ridge

- Recharge from the E and NE controlled by major faults, the caldera wall and other minor structures
Thank You