Geothermal exploration in Karisimbi and NW Rwanda

Technical Workshop on the Geologic Development and Geophysics of the Western Branch of the Greater East African Rift System

Knútur Árnason
ISOR
### Main studies and reports

<table>
<thead>
<tr>
<th>Institution</th>
<th>Authors</th>
<th>published</th>
<th>Title</th>
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<tbody>
<tr>
<td>BRGM</td>
<td>Rancon and Demange</td>
<td>1983</td>
<td>Reconnaissance Géotermique de la République du Rwanda.</td>
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<tr>
<td>Chevron</td>
<td>Newell et al.</td>
<td>2006</td>
<td>Preliminary Assessment of Rwanda’s Geothermal Energy Development Potential</td>
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<td>BGR</td>
<td>Jolie et al.</td>
<td>2009</td>
<td>Geothermal Potential Assessment in the Virunga Geothermal Prospect, Northern Rwanda</td>
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<td>ÍSOR</td>
<td>Ármannsson and Eyjólfsdóttir</td>
<td>2009</td>
<td>Interpretation of geochemical data for Rwanda</td>
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<td>KenGen</td>
<td>Mariita et al.</td>
<td>2010</td>
<td>Geothermal potential appraisal of Karisimbi prospect, Rwanda</td>
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<td>IESE</td>
<td>Browne</td>
<td>2011</td>
<td>Geothermal Prospects in Rwanda</td>
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<td>Thórhallsson</td>
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<td>Review of geothermal development schedule. Rwanda geothermal resource exploration and development strategy</td>
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<td>IESE</td>
<td>Shalev et al.</td>
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<td>Geoscientific Surveys of the Rwandan Kalisimbi, Gisenyi and Kinigi Geothermal Prospects</td>
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<td>EWSA</td>
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<td>Proceedings Validation and Peer Review Geothermal Workshop, Kigali, Rwanda 2\textsuperscript{nd} – 4\textsuperscript{th} April, 2012</td>
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<td>EWSA</td>
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<td>Data and Final Report Validation Workshop, Golden Hills Hotel, Kigali, Rwanda 9\textsuperscript{th} – 10\textsuperscript{th} January 2013.</td>
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<td>JICA</td>
<td></td>
<td>2015</td>
<td>THE PROJECT FOR PREPARATION OF ELECTRICITY DEVELOPMENT PLAN FOR SUSTAINABLE GEOTHERMAL ENERGY DEVELOPMENT IN RWANDA</td>
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</table>
Geology

Two main studies:

1. BGR (Jolie et al. 2009)

2. IESE (Shalev et al., 2012)
BGR (Jolie et al. 2009)

Desktop study using remote sensing technologies to delineate faults, lineaments and breaching angles

Chemical composition of volcanic rocks above the Precambrian basement area interpreted as evidence of differentiation in a magma body within the crust
Conclude that the composition of volcanic rocks indicates their source is a >10 km deep volume of fractionating magma

No report addressing geology at Karisimbi mentions any sort of geothermal manifestations
Geochemistry

- Several sampling campaigns

- Several analyses and interpretation studies (BGR, KenGen, ISOR, IESE, JICA)
Water sampling

Legend:
- Green circle: High carbonate coldspring
- Purple circle: Lake
- Blue circle: Low carbonate coldspring
- Yellow square: Precipitation sample
- Red circle: Thermal water
# Major element analyses of thermal waters in Rwanda

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Sources: 1 = BGR raw data; 2 = Fabriol and Verzier (1983); 3 = Newell et al. (2006); 4 = Fridriksson et al. (2012)

* chbl = charge balance

** Quartz temperature (Fournier and Potter, 1982)
Main findings from water chemistry

- Quartz geothermometers indicate temperatures in the range of 110 to 140 °C
- Cation geothermometers give higher temperatures (180 to 210 °C) but considered unreliable
- High carbonate in geothermal and cold waters
- δ¹³CO₂ values consistent with mantle origin
- Strontium isotopes indicate reaction with Precambrian basement rocks
Soil gas and flux measurements

- Results were inconclusive
- High CO₂ flux in the eastern part of Virunga, probably of mantel origin
Geophysical surveys

1. Thermal surveys

2. Seismic monitoring

3. Resistivity surveys
Thermal surveys

- BGR/KenGen 2008 and KenGen 2009
  Ground temperatures surveys (0.7m depth)

- IESE 2011
  Ground temperatures survey and gradient in 3 m deep holes

- No indication of thermal anomalies except at known thermal springs
IESE deployed 12 portable seismic stations in 2011 and recorded for 15 weeks.

Out of 280 located events, only two were found in the survey area.
Resistivity surveys

The industry standard nowadays in resistivity surveys is to do MT and TEM soundings at the same place. The reason is that MT soundings suffer static shifts but the TEM does not.

Joint inversion of MT and TEM corrects for the shifts and is also a consistency check of the data.
Just MT

Example of static shift correction

Response of MT model

Joint 1D inversion
## Four campaigns

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<th>Performed by</th>
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<td>BGR/KenGen</td>
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BGR/KenGen MT and TEM 2008
BGR/KenGen 2008 2D inversion
BGR/KenGen 2008 2D inversion

Figure 85: Resistivity isomap at 3,000 m bsl

Figure 86: Resistivity isomap at 6,000 m bsl
KenGen 2009

MT

TEM
KenGen 2009 typical MT data
KenGen 2009 typical TEM data
KenGen 2009 2D inversion of MT

2 km bsl.  5 km bsl.
KenGen and IESE MT and TEM 2011
KenGen 2011 typical MT data
KenGen 2011 typical TEM data
Joint inversion of KenGen 2011 MT and TEM

MT and TEM data seem incompatible

Emphasis on MT

Emphasis on TEM
IESE/GDC 2011 typical TEM data
Joint inversion of IESE MT and GDC TEM 2011

MT and TEM data seem incompatible

Emphasis on MT

Emphasis on TEM
IESE 2D inversion of MT

Figure 7.2.42: 2D MT Resistivity cross-section (K1)
IESE 2D inversion of MT
IESE 3D inversion of MT

Figure 5.2.58: A sliced 3D resistivity block of Kalisimbi prospect.
JICA (2015) 3D inversion of the IESE MT

Resistivity at 1500 m depth
Joint 1D inversion of soundings near wells KW-1 and KW-2
Joint 1D inversion of soundings near wells KW-1 and KW-2
Conclusions on resistivity

- MT data are of poor quality due to local nose, except for IESE data from 2011
- TEM data are of very low quality and/or corrupt
- Quality control during data collection inadequate
- Due to low quality, the EM data do not allow state of the art interpretation (TEM would have to be redone)
- 2D inversion gave misleading indications
- Even though of poor quality, the MT data indicate resistivity structure of volcanic material on top of basement
- The resistivity structure was erroneously interpreted as reflecting high temperature geothermal system
Lessons learned

1. Thorough geological and geochemical studies are needed to determine likely type of resource and which geophysical methods should be applied (high temperature geothermal systems generally manifest themselves somehow on surface).

2. Geophysical surveys should be carefully planned and executed.

3. Continuous quality control and preliminary interpretation should be performed concurrently with field work.

4. Validation and distinction between different conceptual models should be done in the cheapest possible way.