Geothermal resource along borders: The Rwanda-DRC case

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Summary

1. The Western Rift: geological background and geothermal characteristics

2. The northern Kivu Rift: a geothermal target
   2.1 Looking for potential reservoir conditions in the basement rocks
   2.2 Structural control of the volcanic and thermal activity
   2.3 Volcanological and hydrothermal context of the Kivu Lake
   2.4. A magmatic heat source: the S-Nyiragongo volcanic system
   2.5. A potential geothermal target along the borderline

3. Conclusions and recommendations
1. The Western Rift: geological background and geothermal characteristics

The East African Rift system, with major fault systems, seismicity (M> 5), manifestations of Quaternary volcanism and plate-motion vectors with GPS velocities (mm/y) (Calais, 2016)

Target: blue square
1. The Western Rift: geological background and geothermal characteristics

Distribution of low-volume melts (alkaline rocks carbonatites, and kimberlites) and Mesozoic to Cenozoic rifts overprinting the velocity structure of cratonic blocks of Africa. Low velocities in blue to black, high velocities in red to white).
Blue polygons = rifts; white asterisks = volcanoes; green stars = carbonatites; pink circles = nepheline syenites; white squares = kimberlites; CVL: Cameroon Volcanic Line. S-wave velocity (Vs) image is in the 100- to 175-km depth slice (from Begg et al. 2009).
1. The Western Rift: geological background and geothermal characteristics

Comparison of the composition of volcanic rocks in 5 types of continental rift systems (West African rift, Rhinegraben rift, Baikal rift, Kenyan rift, Ethiopian rift including Afar): frequency histogram of available whole rock analysis. Plateau volcanics are included.

In the upper figures, rocks are classified into basic (B), intermediate (I), and salic (S) according to an alkalies/silica plot. The lower figures refer to normative compositions, with nephelinites (Ne), basanites (Ba), alkali-basalts (Ab), olivine-tholeiites (Ot) and sub-alkaline basalts (Qz normative= Sb) (after Barberi, et al. 1982).
1. The Western Rift: geological background and geothermal characteristics

Diagram showing the model proposed by Chakrabarti et al. (2009) for the Virunga volcanics in the western rift, compared to the eastern rift.

Nyiragongo lavas are shown to issue from 150 Km deep in the mantle without differentiation, whereas in the eastern rift, magma production and differentiation occur at much shallower depth in a thinned continental crust.
2. The northern Kivu Rift: a geothermal target

Plate-kinematic vectors for the Western Rift. Low rate of extension in a regional context characterizing the boundary between the Nubia and Victoria plates; in the Kivu area extension amounts to approximately 2.7mm/yr and active faulting is less developed (vectors calculated using Euler poles from Saria et al., 2014).

Red arrows denote relative plate-slip vectors. Velocity in mm/yr. Target: blue square.
2. The northern Kivu Rift: a geothermal target

Seismicity of Lake Kivu (in the period 1983-2009, from USGS), and volcano-structural data, showing the contrast between the active western (DRC) border and the presently rather aseismic eastern (Rwanda) shore (Wauthier et al., 2015).

North of 2°, active seismic, tectonic and volcanic activity in Kivu Rift concentrated on the western side (DRC). The rift encountered an earlier normal faulting, now deeply eroded Precambrian rocks of the Butare Horst on the Rwanda side gently dipping towards the lake, whereas the western side in DRC is characterized by active normal faults. Targetted site in blue square.
2. The northern Kivu Rift: a geothermal target

Stylized geological sections illustrating the two kinds of tectonics affecting the Eastern Rift at its early (i.e. Miocene) stage, along the Nubian (upper section) and Somalian escarpments (lower section), (from Beyene & Abdelsalam, 2005).

Compared with the Kivu Rift, the upper figure (once reversed) is analogue to the E Rwanda side, with marginal grabens observed along the escarpment of the Butare Horst and hanging blocks dipping towards the lake.

The lower figure compares with the W DRC side, and characterize most of the presently active system of the asymmetric Kivu Rift.
2. The northern Kivu Rift: a geothermal target

2.1 Looking for potential reservoir conditions in the basement rocks

The Kivu region is dominated by the “Zaire-Nile Crest” of the crystalline basement belonging to the Kibarian Orogen and comprises metasediments, metavolcanics, and granitic intrusions with younger granitic pegmatites and abundant basic intrusions. All of these units have been heavily fractured by later orogenic and extensional processes. This fracturation allowed for the development of permeable formations, particularly in the pegmatites, providing potentially suitable conditions for geothermal reservoirs (GDC/Géo2D, 2017). This also allowed for the recharge of the deep hydrogeological system from the surrounding horsts.
2. The northern Kivu Rift: a geothermal target

2.2  Structural control of the volcanic and thermal activity

The Kivu rift appears as asymmetric:
Although well developed in the Butare Horst, the eastern fault scarp at the level of the Lake is topographically poorly expressed, lacking rectilinear shoreline.
Bathymetric and seismic-reflection data indicate extensional block faulting on the western slope, a phenomenon not visible on the eastern DRC side.
At the bottom of the Lake, the eastern basin has thicker sediments, than the western basin;
The seismic activity reveals frequent events along the western side of the lake and much less pronounced activity on the east. Thermal activity also appears more developed.
Bathymetry of Lake Kivu highlighting the contrast between the north-western basin, defined by NNE-SSW-striking faults, and the N-S-oriented eastern basin, which is delimited by less pronounced rectilinear, less faulted shorelines (from Lahmeyer and Osae, 1998).

2. The northern Kivu Rift: a geothermal target

2.2 Structural control of the volcanic and thermal activity
Comparison of slopes along the western and eastern border of Lake Kivu as shown on seismic reflection profiles across the lake. Profile W (Rwanda) reveal a large, older normal fault with thick sediments that include mass-flow deposits along a steep slope. Whereas the E side (DRC) reveals active normal faulting (from Ross et al. 2014)

2. The northern Kivu Rift: a geothermal target

2.2 **Structural control of the volcanic and thermal activity**
2. The northern Kivu Rift: a geothermal target

2.3 Volcanological and hydrothermal context of the Kivu Lake

Detailed bathymetric survey of the northern part of Lake Kivu showing the sub-lacustrine relief (left), and geological map of the same area (right). Besides sediments, the Kivu rift floor appears to be affected by numerous volcanic manifestations in its northern part, volcanic centres aligned on a NNE fissure (dike). Underlined by the oblique yellow rectangle, this shows the active nature of the Kivu Rift axis (Ross et al., 2014)
2. The northern Kivu Rift: a geothermal target

2.4. A magmatic heat source: the Nyiragongo volcanic system

Synopsis of the 2002 eruptive Nyiragongo event showing the N-S fissure flank eruption and the extent of lava flows, the vertical deformation along the Lake Kivu shore, and the hydrothermal and gas-emission fissures that were active subsequent to the volcanic eruption.

The 2002 event reveals an axial magmatic rift zone linking the Nyiragongo lava lake with the axis of the Kivu Rift. The same system was active during an eruptive episode in 1977.

(Virunga volcano observatory, 2014)
2. The northern Kivu Rift: a geothermal target

2.4. A magmatic heat source: the Nyiragongo volcanic system

Following the last eruption in 2002, new observations and measurements provided a better understanding of this region, involving the existence of a magmatic and hydrothermal system in the axial part of the Lake Kivu-Nyiragongo Rift. In terms of the regional geothermal potential the following aspects are noteworthy:

1. Volcanic eruptions and intrusions took place along a N-S-oriented axis extending from the crater to the lake;
2. Ground deformations with up to 37 cm vertical displacement was documented near the axis of eruption at lake level;
3. Fumarolic and gaseous emissions, including CO$_2$ and CH$_4$, followed the eruption;
4. Radar interferometry suggests diking operated at two different levels:
   - in the volcanic edifice, from the crater to the southern flank,
   - and a along a vertical zone extending southward from Nyiragongo to Lake Kivu at 8 to 2 Km depths.
2. The northern Kivu Rift: a geothermal target

2.4. A magmatic heat source: the Nyiragongo volcanic system

Topographic map (DEM model) showing the location of major faults and the 2002 dyke injection modelled to account for surface deformation based on radar interferometry (from Wauthier et al. 2015). Note the extent of the dike south of the volcano and its alignment with the axis of Lake Kivu at the latitude of the A1 hot springs. Known hot spring occurrences are shown ( ). The red polygon indicate the limits of the area proposed for new geothermal investigations during the borderline survey proposed.

*Base map from GDC/Géo2D, 2017*.
2. The northern Kivu Rift: a geothermal target

2.4. A magmatic heat source: the Nyiragongo volcanic system

Block diagram showing the hypothetical Northern Kivu Rift geothermal conceptual model (drawing by Michel Villey in GDC/Géo2D, 2017, modified).
3. Conclusions and recommendations

Considering the geothermal potential of the area located along the DRC-Rwanda borderline, it is recommended to engage a regional project implying the public concerned institutions of both countries. The area to be investigated extends from the Nyiragongo summit crater down to the eastern and western shores of Lake Kivu.

1. Age determinations of the successive volcanic events along this axis should be considered.
2. Besides surface surveys onshore, the project should also include offshore studies, both along the faulted shore lines and along the N-S axis of the rift where the magmatic dike fed volcanic manifestations on the lake floor.
3. Besides volcanic and tectonic studies, the survey should include mapping and analysis of all present and extinct thermal and gas surface manifestation,
4. eventually with the help of an IR drone.
5. Geophysical survey should include TM-MT survey, as well as gravimetry and micro-seismic studies.

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Thank you ! Merci ! Asante!