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Geological and Geothermal Manifestation Mapping in the Karisimbi Prospect, Nyabihu District, Northwestern Rwanda

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ABSTRACT

The surface investigations of the geothermal resources of Rwanda have been carried out during the last 30 years. The investigations were carried out in two potential prospects; in the young volcanic lava flows of the Virunga massif which host active volcanoes in its western limb in the Democratic Republic of Congo (Nyiragongo and Nyamuragira volcanoes) and in the Late Tertiary volcanic field of the Bugarama graben in the southwestern part of Rwanda. In both domains, geothermal manifestations are mainly hot springs, warm springs, gas-rich mineralized springs, and travertine either along N–S-oriented fault zones of the Virunga area or in the Bugarama graben.

The Virunga geothermal domain was investigated in detail and two of the three planned exploration wells were drilled. The Bugarama, Gisenyi, and Kinigi prospects did not continue beyond the reconnaissance phase.

Sampling of cold waters, hot waters, soil gas and other gases, and rock samples for chemical analyses and interpretation, geophysical measurements (using TEM, MT, passive seismicity, etc.), and finally remote sensing-based geological investigations were used for the reconnaissance survey.

The key outcome of these investigations was that a geothermal resource may exist within the Virunga Massif and/or its surroundings. A cross-check of different lithological units, tectonic features, and different cones/craters was conducted between 29 October 29 and 7 November 2012. Geological and geothermal surveys carried out in the Karisimbi area consisted of detailed mapping. This was done in a stepwise manner with an understanding and description of rock units, the structural features of the study area, geothermal alteration, and relationship between them.

1. HISTORY OF GEOTHERMAL RESOURCES ASSESSMENT IN RWANDA AND OBJECTIVES

Surface investigations of the geothermal resources of Rwanda have been carried out during the last 30 last (Rancon and Demange, 1983; Chevron, 2006; Jolie et al., 2009).

The investigations were carried out in two potential prospects:

1) Young volcanic lava flows of the Virunga massif which host active volcanoes in its western limb in the Democratic Republic of Congo (Nyiragongo and Nyamuragira volcanoes) and,

2) Late Tertiary volcanic field of the Bugarama graben in the southwestern part of Rwanda.

In both domains, geothermal manifestations are mainly hot springs (e.g., Gisenyi, Karago, Ruhwa, Bugarama, etc.), warm springs such as Mbonyebyombi (Kanama Sector-Rubavu District-Western Province), Mpatsi (Karongi District-Western Province), and Bitagata (Rulindo District-Northern Province), gas-rich mineralized springs, and travertines either along the N–S-oriented fault zones of the Virunga area and in the Bugarama graben.

The Virunga geothermal domain was investigated in detail and 2 exploration wells have been drilled. The Bugarama prospect did not continue beyond the reconnaissance phase (Jolie et al., 2009). Methods used during the surface surveys include collection of cold water, hot water, soil gas, and rock samples for chemical analyses and interpretation, geophysical measurements (using TEM, MT, passive seismicity, etc.), and remote sensing-based geological investigations (Jolie et al., 2009). The key outcome of these investigations was that a high enthalpy geothermal resource may exist within the Virunga Massif and/or its surroundings.

Detailed mapping was of the Karisimbi area was conducted from October 29th to November 7th, 2012, to cross-check different lithological units compiled in the geological map of Rwanda as well as tectonic features and different cones/craters reported in Jolie et al. (2009).

The key objectives of the mission were:

- ✓ To verify the geological structures reported by the BGR report (Jolie et al., 2009) that might affect the Karisimbi prospect;
- ✓ To map and describe adventive cones in the Karisimbi prospect which had not been mapped yet and provide recommendation;
- ✓ To collect geological data for the geological map update;
- ✓ To map surface geothermal manifestations such as alteration zones, silica sinters (if any present), travertines, hot springs, cold springs, hot grounds, fumaroles, etc.

- ✓ To check the chemical parameters of the newly-discovered springs within the Karisimbi prospect;
- ✓ To sample the rocks for petrographic analyses including precise identification of lithology, analysis of possible rock-geothermal fluid reactions, characterization of mineralogical and textural features to help correlate them with rocks that may be encountered during exploratory drilling;
- ✓ To train the geothermal staff on how to undertake geological and geothermal mapping.

The geological, geothermal and geochemical mapping report is presented in the following section.

2. GEOLOGICAL SETTING

The Karisimbi prospect lies within the Birunga volcanic zone (Figures 2 and 3). It is hosted by the western branch of the East African Rift System, the main regional geological structure (Figure 1). The lithology consists of K-rich, alkaline rocks and black lava flows which formed as a result of Quaternary to recent volcanic activity (De Mulder, 1985). The latter have built up a range of volcanoes such as Nyamulagira, Nyiragongo, Karisimbi, Bisoke, Mikeno, Sabyinyo, Gahingaö and Muhabura (Figure 2). The volcanic cover is underlain by a basement of Mesoproterozoic age. This basement comprises metasedimentary rocks which were intruded by two generations of granites during the Kibaran Orogeny (Tack et al., 2010; Dewaele et al., 2011). The tectonic features are represented by NW–SE-, N–S- and NE–SW-trending faults. The NW–SE- and N–S-trending structures are older and they are likely associated with pre-rift, Mesoproterozoic basement structures. The NE–SW-trending faults are the youngest generation of fractures and they have been buried underneath the young volcanic rocks (Jolie et al., 2009).

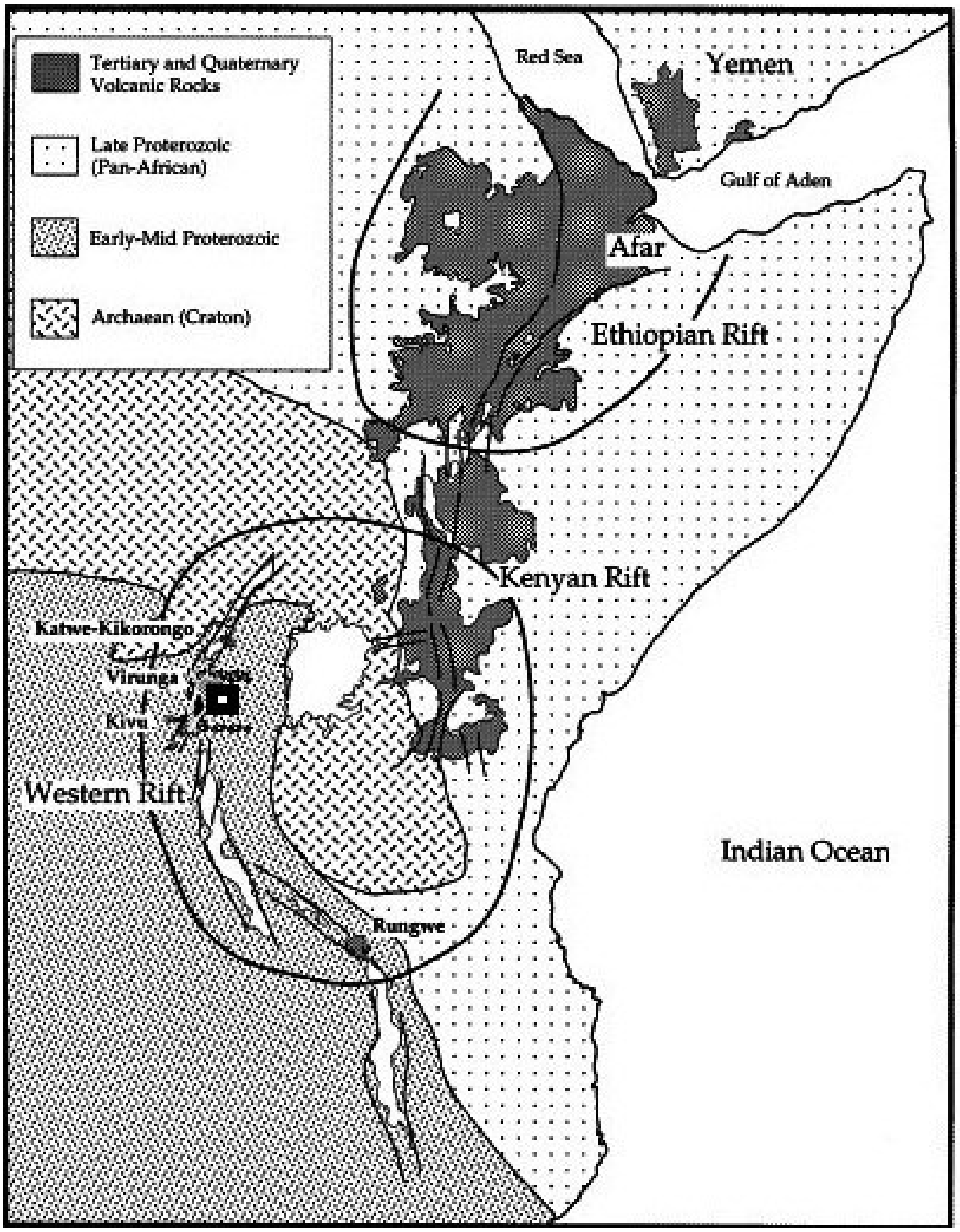

Figure 1: Map showing the East African Rift System (Rogers et al., 1998). The study area is shown by the black rectangle.

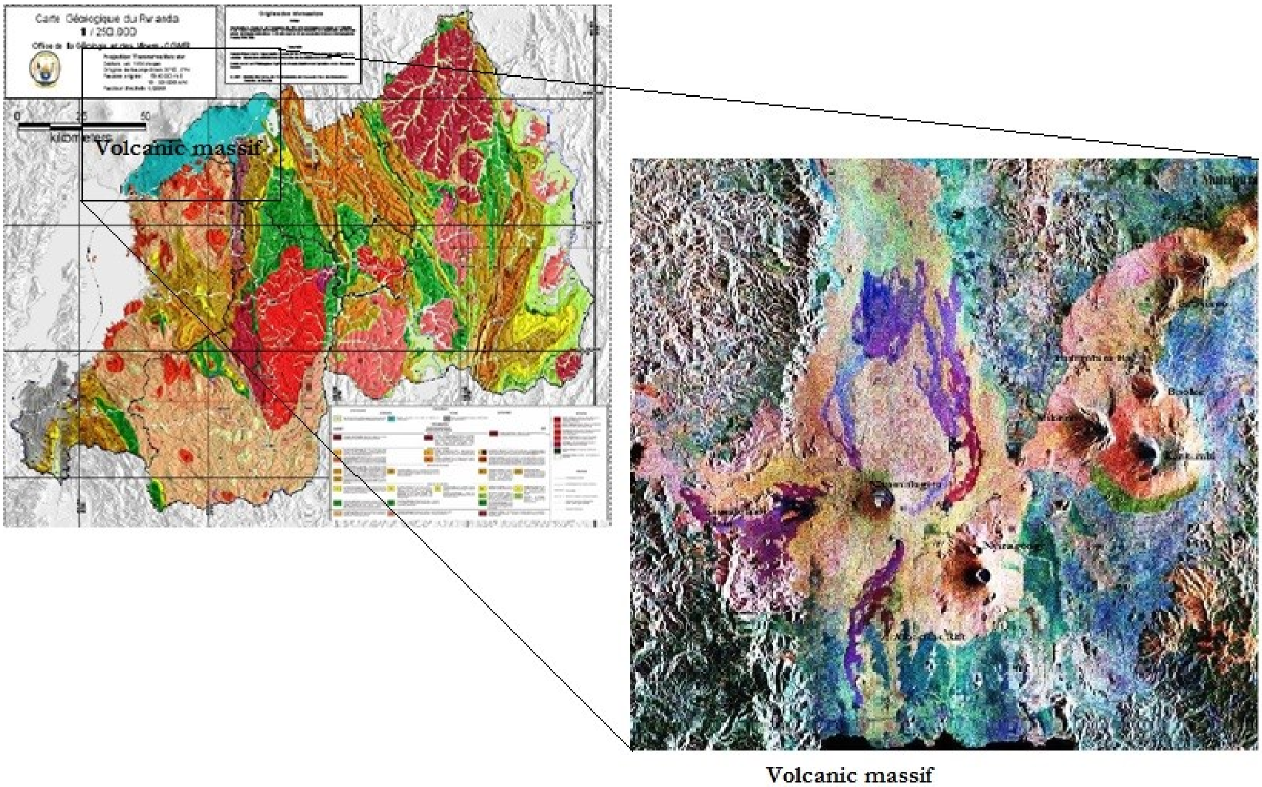

Figure 2: Geological map of Rwanda and image of the volcanic massif (Ngaruye and Jolie, 2008).

3. GEOLOGICAL AND GEOTHERMAL MAPPING

3.1. Methodology

Geological and geothermal surveys carried out in the Karisimbi area consisted of detailed mapping. This was done in a stepwise manner with an understanding and description of rock units, structural features of the study area, geothermal alteration styles, and the relationships between them. The study aimed to conduct field observations using field equipments and tools (e.g., geologic hammer, compass, digital camera, hand lens, aerial photographs, measuring tape, GPS) to locate and track the structural lineaments in addition to mapping the main rock units and areas that show different geothermal alteration styles. Field data was processed for geological and geothermal maps using the Arc-Map program.

3.2 Geological mapping

The first goal of this study was to sort out different lithologies. Three types of young volcanic rock units and two basement units were recognized and mapped. The second objective was to map the tectonic structures of the study area with the main focus on faults, fissure swarms within the basement, and recent basic lava flows. The third goal was to map different forms of geothermal manifestations, extinct geothermal features of all levels of extent (from low to intense), and active geothermal manifestations. Rock samples were also collected for laboratory analyses.

<u>a. Volcanic activity of the Karisimbi area</u>

Volcanic activity at the Karisimbi area was dated between 0.14 and 0.03 Ma. No volcanic eruptions were recognized in the Karisimbi during historic times.

The evolution of Karisimbi can be summarized in three phases; 1) formation of a primitive volcano and a lava plain principally built up by very low viscosity lava flows followed by the collapse of the summit, which resulted in the formation of the Muntango pit crater. 2) explosive activity built up a caldera complex named Caldera Branca in the eastern flank and produced most of the volcanic bombs found on the foot of Karisimbi volcano, and 3) eruption of a steep-sided stratovolcano, which is a summit cone. Additionally, numerous adventive volcanoes and lava flows occurred intermittently. Up to 3 m-thick soils were developed above the lavas of different age or above ash or tephra layers (Figure 5), which emanated from different volcanoes within the Virunga volcanic field. The tephra layers may have been entirely derived from local volcanoes. The surface of the lava flows is mostly flat and smooth. However, in some areas they are in the form of typical Hawaiian pahoehoe lavas (Figure 4).

Figure 3: Picture showing pahoehoe lave (left) and smooth lava (right).

Figure 4: Photos showing volcanic ash and consolidated tephra (scoria) in the SW part of the Karisimbi Volcano.

By studying the soil section and tephra layers, it is often possible to put constraints on the relative ages of individual lava flows using tephrochronology.

b. Rock classification

The topography of the Karisimbi field is dominated by N–S- to NE–SW-trending highs (ridges) and lows (depressions), which possibly follow narrow old graben and horst systems. The basement mostly comprises granitic intrusions and isolated old metasediments, which possibly correspond to the Butare Complex.

Basement

1. Small and limited outcrops of metasedimentary rocks

The oldest metasediments are rare and sparsely distributed within the Karisimbi prospect. They comprise altered biotite-schists in which mylonitization is frequent. They have been located mainly near the contact zones between the basement and recent volcanic rocks. They probably represent the oldest geological formation of Rwanda, corresponding to the Gishwati (or Butare) Complex.

2. Granites and pegmatite intrusions

The dominant formations of the basement are granites and on small pegmatites bodies occurring on top of these granites. These rocks have been deeply weathered into kaolin due to high degrees of hydration. Fresh outcrops show that the granites are fine- to coarse-grained and are therefore extended from granites to pegmatite granites.

Young lava flows

Field observations have shown 4 types of volcanic rocks irrespective of their ages.

1. Pyroclastic rocks comprising pumice and fresh tuffaceous material, which were localized in the vicinity of the Bugeshi Crater. The tuffs are partly lithic and partly crystalline tuffs. Their main component is aphyric clasts with occasional coarse-grained, large volcanic bombs. This scoria seems to represent the most recent eruption within the Karisimbi prospect.

2. Aphyric volcanic rocks, which are hard, massive, and dark colored. They are fine-grained and porous. They have been identified in the southwestern to southern parts of the Muntango pit crater.

3. Volcanic rocks with plagioclase phenocrysts. These are fresh lava flows with small to large plagioclase phenocrysts. They cover more than 80% of the Karisimbi prospect.

4. Lava flows with embedded xenoliths (Fig. 6). Numerous lava flows and pyroclastics of the Karisimbi area enclose bedrock inclusions. Majority of these inclusions are quartz xenocrysts showing little to no interaction with the surrounding magmatic rock. In addition, minor to rare granite, feldspar, metamorphic, and pyroxene xenoliths may occur within the lava flows.

Figure 5: Quartz-dominated xenolith within the volcanic rock. The magmatic fluids were initially gas-rich (vesicles in the figure).

Figure 6: Photo showing the contact between the basement (right side) and the volcanic rocks (left side) - Rukoma quarry on the road to Rubaya.

Field work has shown that the initial viscosity of the magma forming the lava plain was highly varying. This magma flowed into the accommodation zones following the original topography (narrow and wide grabens). Granitic intrusions and hills of the Gishwati Complex of the southern Karisimbi served as a barrier to the magma flow (Figure 7). It is not clear if these lavas were formed in a single eruption or as a result of several eruption events. A total of 29 rock samples were collected for petrographic analysis.

1. Recent sediments and soils

Surroundings of the main faults, micro-grabens, and craters are areas of deposition of the eroded material. These depressions are covered by soils to various extents due specifically to the deposition of aeolian and fluvial materials.

<u>Structural geology</u>

The most important tectonic features possibly controlling the fluid flow in the study area are N–S- to NE–SW-trending faults dissecting the basement rocks. Normal faults are prominent and delimit the accommodation zones in the southern slopes of the Virunga area. The throw of the faults is often difficult to measure, but ranges within hundreds of meters. Faults that dissect the study area are more common within the basement than in the younger lavas where they follow the former micro-grabens dissected in the basement (Figure 8).

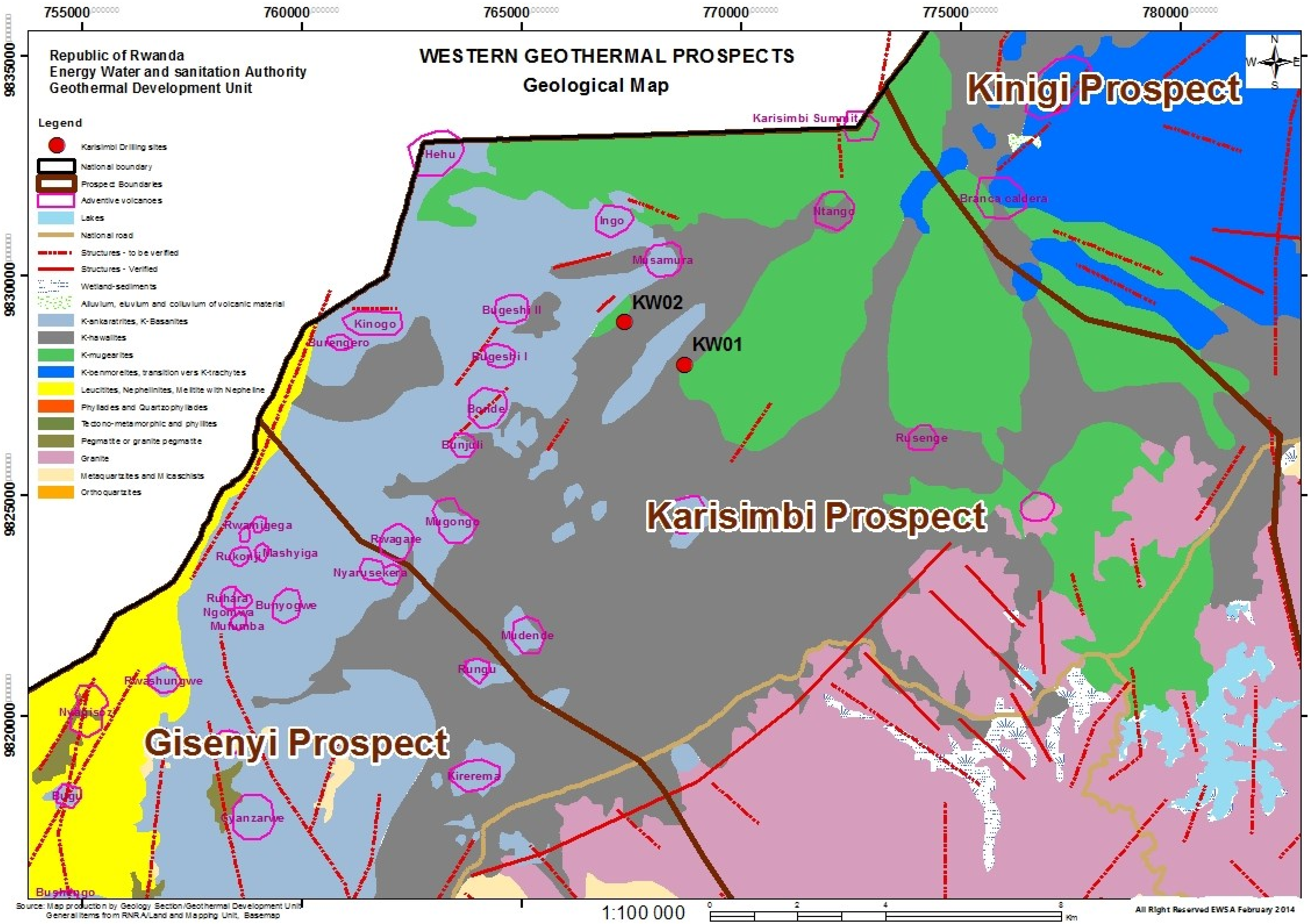

Figure 7: Geological map of the Karisimbi prospect (present work).

Figure 8: View (from the S) of a NE–SW-trending depression – south of the Mukamira Sectoral Office (F1 and F2 delineate a narrow graben).

The faults are simply expressed as radial depressions and ridges around the Virunga area. It should also be mentioned that apart from the normal faults some explosive craters have also been mapped within the Karisimbi area. The most prominent of these are Musamura, Ingo, Bugeshi I, and Bugeshi II. They are generally surrounded by scoriaceous material, which is the first product of the eruptions. The basement units consist of many fractures, which were pointed out and mapped (Figure 9).

Figure 9: Faulted granite (upstream of the Mbonyebyombi River) to the north of the Mbonyebyombi hot spring. The fault is N–S-oriented.

3.3 Geothermal manifestation mapping

The only active geothermal manifestations identified in the Karisimbi prospect are the Karago hot spring, the Mbonyebyombi warm spring and the Ndorwa saline spring (Figure 10). No fumaroles, mud pools or hot grounds were observed.

The Karago hot spring is located at the southern outlet of a N–S-trending open graben occupied by the Gihinga Lake. As witnessed by the local populations, during the flooding events, the hot springs moved from the old shore to the new one and further south of the lake. In each case, the hot waters seem to be originated from the granitic intrusion. However, based on the obtained information, the hot waters might be a southern outflow of a different reservoir utilizing the N–S-trending fault zone. The granite to the south of the lake might have played a role as a barrier to the hot spring, which iss obliged to overturn. Temperature measurements were done using a digital thermometer. The surface temperatures were carefully measured for mapped sites and were in the range of 34°C in Mbonyebyombi up to 64°C in Karago.

The origin and the nature of the swelling dark clays (Figure 11) surrounding the Karago hot springs remain unknown. They are presumably smectites or montmorillonites but this needs confirmation through XRF and XRD analyses. These analyses will help to determine the origin of clay minerals based on their chemical components. Did these clays form from simple weathering/erosion or from hydrothermal alteration of the erupted lavas of the Virunga massif?

Figure 10: Photo showing the emplacement of the Ndorwa saline spring.

Figure 11: The Karago hot spring surrounded by swelling clays.

Rock alteration

The lavas are mostly fresh. Only one type of slight alteration is distinguished in the form of oxidation illustrated by a change in the color of tuffs into much brown to reddish colors. This is probably due to interaction of tuffs with water in the prospect.

4. MONITORING OF GEOCHEMICAL PARAMETERS (KARISIMBI PROSPECT).

During our field work in the Karisimbi prospect, some springs were monitored and in-situ parameters such as electrical conductivity, pH, and temperature were measured. All of the monitored springs have parameters that are same with that of previous surveys. There were no changes compared to the results reported by Fabriol and Verzier (1983), Chevron (2006), and Jolie et al. (2009). A new area of saline springs (Cyabararika 2) was discovered in the south of Cyabararika 1, where the measured pH value was 8.6 indicating more saline waters than Cyabararika 1, where the pH is acidic. This should be due to the presence of travertines near Cyabararika 2. Results of in-situ measurements of Cyabararika 2 and other springs within the prospect are summarized below.

Cyabararika 2: This saline water drainage area is characterized by high pH (8.6) possibly due to the presence of travertine. The pH of Cyabararika 2 is basic, whereas Cyabararika 1 is acidic. Electric conductivity values of both springs are almost same (2660 µS) and their temperatures are around 20.5°C. This drainage zone hosts geothermal grasses.

Cyabararika 1: The electrical conductivity value is the same as the one measured previously by BGR (electrical conductivity: 2862 µS, pH around 6.0). These values indicate same characteristics as it was tested previously by BGR.

Mbonyebyombi hot spring: The measured temperature was 34.2°C, which is almost similar to the previously measured temperature by BGR (34.5°C). The measured conductivity value of 917 µS is slightly different from the BGR value of 921 µS.

Ndorwa saline spring: Conductivity of these saline waters was measured as 2560 µS and the pH as 7.8 (alkaline), and the temperature was ambient (20.5°C). The high conductivity of this spring could be explained by its high dissolved salt concentration. The waters here are used by the locals to feed cattle.

Gahuranda cold spring: This spring was tested for comparison with other springs. The results are similar to the values obtained from other springs (pH:6.4, electrical conductivity: 256 µS, temperature: 21.1°C).

Karago hot spring: The temperature measured as 64.3°C (same as reported by BGR, 2009). The electrical conductivity was 1252 µS and pH was 7.3. These values are similar to the BGR data.

5. CONCLUSIONS AND RECOMMENDATIONS

The Karisimbi prospect exhibits two types of rocks; the basement comprising foliated and mylonitized mica-shists, hard and massive quartzite, pegmatitic granites, gneissic granites and granitic intrusions, and recent lava flows which are originated from the Karisimbi Volcano. These lavas ocassionally contain plagioclase phenocrysts and/or quartz-dominated xenoliths.

The basement has been dissected by N–S- and NE–SW-trending faults. It is difficult to locate the major structures events in the area due to thick cover of mafic volcanic rocks. The method used to track these structures was to identify radial or NE–SW-oriented depressions within the lava field.

The volcanic rocks are fresh and do not show any sign of hydrothermal alteration representing a high enthalpy geothermal system. Hydrothermal alteration is not evident in the area surrounding the hot springs due to permanent flooding. It is recommended:

- ✓ To integrate these data and information and reinterpret previous geoscientific studies.
- ✓ To critically review all available data and to confirm possible heat source at a reasonable depth before drilling any deep geothermal exploratory wells in Karisimbi or in other geothermal prospects in Rwanda.
- ✓ To carry out additional surface data acquisition, slim hole exploration drilling, and a review of data obtained from surface exploration and exploration drilling.

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