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The Geochemistry of Arus and Bogoria Geothermal Prospects

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ABSTRACT

Arus and Bogoria prospects encompasses several features of geological significance that are considered indicators of possible geothermal potential. These include surface manifestations, such as, intense fumarolic activity (Arus), the vigorous geysers and hot springs (L. Bogoria. Loboi, Maji Moto areas). Anomalous hot ground water boreholes (Mugurin, Emining area) and some carbon dioxide emitting holes in the Esageri area. The springs and boreholes have been sampled and their chemical composition determined and evaluated. The geysers of Lake Bogoria discharge mixed fluid of different proportions of lake water, deep geothermal fluid, and shallow ground water. High flows of discharging fluids were recorded around Lake Bogoria and Maji Moto springs. Reservoir temperature estimates using Quartz geothermometer temperature range from 115 to 425 deg C, while the Na/K geothermometer temperature range from 122 to 377 deg C.

Three hundred and thirty-eight (338) random radon and soil gas sampling points were established. The radon-220 distribution, indicate high counts above 3000 cpm in the western and south western areas of the prospects. These areas include, Arus steam jets, Molo Sirwe and the area to the north of Mugurin. The rest of the area has moderate to low radon-220 counts. The radon-222 distribution indicate high counts in the area between the Arus steam jets and Molo Sirwe. The rest of the prospect's area has low counts of less than 500 cpm. The four areas with high concentration of Rn-222, are indicative of areas of high permeability and high heat flow. The ground temperature distribution at 0.7 m depth in the Arus and Bogoria Prospects was determined. The areas around the Lelen swamp, Maji Moto, the southern part of Lake Bogoria, and the area north of Arus. They have anomalous ground temperatures in excess of 38°C. High carbon dioxide concentration in the soil gas, was observed around Arus, Molo Sirwe, Noiwet, and the area south of Lomollo. The areas above coincide with deep-seated faults or fractures where the source may be from a magmatic body.

A geothermal resource exists in Arus and Bogoria prospects. The upflow may be located in the area close to the Arus steam jets and the area north of Mugurin. Both areas have high radon and ground temperature. The proposed first exploration well is sited near the Arus steam jets. The proposed second exploration well is sited north of Mugurin and east of Arus steam jets (coordinates 170000 E, 17500 N).The paragraphs should not have line breaks between them – the Normal style will space the paragraphs automatically.

1. INTRODUCTION

1.1 Location of Study Area

The area referred to as Arus and Bogoria Geothermal Prospects is located within the eastern floor of the Kenya rift valley. It is bound by latitudes 0 m N (Equator) and 55,000 m N and longitudes 145,000 m E and 185,000 m E. Lake Bogoria is a prominent feature occupying part of the Bogoria prospect. The study covered an area of approximately 2000 sq km Figure 1.

Arus and Bogoria prospects encompasses several features of geological significance that are considered indicators of possible geothermal potential. Theses include surface manifestations, intense fumarolic activity (Arus), the vigorous geysers and hot springs (L. Bogoria. Loboi, Maji Moto areas), anomalous hot ground water in boreholes (Mugurin, Emining area) and some CO_2 emitting holes in the Esageri area.

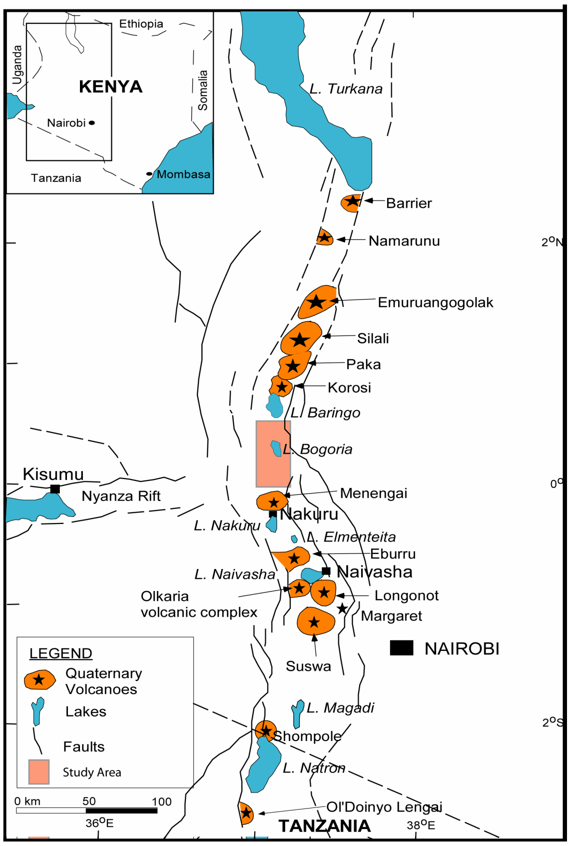

Figure 1: Location of the Arus and Bogoria geothermal Prospects within the Kenya Rift.

1.2 Previous Work

Previous geochemical investigations of this area were carried out by Geotermica Italiana Srl, (1987) and Ministry of Energy (MOE) in 1985-1986 under the auspices of the United Nations Department for Technical Development (DTCD). The work covered the area from Menengai caldera in the south to Lake Bogoria to the north. The work involved sampling water points and a few soil gas surveys targeting mainly carbon dioxide gas. From the previous work, few surface features of geothermal importance were covered and these consisted of hot springs and fumaroles of Lake Bogoria, the steam heated pools of Molo River at Arus and gas discharging boreholes. High flows of discharging fluids were recorded around Lake Bogoria springs and temperature estimates using solute geothermometry from the springs and boreholes ranged from 145-190°C for borehole and spring water. Gas geothermometry gave temperatures between 209-214°C for the Arus steam jets using $CH_4/H2$ and CO_2-CH_4-CO gas functions. There was no work done on soil gas survey in this area during this survey.

Figure 2: Photo showing the sprouting geysers of Lake Bogoria.

1.3 Objectives

The objective of the proposed geochemistry work is to gather enough geochemical data to be able to determine the following:

- Availability of a geothermal resource in this area
- Extent of the resource
- Chemical characteristics of the geothermal fluids present and their suitability for electric power production
- Prevailing reservoir fluid temperatures
- Whether the area deserves further exploration by deep drilling and if so propose exploratory drill sites.

2. METHODOLOGY

The work was divided into three phases;

Phase 1):

Sampling of all boreholes and springs within the Arus and Bogoria prospects,

Phase 2):

Fumarole gas plus steam condensate sampling, soil gas and radon-222, sampling at all steaming or altered grounds. All alteration grounds were visited to establish whether anomalous temperatures or gaseous issuance existed during this phase.

Phase 3):

Soil gas plus Radon surveys on both prospects was conducted, initially at random across the field, followed by traverses along lines running east-west.

3. RESULTS

3.1 Chemical Compositions of Boreholes and Springs

The temperature of the water discharged by the boreholes sampled varied between 24°C for Seretion, to 40°C at the Mogotio boreholes. The pH varied from 7.2 to 9.2, however, 22 out of 31 boreholes discharged water whose pH was between 6.5 and 8.0. With the exception of five samples, the conductivity of the water samples is less than 1000 µS/cm. None of the boreholes have silica concentration exceeding 100 ppm. This implies that the thermal component in the water discharged by these boreholes is small. High concentration of magnesium and calcium is observed in the water discharged by these boreholes.

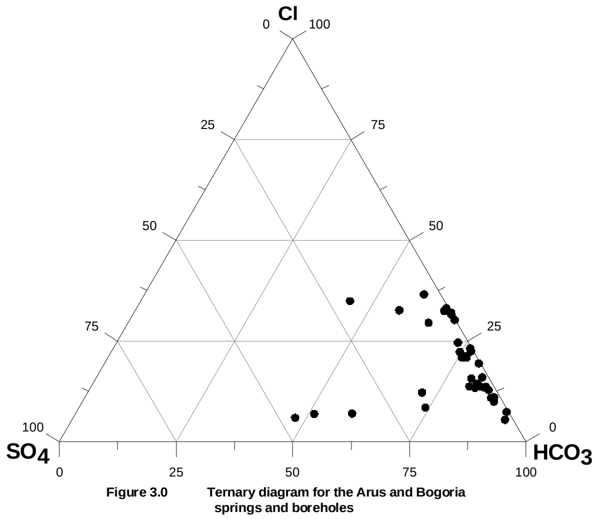

Figure 3: Ternary diagram for the Arus and Bogoria springs and boreholes.

The pH of the samples varies from 7.3 to 9.8 for samples taken from Bogoria spring 8 and Bogoria spring 9. Chloride concentration varies from 31 ppm (BS 5) to 3295 ppm (BS 15). The springs with high chloride concentration happen to have high bicarbonate (Total CO_2), they may be classified as chloride bicarbonate springs (BS-9, BS-10, BS-11, BS-12, BS-13, and BS-15). The chloride-bicarbonate-sulphate (Cl-HCO_3-SO_4) ternary diagram (Figure 3) shows that with the exception of four springs along Lake Bogoria all the boreholes and springs plot around the HCO_3 apex.

The springs in the two prospects discharge fluid that is highly mixed chloride – bicarbonate -sulphate water, which is immature fluid. In addition the springs along the lake discharge fluid that has varied proportions of shallow ground water, deep reservoir fluid and a large fraction of lake water. Therefore, application of solute geothermometers should be done with a lot of caution. The Quartz geothermometer temperature range from 115 to 425 deg C, while the Na/K geothermometer temperature range from 122 to 377 deg C. The outrageous figures have been removed altogether. Further analysis will be done to establish the concentrations of both aluminium and iron in these water samples. These two metal ions together, with Na. K, Ca, and Mg, will assist in evaluation of fluid mineral equilibrium processes.

4. RADON AND SOIL GAS SURVEY

The radon and soil gas sampling points are shown in Figure 4. Three hundred and thirty-eight (338) random radon and soil gas sampling points were established. The following parameters were determined and results recorded, radon-220 and 222, carbon dioxide in the soil gas, and ground temperature measured at 0.7 m. The radon-220 distribution plot, Figure 6, indicate high counts above 3000 cpm in the western and south western areas of the prospects. These areas include, Arus steam jets, Molo Sirwe and the area to the north of Mugurin. The rest of the area has moderate to low radon-220 counts.

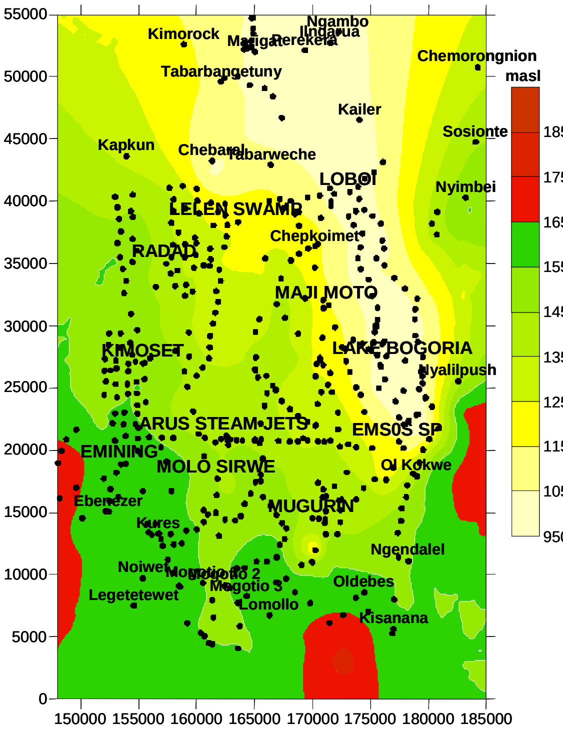

Figure 4: Arus and Bogoria all sampling points plot.

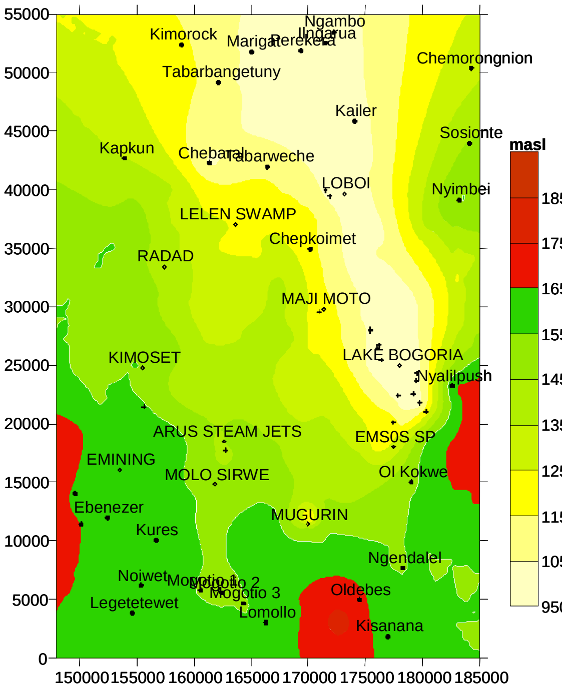

Figure 5: Arus and Bogoria geothermal Prospects Boreholes and springs location.

The radon-222 distribution plot, Figure 7, indicate high counts in the area between the Arus steam jets and Molo Sirwe. The rest of the prospect's area has low counts of less than 500 cpm. The ground temperature distribution plot, Figure 8, reveals high ground temperatures in the following areas, the area north of Arus steam jets, Lelen swamp, Maji Moto, and the southern area of Lake Bogoria. In addition, the area around Loboi and Nyimbei. The western part of the prospect area, with high radon-220 has low ground temperatures. More research is required to unveil this anomaly.

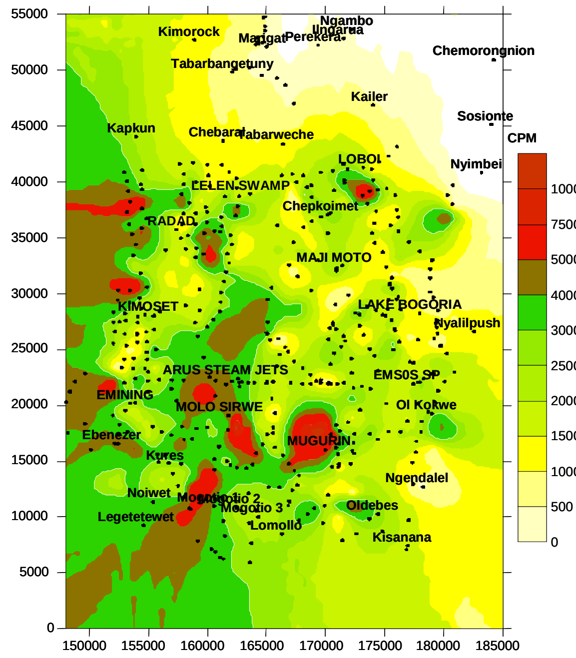

Figure 6: Arus and Bogoria soil gas Radon-220 distribution plot.

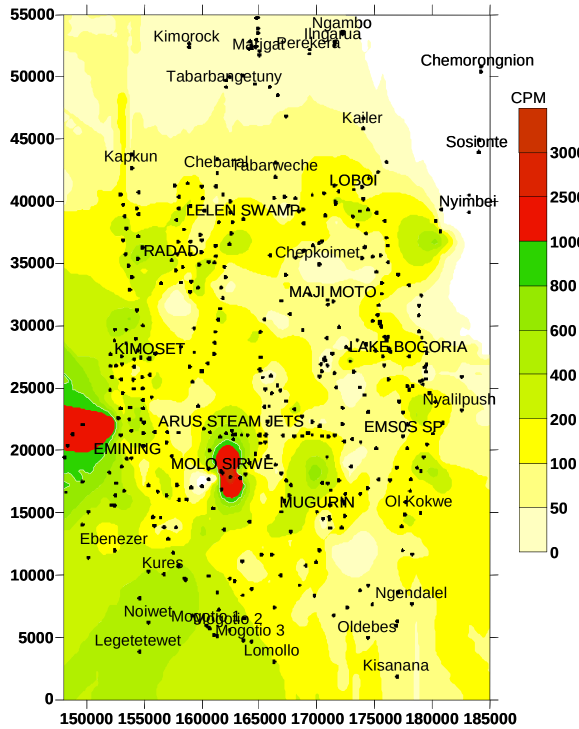

Figure 7: Arus and Bogoria soil gas Radon–222 distribution plot.

The soil gas carbon dioxide distribution plot is shown in Figure 9. The areas of high CO2 gas concentration are, the area between Arus and Molo Sirwe, Noiwet, and the area south of Lomollo. The rest of the area in both prospects has low carbon dioxide in the soil gas. The radon-222 and CO2 gas ratio distribution plot is shown in Figure 10. The anomalous area is around Molo Sirwe, the rest of the prospect area has no clear pattern or anomaly.

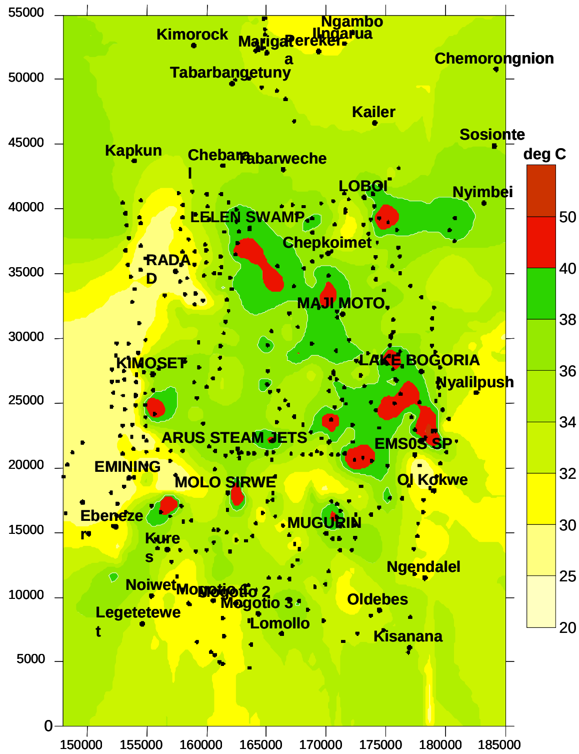

Figure 8: Arus and Bogoria ground temperature distribution plot.

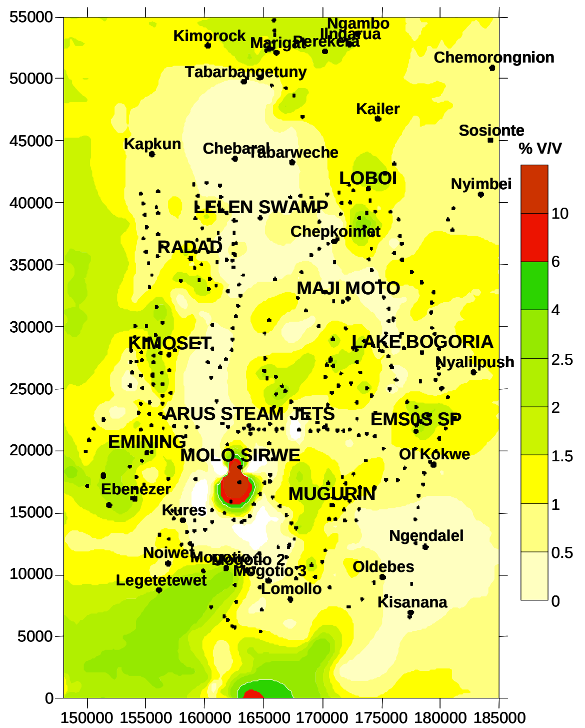

Figure 9: Arus and Bogoria soil gas CO2 distribution plot.

5. DISCUSSION

Geochemical exploration provides greater understanding of the location, nature, origin of the thermal waters in a geothermal system. In addition an insight into the recharge mechanism for the reservoir is obtained. The information is fundamental for the assessment of the relative merits for future exploration and exploitation. Geothermal surface activities in an area can be broadly classified into three types, which include:

- Hot water in form of springs and mud pools,
- Steaming grounds, alteration zones and fumaroles and
- Non-manifestation area where no surface expression of geothermal activity is observed.

The Arus and Bogoria geothermal prospects have very few surface manifestations occurring in the form of fumarole discharges or hot springs. However, ten fumaroles and nineteen (19) springs were located, sampled and analysed except the fumaroles that will be sampled latter.

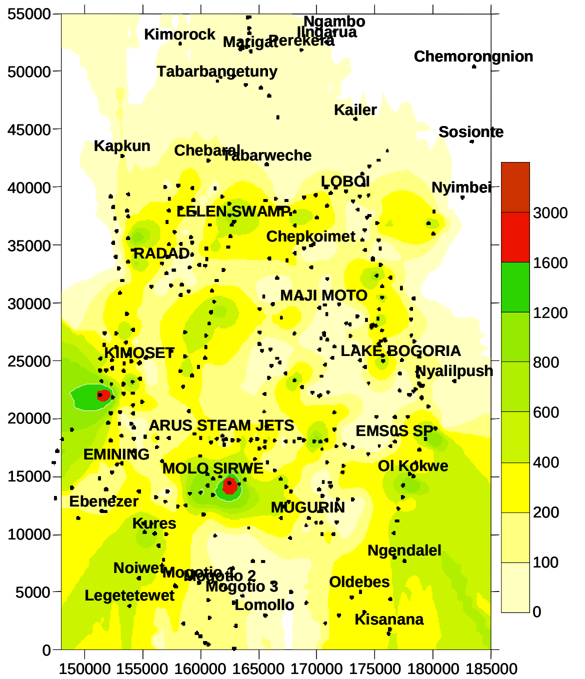

Figure 10: Arus and Bogoria Radon 222-CO2 ratio distribution plot.

Thirty-one (31) shallow boreholes (less than 200 m deep) were available for sampling. The greater proportion of the area shows very little hot and altered grounds or practically no manifestation at all. This therefore, presents a big problem to investigate geochemical indicators during surface exploration stages before deep drilling can be undertaken. To understand the chemical and physical characteristics of the reservoir in the Arus and Bogoria Prospects area, sample collection, chemical analysis and data interpretation was carried out.

5.1 Radon Radioactivity in Soil Gas

Radon has been used in the exploration for geothermal areas with little or no surface expressions and is adopted from mineral exploration techniques. Uranium-238 (U-238) is the parent source of Rn-222 and it is highly mobile and tends to concentrate in the late phases during crystallization.

Radon is a naturally occurring radioactive noble gas, which decays radioactively by emitting alpha particles. There are two isotopes of radon, Rn-222 derived from U-238 decay series and Rn-220 (Thoron) from Thorium-232 decay series. The two isotopes are easily distinguished by their different Half-life. Rn-222 was chosen as an exploration tool mainly due to its short half-life and due to its source, which is mainly magmatic U-238. Since it is a noble gas and is soluble in water, Rn-222 could be used to infer areas of high permeability and also areas of high heat flow. High values of the total radon counts at the surface would be taken to indicate a fracture or a fissure zone where both isotopes can migrate to the surface rather quickly. High temperature fluids carry the Rn-222 by convection to the surface through fissures and crashed rock zones along faults. Radon in the geothermal fluids is a function of porosity and fracture distribution in the geothermal reservoir (Stoker et al., 1975). Where radon reaches the surface quickest, this could be an indication of areas with higher permeability.

Other factors that affect radon counts are distance travelled between the source and the detection point, temperature, and the mineralogy of the reservoir rocks. The short half-life of radon and physical characteristics of the host rock limit the mobility of radon. The four areas with high concentration of Rn-222, Figure 7 are indicative of areas of high permeability and high heat flow. This is confirmed by the ground temperature distribution, Figure 8, where the same areas have high ground temperatures.

5.2 Ground Temperature Distribution in the Soil

Various factors influence the ground temperature distribution in the soil. These include:

- The prevailing weather conditions at the time of taking the measurements
- Physical characteristics of the formation, unconsolidated soils record lower temperatures due to air circulation.
- Proximity to a heat source to the surface, which could be a magma chamber or an intrusive body.

The ground temperature distribution at 0.7 m depth in the Arus and Bogoria Prospects is illustrated in Figure 8. The areas around the Lelen swamp, Maji Moto, and the southern part of Lake Bogoria, and the area north of Arus. They have anomalous ground temperatures in excess of 38°C. The areas also have high radon counts.

5.3 Carbon Dioxide Distribution in the Soil Gas

In an area like Arus and Bogoria geothermal prospects with few surface expressions, carbon dioxide in the soil gas is useful in the search for buried fumarolic activity, or to confirm presence of potential geothermal areas where other evidence is lacking. The porosity of the formation and other biogenic sources also determine the concentration of carbon dioxide measured in the soil gas. High carbon dioxide concentration in the soil gas, Figure 9, was observed around Arus, Molo Sirwe, Noiwet, and the area south of Lomollo. The areas above coincide with deep-seated faults or fractures where the source may be from a magmatic body. The presence of a thick alluvial cover over most of the area may interfere with the movement of carbon dioxide to the surface and hence cause erroneous interpretation.

5.4 Radon-222/CO2 Ratio in the Soil Gas

Interferences due to different sources of Rn-222 and carbon dioxide can be reduced or eliminated by evaluating the Rn-222/CO2 ratio in the soil gas. Radon-222 has a short half-life of 3.82 days, which implies that it has to travel long distances within a short period of time to be detected on the surface. For the detection of high concentration of carbon dioxide on the surface using the Orsat equipment, carbon dioxide has to travel through a relatively permeable zone to avoid dispersion and subsequent dilution. The Radon-222/CO2 ratio distribution in the soil gas is presented in Figure 10. The areas previously highlighted by high concentration of radon-222 and carbon dioxide, are reaffirmed by the ratio.

6. CONCLUSIONS

Nineteen (19) springs plus thirty-one (31) shallow boreholes (less than 200 m deep) were located, sampled, analysed and chemical composition evaluated. Ten fumaroles were located and will be sampled latter. The greater proportion of the area shows very little hot and altered grounds or practically no manifestation at all.

High flows of discharging fluids were recorded around Lake Bogoria springs and temperature estimates using solute geothermometry from the springs and boreholes ranged from 145-190°C for borehole and spring water.

The areas observed to have high radon-220 counts in excess of 3000 cpm are, Arus steam jets, Molo Sirwe and the area to the north of Mugurin. The rest of the prospect’s area has moderate to low radon-220 counts

The radon-222 distribution plot indicate high counts in the area between the Arus steam jets and Molo Sirwe. The rest of the prospect’s area has low counts of less than 500 cpm.

The ground temperature distribution at 0.7 m depth in the Arus and Bogoria Prospects was measured and evaluated. The areas that have anomalous ground temperatures in excess of 38°C, are around the Lelen swamp, Maji Moto, the southern part of Lake Bogoria, and the area north of Arus. The areas also have high radon counts.

High carbon dioxide concentration in the soil gas was observed around Arus, Molo Sirwe, Noiwet, and the area south of Lomollo. The areas above coincide with deep-seated faults or fractures where the source may be from a magmatic body.

A geothermal resource exists in Arus and Bogoria prospects

The upflow may be located in the area close to the Arus steam jets and the area north of Mugurin. Both areas have high radon and ground temperature.

7. RECOMMENDATIONS

The proposed first exploration well is sited near the Arus steam jets.

The proposed second exploration well is sited north of Mugurin and east of Arus steam jets (170000 E, 17500 N).

ACKNOWLEDGEMENT

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