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GEOCHEMICAL SURVEY CASE STUDY OF ARUS AND BOGORIA GEOTHERMAL PROSPECTS

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ABSTRACT

Arus and Bogoria prospects encompass several features of geological significance that are considered indicators of possible geothermal potential. These include surface manifestations, such as, intense fumarolic activity (Arus), vigorous steam jets and hot springs (L. Bogoria, Loboi, and Maji Moto areas), anomalous hot ground water boreholes (Mugurin and 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 steam jets 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 range from 124 – 175°C for Lake Bogoria springs, while the Na/K geothermometer gave temperature values ranging from 119 - 325°C for the same springs. The Arus hot springs give estimated temperatures ranging from 115 – 161°C using the quartz geothermometer. However, the high temperature estimates calculated using the Na/K ratio geothermometer could not be reflective of the actual reservoir temperatures and could have been influenced by other factors like mixing of reservoir fluids and shallow ground waters or lack of fluid-mineral equilibrium. Gas geothermometry indicated temperatures of 248°C for the Arus steam jets using the hydrogen sulphide gas.

High radon –220 counts above 3000 counts per minute (cpm) were measured in the western and south western areas of the prospects (Arus steam jets, Molo Sirwe and north of Mugurin) while high values of radon-222 counts were measured between the Arus steam jets and Molo Sirwe. These areas are considered to have high permeability. The areas around the Lelen swamp, Maji Moto, the southern part of Lake Bogoria, and the area north of Arus have anomalously high 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 results indicate a possible geothermal resource exists in Arus and Bogoria prospects. The resource is possibly characterized by medium to high temperatures. The proposed first exploration well is sited near the Arus steam jets. A second exploration well is proposed near Maji Moto area. These exploratory wells will be used to assess the potential of the prospect areas in terms of available geothermal reservoir.

1. NTRODUCTION

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 0m N (Equator) and 55,000 m N and longitudes 145,000m 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 encompass several features of geological significance that are considered indicators of possible geothermal potential. These include surface manifestations, intense fumarolic activity (Arus), the vigorous steam jets 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.

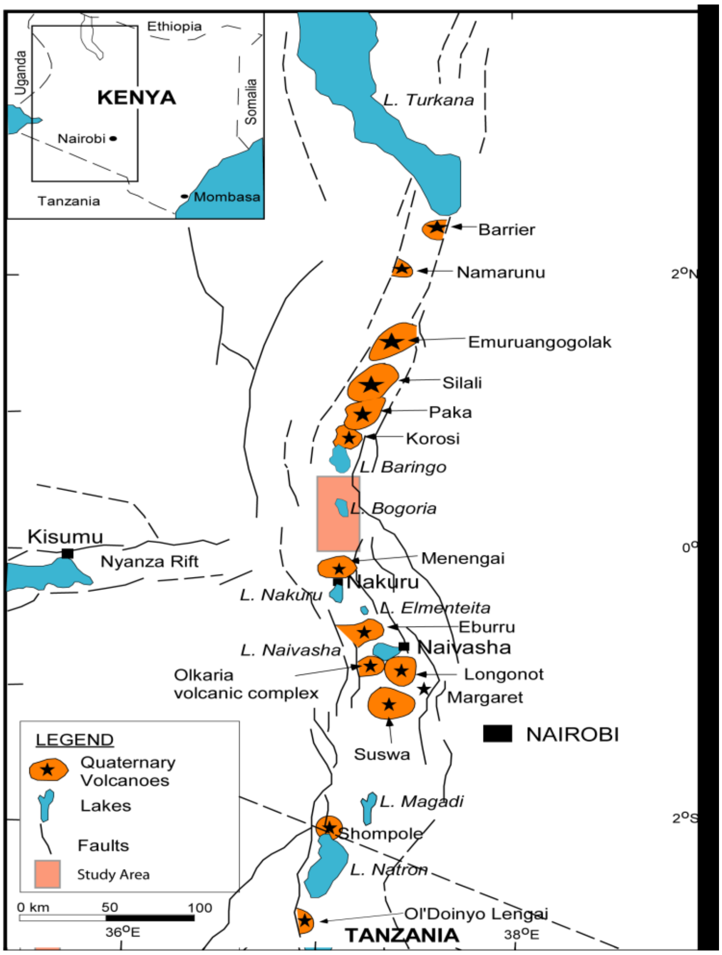

FIGURE 1: Location of the Arus and Bogoria geothermal Prospects within the Kenya Rift

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). In 1969, the Ministry of Natural Resources carried out a regional geological survey which covered the area between Eldama Ravine to the south and Kabarnet to the north. This work mainly covered the geological aspect of the area. However, the hot springs at Arus were sampled during this survey and chemical analysis done. A preliminary interpretation of the data indicated that the hot springs at Arus were as a result of river water entering fault fissures, meeting emanations from cooling magma at depth, being forced to the surface again under pressure of gas and steam developed from the heating.

The work by Geotermica Italiana 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.

1.3 Objectives

The objective of the current geochemical 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 or any other non-electrical uses.
- Prevailing reservoir fluid temperatures
- Whether the area deserves further exploration by deep drilling, and if so propose exploratory drill sites.

2. METHODOLOGY

The geochemical surface exploration was programmed to take one hundred and eighty working days, it was estimated to be adequate to sample all the fumaroles, springs, boreholes, expedite radon and soil gas surveys in the study area. 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 sampling, steam condensates and soil gas and radon –222/220, sampling at all steaming and altered grounds. The located fumaroles and boreholes in the prospects were mapped. All alteration grounds were visited to establish whether anomalous temperatures or gaseous issuance existed during this phase.

Phase 3:
Soil gas surveys on both prospects, for measurements of radon-222/220 radioactivity and carbon dioxide were conducted on the two prospects. Ground temperatures were also measured at a depth of 0.7m.

2.1 Springs and boreholes sampling and analysis

Both cold and hot water samples were collected from the springs in the area for chemical analysis. The area has two types of boreholes, capped or shut-in boreholes and flowing boreholes. Each type of borehole required a different method of sampling. The flowing boreholes were fitted with either an electrical or manual pump and could dispense water sample at the surface once the pump is switched on. The sampling jug was cleaned with de-ionized water and rinsed with the sample at least three times before a sample was taken. The sample taken was divided into several portions after filtration where found necessary. Spring and lake sampling involved using a well rinsed jug to scoop the water sample and divide the sample as described below after filtration.

The first portion was for immediate analysis for hydrogen sulphide (H_2S), carbon dioxide (CO_2), pH, Conductivity, and total dissolved solids (TDS). A measured amount of 5% zinc acetate solution was added to another portion of the sample for the fixation of sulphides. 1ml of concentrated nitric acid was added to a third portion of the sample for the analysis of metal ions. A portion of the sample earmarked for silica analysis was diluted ten times to avoid polymerisation of monomeric silica. The last untreated portion of the sample was reserved for the analysis of Chloride (Cl) and Fluoride (F) ions. Hydrogen sulphide gas (H_2S) was analysed at the sampling site, while carbon dioxide (CO_2), conductivity, total dissolved solids and pH were done at the end of each sampling day at the field laboratory. Silica (SiO_2), sulphates (SO_4), Cl, F and the metals ions were analysed at the main laboratory at Olkaria Geothermal Project Offices.

Both H_2S and CO_2 were analysed by titration methods using 0.01 M mercuric acetate and 0.01 M hydrochloric acid respectively. The conductivity and TDS were measured using the conductivity and TDS meters respectively while the pH was measured using a pH meter. Chloride and fluoride were determined using the Mohr titration method and selective ion electrode method respectively.

2.2 Fumarole steam sampling and radon-222/220 radioactivity measurements

A large funnel was used to cover the mouth of the fumarole and after ensuring thorough sealing, to avoid air contamination, a flexible tube was fixed to the narrow outlet end of the funnel. The fumarole gases were sampled by directing the steam into two evacuated gas sampling flask containing 50 ml of 40% sodium hydroxide solution and with continuous cooling using cold water pouring on the outside of the flask. Carbon dioxide and hydrogen sulphide gases are absorbed by the sodium hydroxide solution and hence create space for the residue gases such as, hydrogen, nitrogen, methane, argon etc. One flask is used for the analysis of carbon dioxide and hydrogen sulphide. While the other flask is earmarked for the analysis of hydrogen, Oxygen, nitrogen and methane at the Olkaria geothermal laboratory using the gas chromatograph.

After the gas samples were collected, the flexible tube was connected to a cooling coil, submerged in cooling water. The coil was then connected to a flask attached to a hand pump or a field pump. Through pumping, the condensate from the steam issuing from the fumarole was collected. The collected condensate was divided into five portions as described in 3.1 above and immediate analysis done. Dry fumarole steam was passed into the radon detector and three radon counts from the LED display of the detector were recorded in one minute intervals. After the radon – 222/220 radioactivity measurement, the flexible tube was connected to the Orsat apparatus, for the determination of CO_2 in the soil gas.

2.3 Radon –222/220 and CO_2 in soil gas survey

Random soil gas stations were established to optimise the available time allowed. The spacing between the sampling stations varied from 1km to 5km. The survey carried out involved measuring CO_2, Radon-222 & Radon – 220, and ground temperature measured at 0.7 m. A spike with an outer steel jacket was used to penetrate the ground to desired depth as described above. The outer jacket was left inside the hole to allow for the sampling after the spike was removed. A stopper attached to a flexible tube was fixed on to the mouth of the outer jacket and by using a hand operated vacuum pump, soil gas was driven into the radon detector. Three radon counts readout from the LED display were recorded in one minute intervals. During this operation, the soil gas sample containing radon is forced into the decay chamber of the emanometer (radon detector) consisting of a cylindrical copper can, whose walls are coated with zinc sulphide where the radon decays into other radioactive nuclides by emitting alpha particles. The alpha emissions are detected by a photomultiplier attached to the detector and a rate meter displays the signals. Three background counts were recorded at one minute intervals prior to introduction of the sample into the emanometer. Both the Rn-222 and Rn -220 are detected by the emanometer but since they have different half lives, it is possible to differentiate between the two. After the radon measurements, the flexible tubing was connected to the Orsat apparatus, for the determination of %CO_2 in the soil gas. Finally, a temperature probe was inserted into the hole made by the spike and after sealing the open-hole, the temperature was noted and recorded from a digital thermocouple thermometer.

3. RESULTS

3.1 Chemical composition of borehole and spring water samples

The chemical composition of the water samples from boreholes and springs are tabulated in Table 1 below:

TABLE 1: Arus and Bogoria geothermal prospects, boreholes chemical composition

NAME	CO_2	SO_4	Cl	TEMP	"pH"	COND	TDS	H_2S	F	SiO_2	B	Na	K	Ca	Mg
CHEPKOIMET	276	226	37	34	7.8	596	292	0.2	4.6	19	0.0	12	1	12	0.1
KIMOROK	398	227	47	39	8.5	905	458	0.2	3.6	18	0.0	15	1	21	0.6
KAILER	1308	296	223	34	8.9	3131	1560	0.2	3.0	15	0.0	724	4	4	0.7
KAPKUN	466		34	33	8.4	905	454	0.3	3.2	21	0.2	104	2	74	23.8
OASIS	374	7	72	34	7.9	530	254	0.2	2.0	88	0.0	125	19	52	11.0
ROSOGA	327	5	41	29	8.8	487	245	0.2		60	0.0	10	2	56	1.8
KURES	334	78	38	34	7.7	474	238	0.2		60	0.0	9	2	52	1.9
MARIGAT	168		46	31	7.9	248	131	0.1		36	0.1	3	0	56	0.7
CHEBARAN	314	16	51	32	8.3	436	222	0.1	1.9	85	0.0	81	8	34	23.6
AIC EBENEZER	444	9	72	33	7.9	592	318	0.1	2.8	44	0.0	129	23	4	20.2
TABARBANGETUNY	444	12	71	33	8.0	590	280	0.1		40	0.3	157	11	29	18.1
NGUBERETI	279	8	76	39	8.2	481	236	0.1	3.0	33	0.0	83	22	19	5.1
LEGETETEWET	383	7	58	40	7.9	563	272	0.1		57	0.5	18	2	21	0.6
KELELWA	155	3	76	33	9.2	301	149	0.1		23	0.4	10	2	3	0.0
OLEDEBES	209	14	36	32	7.7	317	156	0.1	2.4	94	0.0	9	17	10	0.3
NGENDALEL	205	9	57	30	7.4	335	158	0.1	2.7	23	0.4	11	1	8	0.1
OLKOKWE	111	21	64	30	8.3	400	202	0.1	2.5	70	0.5	13	1	10	0.1
MUGOTIO 1	192	6	65	40	7.9	530	360	0.1	3.4	44	0.0	10	2	15	0.1
MUGOTIO 2	207	9	62	40	8.0	540	358	0.1	4.4	44	0.0	12	2	13	0.2
MUGOTIO 3	173	7	31	30	7.3	470	319	0.1	2.7	56	0.1	10	1	11	0.0
LOMOLO	295	7	33	31	7.4	610	407	0.1	3.0	63	0.0	15	9	10	0.0
KISANANA CENTER	273	7	34	32	7.2	510	343	0.1	2.1	52	0.0	101	10	5	0.4
TABARWICHE	355	7	21	30	7.8	705	352	0.1	2.1	19	0.7	16	1	26	1.2
KASIELA	202	7	33		8.9	463	230	0.1		41	0.4	63	2	0	0.0
CHEMORONGNYON	164	8	32	34	8.3	421	210	0.2	2.7	19	0.0	67	4	19	4.5
SOSIONTE	611	6	178	30	7.6	1136	540	0.1		65	0.6	139	15	61	45.6
PERKERA	1085		70	31	8.3	2045	1044	0.3	1.1	47	0.0	476	8	10	0.0
SERETION	71	7	33	24	8.5	238	118	0.3		19	0.0	46	8	12	0.0
NGAMBO	2002	16	1000	35	8.0	13965	6975	0.3	3.3	79	0.0	300	3	45	1.2
ILNG'ARUA	1834	10	147	34	7.7	9165	4575	0.4		63	0.9	2000	26	68	15.3

The measured temperatures 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. Solubility of magnesium in water is inversely related to temperature while the solubility of calcium is highly controlled by the partial pressure of carbon dioxide gas. A high CO_2 concentration in the water, which is the case in the samples from these boreholes, is responsible for the high calcium levels in the water samples.

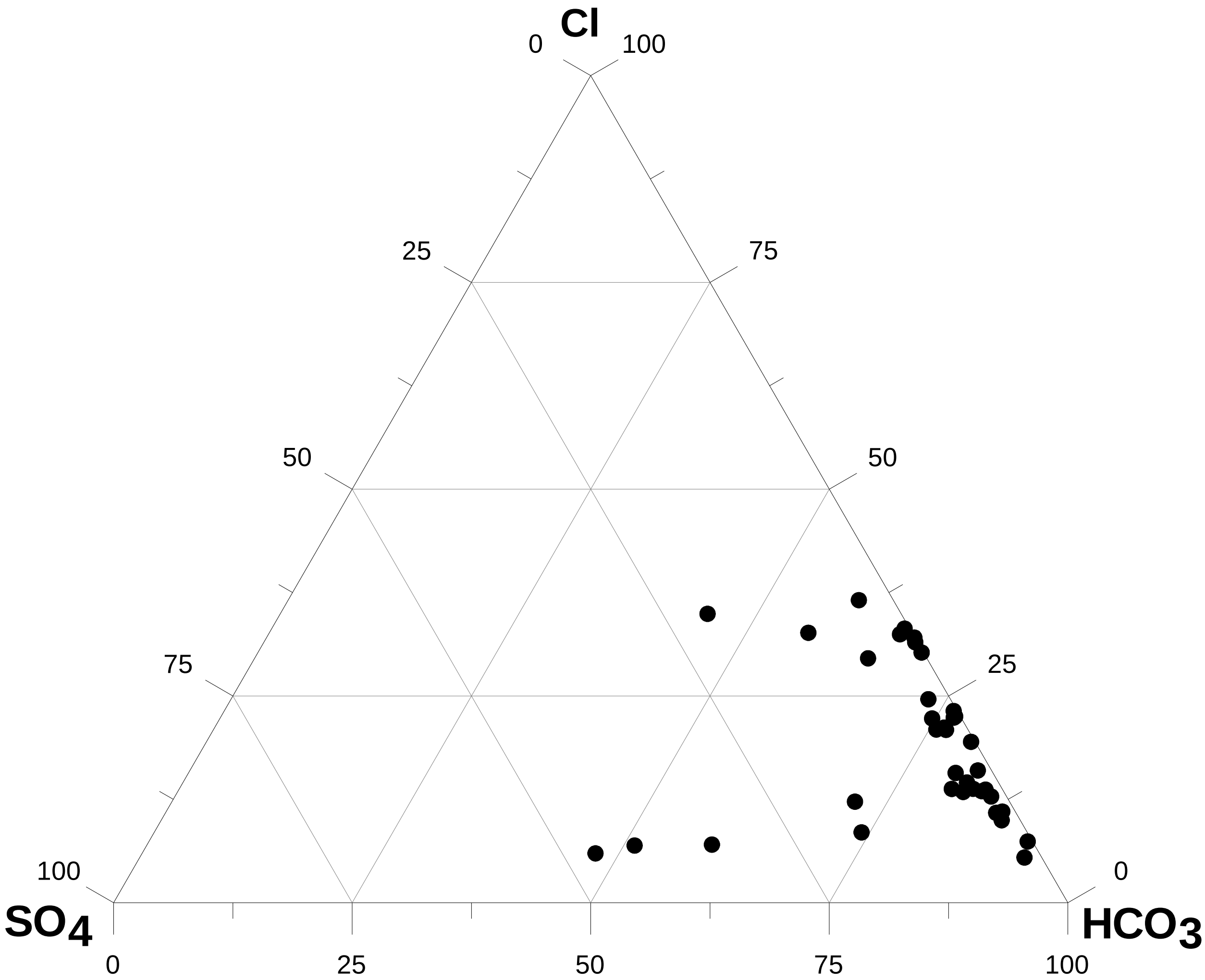

Figure 3.0 Ternary diagram for the Arus and Bogoria springs and boreholes

The majority of the boreholes in the area produce bi-carbonate type of water with a few samples discharging a mixture of sulphate-carbonate type. Both Cl and B levels are quite low in the water samples indicating limited residence time in the reservoir and also limited water-rock interaction. Bi-carbonate waters mainly form due to mixing of high Cl waters with near surface groundwaters and also due to condensation of CO_2 in near surface waters. Most of the hot spring waters in both Arus and Lake Bogoria areas plot to the bi-carbonate end of the ternary diagram above. These hot springs discharge water at the local boiling pressure and contain high amounts of dissolved CO_2. It is possible that these springs result from ground waters being heated by steam and due to the high CO_2 levels, the bi-carbonate content increases in the waters.

The chemical composition of the water samples collected from the springs in Arus and Bogoria is tabulated in Table 2 below.

The pH of the samples varies from 7.3 to 9.8 for samples taken from L. Bogoria spring 8 (BS 8) and L. Bogoria spring 9 (BS9). 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 3.0) shows that with the exception of four springs along Lake Bogoria all the boreholes and springs plot around the HCO_3 apex.

TABLE 2: Chemical composition of the Arus and Bogoria Springs

NAME	**pH**	**CO_2**	**SO_4**	**Cl**	**TEMP**	**H_2S**	**F**	**SiO_2**	**B**	**Na**	**K**	**Ca**	**Mg**	**TDS**	**T Qtz**	**T Na/K**	**TH_2S**
Bogoria spring 8	7.3	276			39		10.0	168	0.0	13	1	6	0.1	288	168	230	
Bogoria spring 6	8.0	167			35		7.6	78	0.2	67	85	17	1.9		124		
Bogoria spring 7	7.9	176			38		12.4	112	0.0	10	1	9	0.2	232	144	224	
Bogoria spring 5	8.3	243	238	31	33	0.2	3.2	29	0.3	11	1	11	0.1	2520		229	
Bogoria spring 9	9.8	6849	20	2979	102	9.9	6.0	88	1.8	498	85	0	0.0	8100	130	257	
Bogoria spring 10	9.7	5938	22	2739	100	9.5	6.5	202.7	0.9	340	14	3	0.0	7040	180	119	
Bogoria spring 11	9.2	2057	15	602	89	0.5	4.2	126	0.3	142	37	1	0.0	2560	151	322	
Bogoria spring 12	8.8	2240	12	544	86	0.2	1.9	77	0.9	1240	37	8	0.0	2440	123	151	
Bogoria spring 13	9.3	2206	11	669	96	0.4	3.6	185	0.8	14	4	3	0.0	2810	175	325	
Bogoria spring 14	8.1	264	8	73	45	0.2	3.7	44	1.6	110	15	23	3.6	285		255	
Bogoria spring 15	9.7	6978	6	3295	96	8.8	7.8	148	0.5	494	2	1	0.1		160		
Arus spring 1	7.7	44	20	34	89	0.2	2.7	66	0.4	9	12	7	0.0	90.2	115		
Arus spring 2	6.4	71.5	10	20.9	92	0.176	0.704	111	0.05	5.75	16	4	1	121	139		248
Arus spring 3	6.2	71.5	14	17	90	0.09	0.7	150	0.09	5.17	13	3.2	2.4	108	161		
Embogong spring	6.5	113	7	69	28	0.1	3.3	22	0.5	42	8	13	1.6	125		293	

The very low levels of both total dissolved solids and boron would result from limited residence time of the water in the reservoir and also lack of deep circulation of the water.

The springs in the two prospects discharge fluid that is highly mixed chloride – bicarbonate -sulphate water, which is interpreted as 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. From Table 2 above, the quartz geothermometer temperature calculated for Lake Bogoria springs range from 124 – 175°C while Arus springs gave temperatures ranging from 115 – 161°C using the same geothermometer. The Na/K ratio geothermometer gave temperature estimates ranging from 119 – 325°C for Lake Bogoria springs. There were no temperatures calculated for Arus springs using Na/K ratio. This was mainly due to the very low sodium (Na) concentration in the water samples from these springs. The Na concentrations were lower than the potassium (K) values in water samples and this gives negative results. Application of gas based geothermometers was hampered by lack of suitable gas samples from both prospect areas. Only one gas sample was obtained from the Arus area which gave temperature estimate of 248 °C using the H_2S geothermometer by Arnorrson et al.

3.2 Soil gas survey

The soil gas sampling points are shown in Figure 4.0. Three hundred and thirty-eight (338) radon-222/220 and CO_2 gas samples were collected and results recorded together with ground temperatures measured at 0.7m. The radon –220 distribution plot, Figure 4.2, indicate high counts above 3000 cpm in the western and south western areas of the prospects. These areas include, area around 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 plot, Figure 4.3, 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 4.4, reveals high ground temperatures in the following areas, the area north of Arus steam jets, Lelen swamp, Maji Moto, and the southern part of Lake Bogoria and also the area around Loboi and Nyimbei.

The soil gas carbon dioxide distribution plot is shown in Figure 4.5. The areas with high CO_2 gas concentration are between Arus and Molo Sirwe, Noiwet, and the area south of Lomollo. The rest of the area in both prospects has low CO_2 in the soil gas. The radon- 222 and CO_2 gas ratio distribution plot is shown in Figure 4.6. The anomalous area is around Molo Sirwe. The rest of the prospect area has no clear pattern.

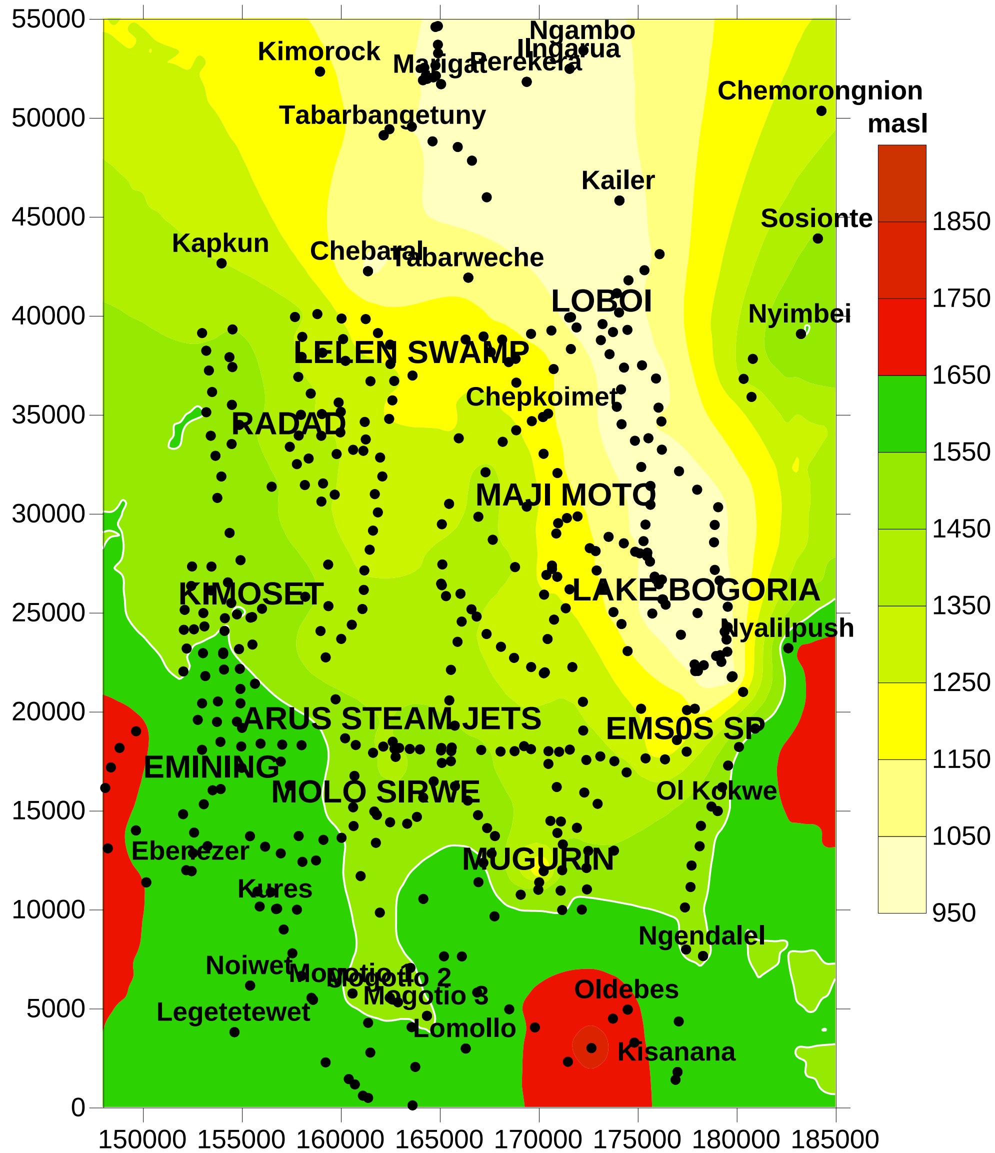

Figure 4.0 **Arus and Bogoria all sampling points plot**

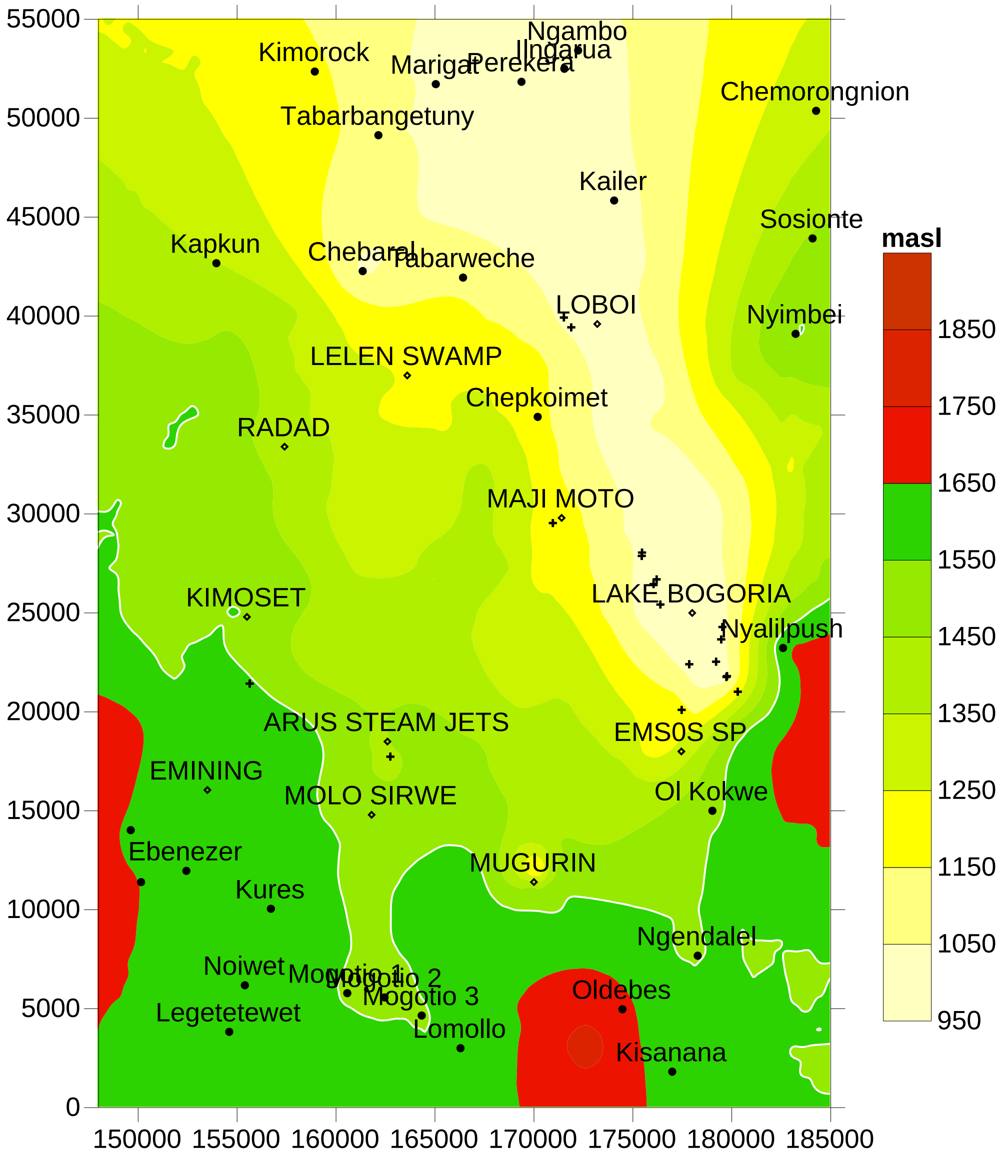

Figure 4.1 Arus and Bogoria geothermal Prospects Boreholes and springs location

4. 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 envisaged. The information is fundamental for the assessment of the relative merits for future exploration and exploitation of a potential geothermal field. 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.

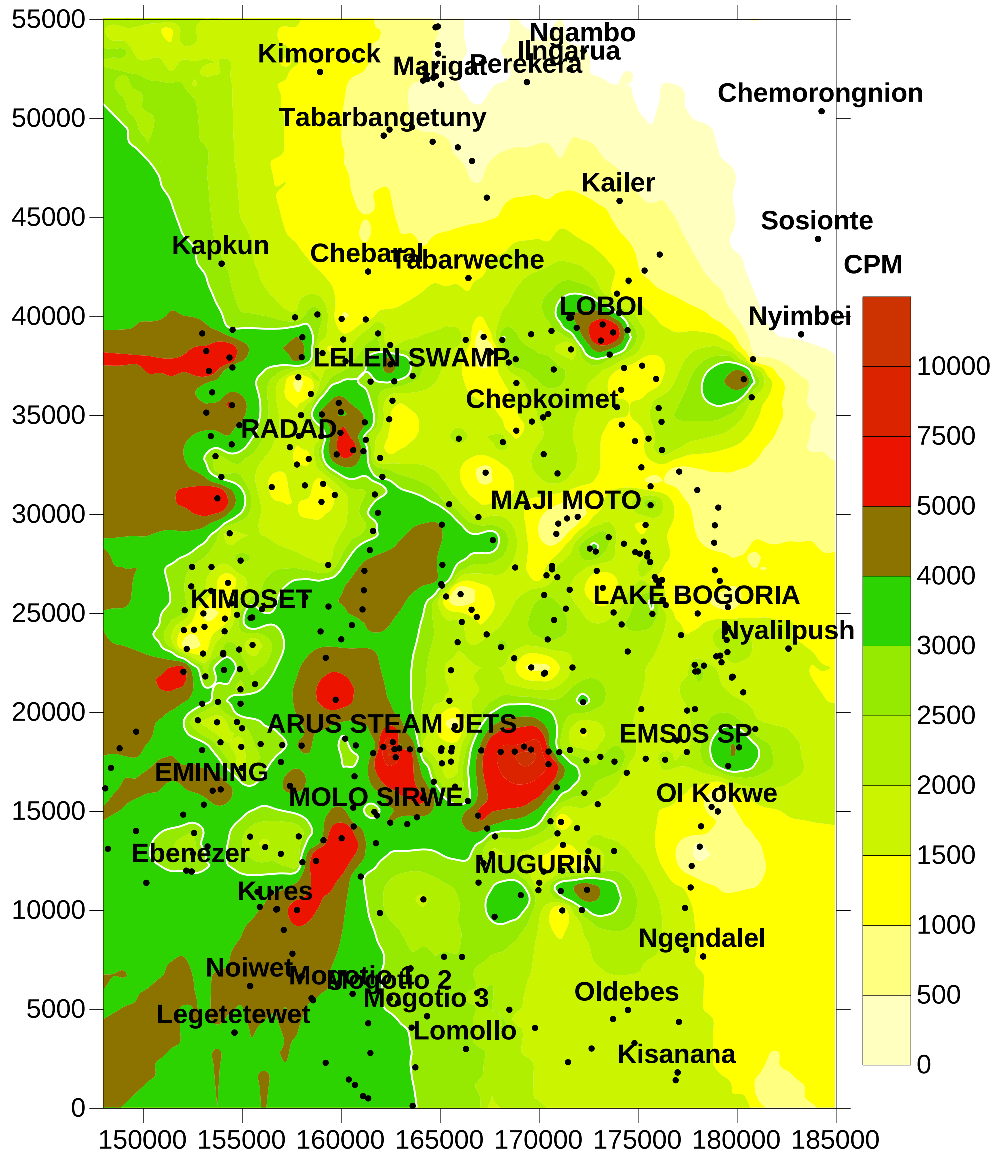

Figure 4.2 **Arus and Bogoria soil gas Radon 220 distribution plot**

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. Thirty-one (31) shallow boreholes (less than 200 m deep) were also sampled. 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 is undertaken. To understand the chemical and physical characteristics of the reservoir in the Arus and Bogoria Prospects sample collection, chemical analysis and data interpretation was carried out.

4.1 Radon-222/220 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. Below is the decay series for U-238 where the precursor for the decay starts with the loss of an alpha particle ($^{4}_{2}He$).

$^{238}U \rightarrow {}^{234}U \rightarrow {}^{230}Th \rightarrow {}^{226}Ra \rightarrow {}^{222}Rn \rightarrow {}^{218}Po$

$\rightarrow {}^{214}Pb \rightarrow {}^{214}Bi \rightarrow {}^{214}Po \rightarrow {}^{210}Pb \rightarrow {}^{206}Pb$

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-lives. 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. 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 4.3 may be indicative of areas of high permeability and high heat flow. This is confirmed by the ground temperature distribution, Figure 4.4, where the same areas have high ground temperatures.

4.2 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 atmospheric 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 0.7m depth in the Arus and Bogoria Prospects is illustrated in Figure 4.4. The areas around the Lelen swamp, Maji Moto, and the southern part of Lake Bogoria, and the area north of Arus have anomalously high ground temperatures in excess of 38°C. The same areas also have high radon counts.

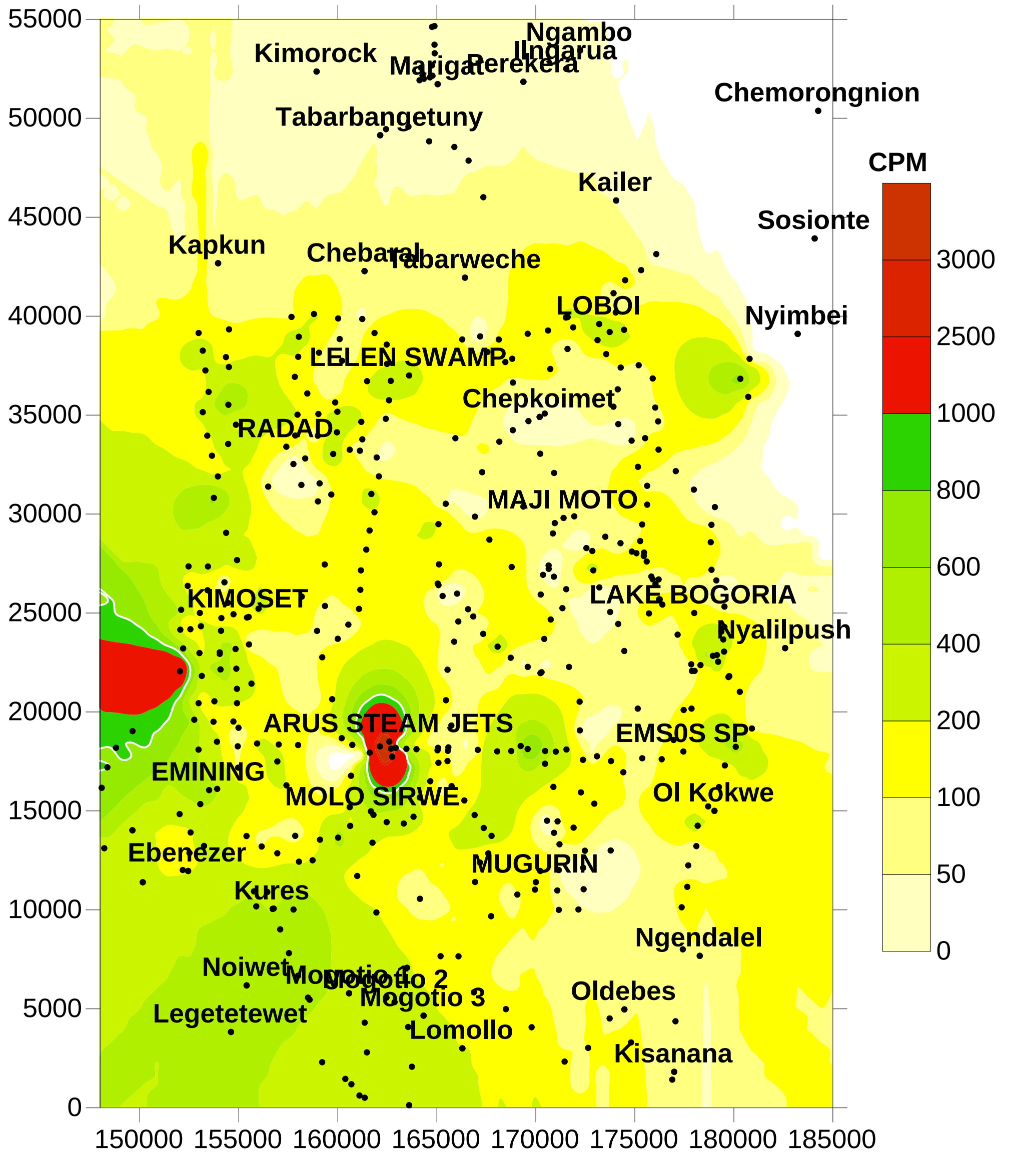

Figure 4.3 Arus and Bogoria soil gas Radon - 222 distribution plot

4.3 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 4.5, was observed around Arus, Molo Sirwe, Noiwet, and the area south of Lomollo. These areas coincide with deep-seated faults or fractures where the source may be from a magmatic body (Lagat, per. Com.). 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.

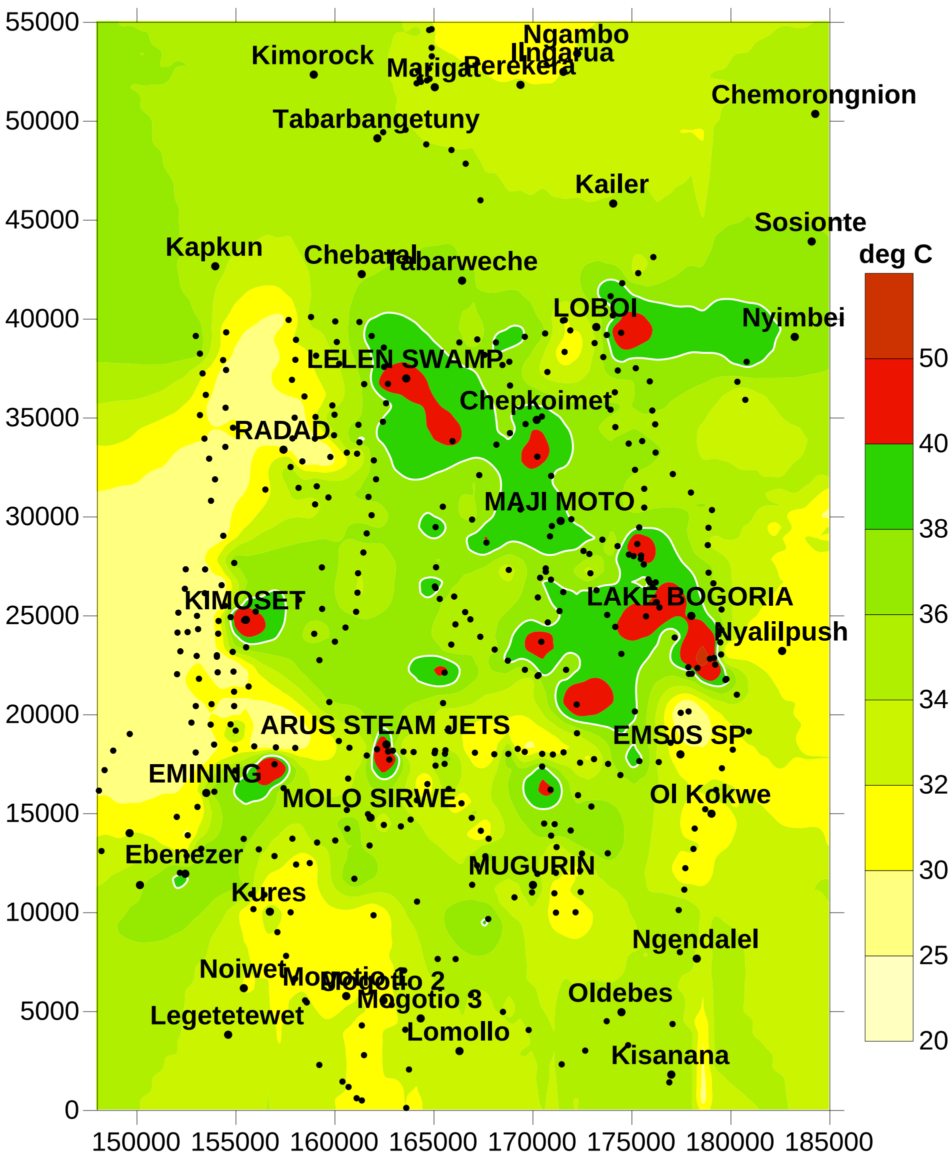

Figure 4.4 Arus and Bogoria ground temperature distribution plot

4.4 Radon-222/CO_2 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/CO_2 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, the gas has to travel through a relatively permeable zone to avoid dispersion and subsequent dilution. The Radon-222/CO_2 ratio distribution in the soil gas is presented in Figure 4.6. The areas previously highlighted by high concentration of radon-222 and carbon dioxide, are reaffirmed by the ratio.

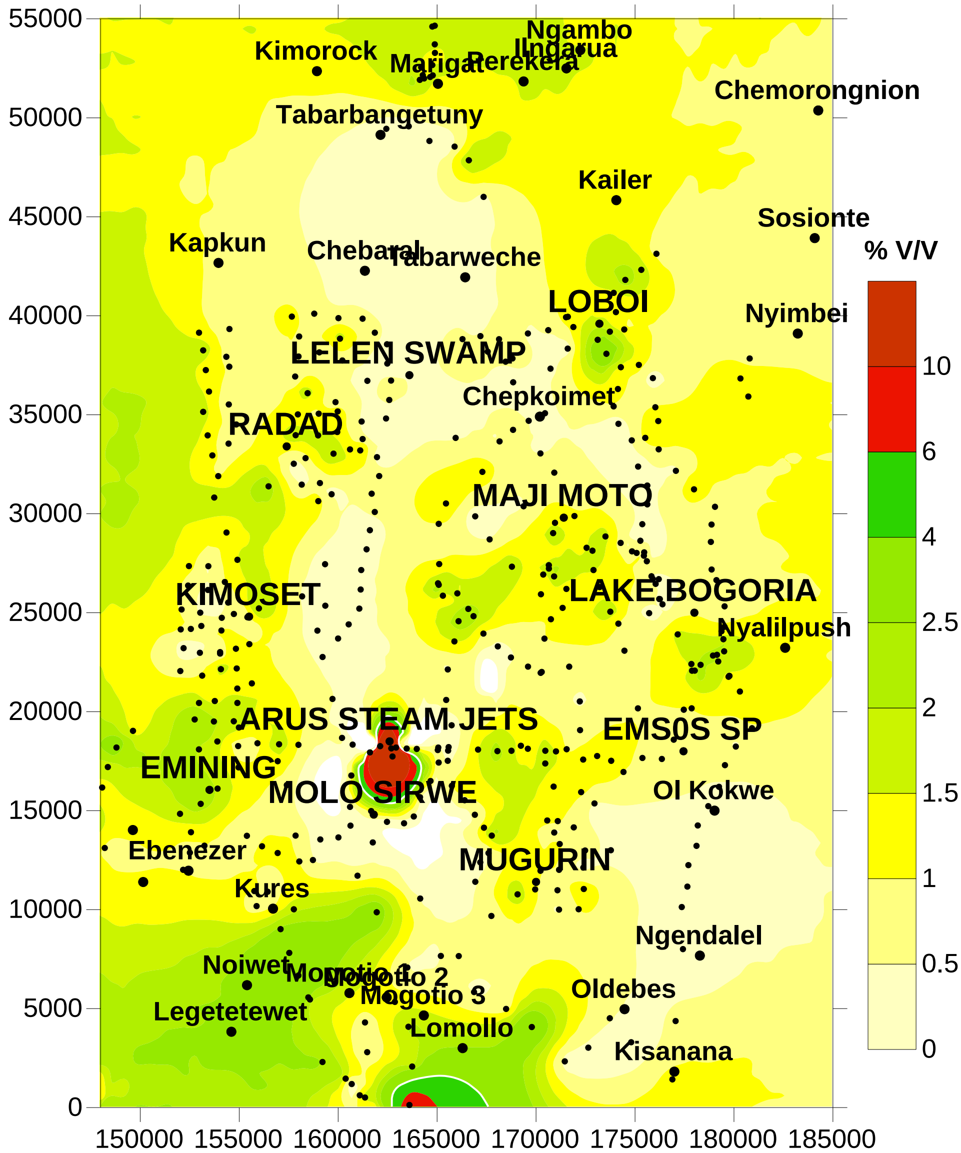

Figure 4.5 Arus and Bogoria soil gas CO2 distribution plot

4.5 Geothermometry

Geothermometry is used to estimate subsurface temperatures (temperatures expected to be encountered during deep drilling) using the chemical composition of hot springs and fumarole discharges. Both chemical and isotopic geothermometers constitute the most importan5t geochemical tool for the exploration and development of geothermal resources. During their application a basic assumption of temperature dependent chemical equilibria is always made. The geothermometry results calculated for the samples collected during this survey gave estimated temperatures ranging from 115 – 175°C for hot spring water samples from both Lake Bogoria and Arus. Highest temperature estimates for Arus hot springs is 161°C while for Lake Bogoria is 175°C calculated using the quartz geothermometer by Fournier (1977). The Na/K ratio geothermometer gave temperature estimates ranging from 119 – 325°C. Lake Bogoria springs had highest temperature estimates at 325°C. The high temperature estimates given by the Na/K ratio geothermometer could be unrealistic for various reasons. It is assumed that the Na/K ratio in the aqueous state is controlled by the equilibrium between the geothermal water and the alkali feldspar minerals. If other mineral phases are involved in the control of this ratio, then the assumption of temperature dependency and equilibrium becomes misplaced and this could give unrealistic values. Arnorsson et al, noted that Na/K ratio geothermometer re-equilibrates rather slowly in environments of high salinity like Lake Bogoria and this could also contribute to unrealistic temperature estimates calculated using this ration.

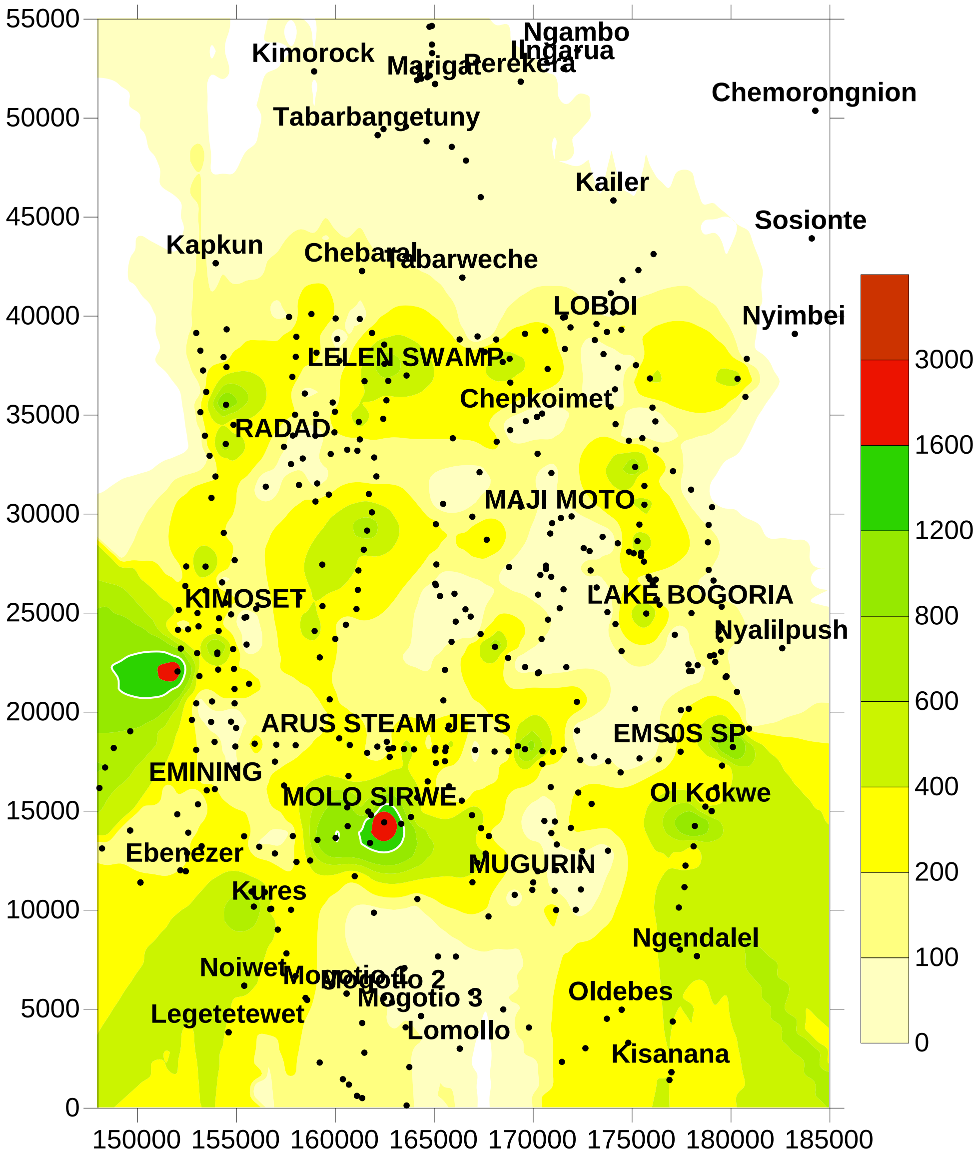

Figure 4.6 Arus and Bogoria Radon 222-CO2 ratio distribution plot

5. CONCLUSIONS

- The reservoir temperatures estimated by use of silica based geothermometry for Lake Bogoria springs is about 180°C. The Na/K ratio geothermometer gave temperature estimates which were not consistent and are assumed not very reliable. The Arus hot springs gave calculated source temperature estimates of about 161°C.

- The high radon counts and CO_2 measured close to the Arus steam jets and north of Mugurin indicates areas of enhanced permeability. These areas require to be explored further by deep drilling.

- A geothermal resource characterised by medium to high temperatures (161-180°C) exists in Arus and Bogoria prospects.

6. RECOMMENDATIONS

- It is recommended that an exploration well be sited near the Arus steam jets. This well will be used to probe the relatively high temperatures estimated in this area.

- A second exploration well should be sited to the north of Mugurin. This area is characterised by high radon counts, high ground temperatures and high CO_2.

7. FURTHER GEOCHEMICAL WORK

- Further Geochemical work is recommended to supplement the radon survey in the soil gas. In addition to radon radioactivity, it is recommended that measurement of mercury vapour be conducted in the area since it is known to be a good tracer for geothermal steam.

- Detailed work on sampling, chemical analysis and data interpretation of the hot discharges around Maji Moto, Lake Bogoria and Arus areas is necessary to establish possibilities of low temperature uses of the available geothermal fluids in these areas. Chemical determination of Aluminium and Iron species in these water samples will assist in evaluating the fluid – mineral equilibrium processes.

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