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Geochemistry of Katwe-Kikorongo, Buranga and Kibiro Geothermal Areas, Uganda

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ABSTRACT

Reconnaissance surveys have been carried out on the geothermal areas of Uganda since 1935 when the first documentation of Uganda's hot springs was made. Recent studies have focused on three geothermal systems of Katwe, Buranga and Kibiro all located in the active volcanic belt in the Western Rift valley along the border of Uganda and the Democratic Republic of Congo. The Western Rift Valley is characterised by geothermal systems and saline and fresh water lakes. The three areas were chosen for the study because of their volcanic and tectonic features that indicate a powerful heat source and high permeability. The objective of the study is to develop geothermal energy to supplement hydro and other sources of power to meet the energy demand of rural areas in sound environment.

The results from geological and geochemical studies indicate that all the three areas are potential geothermal prospects. Their hydrothermal systems appear to be relatively old and rise from volcanic basement rocks rather than from the young overlying sediments. Stable isotope data suggests a similar origin of the geothermal fluids and the meteoric water. The high carbonate contents and salinity in the range of 25,000 - 30,000 and 14,000 - 17,000 mg/kg total dissolved solids of the geothermal waters from Katwe and Buranga respectively, affect their magnesium and calcium concentrations hence throwing the validity of some conventional methods of interpretation into doubt. Taking these doubts into account, reservoir temperatures of 150 - 220˚C and 120 - 150˚C are inferred by geothermometry for Katwe and Buranga respectively. Mixing models applied to the Katwe waters predict a reservoir temperature of about 230˚C. The chemistry of the surface fluids from Kibiro on the other hand suggests a mixture of thermal and cold waters with a pH of 6 to 8, and salinity of up to 4,000 - 5,000 mg/kg total dissolved solids. The fluids are relatively dilute compared to those of Katwe and Buranga and would probably cause a few problems on exploitation. Geothermometry and mixing models predict a reservoir temperature of 200˚C and above for Kibiro.

The predicted reservoir temperatures for the three areas could be suitable for electric power generation and direct use in industry and agriculture.

1. INTRODUCTION

The three geothermal areas namely Katwe-Kikorongo (Katwe), Buranga and Kibiro are situated in the Western branch of the East African Rift System that runs for most of its length along the border of Uganda with the Democratic Republic of Congo (DRC) (Figure 1). The Western Rift valley is marked by intensive faulting, often accompanied by volcanic and seismic activities, and commonly geothermal systems. Geothermal resources are estimated at about 450MW in the Ugandan Rift System (McNitt, 1982).

Since 1992 systematic exploration has been going on in three geothermal areas of Katwe-Kikorongo, Buranga and Kibiro located in the districts of Kasese, Bundibugyo and Hoima respectively. The three areas were chosen as priority areas because of their volcanic and tectonic features that are indicators of heat sources and high permeability. The exploration has been centered on geological, geochemical, hydrological and geophysical investigations with the aim of locating suitable sites for drilling. This paper presents the current status of the geochemical model of the three study areas.

2. THE STUDY AREAS

2.1 Katwe Geothermal Prospect

The Katwe geothermal prospect is situated in the Katwe-Kikorongo Volcanic Field (KKVF), south of the Rwenzori massif in Kasese district. The KKVF is bordered to the south by the Lake Edward and Kazinga Channel and to the east by Lake George (Figure 2). The prospect stretches from Lake Katwe to Lake Kikorongo and is bordered to the south by Lake Edward and the Katwe – Katunguru road, to the west by River Nyamugasani, to the north by the Kikorongo – Bwera road and to the east by the Katunguru – Kasese road.

The geology of the Katwe geothermal prospect is dominated by explosion craters, ejected pyroclastics, tuffs with abundant granite and gneissic rocks from the basement (Figure 2). The volcanic rocks, composed mainly of pyroclastics and utramafic xenoliths, are deposited on the extensive Pleistocene lacustrine and fluvial Kaiso beds and in some places directly on Precambrian rocks. Minor occurrences of lava are found in the Lake Kitagata and Kyemengo craters. The age of the volcanic activity has been estimated as Pleistocene to Holocene (Musisi, 1991).

The deposit is greyish, generally coarse-grained and calcareous. Travertine cones (Tufa), which are indicators of extinct hot spring activity, are a common feature in the Lake Katwe crater. Other travertine deposits have been found in Lake Nyamunuka, Lake Kasenyi, and Lake Kikorongo and at Kikorongo junction. The volcanic setting of this prospect gives an indication of a heat source. Outside the crater area the geology is characterized by surficial deposits to the east and the west, and to the north lie the Rwenzori Mountains whose geology is dominated by gneisses and in some places granites and quartzites along the Kikorongo - Kasese road. South of Lake George lies the Bunyaruguru volcano which has a number of craters and crater lakes, believed to have been formed at the same time as the KKVF but has no surface geothermal manifestations. East of the Bunyaruguru volcano and Lake George from south to north are phyllitic stales, quartzites, gneisses and schists (mica and talc).

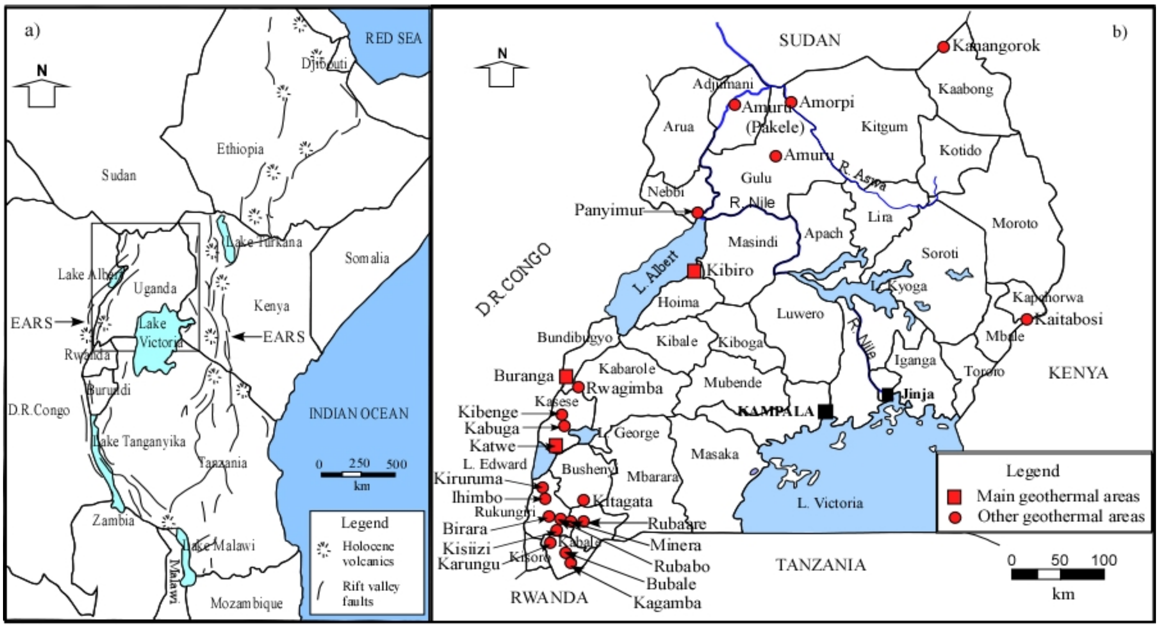

Figure1: a) East African Rift Systems (EARS) b) Location of the Geothermal areas in Uganda.

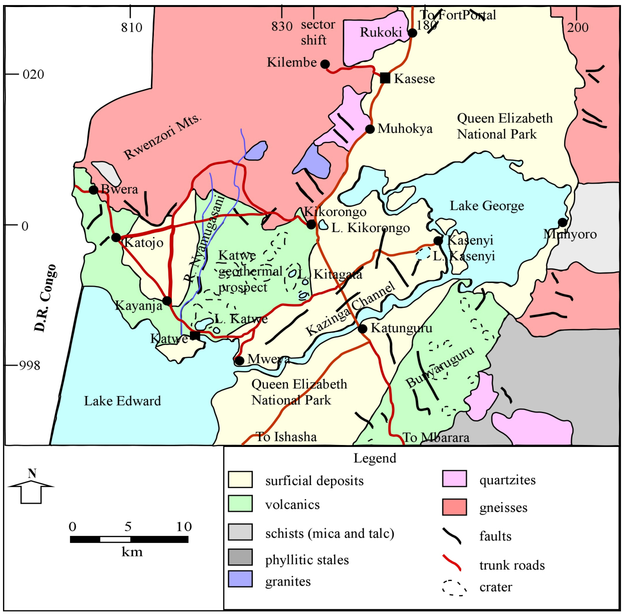

Figure 2: The geology of the Katwe-Kikorongo volcanic field and surroundings.

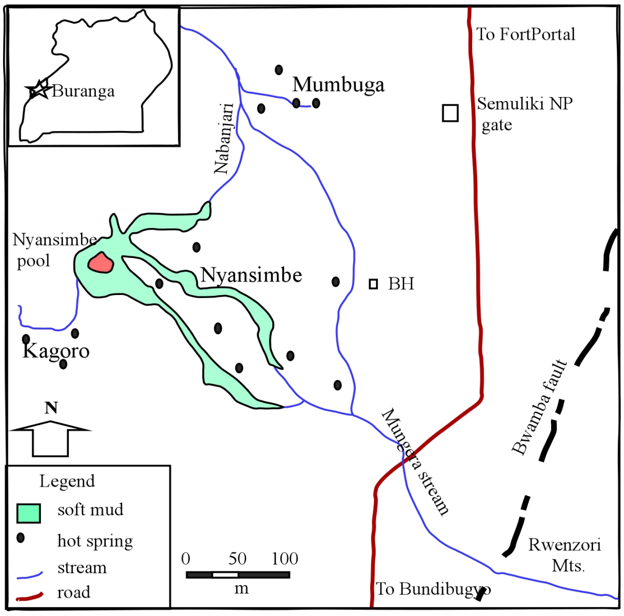

Figure 3: Buranga geothermal area, Location of hot springs.

2.2 Buranga Geothermal Prospect

The Buranga geothermal prospect is located at the foot of the Rwenzori massif in Bundibugyo district, West Uganda (Figure 3).

Buranga is localized by the major Rift Valley faults. It has a simple geology characterized by 'Epi - Kaiso' beds and 'Peneplain Gravels' (of Upper to Middle - Tertiary age), sediments which consist of boulder beds and unsorted scree overlying sands and clays. These sands and clays are described as Kaiso - Kisegi beds. They have been thrown against Pre-Cambrian migmatites and gneisses by the main fault, which strikes at 45˚ azimuth and dips at 60 - 65˚NW. Buranga has no evidence of volcanism but is highly tectonically active.

2.3 Kibiro Geothermal Prospect

The Kibiro geothermal prospect is located on a small peninsula in Lake Albert under the Rift Valley escarpment in Hoima district (Figure 4).

The Kibiro geothermal prospect is divided into two entirely different geological environments by the escarpment, which cuts through the field from SW to NE. To the east of the escarpment the geology is dominated by an ancient crystalline basement, characterized by granites and granitic gneisses. To the west lie a thick accumulation of thick sequences of rift valley sediments of at least 5.5 km, but without any volcanic rock on the surface (Figure 4).

Along the escarpment and NE of Kibiro is a stretch of quartzites, which are also found SW of Kibiro. Laterite is the main feature along the Kigorobya–Biiso–Masindi road. Also present are mafic intrusives along the Kachuru Kigorobya–

Kibiro road and extreme SW near Buseruka and Tonya. South of Kigorobya lie the Bunyoro (Hoima) series which are sedimentary beds (meta-sediments) mainly represented by phyllites, tillites and sandstone.

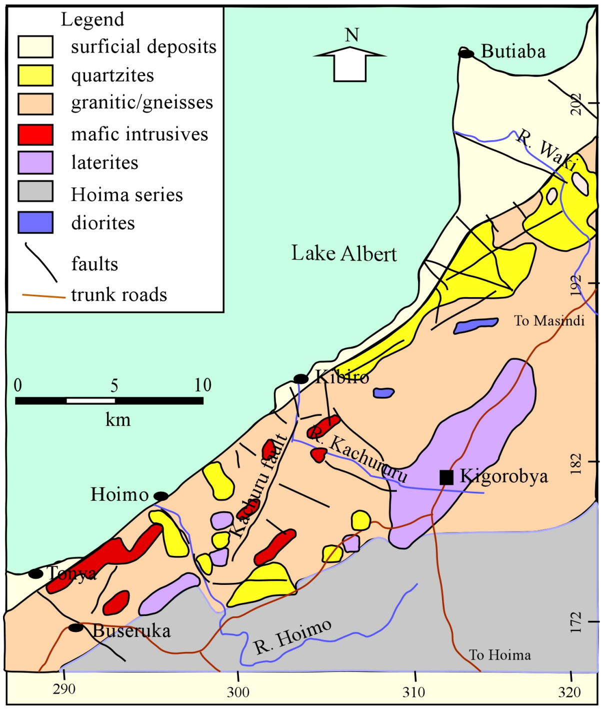

Figure 4: The geology of the Kibiro geothermal prospect and surroundings fault.

Recent geological and geophysical studies show that the geothermal resource can be traced along faults in the block faulted granites to the east away from the rift. The Albertine rift is seismically active, characterized by deep-seated (27 – 40 km) large earthquakes. The tectonic pattern within the Kibiro geothermal area is very complex, and this complexity may well be the main contributor to the existence of a potential geothermal reservoir (Gislason et. al., 2004).

3. FIELD ACTIVITIES

The main activities of the geochemical investigation centred on chemical sampling of geothermal surface manifestations (hot springs), surface and ground waters temperature, pH-field and conductivity measurements; analysis of the samples for major and minor components and stable isotopes; and data analysis and interpretation. The sampling was done in 1993-1994 during the Geothermal Energy Exploration I project. The sampling locations are presented in figures 5, 6 and 7.

Hot springs with flow over 0.5 L/s were preferentially sampled since these were less likely to have been affected by dilution and evaporation (Mohan, 1963). Water samples were collected in a jug (on a rod, at Nyansimbe pool) so that they could be obtained from the center of the spring. Each spring was sampled at its hottest part, which was presumed to be the point where hot water enters the pool. The waters were transferred to a rinsed 100ml plastic bottle.

The untreated water samples were to be analyzed for pH-lab, SO_4, and bicarbonate. PH was also measured at the time of field collection. Another set of water samples were treated at the time of collection (filtered through 0.4µm filters and acidified with a measured amount of Nitric acid, 1ml of acid per 100ml of water sample). This was to ensure that the analyses represent the chemistry of the thermal waters as closely as possible. This was collected into a rinsed 50-ml polythene bottles and was to be analyzed for Chloride, silica and major cations. By bottling the samples at the sampling temperature, errors arising from evaporation were minimized (Mahon, 1961).

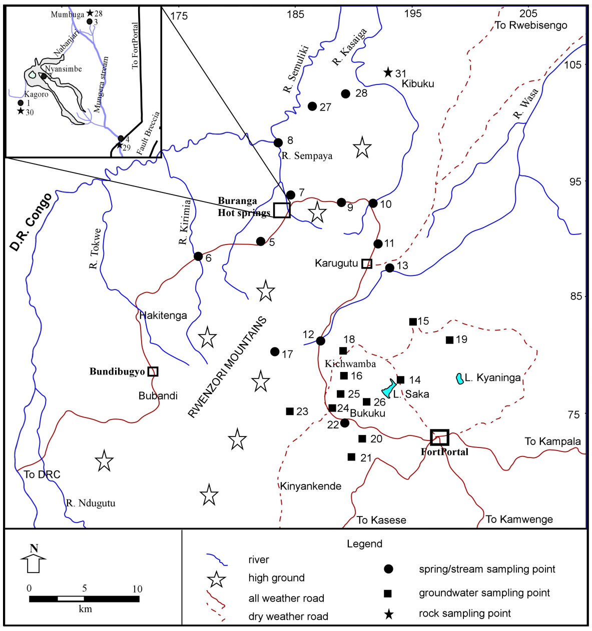

Figure 5: Buranga Geothermal, surface and ground water sampling points.

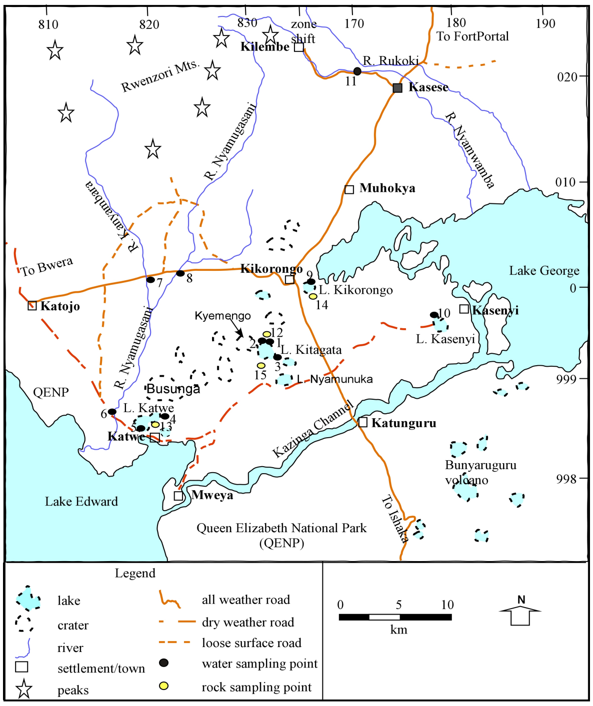

Figure 6: Katwe Geothermal, surface and ground water sampling points.

4. RESULTS CHEMICAL ANALYSIS AND DISCUSSION

Laboratory analysis was carried out at BGR, Germany. The results are summarized in table 1 below. All samples are near neutral to slightly alkaline.

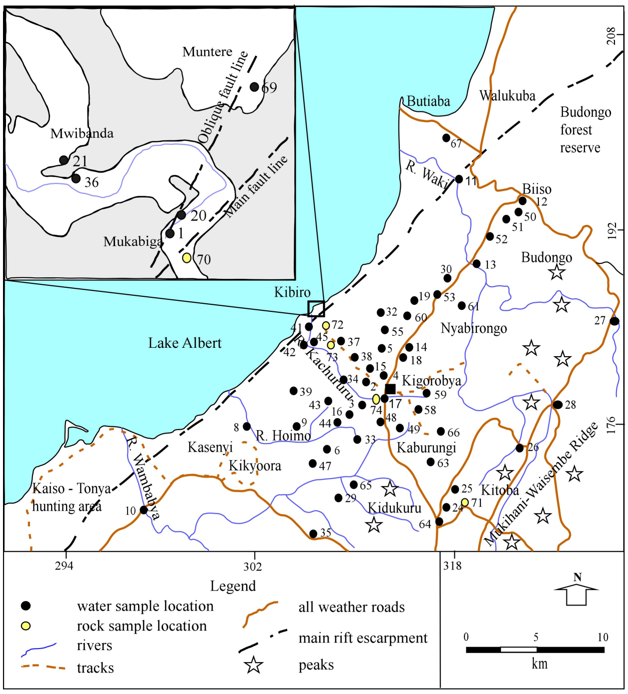

Figure 7: Kibiro Geothermal, surface and ground water sampling points.

4.1 Katwe

The geochemistry results reveal the existence of a geothermal system in the Katwe prospect. The geothermal fluids are characterized by high carbonate contents and salinity, two of the hot springs sampled in the Lake Kitagata crater, HS-02 and HS-05 have a salinity of 19,410 and 27,770 mg/kg total dissolved solids respectively. The high carbonate affects the concentrations of Ca and Mg which are less mobile and tend to precipitate out of solution as Ca and Mg carbonates rendering the geoindicators involving the two cations unreliable. Solute geothermometers have been difficult to use in Katwe due the high salinity of the fluid. The sulphate concentrations are relatively high and all indications suggest that the geothermal system is relatively old. Relatively low B values compared to Cl and Li suggest that the fluids are more likely to originate from volcanic basement rocks rather than from the young overlying sediments. Some indications of possible mixing with groundwater were inferred from log (Q/K) diagrams (Ármannsson 1994) predicting a temperature of 140 - 160°C. The NaK geothermometer (Arnórsson et al., 1983b) and quartz geothermometer (Fournier and Potter, 1982) give temperatures of 140 – 160°C and 120 - 140°C respectively for the on shore hot spring waters in the Lake Kitagata crater (Ármannsson (1994). It was difficult to get a representative sample from the offshore hot springs in Lake Kitagata during the study. The samples collected at different times were variable mixtures of the geothermal water and lake water. However high levels of H_2S (7 - 40 ppm) measured in the mixed water at the different times suggest the source of the geothermal water to be volcanic and hydrothermal.

4.2 Buranga

The fluids are neutral with a PH of 7-8 and salinity of 14,000 – 17,000 mg/kg total dissolved solids. In the earlier study by Ármannsson (1994) a good agreement was obtained for all solute geothermometers tested for several hot springs and pools in Buranga and it was concluded that the subsurface temperature was 120-150°C. Gas analysis did not show presence of hydrogen indicating that the subsurface temperature cannot exceed 200°C. There are no indications of mixing of the geothermal and cold water.

4.3 Kibiro

The geochemistry results suggest a high temperature geothermal system in the Kibiro geothermal prospect. The fluids are characterised by a neutral pH, and salinity of up to 4,000 - 5,000 mg/kg total dissolved solids. Cl of the geothermal waters is high compared to the SO_4 and HCO_3 concentration and is classified as mature waters suitable for application of geoindicators. Relatively low B values compared to Cl and Li suggest that the fluids are more likely to originate from volcanic basement rocks rather than from the young overlying sediments. Ármannsson (1994) found that results for different geothermometers for hot water samples from Kibiro fell into two groups, one showing a temperature of about 150°C and another 200 - 220°C. The geothermometers that gave the lower temperature were one component solute geothermometers, e.g. quartz, and geothermometers based on ratios of components that equilibrate fast, e.g. K-Mg. The higher temperature was obtained by geothermometers based on ratios between components that equilibrate more slowly, e.g. Na-K, and gas geothermometers. The use of mixing models (SiO_2-enthalpy, SiO_2-CO_2) and the construction of log (Q/K) diagrams supported this model. These observations suggest that the geothermal fluid is a mixture of a hot water component at 200 - 220°C and cold water producing a second equilibrium at 150°C. A subsurface temperature of 200 - 220°C is therefore inferred by geothermometry and mixing models for Kibiro. The fluids are relatively dilute and would probably cause few problems on utilization.

5. CONCLUSIONS

From the chemistry of the waters from the surface manifestations, hot springs, there are indications of high subsurface temperatures in the Katwe geothermal prospect. Geothermometry has predicted reservoir temperatures in the range of 150 - 200˚C. The fluids in the crater lakes and springs are saline and alkaline and are probably concentrated by evaporation and/or modified by near surface processes, but the reservoir fluids may be more dilute. This is supported by the low salinity of the geothermal waters sampled from the hot springs in the Lake Kitagata crater as compared to its lake water. The fluids would be suitable for direct power production.

The reservoir temperatures for Buranga are estimated at 120 - 150˚C by geothermometry. There is plentiful supply of fluid, which is fairly saline with total dissolved solids of up to 14,000 - 17,000 mg/kg. This fluid would be suitable for binary turbine power production and industrial use.

Chemistry and stable isotope data interpretation has indicated mixing of geothermal water and cold groundwater in Kibiro. A subsurface temperature of 200˚C and above is predicted by geothermometry and mixing models. The geothermal fluid is less saline, neutral, with total dissolved solids of approximately 4,000 - 5,000 mg/kg. This fluid would be suitable for direct power production.

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Table 1: Katwe analytical results. Concentrations in (mg/kg) and (‰) for stable isotopes.

Location	Sample No.	Temp. (°C)	pH	CO_2	H_2S	SiO_2	Na	K	Ca	Mg	SO_4	Cl	B	Li	$\delta^{18}O$	δD	TDS
LKatwe13	UG-93-01	28.6	7.61	156	0	29.3	44.7	35.1	10.1	5.92	7.0	3.9	0	0.003	-3.52	-9	132
L.Katwe6	UG-93-02	28.5	9.64	11316	5.3	88.6	25600	3500	0.1	0.95	9940	19000	1.9	0.067	1.9	-6	72000
L.Nyamunu1	UG-93-03	27.5	9.42	5523	0	32.2	8950	722	0.13	0.49	6450	3340	0.27	0.025	1.12	9.1	24690
L.Edward1	UG-93-04	23.3	8.55	223	0	18.2	83.7	41.5	16.8	27.3	18	20.2	0	0.01	2.52	22.1	254
Katunguru1	UG-93-05	26.6	6.95	1000	0	53.7	952	89.7	296	232	1800	723	0	0.023	-1.88	-8	4870
L.Kitagata5	UG-93-06	66.6	8.41	3105	0	91	9310	644	0.6	0.85	13400	2430	0.82	0.063	-0.73	0.5	27770
L.Kitagata2	UG-93-07	56.6	8.03	2544	0	105	6510	523	1.45	6.27	8970	1770	0.59	0.031	-0.6	3.2	19410
KazingaCh1	UG-93-08	26.2	8.28	108	0	21.5	38.5	7.8	22.9	11.2	11	10.3	0.06	0.005	0.98	12.6	180
L.Kitagata1	UG-96-06	61.1	9.33	10350	19.4	210	33600	1840	4.1	2	44000	8370	2.77	0.16	2.2	0	99515
L.KitagataW	UG-93-28	36	9.57	19470	0.3	389	87300	4780	4.3	1.47	110300	22200	6.9	0.08	10	24	256000
L.KatweW	UG-93-29	28	9.55	9008	4.8	237.6	124500	22500	5.3	32.5	71300	86600	17.5	0.11	9.6	24.5	372000

Table 2: Buranga analytical results. Concentrations in (mg/kg) and (‰) for stable isotopes.

Location	Sample No.	Temp. (°C)	pH	CO_2	H_2S	SiO_2	Na	K	Ca	Mg	SO_4	Cl	B	Li	$\delta^{18}O$	δD	TDS
Mumbuga2	UG-93-09	93.4	7.87	2445	0	76.9	5320	195	2.45	2.13	3720	3580	4.3	1.34	-3.6	-17.1	14600
Mumbuga5	UG-93-10	93.6	7.73	2411	0	76.4	5160	190	2.56	2.27	3570	3490	4.2	1.3	-3.49	-12.8	14030
Nyansimbe9	UG-93-16	95.8	8.15	2638	0	87.7	5940	222	0.95	1.74	4180	4010	4.71	1.48	-3.21	-12.2	16250
Nyansimbe13	UG-93-11	80.3	7.61	2889	0	88.6	6160	230	2.1	2.63	4330	4160	4.96	1.51	-3.54	-12.4	17050
Nyansimbe17	UG-93-32	98.2	8.57	2635	0	85.1	6270	235	0.39	0.28	4400	4210	4.96	1.51	-3.45	-13.4	17080
Nyansimbe19	UG-93-13	85.8	7.81	2878	0	85.7	6300	234	2.04	1.98	4420	4240	4.8	1.54	-3.46	-12.9	17050
Kagoro20	UG-93-12	89	7.50	2798	0.3	81	5950	219	2.69	2.19	4160	4030	4.7	1.47	-3.69	-12.7	16400
R.Mungera	UG-93-15	21.8	7.52	57	0	37.2	11.1	3.7	11.2	3.61	1.7	1.8	0	0.008	-2.24	-3.7	74
Kyakatimba1	UG-93-17	23.8	7.54	197	0	36.3	21.2	8.1	54.7	14.3	27.6	2.1	0	0.034	-2.57	-4.6	208

Table 3: Kibiro analytical results. Concentrations in (mg/kg) and (‰) for stable isotopes.

Location	Sample No.	Temp. (°C)	pH	CO_2	H_2S	SiO_2	Na	K	Ca	Mg	SO_4	Cl	B	Li	$\delta^{18}O$	δD	TDS
Mukabiga2	UG-93-19	86.5	7.06	146	10.4	129	1530	169	62	8.14	46.7	2500	2.26	1.5	-2.01	-11.3	4576
Mukabiga5	UG-93-20	81.1	7.14	155	13	125	1490	164	62.9	7.96	26.4	2450	2.23	1.48	-2.08	-11.8	4436
Mwibanda14	UG-93-21	71.8	7.14	155	17.3	122	1480	165	65.7	9.21	15.4	2440	2.21	1.46	-1.98	-10.6	4384
Muntere15	UG-93-22	39.5	8.05	115	0	135	1570	182	75.9	8.71	49.9	2580	2.47	1.53	-1.01	-3.9	4548
L.Albert	UG-93-23	30	8.93	236	0	0.5	72.3	49.4	9.75	27.3	19.3	24.2	0	0.012	5.47	39.8	338
Wantembo	UG-93-24	29.8	6.89	367	0	90.5	87.5	7.7	75.8	39.5	139	31.2	0	0.016	-3.58	-15.2	662
Kiganja1	UG-93-25	23.6	6.26	130	0	70.8	12.4	2.6	14.8	8.03	5.3	5.2	0	0.003	-1.57	-4.1	124
Ndalagi1	UG-93-26	24.9	6.72	232	0	76.1	50.6	7.5	138	39.5	227	123	0	0.015	-2.08	-5.2	680