GEOCHEMISTRY OF RWENZORI HOT SPRING WATERS

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INTRODUCTION

Rwenzori springs refer to hot and cold mineralized springs around Rwenzori Mountains. A chemical sampling campaign was undertaken as part of the GEOTHERM programme, a technical cooperation project between the Government of Uganda and Germany. The geochemical sampling programme was part of the field investigations, which included gravity survey, Transient Electromagnetic (TEM) survey and Schrumberger Sounding. Geological mapping was supplemented by Aster image interpretation.

Geophysical work was focused around Buranga hot springs, on the western side of Rwenzori. However, geochemical sampling was regional in scope, to understand the relationship of the neighboring thermal manifestations to Buranga hot spring system. Work was carried out between 21st February to 5th March 2005. It involved sampling hot spring water and hydrothermal deposits, measuring of surface temperature, conductivity and pH. The samples were to be analyzed for trace and major elements. Geothermal sites sampled included Lake Kitagata, Muhokya, Kibenge, Bugoye, Rwimi, Rwagimba, Nyansimbe, Kagoro, Mumbuga and Kibuku. This report is an integrated field and laboratory studies carried out on Rwenzori hot springs.

GENERAL GEOLOGY

Rwenzori region is a zone of crustal uplift and volcanism as evidenced by quaternary (young) alkaline volcanic centers around Fort Portal and Katwe-Kikorongo. Lithologically, it is made up of banded gneiss, granite and schist. Peaks are made up of amphibolites, hornblende gabbros and metasediments, which make up Stanley Series. The western boundary is made up of banded biotite gneiss. The axis of Rwenzori runs about N30°E. The area is seismically active. The hot springs appear to be structurally controlled by faults and most of them are associated with travertine mounds. Hot spring tufa deposits are reported in some of the explosion craters around Fort Portal (Saka, Kasekere and Nyabusozi) on the eastern side of Rwenzori. Tufa deposits is reported on the northern end of Rwenzori nose, around Kibuku area, at Kikyo and are regarded as field-wide characteristics of Rwenzori thermal springs. Almost all springs are associated with tufa deposits with the exception of Kibenge and Muhokya.

FIELD ACTIVITIES

The fieldwork was carried on between 21st and 5th March 2005 and included chemical sampling of hot water samples, temperature, pH-field and conductivity measurements. Sampling points are shown in figure 1.

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 100-ml 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).

RESULTS OF CHEMICAL ANALYSIS

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

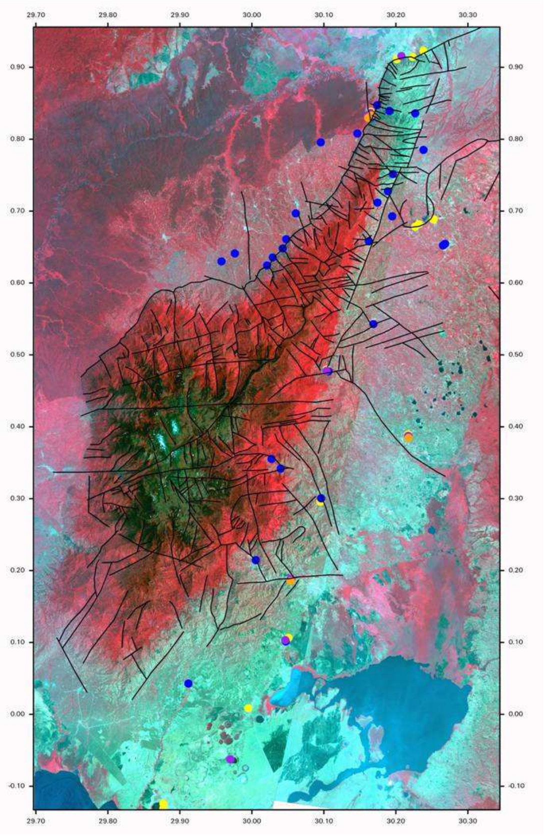


Figure 1: Sampling points of Rwenzori system

Table 1: Chemical composition of Rwenzori hot springs in ppm (mg/kg)

Location	**Temp**	**Ph**	**Cond**	**SiO_2**	**HCO_3^-**	**Cl^-**	**SO_4^{2-}**	**Na^+**	**K^+**	**Ca^{2+}**	**Mg^{2+}**	**Li^+**	**B**	**Al**	**Fe**
Mumbuga	94	8.7	17900	70	2850	3133	3222	4716	166	6.24	1.94	1.2	14.8	0.015	0.02
Nyansimbe	75.4	8.4	22400	77.4	3630	4019	4186	5991	218	6.55	1.97	1.51	18.1	0.02	0.02
Kagoro	88	8.6	21000	76.6	3360	3735	3842	5561	199	7.01	1.97	1.41	17.2	0.71	0.91
Well-1	62	8.3	21500	73.5	3440	3839	4001	5738	209	7.11	1.77	1.45	17.5	0.031	0.16
L. Kitagata	64	8.7	31300	81.7	4160	2447	12959	9237	634	2.41	0.86	0.048	3.22	0.02	0.02
Kibenge	42.5	8.2	3580	44.5	98	585	894	550	24.3	226	6.4	0.221	1.89	0.163	0.3
Muhokya	41	8.2	8460	50.9	143	460	1075	586	18.8	206	13.1	0.062	1.42	0.039	1.05
Rwagimba	69	8.1	6390	62.5	800	838	1468	1480	41.6	74.1	5.38	0.452	2.77	0.01	0.48
Rwimi-1	25.9	7.2	3880	92.7	2100	232	693	424	60.7	380	198	0.071	0.94	0.154	6.42
Rwimi-2	24.6	7.1	3640	84.8	2020	189	523	356	56.8	361	181	0.056	0.73	0.031	6.25

ION BALANCE

Ion balance was carried out to assess the quality of chemical analysis. This involved comparing the sum of the molal concentration of the major positively charged species times their valence (charge) against the sum of the molal concentration of the major negatively charged species. Prior to carrying out ion balance, chemical data was converted from ppm (mg/kg) to molal units. Again for convenience in determining the ion balance, molal units were converted to millimolal units (1 mole = 1000 millimoles).

Table 2: Chemical analysis in millimolal units

Location	HCO_3^-	Cl^-	SO_4^{2-}	Na^+	K^+	Ca^{2+}	Mg^{2+}	Δ charge %
Mumbuga	46.7	88.3	33.56	205	4.2	0.16	0.07	+1.83
Nyansimbe	59.5	113.2	43.6	260	5.6	0.16	0.08	+1.17
Kagoro	55.1	105.2	40.02	241	5.1	0.17	0.08	+1.29
Well-1	56.4	108.1	41.7	249.5	5.3	0.18	0.07	+1.47
L. Kitagata	68.2	68.9	134.9	402	16.2	0.06	0.04	+1.39
Kibenge	1.61	16.5	9.3	24	0.6	5.65	0.26	-0.39
Muhokya	2.34	12.9	11.2	25.5	0.5	5.15	0.54	-0.34
Rwagimba	13.1	23.6	15.3	64	1.06	1.85	0.22	+1.39
Rwimi-1	34.4	6.54	7.2	18	1.5	9.5	8.15	-0.49
Rwimi-2	33.1	5.32	5.4	15.5	1.5	9.03	7.44	+0.72

A reasonably adequate ion balance is good within 5%. According to table 2 above, all sample analysis fall within the acceptable range, that is below 5%. Hence, the analysis was generally good and of adequate quality. The results compares reasonably with earlier analysis (Sharma, 1971, Armannsson, 1994).

CLASSIFICATION OF WATERS USING RELATIVE CL-, SO42- & HCO3-

Chloride, sulphate and bicarbonate are the three major and most frequently analysed anions of thermal waters. These are used to characterize the thermal water and ascertain its evolutionary trend processes. The chloride and sulphate contents of Rwimi, Rwagimba, Mumbuga, Nyansimbe, Kagoro, Kibenge and Muhokya exhibit a high degree of co-variance ($R^2 = 0.9935$). Lake Kitagata is excluded in this compositional range and possibly belongs to a different geothermal reservoir.

The highest concentration of chloride and sulphate (Mumbuga, Nyansimbe, well-1 and Kagoro) are possibly influenced by magmatic HCl and SO_2 input. The lowest values at Rwagimba, Rwimi, Kibenge and Muhokya are reflecting little input from lithological sources (evaporates, sulphate-enriched) for these parameters. Mumbuga, Nyansimbe, Well-1 and Kagoro waters are chemically similar implying they are emanating from the same source and along the same migratory path. In their pure form, the various water types plot close to corners or along the axes of Cl-SO_4-HCO_3 ternary plot. **Partial equilibration** and **mixing** among the different water may have given rise to the formation of intermediate / hybrid waters as represented by Buranga hot water samples.

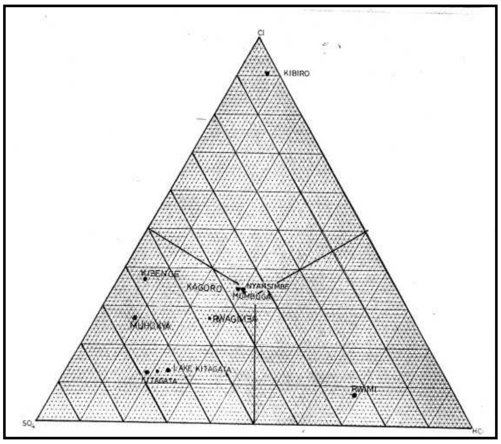


Figure 2: Relative contents of Cl, HCO and SO4 in ppm

Lake Kitagata, slightly alkaline, is characterized by high sulphate content possibly attributed to magmatic SO_2 input. The sample has the highest sulphate to chloride ratio possibly attributed to magmatic vapor input. Since it is plotting in the corners or along the axis, it must have been affected by mixing of sulphate waters with some meteoric waters. Sulphate waters sometimes contain appreciable amounts of chloride (>1000ppm Cl) as in case of Lake Kitagata

(2447ppm). The presence of high chloride contents, distinguish magmatic or volcanic sulpahte sources from sulphate waters of steam-heated origin, which have very little chloride content. The source of chloride like sulphate in Lake Kitagata hot water sample is possibly due to absorption of HCl bearing volcanic gas into meteoric water. This is supported by isotopic evidence (IAEA TC-PROJECT UGA/8/003).

Kibenge thermal waters are slightly alkaline with appreciable sulphate contents relative to other major anions. These can be described as **chloride-sulphate** waters, plotting almost on the axis. It appears to be of steam-heated origin rather than volcanic origin. The high magnesium contents might be attributed to mixing with meteoric ground-waters.

Muhokya thermal waters are slightly alkaline and can be classified as **chloride-sulphate** waters. High mg contents might indicate mixing with meteoric waters. It appears to be of steam-heated origin rather than volcanic origin.

Rwagimba thermal waters are slightly alkaline and have more sulphate than chloride and bicarbonate. These **chloride-sulphate** waters are possibly steam-heated waters rather than volcanic in origin.

Rwimi samples are **bicarbonate waters** (CO_2-rich waters) with appreciable amounts of bicarbonate. They have low chloride content and variable sulphate contents. Bicarbonate waters typically form in the marginal / peripheral zone and shallow subsurface region where CO_2 gas is absorbed and steam is condensed into cool ground waters.

RELATIVE NA, KAND MG CONTENTS

According to the ternary plot, Rwimi samples plot close to the Mg corner reflecting their high immaturity. Rwimi samples exhibit higher than equilibration Mg contents (181-198ppm). These are typical of low temperature environments created by the underground absorption of CO_2-rich vapours into meteoric groundwater. It is not justifiable to apply geothermometry on such non-equilibrated waters. Rwimi samples represent solutions affected largely by rock dissolution rather than fluid equilibration.

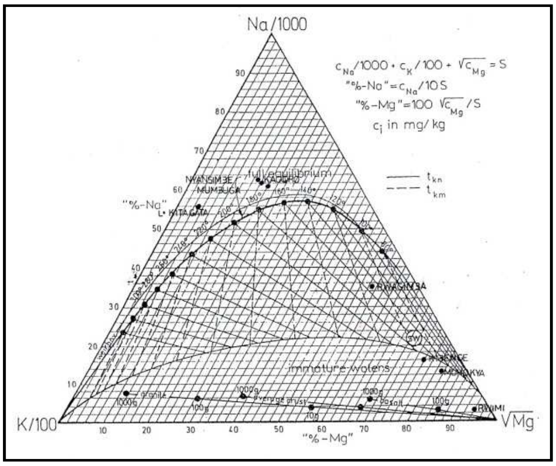


Figure 3: Relative contents of Na, K and Mg, showing dilution / mixing trend towards mg rich waters

Buranga samples plot above the full equilibrium line, possibly indicating boiling / steam loss which might have led to increase in the absolute solute contents.

Rwagimba sample occupy intermediate position reflecting partial attainment of equilibrium with rock at generally low temperatures. Indicated temperatures is between $T_{K\text{-}Na}$ 140-160^{o}C and that of $T_{K\text{-}Mg}$ of 100-120^{o}C, having acquired mg during their rise to lower temperatures without readjustment of K/Na ratios. Lake Kitagata waters plot above the equilibrium line possibly due to steam loss / boiling. Kibenge thermal waters plot on boundary between immature waters and partially equilibrated water, application of geothermometer is not justifiable on such immature waters. Muhokya waters are plotting in the immature zone and application of geothermometer is not justifiable also. All assumed steam-heated waters (Muhokya, Rwimi, Kibenge, Rwagimba) occupy positions close to the Mg corner, reflecting their highly immature state. In their case, application of solute geothermometers, based on assumption of attainment even of only partial equilibrium is not justified. These form end-members water-type.

Thermal waters from Kagoro, Mumbuga, Nyansimbe, Well-1, Rwimi, Muhokya, Kibenge and Rwagimba seem to be highly correlated (R^2=0.9978). Because of non-linear relationships among Na, K and Mg, the square root was taken for Mg contents. This high correlation might be attributed to genetic relationship and might point to single source of these thermal waters and the same migratory path-way, possibly reflect mixing between "dissolved rock" and fully equilibrated waters, obvious from the diagram.

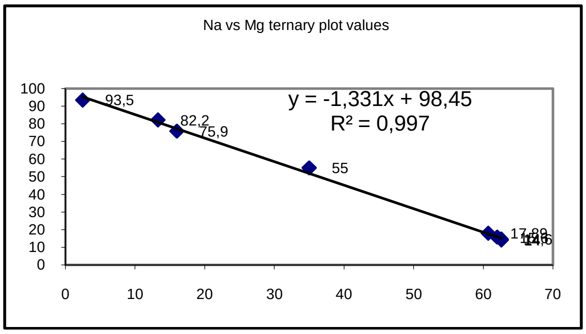


Figure 4: Graph showing sodium values plotted against magnesium values.

RELATIVE CL-LI-B CONTENTS

According to the ternary plot (figure 5), all thermal water samples plot close to the Cl corner. Since lithium tend to remain in solution, it is the relative Cl and B contents which are likely to change the B/Cl ratio. Low B/Cl ratio in steam is likely be brought about by addition of more chloride from a magmatic source not from simple rock leaching or from progressive boiling over time, which might have resulted in a low B/Cl ratio in a mature system. This might indicate that all chlorides are supplied after rock dissolution possibly absorption of low B/Cl magmatic vapors. A magma chamber is the most reasonable source of huge quantities of CO_2, B and Li.

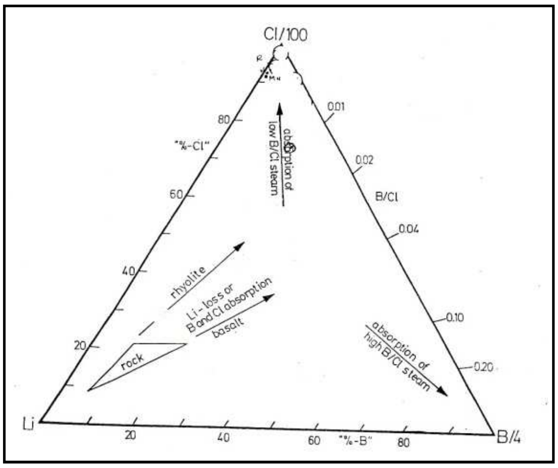


Figure 5: Relative contents of Li, B and Cl

CHEMICAL GEOTHERMOMETRY

Location	Qtz no steam loss	Qtz max steam loss	Na-K (Fournier)	Na-K (Giggenbach)
Mumbuga	118.3	116	140.9	161.4
Nyansimbe	123.4	121.1	143.7	162.7
Kagoro	122.9	120.7	142.3	162.7
Well-1	120.8	118.8	143.8	162.7
L.Kitagata	126.3	123.6	186.2	204.7
Kibenge	96.6	98	155.5	175.4
Muhokya	102.8	103.4	135.9	156.0
Rwagimba	112.6	119.2	128.6	148.2
Rwimi-1	132.2	128.6	249.3	262.0
Rwimi-2	128.5	125.4	260.7	272.1

The results indicated by Na-K geothermometers are not reliable for Rwimi waters, since they contain appreciable quantities of Ca (361-380ppm) and deposit travertine. Such geothermometer are not ideal for cool, CO_2-rich springs like Rwimi and hence results should be used with caution. Kibenge, Muhokya, Rwagimba and Rwimi do not contain reasonable contents of chloride, hence K/Na temperatures are not representative of those of the deeper neutral Cl water. Otherwise they are likely to reflect the lower temperatures (~150^{o}C) typical of environments created by the underground absorption of CO_2-rich vapors into groundwater at the periphery or margins of a system.

RELATIVE PROPORTIONS OF B, CL AND NA

There is an indicated high correlation (R^2=0.9966) between sodium and chloride of thermal waters at Buranga, Rwimi, Muhokya, Kibenge and Rwagimba (Figure 6). This points a possible genetic relationship between these waters possibly influenced by mixing process.

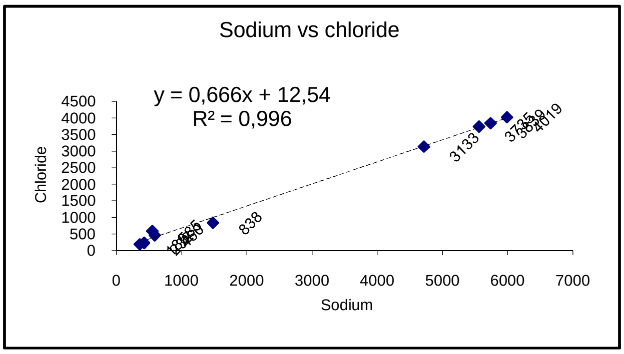


Figure 6: Graph showing chloride conc. (ppm) versus sodium conc. (ppm). Note the near linear relationship

There is a highly correlated linear trend (R^2=0.9976) between chlorine and boron values of Nyansime, Kagoro, Mumbuga, Rwimi, Muhokya, Kibenge and Rwagimba. Again this might point to a genetic relationship between these waters. A high correlation (R^2 = 0.9997) is observed between potassium and chloride, for springs Nyansimbe, Kagoro, Mumbuga, Rwagimba, Muhokya and Kibenge. Rwimi and Lake Kitagata hot springs plot in different compositional field. This correlation possibly points to the different environment, that is sediment starved systems versus sediment-hosted systems. There is a systematic change of K with respect to chloride. Potassium increases in a linear fashion with chloride in the sediment-starved systems, while sediment-hosted systems show high potassium with no systematic trend relative to Cl. The high K/Cl at Lake Kitagata and Rwimi possibly reflect the much greater concentrations of potassium relative to chloride in sediments relative to sediment-starved systems.

The increase in cationic charge from calcium exactly compensates the decrease in charge due to loss of sodium, which is especially evident at high chloride concentrations. This can be demonstrated by plotting Na plus two times Ca (**Na+2Ca**) versus Cl, which gives a highly correlated trend (R^2=0.9988) for springs at Mumbuga, Nyansimbe, Kagoro, Rwagimba, Muhokya and Kibenge. Rwimi and Lake Kitagata are out of the compositional range again due to anomalous Ca and K contents respectively.

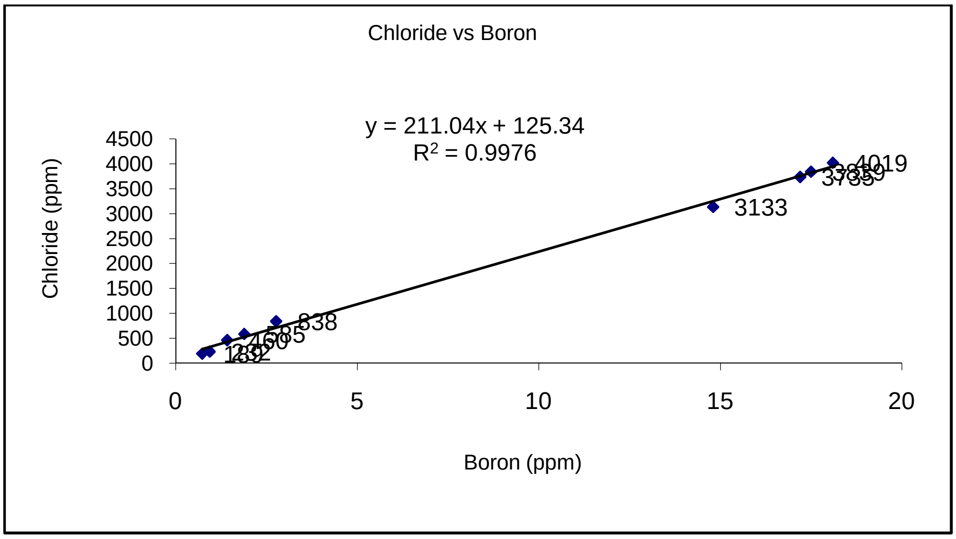


Figure 7: Graph showing chloride conc.(ppm) versus Boron conc. (ppm)

SALINITY ANALYSIS

A plot of bromine versus chlorine for waters of Nyansimbe, Mumbuga, Kagoro, Rwagimba, Rwimi, Muhokya and Kibenge reveal a high correlation (R^2=0.9976). This highly correlated linear trend points a possible genetic relationship possibly influenced by mixing and partial equilibration. The Br/Cl ratios fall in a range 0.00451 to 0.01120. This is somewhat higher than seawater (typically 0.00347). Br/Cl increased ratios might be due to increased Br or reduced Cl contents. The latter seems more probable. This may suggest that chloride salinity may be largely derived from silicate rock-water interaction / fluid inclusion leaching, rather than from modified seawater or from evaporates at depth. It points to a non-marine, non-evaporitic source of bromide and chloride (Andreasen & Fleck, 1997).

Sometimes higher Br/Cl ratios occur at lower chloride concentration due to analytical errors (i.e. greater relative error in Br determination in low salinity waters). However, for Buranga hot springs, the high salinity and presence of predominant sulphate may suggest that magmatic or volcanic sources are of major importance. This has been indicated by isotopic studies using strontium isotope $^{87}Sr/^{86}Sr$ (IAEA TC-PROJECT UGA/8/003). Sediment starved hot spring system like Kibenge have slightly higher $^{87}Sr/^{86}Sr$ values (0.7342) than in Buranga (0.7195-0.7287).

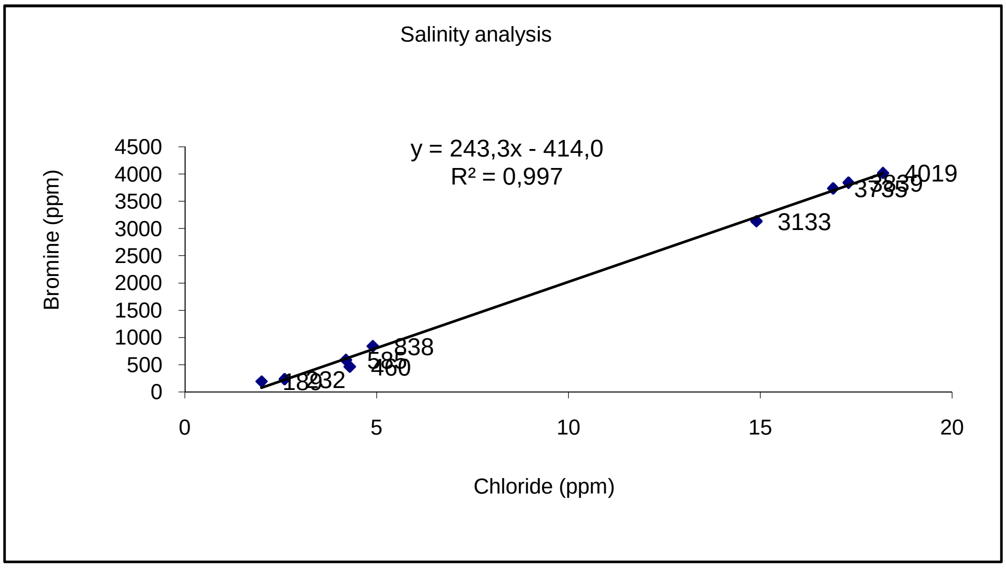


Figure 8: Bromine (ppm) versus Chlorine (ppm)

ISOTOPIC GEOCHEMISTRY

Carbon-13 and Oxygen-18 of travertine and limestone samples were analysed at the Institute of Geological and Nuclear Sciences, in New Zealand. Buranga travertine plot in carbonatite magma field (See figure 3), hence are a hydrothermal equivalent of carbonatite, i.e. the isotopic range of samples indicates magma-derived carbon as the probable origin of the carbon dioxide that dissolved into the fluid from which travertine precipitated.

(All measurements ± 0.1‰)

No.	Locality	$\delta^{13}C_{PDB}(CO_2)$	$\delta^{18}O_{PDB}(CO_2)$
1	Buranga	-3.78	-17.10
2	Buranga	-2.67	-16.04
3	Buranga	-2.54	-15.95
4	Buranga	-3.68	-15.21
5	Katwe	1.41	5.16
6	Katwe	2.87	7.36
7	Muhokya	0.89	-3.27
8	Lincoln carbonate	2.11	-6.55
9	GNS Marble	2.11	-6.55

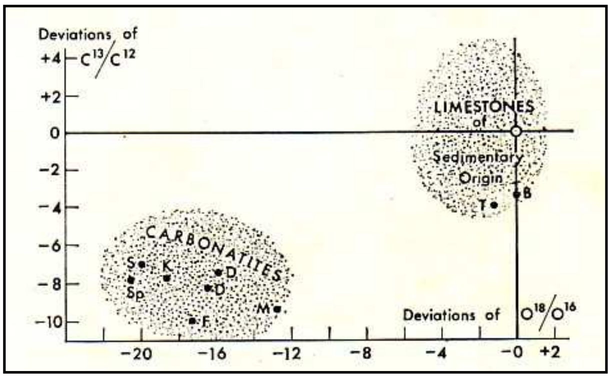
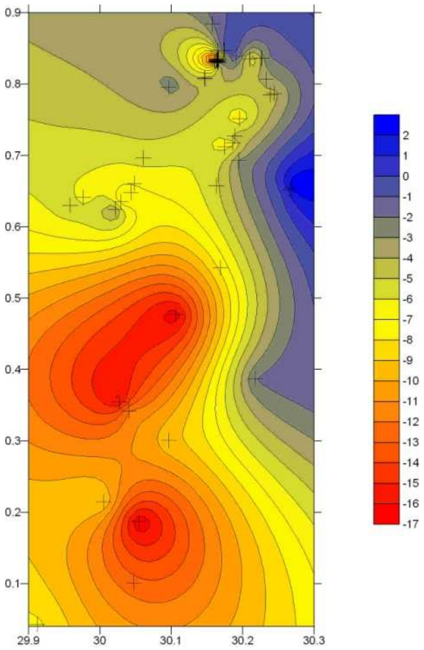


Figure 9: Buranga travertine plot in the carbonatite fields together with samples from Katwe, Mbuga crater, Fort Portal and Sukulu. Bunyrauguru and Muhokya limestone samples plot in the sedimentary field.

The points represent deviations of $^{18}O/^{16}O$ from arbitrary standard limestone (marked 0), plotted against the corresponding deviations of $^{13}C/^{12}C$, and fall into well-separated fields (shaded) for magmatic carbon and thermally derived sedimentary carbon respectively (Holmes, 1964). According to Allard et al, 1977; Allard, 1979; Rollinson, 1993, evidence for significant magmatic carbon input to a system should have a value of –4 to 8%$_o$. Isotopic evidence favors meteoric recharge from Mt Rwenzori (Armannsson, 1994; Kato, 2000; IAEA TC-PROJECT UGA/8/003) possibly from melt water.

D/H values of geothermal waters are not controlled by the exchange processes, because the rocks contain so little initial hydrogen compared to the amounts of H_2O typically involved. Instead, the δD values remain constant. If it is assumed that Rwenzori thermal springs are genetically related, their δD values would reasonably compare, save for some processes due to no-equilibration evaporation of steam at temperatures of 70-90^oC (Giggenbach, 1978). Kibenge δD values (-20.2) compares reasonably with Kagoro values (-19.4) according to IAEA TC-PROJECT UGA/8/003 (2003). The hot springs are nearly identical in deuterium content and indicate no appreciable oxygen shift that is observed in some high-temperature hot-springs. According to deuterium map, Buranga hot springs have deuterium values similar to Mubuku river, indicating a possible recharge from the glaciers.



Deuterium map of Rwenzori springs

According to isotope geochemistry, Kibenge and Buranga thermal waters have no detectable tritium contents (IAEA TC-PROJECT UGA/8/003, 2003). These springs do not prove entry of meteoric water of high T content and very short subsurface travel time since they escape isotopic detection. Possibly, the greatly dominant component of these thermal waters is concluded to be of meteoric origin (Armannsson, 1994; Kato, 2000; IAEA TC-PROJECT UGA/8/003, 2003) with an age of at least more than 88 years since isolation from direct contact with the atmosphere.

Thermal waters are on both sides of Rwenzori block and Rwenzori is made of crystalline basement rocks (granite / granitic gneiss, schist, amphibolite gneiss). These rocks are not sufficiently permeable to form a natural hydrothermal reservoir, hence the only plausible permeable structures indicated are faults or fractures. The geothermal reservoir is most likely to be fracture controlled not porosity controlled. Most of the Rwenzori rocks are not highly porous and thus hot water is likely to be located primarily in fractures. It is important to locate the orientation of the most important hot-water bearing fractures, to be consistent with the regional extension trend. Isotopic studies $^{87}Sr/^{86}Sr$ (IAEA TC-PROJECT UGA/8/003) point to water-rock interaction with granitic gneiss for Buranga thermal waters. Felsic type of igneous rocks (gneiss, granitic gneiss) tend to have high mean florine contents. This is also evidenced in the thermal waters of Buranga, possibly suggesting a fracture-controlled geothermal reservoir in the crystalline basement rocks.

DISCUSSION

According to isotopic evidence, Buranga geothermal system has a magmatic heat source. Since the chemistry of Rwenzori springs (Buranga, Rwimi, Kibenge, Muhokya, Rwagimba) is highly correlated, it might imply that there are genetically related and possibly influenced by partial equilibration and mixing. Lake Kitagata seems to belong to another geothermal system other than the Rwenzori hot spring system. The magma chamber is the most reasonable source of huge quantities of CO_2 discharged at Mulyambuzi cave (Fort Portal), Buranga and Rwimi. As Beall and Box (1993), noted, an increase in contents of CO_2, might be attributed to change in geothermal reservoir pressure, causing open-system flow of CO_2-rich gases into the Rwimi area, from below the geothermal reservoir.

Qualitatively high HCO_3 contents can be taken as an indication for comparatively low temperature system. Since most hot springs (Buranga, Rwimi, Rwagimba, Kibuku, Fort Portal craters) are depositing travertine, these are likely to be outflows of a system possibly in the Rwenzori mountain. This system is likely to be fracture controlled in a steep terrain of Rwenzori. This might be explained by an interaction of CO_2-rich waters with rock at shallow levels. Such CO_2-charged waters are formed by under-ground absorption of vapors separated from deeper Cl water into cooler groundwater (Hedenquist, 1990; Lonker et al., 1990). Isenthalpic expansion of steam, separated from a deeper liquid phase, to close to atmospheric pressures, is accompanied by a drop in temperature to about 160^{o}C.

The temperatures of secondary bicarbonate waters formed in this way are therefore in the vicinity range of 150-160^{o}C (Giggenbach, 1978; Cioni et al., 1984; Hedenquist, 1990). According to geothermometry, Buranga, Kibenge, Muhokya and Rwagimba fall in the range 150-160^{o}C (Armannsson, 1994), possibly indicating that these are outflow of a geothermal system of Rwenzori. Travertine occurs at Rwimi, Buranga, Bugoye, Rwagimba, Kibuku, Kikyo and in volcanic craters at Fort Portal (Saka, Kasekere and Nyabusozi). Considering the geographical variation of bicarbonate, silica and chloride contents in Rwenzori hot springs, Buranga hot springs are nearer to the upflow zone than Rwimi, Muhokya, Rwagimba and Kibenge. More work should be concentrated around Buranga hot springs focused on Rwenzori.

Deuterium mapping shows that Buranga hot springs have relatively similar values with water from Mubuku hot springs indicating that glaciers drained by Mubuku are likely to be recharging source for this system.

CONCLUSION

The constancy of ratios as evidenced by high correlation values may indicate that Rwenzori thermal springs have a single geothermal reservoir. Buranga thermal waters cluster an evidence of single source system. Evidence for recharge of meteoric waters points at Rwenzori mountain while a fracture controlled crystalline basement reservoir is indicated by strontium ratio values. Buranga (Nyansimbe, Kagoro and Mumbuga) thermal prospect has impressive surface manifestations, occurring in steep mountain terrain hence could easily be mistaken for up flows of a reservoir system. The upflow system surface manifestation is still elusive. This is very common with high temperature systems in steep mountain terrain often associated with concealed outflow structures.

The springs indicate a low temperature system, possibly an outflow as indicated by low SiO_2 contents and high bicarbonates. The high salinity at Buranga could be explained by magmatic input not simple leaching of rocks. Contribution of magma-derived carbon to Buranga geothermal system has been indicated by carbon-13 vs Oxygen-18 analyses from Buranga, travertine falling between –2.54 to –3.78%$_{o}$. Surface manifestation at Rwimi (high CO_2 contents) could be explained by magmatic gas contribution in a low-pressure zone. Geochemically, there are a number of chemical trends that differentiate Lake Kitagata from the Rwenzori thermal springs. Rwenzori thermal springs are as a result of different degree of mixing and partial equilibration.

Efforts should be directed to identify crustal magma bodies by means of innovative geophysical studies, including seismic tomography. Seismic-velocity data could give clues about rock type, geologic structures and temperature beneath surface. Stable isotopes of the Rwenzori hot springs should be studied to investigate further their assumed relationship.

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Table: Rwenzori thermal springs field description.

Spring/pool No	UTM Coordinates	Location	Geologic setting	Description	Field analysis
Mumbuga	0184418E 0092769N	Located at Sempaya, just a few hundred meters on Fort Portal – Bundibugyo road, about 52 km from Fort Portal	The rocks surrounding the springs are mainly alluvial material washed down from Rwenzori.	Spouting hot springs with a large flow rate of about 1.5L/sec, clear water, but some milky water discharge into one of the pool of 2m diameter, temperature range between 41-94°C, moderate to vigorous gas bubbling, strong odor of H_2S, travertine moulds are found all over the place. Conductivity measured was 18.68ms/cm.	Slightly alkaline Gas-mainly CO_2 and H_2S
Nyansimbe pool	0184133E 0092497N	South of Mumbuga spring	The rocks surrounding the springs are mainly alluvial material washed down from Rwenzori.	A circular pool of hot water with a temperature of about 75°C, measuring 5 meters deep and about 30 meters in diameter. It reported that the base is about 60 m inferring a conical shaped body of hot water. Slight gas bubbling, some travertine deposits covering the pool of water,	Slightly alkaline Gas-mainly CO_2 and H_2S
Kagoro	0183950E 0092324N	South of Nyansimbe pool	The rocks surrounding the springs are mainly alluvial material washed down from Rwenzori	Temperature of about 84-88°C with a flow of about 0.8l/sec with slight gas discharge, faint H_2S gas smell, travertine deposits forming moulds.	Slightly alkaline Gas-mainly CO_2 and H_2S
Well-1	0184423E 0092288N	Located nearly between Mumbuga and Nyansimbe pool	The rocks surrounding the springs are mainly alluvial material washed down from Rwenzori	Flows ranging from 0.4-0.8l/sec clear hot water with temp 62°C,	Slightly alkaline Gas- mainly CO_2 and H_2S

Katwe-travertine	0820299E 09986260N	Located in the south western crater rims of Lake Katwe explosion crater.	Volcanic rocks possibly laid down in water.	Travertine moulds up to 10 meters high, scattered around the area. Others are included in the water laid tuffs.	No field analysis.
L. Kitagata hot spring	0830639E 9993296N	Located on the crater rims of Lake Kitagata, some seepages reported in the lake	Volcanic tuffs with visible blocks and bombs of crystalline basement rocks.	Clear hot water, Temp 64^{o}C; a faint odor of H_2S. Salt crust deposits are found in the area.	Slightly alkaline , conductivity measured 29.0ms/cm
Kibenge hot spring	0172004E 0021030N	Located on Kasese – Kilembe road just after the junction to Marigerita Hotel	Alluvial material from Rwenzori.	Temp of about 43^{o}C, clear water, in form of a pool, bubbling	Conductivity measured was 3.6ms/cm.
Muhokya	0171201E 0011651N	Located on Mbarara Kasese road just near Muhokya lime works.	Possibly in alluvial materials from Rwenzori.	Temp of about 41^{o}C, clear water, gas bubbles.	Conductivity of 3.5ms/cm
Bugoye	0176634E 0032747N	Near Bugoye Gombolora head quarters.	Weathered Phyllitic schist rocks covered with terraces of travertine. No spring could be located. Possibly it is a cold spring.	Cold clear water was flowing over terraces of travertine. No bubbles were observed. It appears like fossil hydrothermal features. Geothermal glass covers the area.	No analysis
Rwagimba	0177588E 0053078N	Located in Rwenzori mountains along Rwagimba valley. You branch off at Kibito.	Crystalline granite gneiss of Rwenzori.	Hot clear water, with observable travertine, gas bubbles, reddish iron stains, with a maximum surface temp of 69^{0}C.	Slightly alkaline.
Rwimi (a)	0190150E 0042846N	Located in the land of Mr. Yozefu Buhanga, near Rwimi Town on Fort Portal-Kasese road.	No observable outcrops.	Cold water issuing with vigorous bubbling. Tem p recorded was 25.9^{o}C from a pool 5 x 2.5 m, iron oxides visible, reported to be used for healing diseases.	Near neutral with carbon dioxide bubbling
Rwimmi (b)	0190206E 0043062N	Just a few meters from Rwimi (a)	No observable outcrops	Travertine mould standing about 1.5m high, clear water flowing from the base of mould, temperature 24.6^{o}C, conductivity was 3.8ms/cm, iron oxide residues, few gas bubbles not as vigorous as in Rwimmi (a)	Near neutral with carbon dioxide bubbling.