PRELIMINARY INVESTIGATIONS OF GEOTHERMAL AREAS IN UGANDA, OTHER THAN KATWE-KIKORONGO, BURANGA AND KIBIRO

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ABSTRACT

Preliminary geothermal investigations have been carried out on the other geothermal areas out side the active volcanic belt in Southwest, West, North and North-east Uganda. Previuos studies had focused on three areas Katwe, Buranga and Kibiro which were considered as most promising because of their volcanic and tectonic features. The aim of the the study was to select other areas for cascadede geothermal exploration and development.

The geochemical results indicate a good agreement between the Na/K and the silica geothermometer temperatures in some areas. The magnesium concetration is high in most of the samples suggesting a substancial influence of cold groundwater. Subsurface temperatures have been predicted with reasonable certainity for 8 of the 23 areas. The most promising areas based on permeability and their subsurface temperatures are Rubaare (134 - 140˚C), Kitagata (120 - 140˚C) and Kanangorok (140 - 160˚C) with reliable Na/K and silica geothermometers. The presence of hydrogen sulphide in Ihimbo (80 – 100˚C) and Panyimur (80 - 120˚C) waters suggest that these sources might be hotter than predicted by geothermometry. Another group worth investigating includes Birara (140 - 160˚C), Minera (120 – 130˚C) and Rubabo (120 – 140˚C) whose subsurfaces temperature predictions using the silica and Na/K geothermometers are in agreement. The rest of the areas are good for direct uses in Industry and agriculture.

1. Introduction

Hot springs and mineral springs in Uganda were first recorded by Stanley (1890) but the first comprehensive list was presented by Wayland (1935) who described 10 spring areas outside Katwe-Kikorongo, Buranga and Kibiro and came to the conclusion that the majority of the springs are closely related to the rift and volcanic extrusions.

Geothermal investigations were done in active volcanic areas of western Uganda along the Western Rift Valley system under the Geothemal Energy Exploration I project (UGA/92/002) during 1993-94. The investigations focussed on the major geothermaal areas of Katwe-Kikorongo (Katwe), Buranga and Kibiro in the districts of Kasese, Bundibugyo and Hoima respectively. It included geological study, geochemical sampling of the surface manifestations which are hot springs, chemical analyses of the water samples and interpretation of data (Armannsson 1994). The project recommended that the hot springs out side the active volcanic areas be investigated and results compared with those from the active volcanic areas.

Bahati (1995, 1996) visited nine of these areas in SW Uganda, carried out preliminary investigations, and found promising geothermometer temperatures (>100°C) in Rubabo, Minera, Birara and Ihimbo. Ármannsson (2001) visited Karungu, Minera, Ihimbo and Kitagata with the Geological Survey and Mines geochemical team and found them promising. Sharma (1971) studied 15 springs from these areas and Kato (2003) has reviewed his results.

The preliminary investigation resumed in 2005 under the a project of the Government of Uganda with support from the World Bank (WB) and the Icelandic International Development Agency (ICEIDA) which has since ended. The aim of the study was to rank the geothermal areas out side the tectonic and volcanic areas of Uganda in terms of their geothermal potential for detailed surface geothermal exploration. This paper summarises the results of this study.

2. Study areas

Recent geothermal investigations have been focused on three areas namely Katwe, Buranga and Kibiro all in west Uganda. The three were chosen for study because of their volcanic and tectonic features that indicate a powerful heat source and high permeability.

Other areas are located within or on the outskirts of the rift valley in southwest, west, north and northeast Uganda (Figure 1). This study, therefore, will cover areas in the following regions of Uganda; southwest (Kabale, Kanungu, Rukungiri and Bushenyi districts), west (Kasese and Kabarole districts), northwest (Nebbi district), north (Gulu and Adjumani districts), east (Sironko district) and northeast (Kaabong district), and additional investigations of Kibiro and Katwe prospects. The location and basic geological and physical characteristics of the study areas are summarizes as follows.

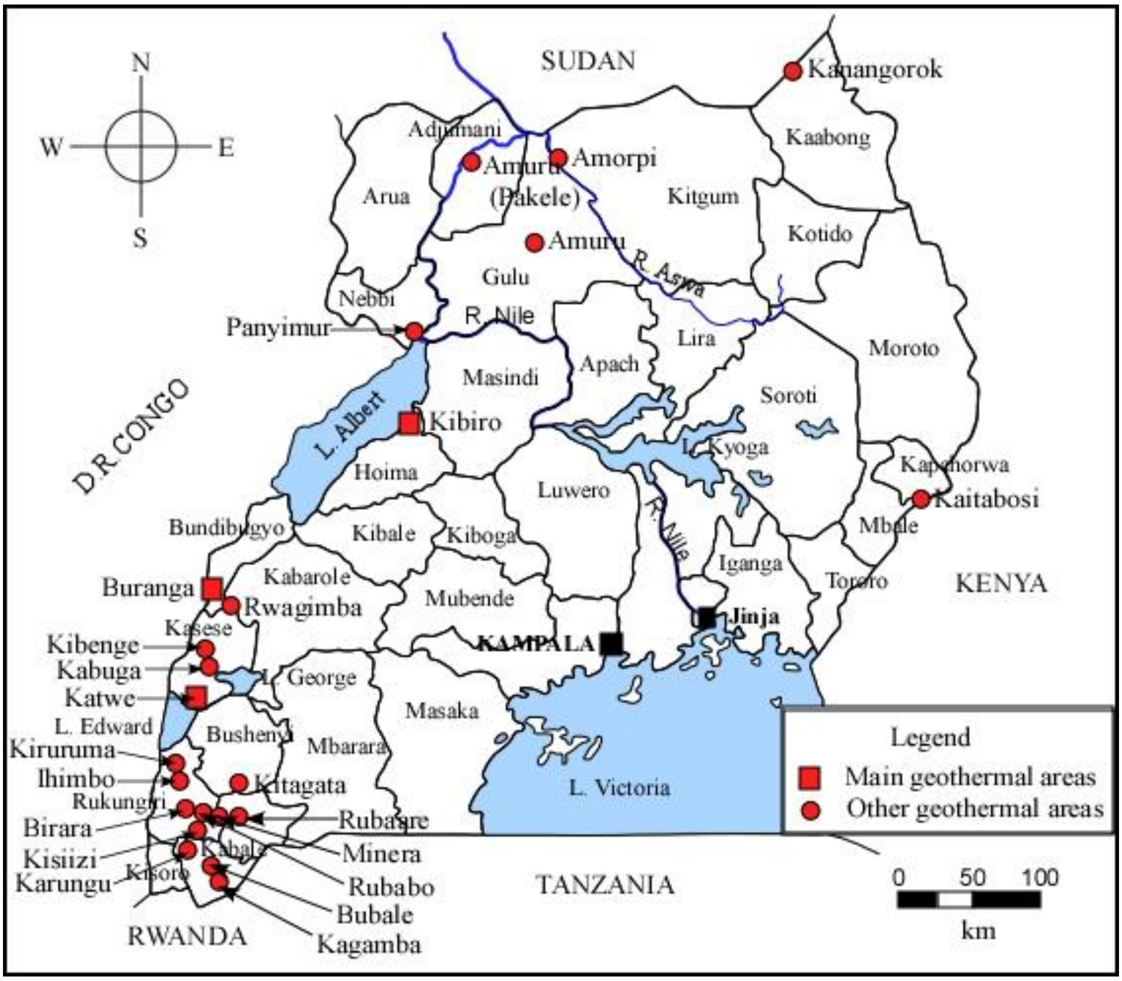

Figure 1: Uganda geothermal areas.

2.1 Kagamba

Kagamba thermal area is located on Kabale – Katuna road approximately 10km from Kabale town. Clear fresh water is seeping under a pool of water (30m x 10m). The area is swampy and characterized by clay soils of a wetland type which is generally representative of the low lands of Kabale district. Presence of molds of travertine is evidence for a system that was thermally active in the past and has since cooled down. No outcrop was seen around but floats of ferrugnised phyllites / slates and quartzite were noticed. Just about 50m across the road, ferrugnised quartzite is quarried for aggregates. A fault is inferred in the area striking in the north-south direction and possibly controlling the hot springs. Water issues at about 35^{o}C with intermittent gas bubbling. The flow rate is estimated at 0.1 l/s. This flow has formed a pool of water (30 m x 10 m).

2.2 Karungu

Karungu geothermal area is located in Hamurwa Subcounty, Rubanda County in Kabale district (Figure 1). The thermal area is situated south of the Kerere Forest Reserve, which is at a distance of approximately 35 km from Kabale town along Kabale-Kanungu road. The thermal area can be easily accessed by road through Nyamasiizi on Kabale-Kisoro road. There are about 12 hot springs in the area which issue from the bed of Ishasha river (trending

E-W) from two sets of very narrow cracks, one coinciding with the bedding plane and the other with a joint plane, which run at an angle to the bedding plane.

The area is underlain by hard ferruginised Karagwe-Ankolean phyllites / slates, jointed and bedded (trending north and dipping East). Some joints are nearly vertical. A faulted plane is inferred along river Ishasha gorge. The hot water issues at a temperature between 34.4 and 65^{o}C. Intermittent gas bubbling was observed in almost all the hot springs. The nearest volcano is at Kitunga with lava flows some 30 km away along the Kabale – Kisoro road. The hot spring water is used by locals for bathing, watering animals and as tourist attraction.

2.3 Bubare

Bubare thermal area is located on Kabale-Kisoro road approximately 4.8 km from Kabale town. The area is underlain by ferruginous phyllites and slates of Karagwe-Ankolean system. The thermal water is issuing at a temperature of 34^{o}C. Intermittent gas bubbling was noticed in a pool of warm water (10 m x 5 m). At a distance of 150 m is another warm spring that has created a pool of water (1 m x 1 m) with a temperature of 28^{o}C. The first pool has a flow rate of 1.7 l/s and was sampled during this field trip.

2.4 Rubaare

The geothermal area is located in Rugarama sub-county, Rushenyi county in Ntungamo District. There are two hot springs one of which has formed a pool of about 15 m diameter and the second located 100m from the first one is a small pool of 2m in diameter. Some sort of structural control is inferred. The water was clear and inactive fossil travertine (older spring deposits) was noted at high elevation within a radius of 200m from the hot spring. The springs have thus been active at a higher elevation than today. The current extent of travertine appears disproportionately large relative to the current rate of spring overflow. Water is issuing from fractured quartz rich pegmatite granitoid rock, with muscovite sheets and tourmaline. Presence of algae is highly pronounced in the smaller pool than the bigger one possibly because of little surface area exposed. Surface water temperature was measured at 54^{o}C in both springs with a flow of about 2 l/sec from the bigger pool.

2.5 Kitagata

Kitagata geothermal area is located in Kitagata subcounty, Igara county, Bushenyi district (Figure 1). It is situated on Ishaka - Kabale road at a distance of approximately 16 km from Ishaka town and 0.8 km from Kitagata trading centre. The thermal area is characterized by a number of hot springs issuing from banded fractured biotitic granitic gneiss, which is jointed (four sets), in the broad Rwabanjari valley. There is a presence of gas bubbling which is a characteristic of nearly all the hot springs in SW-Uganda. The temperature of the water at the sampling point was 67^{o}C. The total flow rate is 4.1 l/s.

Striations were noted on the gneiss, an indication of a possible fault in this area, trending approximately N-S. E-W foliation trends were observed and N-S almost vertical joints. A pool of water (7 m x 10 m) has been curved out for bathing and is fed by water from the hot springs. Some iron oxide mineralisation was observed. About 300 m away is another hot spring (Omugabe pool), discharging at 2.8 l/s. This also issues from granitic gneiss forming a pool of about 9 m in diameter. Again intermittent gas bubbling was noticed. White oolitic spring deposits were noticed on the gneiss surface and along fracture planes. It reacted slowly with acid. The hot spring water is used by locals for bathing, watering animals and as a tourist attraction.

2.6 Ihimbo

Ihimbo geothermal area is located in Bwambara subcounty, Rujumbura county, Rukungiri district (Figure 1). The geothermal area is situated in Ihimbo forest at a distance of about 1.5 km from the Rukungiri - Kihihi road via Bugangari, Bwambara and Nyamirama and about 2 km from River Ntungwa, River Birara being its main tributary. It is located on or close to the presumed major boundary step rift fault, at the escarpment front of the western Rift Valley. The springs are issuing from tertiary rift sediments (conglomerates, clays, silts and sands). The grains and pebbles of quartz are rounded to sub angular and the beds appear to contain iron oxide deposited from infiltration solutions, which give the beds their rusty brown color. The highest temperature of 70^0C was measured in one of the springs with the highest flow rate of 3 l/s. There are three groups of springs with temperatures of 70, 50 and 68 all in a line 150 m long an indication that the thermal area is large. These hot springs are aligned in an approximately N-S direction possibly related to the major Rift. Intermittent gas bubbling was noticed. A presence of travertine is on record (Sharma, 1971). The thermal waters are used by people from all walks of life for bathing and are believed to cure several diseases.

2.7 Kanyinabarongo

Kanyinabarongo warm spring is located in Bwambara sub-county, Rujumbura county in Rukungiri district (Figure 1). Kanyinabalongo thermal springs are located north but not far from Ihimbo and seem to be aligned in North-South direction. They issue from a pebbly clay (Pleistocene sediments) environment in the Rift Valley. More warm springs are reported in the area but this was the most pronounced. The surface water temperature is 38^oC with a flow of about 4 l/s. A pool of about 4 meters in diameter is used by locals for its therapeutic values.

2.8 Birara

Birara geothermal area is located in Buyanja sub-county, Rubabo county in Rukungiri district (Figure 1). The area is situated on the banks of River Birara gorge with the hot springs issuing fresh clear water with a lot of gas bubbling which may be mistaken for boiling in some of the springs. River Birara gorge is likely to be a fault through mica schists grading into gneiss. These rocks look ferruginous in places and micaceous.The highest temperature measured is 63ºC in one of the springs. At this site River Birara passes between two ridges of about 800m high and the hot springs are believed to be fault controlled. Despite the difficult terrain, the hot spring water is used by locals for bathing, watering animals and as tourist attraction.

2.9 Minera

Minera geothermal area is located in Buyanja subcounty, Rubabo county in Rukungiri district (Figure 1). The area is situated on the banks of River Birara at a distance of about 20 km on Rukungiri-Kabale road via Kebisoni trading centre. Several points of fossil thermal features could be noticed around the hot springs including geothermal grass and salt gardens. It is about 25 km from the edge of the rift valley. Minera hot springs issue clear water with moderate gas bubbling at some points. Gas seeps were noticed along the river at a distance of 20 m downstream. Water issues from fractured crystalline basement rocks (granitic gneiss rock, with quartzite bands of Karagwe-Ankolean system), jointed with different sets. A flow rate of 0.5 l/s and a maximum temperature of 58^{o}C in the main spring were recorded. The hot spring water is used by locals for bathing, watering animals and as tourist attraction.

2.10 Rubabo

Rubabo geothermal area is located in Nyarushanje subcounty, Rubabo county, Rukungiri district (Figure 1). This area is also situated on the banks of River Birara at a distance of 10 km down stream from the Minera geothermal area and on Rukungiri-Kabale road. The thermal area can be divided into two groups of hot springs namely Rubabo1 and Rubabo2 both of which were sampled.

The hot springs issue from a fractured crystalline basement (jointed and fractured) granitic gneiss rock, along the deeply incised Minera river gorge, some 20 km from the rift valley. The temperature ranges from 58^{o}C to 60^{o}C. The thermal water is clear and fresh with a flow rate of 3 l/s., and intermittent gas seeps from nearly vertical joint sets (N-S). Another joint set was recorded as 110^{o}/60^{o}SW. The flow is fracture controlled in crystalline basement rocks. In the neighbourhood is limestone deposits in a swamp. The hot spring water is used by locals for bathing, watering animals and as tourist attraction.

2.11 Kiruruma

Kiruruma geothermal area is located in Kihihi subcounty, Kinkizi county in Kanungu district (Figure 1). The thermal area is situated at a distance of about 10km on Kihihi-Katunguru road and on the banks of River Kiruruma. It issues from unconsolidated rift Pleistocene sediments (conglomerates, sands, silts and clays) at a distance of about 50 m from the river and has low surface temperature with a maximum of 36^{0}C. A number of warm springs issue clear fresh water, with intermittent gas bubbling. The sediments are ferruginised in some places according to observable rusty stains. Thermal springs are located at or near a fault plane. A flow rate of about 1 l/sec was recorded. The hot springs water is used by locals for bathing, watering animals and as tourist attraction.

2.12 Kisiizi

Kisiizi warm spring is located in Nyarushanje subcounty, Rubabo county in Rukungiri district (Figure 1). The thermal area is situated close to Kisiizi hospital along the Kabale – Rukungiri road. Kisiizi thermal springs issue clear warm water of about 30°C. Fractured silicified quartzitic rocks and granitic gneisses of Karagwe-Ankolean system, underlies the area. The thermal springs are probably controlled by fractures with an average flow of about 0.5 l/s. The warm water is currently used by Kisiizi hospital for bathing and other domestic uses. This is the only direct application of geothermal heat in Uganda.

2.13 Kabuga

Kabuga hot springs are located in Muhokya subcounty, Busongora county in Kasese district (Figure 1). The thermal area is situated close to Muhokya limeworks on Katunguru–Kasese road. Kabuga warm springs are sometimes referred to as Muhokya warm springs. The water is clear with gas bubbling. A temperature of 41 and 42°C was measured in two of the springs with a total flow rate of 1 l/s. There is no rock exposure but surface geology indicates that the springs are probably issuing from the alluvial and pediment gravel materials at the base of the Rwenzori Mountains. It is likely that this thermal spring is controlled by the major Rwenzori fault that extends to Lake Kitagata in the Katwe geothermal prospect.

2.14 Kibenge

Kibenge thermal spring is located on Kasese – Kilembe road after the junction to Hotel Margherita in Kasese district (Figure 1). It is located in a valley and issues from alluvial and pediment gravels overlying fractured Precambrian basement rocks (gneiss, amphibolites, quartzite and schists). Local people use a pool of 7 m diameter, recharged from the hot springs, for therapeutic purposes. It has a temperature of about 45°C and with intermittent gas bubbling. It is also likely to be related to the major Rwenzori fault like Kabuga hot springs.

2.15 Ndugutu (Bugoye)

Ndugutu cold springs are located in Bugoye subcounty, Busongora county in Kasese district (Figure 1). The cold springs, located west of River Sebwe, flow into river Sebwe. Geothermal grass and fossil travertine terraces upon basement rocks, characterize the cold springs. The current extent of the travertine terraces is disproportionately large relative to the current rate of spring overflow. The area has a number of cold springs in an area of about 50 m in diameter with a temperature range of 21 -22°C and a flow rate of about 0.1 l/sec was estimated at one of the main outlets. Surface geology reveals that the area is underlain by fractured quartzite, phyllitic schists and granitic gneisses covered by travertine mounds. Feeble gas bubbling was noticed in the highest point terrace. The fossil travertine terraces are an indication of a system that was active some time back and has since cooled down.

2.16 Rwimi

Rwimi thermal area is located in Mirambi subcounty and close to Rwimi trading center in Kabalore district (Figure 1). Effervescence of dissolved carbon dioxide is characteristic of Rwimi warm springs. Clear to cloudy water is issuing under a pool of cold water that is approximately 2.5 m in diameter. There is vigorous gas bubbling (ebullition caused by CO_2 discharge) and with a pH of 7.09. The travertine deposits rise to a height of approximately 1.5

m at one of the springs. The surface water temperature ranges from 24-25^oC. The area is swampy with no rock outcrop. Surface geology reveals limestone nodules in the vicinity. Iron oxide stains are visible. Rwimi thermal area is possibly related to mountain front faults or ragged front fractures. A magma chamber might be the reasonable source of huge quantities of carbon dioxide discharging at Rwimi but it might as well be a low temperature non volcanic travertine depositing system. This spring is located in the vicinity of the Kyatwa volcano that is characterized by carbonatite deposits that could influence the composition of the gas discharges in this area.

2.17 Rwagimba

Rwagimba geothermal area is located in Kibito subcounty, Bunyangabu county, Kabarole district (Figure 1). Surface geothermal manifestations in the area include travertine mounds (not pervasive), gas emission and water with a temperature ranging from 40 to 69^oC on a stretch of more than 30 m along the Mubuku river. The area is underlain by fractured crystalline basement rocks (undifferentiated granitic gneisses), along river Mubuku. The flow rate is estimated at 1.5 l/s in the main hot spring. The river gorge seems to be a fault line structurally controlling the hot water flow. There is evidence of ferruginisation in the rocks, in form of yellowish brown (reddish iron) stains.

2.18 Kanangarok

Kanangorok geothermal area is located in the Kidepo Valley National Park, Kaabong district near the border of Uganda, Sudan and Kenya (Figure 1). This area is located 9 km south of Mt. Lotuke that marks the border of Uganda and Sudan. There are two main groups of hot springs, HS-01 and HS-02, with a temperature of 60˚C and 42˚C respectively. HS-02 is located at a distance of 67m from HS-01. The third hot spring is tapped through a borehole at a temperature of 38˚C and is located approximately 600 m from the two hot springs. This indicates that the geothermal area covers a considerable area. All the three locations were sampled. The area is general flat with vegetation of a woodland type. The area around the two hot springs has travertine deposits and is covered by geothermal grass for almost half a km^2 but this grass does not extend to the borehole that is discharging warm water. The elevation is approximately 1076 meters above sea level.

A siliceous rock is reported in the area as well as a pink-grained limestone. The hot water is reported to issue from fractured granitic gneiss (Precambrian basement rocks). An under-saturated dyke rock is reported 0.8 km NE of Kanangarok hot springs while a basement carbonate rock is reported 1.6 km further in the same direction. Fossil thermal features (travertine deposits) are reported to the east of Mt. Lotuke which indicates that the geothermal activity has been migrating from that direction to the current location.

2.19 Kaitabosi

Kaitabosi thermal area is known to occur close to the summit of Mt. Elgon, on the rim of a 6 km radius caldera in Sironko District, on the Uganda-Kenyan border. The area gets its name from one of the peaks of Mt. Elgon on the Kenyan side of the mountain. The thermal area can be accessed through Budadiri town and then Bumasora trading center, which is the last access point by road. The journey takes a minimum of two days to reach the hot spring. Warm water issues with a temperature range of 45-48^oC, from fine-grained volcanic basaltic agglomerates and tuffs (Miocene-Pliocene). These volcanic rocks are older than the volcanic rocks of the western Rift Valley. Mount Elgon volcano is believed to have last erupted 24 million years ago and has no signs of activity. There is presence of hydrogen sulphide in the geothermal water and other surface manifestation include thermophyllic grass spread across the caldera. The thermal area is likely to be controlled by an E-W and ENE-WSW trending faults and the circular fracture of the caldera.

2.20 Panyimur

Panyimur hot springs are located on escarpment front just near the shores of Lake Albert, in Panyimur subcounty, Nebbi district. The thermal area can be divided into three groups of hot springs namely Amoropii, Okumu and Avuka all along the escarpment of the rift valley. The hot springs are aligned in a northwest direction possibly controlled by the major normal boundary rift fault for a distance of approximately 1.5 km with Amoropii further east and Avuka further west. It is anticipated that the springs rise at or close to the fault. Other surface manifestations reported include deposits of travertine, sulphurous algae and smell of hydrogen sulphide characteristic of a high temperature area. The temperature ranges from 35˚C at Avuka to 58˚C at Amoropii. Fractured crystalline basement rocks such as coarse hornblende gneiss, coarse hornblende garnet rock, talcose rock and a pegmatitic vein are all reported in a gorge that dips into the escarpment from the hot springs. A foliation/basement schistose trend NNE-SSW. Others schistose trend almost NE, parallel to the local major faults.

The Okumu hot spring is tapped through a protected spring with inactive travertine mounds (old spring deposits) as high as 3 meters and approximately 5 m north of the hot spring. The Avuka thermal area is characterized by thermophyllic (geothermal) grass in a boggy environment with hot springs issuing at different locations with a highest temperature of 44˚C. These discharges are characterized by gas bubbling. This area was difficult to sample but a hot spring in the vicinity at a higher ground with a temperature of 35˚C was sampled. Rocks in the area include crystalline basement rocks (coarse jointed granitic-gneiss outcrops to the west) and Pleistocene sediments to the east of the rift fault boundary.

2.21 Amuru hot springs (sheet 21/1)

Amuru hot springs are located a few kilometers west of Gulu towm, Gulu district (Figure 1). The springs have a total discharging at about 2.5 l/sec with a maximum surface discharge temperature of 51^oC. The area is reportedly underlain by fractured crystalline basement rocks (biotitic granitic gneiss, amphibolites and schist). Other geothermal surface manifestations include travertine mounds and gaseous emissions. Foliations trending NNE-SSW and joints trending NE-SW in quartzite as observed.

2.22 Amuru (Pakele) hot spring (sheet 13/4)

Active hot springs occur at Amuru-Paloga village, in Pakele sub-county, Adjumani district (Figure 1). The two main hot springs issue at a temperature of 46 and 51^oC and are 20 m apart. Intermittent gas bubbling is reported from three thermal springs in the area.

3. Sampling and field measurements

The investigation involved geochemical sampling of the hot springs, measurement of physical parameters, analysis of the water samples collected for volatile components in the field laboratory. A total of 35 water samples were collected. Also collected are rock samples for mineralogical analysis to determine the source of salinity in the geothermal fluids. This survey is preliminary and will be followed by detailed surveys on selected areas.

The coordinates of the sampling points, physical parameters measured, and chemistry of the volatile components are presented in Table 1.

Table 1: Uganda geothermal areas. Sample site information and results of volatile components.

Sample No.	Location	Date	Eastings	Northings	Elevation (m)	Temp. (◦C)	Cond. (uS)	pH	CO_2	H_2S	TDS
UG-05-15	Kagamba	29/07/2005	833389	9853726	1811	35	467	7.49	186	0	234
UG-05-16	Karungu	30/07/2005	819757	9881140	1832	65	846	7.09	111	0	423
UG-05-17	Bubale	30/07/2005	829628	9863762	1820	34	578	6.29	406	0	288
UG-05-18	Rubaare	31/07/2005	175226	9901026	1380	54	1600	7.52	85	0	800
UG-05-19	Kitagata	01/08/2005	183938	9924709	1495	66	1110	7.92	56	0	552
UG-05-20	Ihimbo	02/08/2005	813593	9924179	1028	70	893	9.2	45	0.92	444
UG-05-21	Kanyinabarongo	02/08/2005	810489	9928818	999	38	992	7.37	58	0	492
UG-05-22	Birara	03/08/2005	820887	9901717	1285	63	1072	7.44	647	0	536
UG-05-23	Rubabo1	03/08/2005	827785	9900154	1316	58	1069	7.14	230	0	532
UG-05-24	Rubabo2	03/08/2005	827934	9900287	1306	60	1077	7.5	235	0	537
UG-05-25	Kiruruma	04/08/2005	805752	9926349	994	36	609	7.09	124	0	304
UG-05-26	Kisiizi	05/08/2005	827673	9889841	1666	30.1	292	7.43	106	0	144
UG-05-27	Minera	05/08/2005	167309	9899970	1345	58	2180	6.88	547	0	1080
UG-05-29	Kabuga	11/08/2005	171184	11663	1005	42	3290	7.42	110	0	1650
UG-05-30	Kibenge	11/08/2005	172001	21027	1094	48	3300	7.5	79.2	0	1660
UG-05-31	Ndugutu	12/08/2005	176621	32737	1234	22	17580	8.5	1918	0	8770
UG-05-32	Rwimi	12/08/2005	190213	43093	1108	24	3160	7.09	1620	0	1560
UG-05-33	Rwagimba	15/08/2005	177800	53083	1555	69.2	6400	6.87	651	0	3190
UG-05-58	Kanangorok-1	06/08/2005	584944	441937	-	60	1631	8.35	216	0	815
UG-05-59	Kanangorok-2	06/08/2005	584905	441923	-	42	1627	8.39	207	0	812

Sample No.	Location	Date	Eastings	Northings	Elevation (m)	Temp. (◦C)	Cond. (uS)	pH	CO_2	H_2S	TDS
UG-05-60	Kanangorok-BH	06/08/2005	584718	442176		38	1658	8.44	207	0	825
UG-05-61	Kaitabosi	18/09/2005	675501	127126	3559	48	1038	10.55	155	8.3	518
UG-05-62	Amoropii	22/09/2005	313637	252981	648	58	1790	8.66	71	5.61	890
UG-05-63	Okumu	22/09/2005	313319	252381	666	45	1590	8.45	109	2.48	794
UG-05-64	Avuka-2	22/09/2005	312946	251998	654	35	676	7.56	142	0	337
UG-05-65	Lusonga-BH	24/09/2005	819742	9986111	896	32	46300	7.57	2218	0	23000
UG-05-117	Amuru (Pakele)	25/10/2005	377072	368562	716	49	449	9.06	95.5	0	nd
UG-05-118	Amuru	01/10/2005	422168	306597	1102	48	508	8.23	91.1	0	nd

4. Analytical results

The water samples were analysesd by a contarcted laboratory at the Institute of Geological and Nuclear Sciences, New Zealand.

The analytical results are presented in the Tables 2 and 3.

Table 2: Analytical results of major constituents in waters from the geothermal areas of Uganda. Concentrations in (mg/kg).

Location	Sample No.	Type	Temp. (ºC)	pH	EC (µS)	CO2	H2S	SiO2	Na	K	Ca	Mg	SO4	Cl	F
Kagamba	UG-05-15	GTH	35	7.49	467	186	0	26	13.2	4.7	29	44	37	<20	1.8
Karungu	UG-05-16	GTH	65	7.09	846	111	0	49	149	9.4	29	3.8	206	44	5.4
Bubale	UG-05-17	GTH	34	6.29	578	406	0	19.2	61	5.7	60	38	73	<20	0.69
Rubaare	UG-05-18	GTH	54	7.52	1600	85	0	106	285	14.9	70	1.4	417	177	6
Kitagata	UG-05-19	GTH	66	7.92	1110	56	0	76	203	10.7	36	0.28	346	55	7.4
Ihimbo	UG-05-20	GTH	70	9.2	893	45	0.92	66	186	5.6	3.8	0.02	219	71	6
Kanyinabarongo	UG-05-21	GTH	38	7.37	992	58	0	34	173	9	31	4.5	280	92	2.6
Birara	UG-05-22	GTH	63	7.44	1072	647	0	103	210	13.6	70	10.5	208	80	6.2
Rubabo1	UG-05-23	GTH	58	7.14	1069	230	0	81	216	11.2	41	8.3	184	93	3.9
Rubabo2	UG-05-24	GTH	60	7.5	1077	235	0	80	216	11.3	41	8.3	183	90	3.9
Kiruruma	UG-05-25	GTH	36	7.09	609	124	0	57	110	9.4	36	2.9	182	22	2.7
Kisiizi	UG-05-26	GTH	30.1	7.43	292	106	0	17.5	5.8	3.8	30	18.9	14.7	<20	0.18
Minera	UG-05-27	GTH	58	6.88	2180	547	0	83	482	23	70	22	361	181	2.5
Kabuga	UG-0529	GTH	42	7.42	3290	110	0	53	622	21	208	13.2	1071	474	2.7

Location	Sample No.	Type	Temp. (ºC)	pH	EC (µS)	CO2	H2S	SiO2	Na	K	Ca	Mg	SO4	Cl	F
Kibenge	UG-05-30	GTH	48	7.5	3300	79.2	0	46	581	26	233	6.5	889	589	4.2
Ndugutu	UG-05-31	GWS	22	8.5	17580	1918	0	40	4482	268	25	11.2	3469	2931	16.5
Rwimi	UG-05-32	GWS	24	7.09	3160	1620	0	94	382	61	384	191	523	211	1.3
Rwagimba	UG-05-33	GTH	69.2	6.87	6400	651	0	65	1481	46	75	5.1	1527	905	8
Kanangorok-1	UG-05-58	GTH	60	8.35	1631	216	0	118	322	17.7	24	2.7	341	95	12
Kanangorok-2	UG-05-59	GTH	42	8.39	1627	207	0	129	323	19.2	21	1.5	343	97	13.8
Kanangorok-BH	UG-05-60	GWB	38	8.44	1658	207	0	129	342	22	21	1.5	352	96	13
Kaitabosi	UG-05-61	GTH	48	10.55	1038	155	8.3	157	248	7	0.52	0.014	36	<20	22
Amoropii	UG-05-62	GTH	58	8.66	1790	71	5.61	73	352	10.9	4.5	0.36	26	470	5.2
Okumu	UG-05-63	GTH	45	8.45	1590	109	2.48	69	321	9.5	8.5	0.68	36	379	4.7
Avuka-2	UG-05-64	GTH	35	7.56	676	142	0	54	138	7.3	8.4	3.1	19	83	2.4
Lusonga-BH	UG-05-65	GTH	32	7.57	46300	2218	0	53	42	316	163	243	3313	3385	0.32
Amuru (Pakele)	UG-05-117	GTH	49	9.6	449	95.5	0	70	110	2.6	1.4	0.04	4.4	53	6.6
Amuru	UG-05-118	GTH	48	8.1	508	91.1	0	68	111	3.9	6.6	0.76	73	51	8

Table 3: Analytical results of minor constituents and stable isotopes in waters from the geothermal areas of Uganda. Concentrations in (mg/kg) and (‰) for stable isotopes.

Location	Sample No.	Type	Fe	B	Cd	Sr	NH3	Li	Mn	Br	δ18O	δD
Kagamba	UG-05-15	GTH	<0.02	0.3	0.0002	0.2	0.13	<0.05	0.047	<0.20	-4.7	-17.1
Karungu	UG-05-16	GTH	0.9	0.44	0.00006	1.5	<0.1	0.38	0.15	<0.04	-3.97	-9.6
Bubale	UG-05-17	GTH	1.8	0.27	<0.00005	0.5	0.1	0.23	0.25	<0.02	-3.93	-9.1
Rubaare	UG-05-18	GTH	0.08	0.78	<0.0001	1.1	0.48	0.29	0.075	1.2	-4.2	-12.1
Kitagata	UG-05-19	GTH	0.05	0.61	<0.00005	0.77	0.41	0.5	<0.005	0.36	-3.3	-3.1
Ihimbo	UG-05-20	GTH	0.08	0.27	<0.00005	0.24	0.58	<0.05	0.009	0.42	-3.45	-4.1
Kanyinabarongo	UG-05-21	GTH	6.8	0.66	0.00006	0.74	0.63	0.05	2	0.54	-3.45	-5
Birara	UG-05-22	GTH	0.25	0.33	<0.00005	1.1	0.25	0.21	0.34	0.35	-3.51	-7.2
Rubabo1	UG-05-23	GTH	0.04	0.27	<0.00005	1.2	0.19	0.09	0.11	0.4	-3.61	-8.5
Rubabo2	UG-05-24	GTH	0.09	0.26	0.00009	1.2	0.25	0.09	0.11	0.39	-3.58	-7.2
Kiruruma	UG-05-25	GTH	0.4	0.34	<0.00005	0.79	0.95	0.08	1	<0.2	-3.28	-4.7
Kisiizi	UG-05-26	GTH	0.04	<0.10	<0.00005	0.07	0.15	<0.05	<0.005	<0.04	-3.69	-7.9
Minera	UG-05-27	GTH	0.23	0.65	<0.0001	1.5	0.21	0.7	0.11	0.88	-4.13	-10.7

Location	Sample No.	Type	Fe	B	Cd	Sr	NH3	Li	Mn	Br	δ18O	δD
Kabuga	UG-0529	GTH	0.38	0.42	<0.0003	1.5	<0.1	0.1	0.19	3.5	-4.33	-11.4
Kibenge	UG-05-30	GTH	0.15	0.52	<0.0003	3.3	0.1	0.26	0.16	3.9	-4.9	-15.7
Ndugutu	UG-05-31	GWS	0.04	3	<0.001	2.9	0.43	1.9	0.046	<0.2	-2.94	-4.4
Rwimi	UG-05-32	GWS	7.5	0.53	0.0001	8.9	0.25	0.11	0.33	1.3	-2.61	1.9
Rwagimba	UG-05-33	GTH	0.8	0.94	<0.0005	3.3	<0.1	0.59	0.11	4.1	-4.8	-14.7
Kanangorok-1	UG-05-58	GTH	0.08	0.18	0.0022	0.77	<0.1	0.19	0.053	<0.2	-4.92	-18.8
Kanangorok-2	UG-05-59	GTH	0.18	<0.1	0.0011	0.71	<0.1	0.2	0.02	<0.2	-4.83	-17.2
Kanangorok-BH	UG-05-60	GWB	0.32	0.76	0.0009	0.73	0.15	0.22	0.012	<0.2	-4.88	-16.6
Kaitabosi	UG-05-61	GTH	0.03	0.17	0.0001	0.1	0.15	0.08	0.017	<0.20	-5.91	-25.3
Amoropii	UG-05-62	GTH	0.06	0.65	0.0003	0.27	2.1	0.12	0.023	1.5	-3.52	-7.7
Okumu	UG-05-63	GTH	0.02	0.58	<0.0001	0.2	1.6	0.08	0.024	0.93	-3.29	-5.5
Avuka-2	UG-05-64	GTH	0.23	0.22	<0.00005	0.07	0.25	<0.05	0.011	0.17	-2.5	1.9
Lusonga-BH	UG-05-65	GTH	1.2	0.85	<0.001	2.4	10.7	0.18	0.87	22	-3.42	-7.3
Amuru (Pakele)	UG-05-117	GTH	0.1	<0.1	<0.00005	0.02	<0.1	<0.05	<0.005	0.29	-2.48	-1.9
Amuru	UG-05-118	GTH	0.04	0.2	<0.00005	0.07	<0.1	<0.05	<0.005	0.45	-1.95	2.5

4. DISCUSSION OF RESULTS

4.1 General observation

In general the composition of the samples is benign, pH from 6.84 to 10.55, and trace element content for the most part very low. As was high in two samples, from Ndugutu and Rwagimba so that measures would have to be taken if water from these places were to be utilised. Cd was higher than in most geothermal water in the three samples from Kanangorok but not so high that it would be likely to cause harm.

More than half of the waters are sulphate waters even though the pH is relatively high. This is unusual in geothermal areas but this is so in Katwe-Kikorongo, and in Buranga sulphate, chloride and carbonate are of a very similar concentration. Chloride is the main anion in only two samples, from Okumu and Amoropii. The rest are bicarbonate waters and there is a tendency for these to be cooler than the sulphate and chloride water, probably being affected by cold groundwater.

4.2 Deuterium and oxygen-18.

Hydrogen and oxygen isotope ratios have been determined in all samples and the results are shown in Figure 2 relative to the Local Meteoric Water Line (LMWL) determined by the IAEA (GNIP 1999). The results for all the samples fall well above the line, i.e. suggest a deuterium excess. Assuming that the conditions used for constructing the LMWL apply this means that in all cases the water has fallen as rain in conditions where air moisture was lower than to-day. It could also mean that the meteoric line for precipitation at Entebbe does not apply for the whole of Uganda and that one closer to the present results need be established.

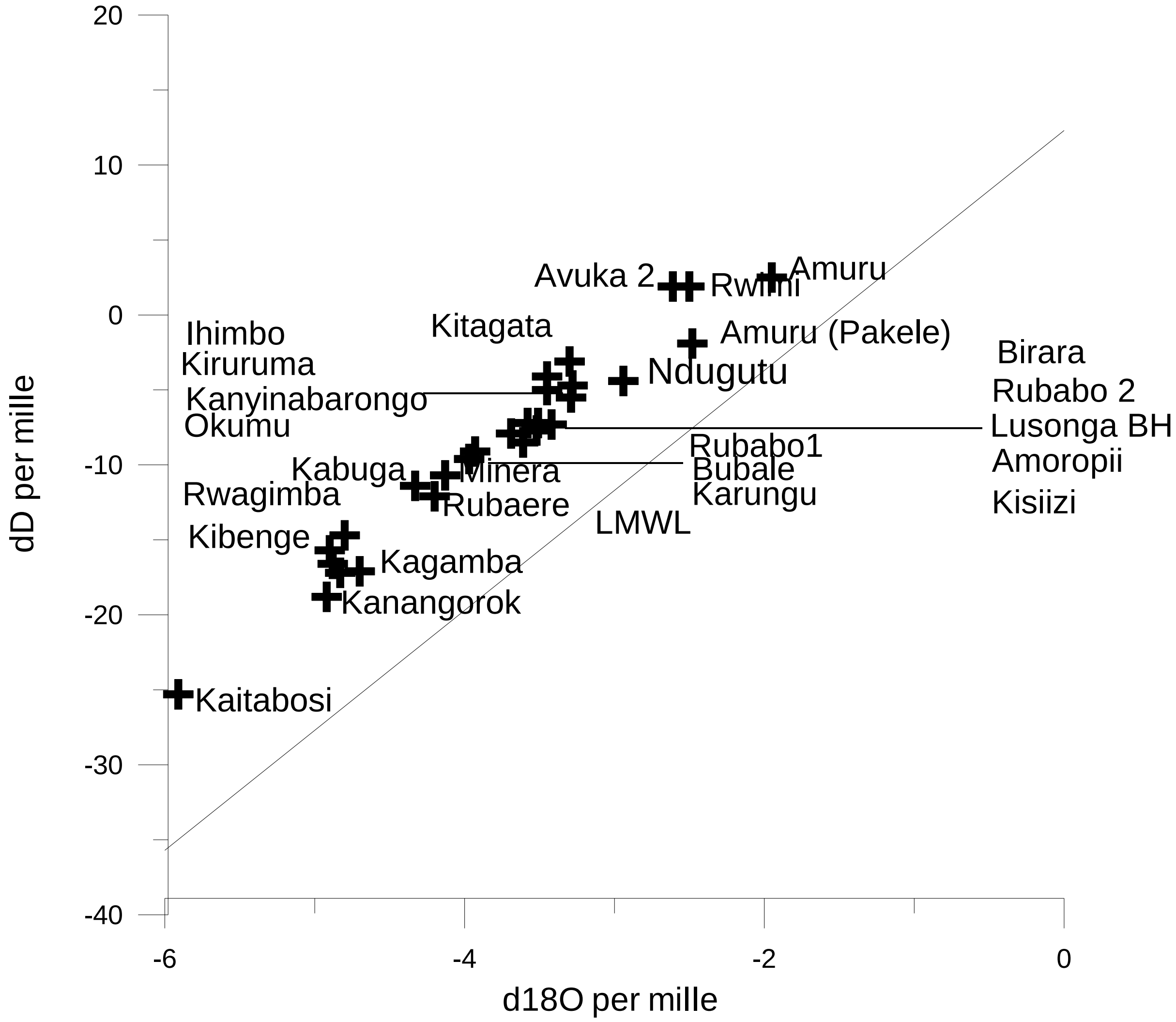

Figure 2: Deuterium and Oxygen-18 isotope ratios

On the other hand this means that there are no signs of an oxygen isotope shift in any of the samples. Thus it seems that permeability is likely to be relatively good but it could also show that none of these areas are likely to be high-temperature geothermal areas. In the absence of a map showing the distribution of deuterium and oxygen-18 in present day precipitation in Uganda it is somewhat difficult to draw conclusions about the origin and flow of the fluids studied. Some inferences can however be drawn.

The water at Kaitabosi is different from that of the other locations in that its pH is very high. The low deuterium value reflects the high altitude of the springs.

The Kanangarok springs are at an elevation of 1076 m a.s.l. but the relatively low δ^2H value suggests that the origin of the water is at an even higher altitude. Flow was apparently not recorded but if this is reasonable there is a reason to believe that this might be a promising source.

The Kagamba spring is relatively cool and there is a small flow from it but its low δ^2H value suggests that the origin of the water is at a relatively high altitude.

It has been suggested that the source of the water of the Kibenge Spring is high up in the Rwensori mountains at a similar altitude as the source of the Buranga springs (Bahati et al. 2005). Like the Kabuga spring it is apparently related to the major Rwenzori fault although the higher δ^2H value at Kabuga suggests that it is recharged at a lower altitude than Kibenge. The flow of the Kabuga springs is moderate.

Rwagimba is another area at the foot of the Rwensori mountains with a low δ^2H value suggesting recharge at a relatively high altitude in the mountains., probably close to the source(s) of Kibenge and Buranga. It seems to cover a relatively large area and the one spring that was measured had a reasonable flow.

Rubaare, Minera, Karungu, Bubale, Rubabo, Kisiizi, Birara, Kanyinabarongo, Kiruruma, Ihimbo and Kitagata seem to be recharged at moderate altitudes although not locally. Most of them have reasonable flows.

Ndugutu is located a little further to the north and the springs sampled are cold. The δ^{18}O value is a little higher than in the hot springs with similar δ^2H values which might indicate another source although from a similar altitude. Rwimi is also a cold spring from a nearby area. It is probably quite locally recharged or it may possibly be partly evaporated.

Avuka 2 appears possibly recharged locally or it may have lakewater component. The δ^2H values for the other Panyimur springs Okumu and Amoropii are considerably lower suggesting recharge from a higher altitude or at least less mixing with local groundwater.

The spring waters at Amuru and Amuru (Pakele) are probably local in origin.

4.3. Geothermometry

Quartz, chalcedony and Na/K temperatures have been obtained for these samples and are presented in Table 4. In many instances there is not a good agreement between the Na/K temperature and the silica temperatures. From the analyses it is seen that the magnesium concentration is high in these samples suggesting a substantial influence of cold groundwater rendering the Na/K geothermometer unreliable, and especially for low temperatures the silica geothermometers are not dependable either.

Table 4. Measured temperatures and geothermometer temperatures for samples from 25 geothermal areas in Uganda.

Location	Sample No.	Measured temp. °C	Quartz temp. °C	Chalcedony temp. °C	Na/K temp. °C
Kagamba	UG-05-15	35	73.9	41.8	338.9
Karungu	UG-05-16	65	101.1	70.7	153.9
Bubale	UG-05-17	34	62.6	30.3	194.7
Rubaere	UG-05-18	54	138.8	112.1	134.6
Kitagata	UG-05-19	66	120.1	91.4	136.1
Ihimbo	UG-05-20	70	83.8	52.2	96.0
Kanyinabarongo	UG-05-21	38	85.0	53.4	136.4
Birara	UG-05-22	63	136.1	109.1	155.8
Rubabo1	UG-05-23	58	125.0	96.9	136.2
Rubabo2	UG-05-24	60	123.2	94.9	137.0
Kiruruma	UG-05-25	36	108.2	78.4	183.9
Kisiizi	UG-05-26	30.1	58.6	26.4	n.a.
Minera	UG-05-27	58	126.8	98.8	128.1
Kabuga	UG-05-29	42	104.0	73.8	100.2
Kibenge	UG-05-30	48	97.5	66.8	121.6
Ndugulu	UG-05-31	22	79.7	47.9	141.3
Rwimi	UG-05-32	24	133.2	105.9	250.3
Rwagimba	UG-05-33	69.2	114.3	85.0	93.1
Kanangorok-1	UG-05-58	60	138.4	111.6	139.4
Kanangorok-2	UG-05-59	42	145.0	119.0	146.0
Kanangorok-BH	UG-05-60	38	144.9	118.9	153.2
Kaitabosi	UG-05-61	48	26.9	-3.1	93.7
Amoropii	UG-05-62	58	111.3	81.8	98.5
Okumu	UG-05-63	45	112.9	83.6	95.4
Avuka-2	UG-05-64	35	104.6	74.5	139.6
Amuru (Pakele)	UG-05-117	49	78.7	46.7	82.5
Amuru	UG-05-118	48	114.0	84.7	106.8

Results from a number of samples from Ihimbo, Okumu, Rubaare, Amuru, Amuru (Pakele), Amoropii, Kitagata, Kanangorok-1, Kanagorok-2 and Kanagngorok-BH were protted in the ternary diagram (Giggenbach 1988) (Figure 3). In some cases the magnesium concentration was however relatively low and the samples plot in the fully or partially equilibrated fields of the Na-K-Mg ternary diagram. In this diagram the equilibration curve is based on results by Arnórsson et al. (1983) for icelandic basalts. One sample (from Ihimbo) plots above this curve close to the equilibrium curve obtained by Giggenbach (1988) for andesites. The Na/K temperature for these samples can be expected to be reasonable. A study of the rocks from which these waters emerge suggests that quartz rather than chalcedony controls the solubility of silica down to at least 100°C. The most important properties of these springs with mean predicted temperatures are listed in Table 5. All the fluids listed in Table 6 are relatively dilute and should be good for production.

For one more group of samples there is reasonable agreement between Na/K and silica temperature although the Mg concentration is relatively high. The subsurface temperatures predicted for these are more uncertain but they are shown in Table 3.

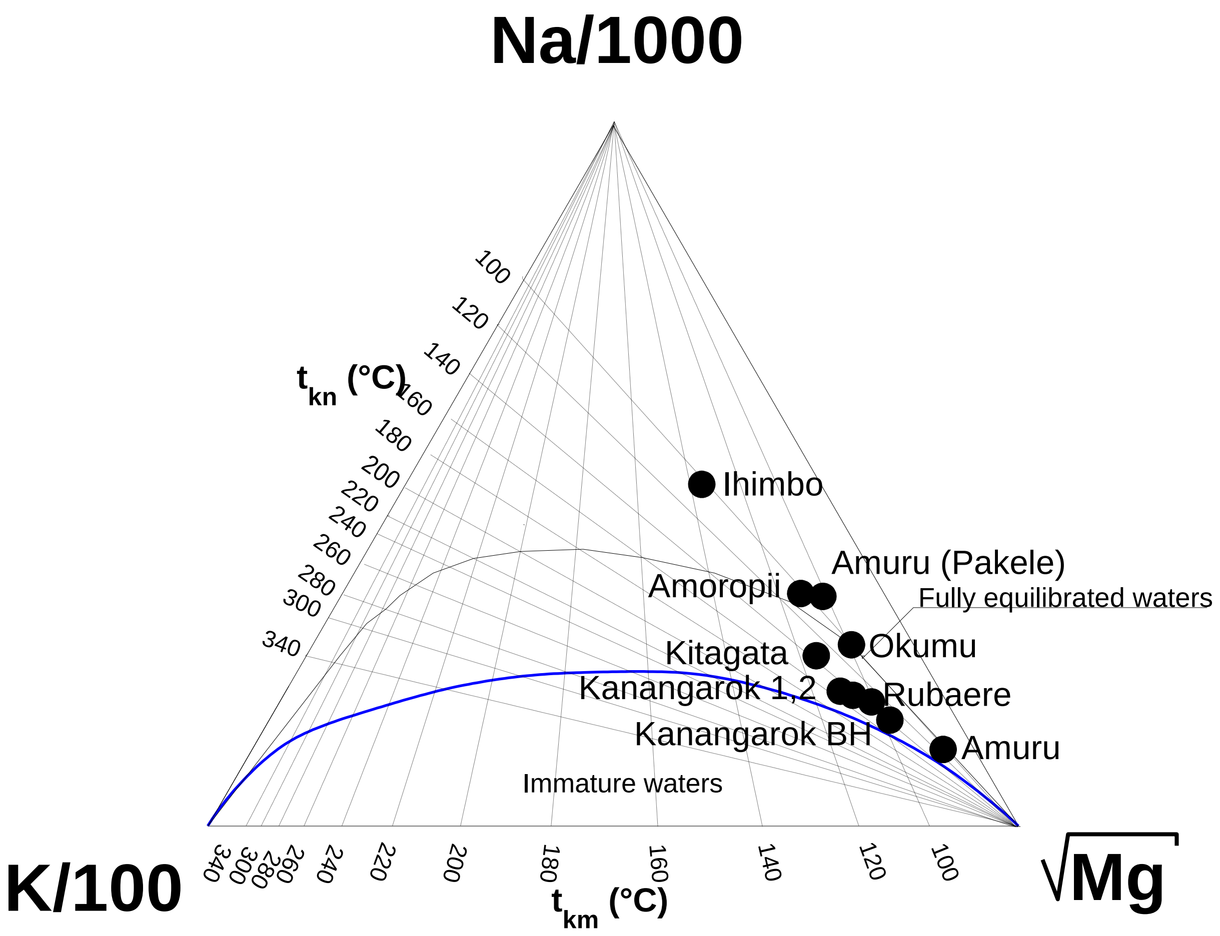

Figure 3. Na-K-Mg diagram for selected samples

An indication of a relatively high subsurface temperature is the presence of H_2S which is found in three of the samples from Ihimbo, Amoropii and Okumu. These are not the ones showing the highest geothermometer temperatures and the prtesence of H_2S is possibly an indication of a higher subsurface temperature than shown by geothermometry.

Table 5. Properties of fluids for which reliable subsurface temperatures have been predicted

Location	Rock/deposits	Flow l/s	δ^2H‰	Con-duct-ivity µs	Major anion	H_2S mg/l	Measured temp. °C	Mean geothermo-meter temp. °C
Rubaare	Quartz rich pematite, granitoid muscovite,tourmaline/travertine	>2	-12.1	1600	SO_4^{-2}	0	54	137
Kitagata	Granitic gneiss/Fe_2O_3,oolite	4.1	-3.1	1110	SO_4^{-2}	0	67	128
Ihimbo	Tertiary rift sediments/ Fe_2O_3	>3	-4.1	893	SO_4^{-2}	0.92	70	90
Kanangorok	Granitic gneiss/ travertine	n.d.	-16.6 to -18.8	1627 to 1658	SO_4^{-2}	0	38-60	139-149
Amoropii	Hornblende gneiss, garnet, talcose, pegmatite	n.d.	-7.7	1790	Cl^-	5.61	58	105
Okumu	Hornblende gneiss, garnet, talcose, pegmatite/ travertine	n.d.	-5.5	1590	Cl^-	2.48	45	104
Amuru (Pakele)	n.r.	n.d.	-1.9	449	HCO_3^-	0	49	81
Amuru	Biotitic granitic gneiss, amphibolites, schist/ travertine	2.5	+2.5	508	HCO_3^-	0	48	110

Table 6. Properties of fluids for which less reliable subsurface temperatures have been predicted

Location	Rock/deposits	Flow l/s	δ^2H ‰	Conduct-ivity µs	Major anion	H_2S mg/l	Meas. Temp. °C	Mean geothermometer temp. °C
Birara	Mica, gneiss	n.d.	-7.2	1072	HCO_3^-	0	63	146
Rubabo	Granitic gneiss/limestone	3	-7.2 to -8.5	1069-1078	HCO_3^-	0	58-60	130-131
Minera	Granitic gneiss	0.5	-10.7	2180	HCO_3^-	0	58	127
Kabuga	Alluvial, pediment gravel	1	-11.4	3290	SO_4^{-2}	0	42	102
Kibenge	Gneiss, amphibolite, quartzite, schists	n.d.	-15.7	3300	SO_4^{-2}	0	48	110
Rwagimba	Granitic gneiss	>1.5	-14.7	6400	SO_4^{-2}	0	69	104

5. Conclusions and recommendations

Subsurface temperatures can be predicted with reasonable certainty for 8 of the 24 areas investigated and are in the range 80-150°C. There are indications that permeability is reasonable in these areas. Rubaare, Kitagata and Kanangarok are candidates for binary power production if there is a market for electricity in these areas. The presence of H_2S in samples from Ihimbo, Amoropii and Okumu suggests that these sources might be hotter than is predicted by geothermometry so there are ample reasons to make a futher investigation.

There are also good reasons for further investigations in at least three of the areas listed in Table 2, i.e. Birara, Rubabo and Minera where the subsurface temperature predictions using the silica and NaK geothermometers are in agreement. Kabugu, Kibenge and Rwagimba are apparently cooler and also more saline and not as attractive for production. Of the areas not included in Tables 2 and 3 Karungu might well be a good source and Kaitabosi cannot be excluded even though its location renders it unlikely to be utilised for power production or industrial use. Finally all these sources could be utilised for industrial purposes if there is potential for that in each area.

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