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Challenges and Opportunities of Geothermal Exploration and Development in the Western Branch of the East Africa Rift Valley

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ABSTRACT

In this paper we present the challenges and opportunities of geothermal exploration and development in the Western Branch (WB) of the East Africa Rift Valley (EARV). The main challenges include inadequate data especially across the borders on shared resources, inadequate and predictable funding, inappropriate exploration philosophy and conceptual modelling because of the unique geology, volcanic activity and structural setting. The models from other regions cannot be applied directly to evaluating the geothermal potential of the WB rift. The complex interconnection between young faults and tectonically activated older fracture systems due to kinematic extension of the Somalian plate causes heterogeneity and anisotropy which determines fluid movement and targets for geothermal exploration and production wells. Drilling shallow wells or targeting areas of hot springs might therefore be completely misleading and the results might not be meaningful in evaluating the geothermal potential. The best targets for drilling geothermal production wells might be on the deep fractures in the basement rocks that are aligned with the old tectonically activated fractures in the vicinity of a heat source which may be associated with the interpreted aligned melt zones. Opportunities therefore exist for research, data acquisition and interpretation, exploration drilling and development of the geothermal resources for direct uses, power generation and geothermal tourism.

1. INTRODUCTION

The Western Branch (WB) of the East Africa Rift Valley (EARV) is composed of the Malawi Rift (MR), Tanganyika Rift (TR), Kivu Rift (KR) and Albert Rift (AR). It forms a giant arc from Uganda to Malawi, interconnecting the very deep famous rift lakes of Eastern Africa (Figure 1). The AR which is postulated to be the same age as the Eastern Branch of the EARV commonly known as the Gregory Rift (GR) is characterized by active volcanic centres in the Virunga Volcanic Province and deep lakes to the north and south of the mountains. The mountains are composed of uplifted Pre-Cambrian basement rocks as a result of tectonic movements that are gradually splitting the Somalian Plate away from the rest of the African continent (Figure 2). In the areas surrounding the mountains and volcanic centres, the uplifted basement rocks are covered by recent volcanic rocks and metamorphosed sediments of volcanic origin (Phyllites).

Some studies indicate an oblique extension rate of 2 to 5 mm/yr (Figure 3) which is accommodated by extension across the Western Rift, with present-day rates increasing from north to south. This extension in the Albert Rift at the northern end of the Western Rift is consistent with seismic reflection data showing a significant strike-slip component (Abeinomugisha et al. 2004). This southward increase in extension rate correlates with increased seismicity around the Virunga Volcanic Province that extends to the active volcanoes of Nyamuragira and Nyirangogo in DRC. The active volcanism and extension may produce active faults which can be channels of movement of geothermal fluids due to enhanced permeability. Seismic anisotropy measurements and azimuthal variations in surface wave models from local, surface-wave and SKS-splitting measurements indicate strong NE anisotropy attributed to aligned melt zones in the mantle lithosphere (Kendall et al. 2006).

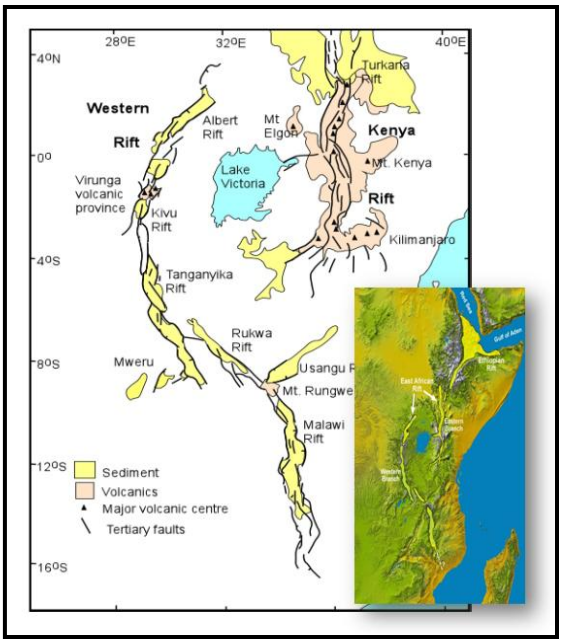

Figure 31: Location of the western and eastern branches of the East Africa Rift Valley extending to the Red Sea

The postulated increased permeability due to extension and the heat interpreted melt zones may be responsible for the many springs which occur in lowlands sometimes more than 30km away from any active volcanic zones. Some of the springs like Semuliki geothermal area bordering DRC have some spectacular two-meter spray of hot water

(130°C) and a pool (12m diameter) discharging hot water (106°C).

2. GEOLOGY, STRUCTURAL SETTING AND SURFACE MANIFESTATIONS

The WB of the Rift is an example of a divergent plate boundary - where extensional tectonic forces are pulling the Nubian and Somalian plates apart and creating new continental crust. The geology of the WB of the Rift which is probably the same age as GR, is significantly different. The WB Rift is dominated by Quaternary Volcanics (basanites, trachy-andesites and pyroclastics of different ages), volcanic metasediments, granite and granitic gneisses. The granites contain grains of quartz, K-feldspar, sodic plagioclase, muscovite, biotite and apatite. Most of the granites have no intergranular permeability. Some of the granites show secondary veins along fractures and some alteration to clay minerals (illite).

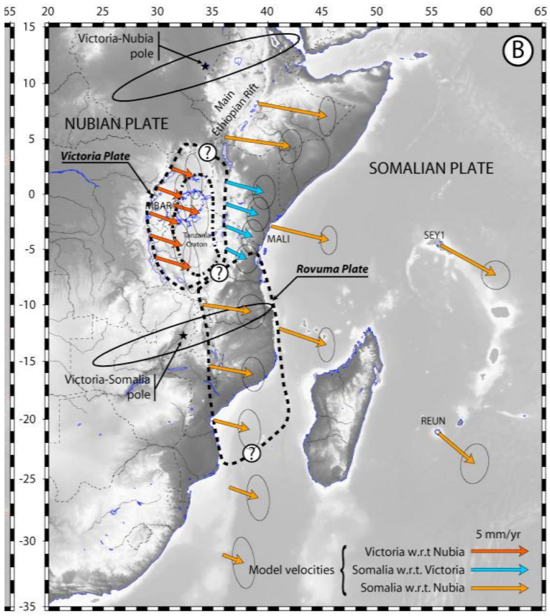

Figure 32: Kinematic extension direction and rate predicted modelling of earthquake slip vector data which predicts oblique extension in the Albert rift with a significant strike-slip component (Abeinomugisha et al. 2004, Stamps et al., 2008)

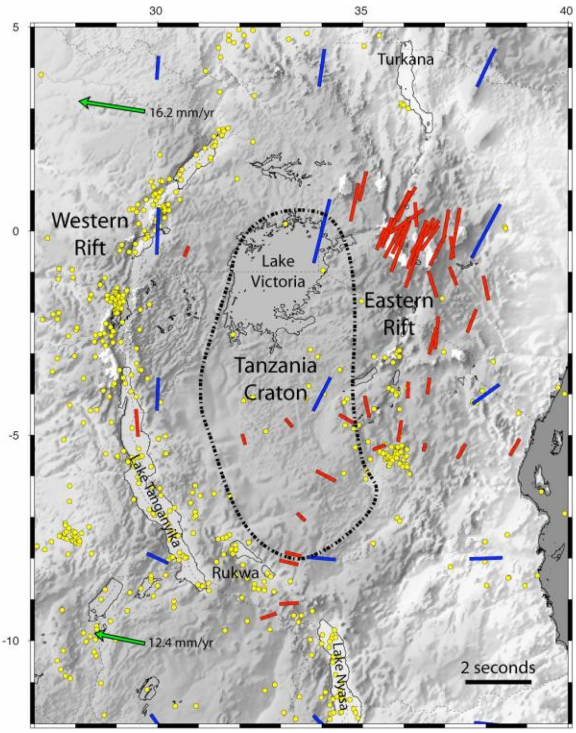

Figure 33: Location of earthquakes (yellow spheres) and seismic anisotropy in the NE direction from SKS-splitting which is attributed to aligned melt zones in the mantle (Kendall et al. 2006)

The Proterozoic granites and metasediments bordering the WB Rift zone are associated with important deposits of Sn, Nb, Ta and W. These mineral deposits mainly occur in pegmatites and hydrothermal quartz veins which are controlled by NW trending faults and fractures. The mineralized quartz veins contain mineralizing fluids have a H_2O–CO_2–CH4–N2–NaCl composition, a moderate salinity (7.4-9.9 eq. wt.% NaCl) and a minimum temperature of 300°C. The isotopic composition of the fluids indicates that the mineralised quartz veins most likely formed from a fluid largely influenced by metamorphic processes (De Clercq et al., 2008). It is not conclusively established whether the mineralization is due to magmatic or metamorphic fluid. It is therefore anticipated that exploration of geothermal potential in the WB Rift must take into account the unique geology and structural setting to evaluate the geothermal potential. Models from other geological regimes can therefore not be applied to the WB Rift as the basis of interpretation of data. The WB Rift has to be considered in its own uniqueness, taking into account the unique geology, tectonic setting as well as the interplay between volcanisms and metamorphism.

The unique geology composed of Quaternary volcanics overlaying Precambrian basement and metamorphosed sediments together with high relief of strato volcanoes, deep valleys and fractures have a direct bearing on the locations of geothermal manifestations. Most hot springs (Figure 4) are found in lowlands especially at the contacts of the volcanics and the uplifted Precambrian rocks. Unlike in the GR, it is expected that any geothermal reservoir would be hosted in the Precambrian rocks. There are generally more volcanoes, earthquakes and hot springs in the WB of the Rift Valley than in the GR. This clearly demonstrates the relationship between volcanic activity, fluid flow and earthquakes. In 2008, a magnitude 6 earthquake in the south west of Rwanda stopped some springs and initiated new ones

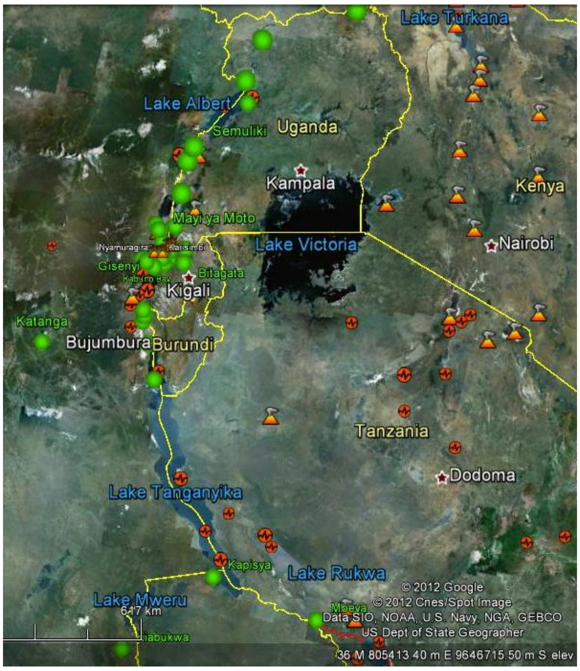

Figure 34: Google map showing location of hot springs (green spheres), Volcanoes and Earthquakes.

The results of geological surveys in geothermal prospects in Uganda and Rwanda indicates that the geology is dominated by lava flows, explosion craters, pyroclastics, tuffs, metasediments, gneisses and abundant granites. The volcanic rocks are mainly composed of lava flows and pyroclastics deposited sometimes on metasediments or directly on Precambrian rocks. Travertine deposits are found in many areas of the Albert and Kivu rifts indicating past hydrothermal activity. The Travertine deposits are mined for making cement. The lavas from the Karisimbi area of the Virunga Volcanic area show evidence of a differentiating mafic magmatic system which could be the heat source for the geothermal system. Some of the lavas show significant mineralogical and chemical differences but are generally shown to be mixtures of latites and a silicic melt derived from the crust (Rogers et al 1998). Some xenoliths that erupted from the basalt cones show some evidence of hydrothermal alterations and it would be useful to carry out a regional mineralogical and chemical sampling of the rocks in all the countries covering the Albert and Kivu rifts.

Generally there are more hot springs in the lowlands around the Virunga Volcanic Province and the Kivu Rift than in the southern and northern parts of the WB of the Rift. It is also generally noted that the WB of the Rift has more hot springs than the GR. Furthermore, some hot springs like in Katanga and Kiabukwa in DRC occur more than 400km from the rift axis which could signify high regional heat flow. There is also very high rainfall in the high relief volcanic areas of the WB of the Rift which could conceal any geothermal activity. Based on the tectonic, hydrogeological, geological and volcanic setting, the geothermal potential areas of the WB Rift can broadly be subdivided into 3 areas of (i) Albert and Kivu rifts (ii) Tanganyika and Rukwa rifts and (iii) Malawi and Southern rifts.

2.1 Albert and Kivu Rifts

Geothermal activity in the Albert and Kivu rifts occurs within the rift zones and tens of kilometres in the basement rocks. Geothermal manifestations in the form of extensive travertine deposits, fumaroles, hot springs and gas emissions in springs occur in lowlands along faults, within the volcanic fields and along NW trending faults in the basement rocks. Analyses of isotopes support the interpretation that the springs in the lowlands originate in the highlands which act as a recharge. The number of hot springs decreases both southwards and northwards from the volcanic region (Figure 4 and 5). Subsurface temperatures of approximately 140°C -200°C for Katwe, 120°C -150°C for Buranga and 200°C -220°C for Kibiro have been predicted by geothermometry and mixing models. These are similar to those determined from hot springs in Rwanda (Jolie, 2010). The major issue is whether the interpreted temperatures represent the actual reservoir temperatures. There has to be a re-evaluation of the routinely used geothermometers especially once deep wells are drilled into the actual reservoir.

Fault controlled manifestations occur at Buranga (Figure 6) at the foot of Ruwenzori massif as well as at Kibiro near Lake Albert in Uganda. The manifestations at Buranga discharge at boiling point. It is inconceivable that an area with such high temperature springs can only have a low temperature geothermal system. Hot springs also occur in the Katwe-Kikorongo and Virunga volcanic fields where they are associated with young volcanoes. Geothermal manifestations occur outside of the Rift both in Uganda (Bahati et. al., 2010) and Rwanda and they always tend to have lower surface temperatures due to probably cooling at mixing. Fault controlled manifestations are also found at Gisenyi in Rwanda and they discharge bicarbonate waters at more than 70^{O}C (Figure 7). This is in conformity with the interpretation that most hot springs are not in the upflow zones.

The results from the temperature gradient measurements in Uganda show almost linear profiles indicating conductive heat transfer (Gislason et. al., 2004, 2005, and 2008). However, the values between 30°C/km and 36°C/km were interpreted as slightly above the global average of 30°C/km. The interpretation given was that the geothermal reservoir is either deep-seated or offset from the drilled sites (Gislason et. al., 2008). Given that the geothermal areas are highly heterogeneous and anisotropic; this raises the question of the exploration philosophy and the rationale of drilling shallow wells that do not target the actual reservoir. Some areas like the Olkaria Domes area shows very low temperatures at shallow depths but very high reservoir temperatures.

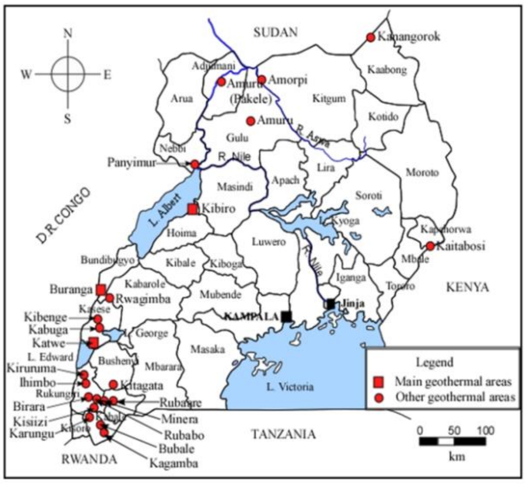

Figure 35: Geothermal manifestations and areas in Uganda (Bahati et. al., 2010).

Figure 36: Hot spring at the Buranga geothermal prospect, Uganda which is 98°C at the surface

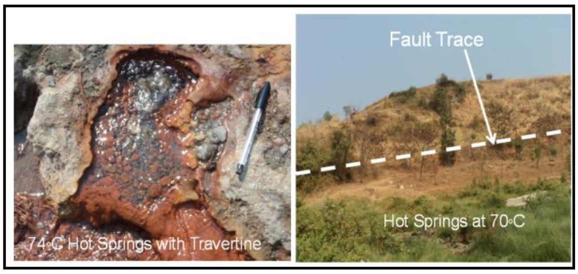

Figure 37: Fault controlled surface manifestations at Gisenyi that deposit travertine and discharge hot water at more than 70°C

The temperature gradient wells at both Katwe and Kibiro geothermal prospects (Figures 8 and 9) were drilled in areas of high and low resistivity at 300 masl. It is however not clear from the locations of the wells what the rationale of the targets was. The wells should have targeted the fractures or intersection of fractures in the basement. This would have helped in understanding the causes of both the low and the high resistivities.

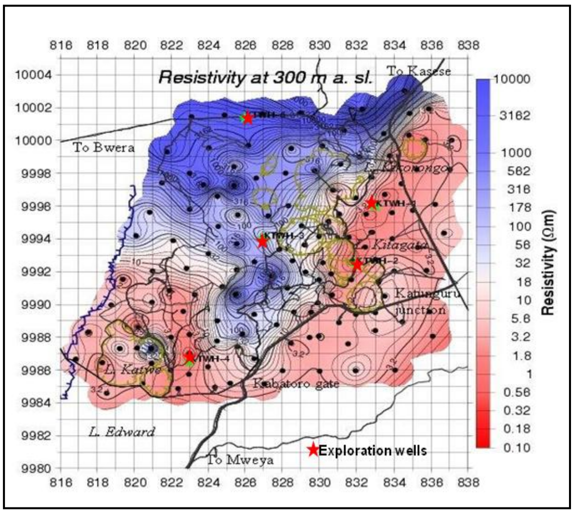

Figure 38; Resistivity map at 300 masl for the Katwe geothermal prospect in Uganda (in Bahati et. al., 2010)

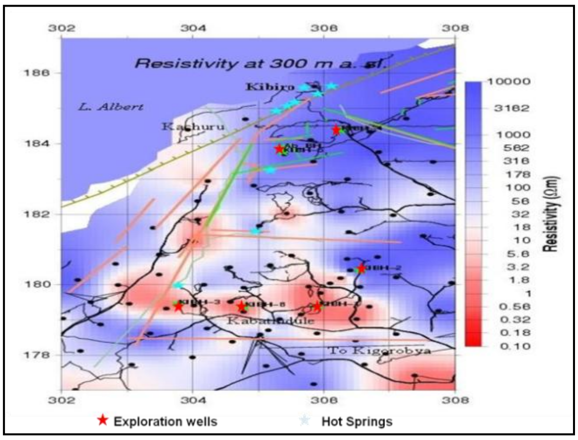

Figure 39: Resistivity map at 300masl at the Kibiro geothermal prospect (in Bahati, et. al., 2010)

2.2 Tanganyika and Rukwa Rifts

The Tanganyika and Rukwa rifts show fewer surface manifestations and lower volcanic activity. This area shows very high levels of seismicity aligned to NW and NE trending faults which also control the occurrence of surface manifestations (Figures 3 and 4). The high seismicity which extends outside the rift zone may indicate the area still is magmatically and tectonically active. The manifestations include hot springs and fumaroles at temperatures of up to 86°C around Mbeya. The manifestations occur at the intersections of NW and NE trending structures which are also closely associated with the Quaternary Rungwe Volcanic Field. Other hot springs occurring in Malawi and Mozambique are fault controlled and are associated with the border faults.

2.3 Malawi and Southern Rifts

Geothermal activity in Zambia and southern DR Congo occurs within the south-western Rift. The geothermal manifestations that include hot springs occur at Kapisya which discharge at 85°C near Lake Tanganyika. Other springs occur at Chinyunyu (60°C) near Lusaka, Lake Mweru and several other localities in Zambia. The hot springs are all related to the rift faults.

The Kiabukwa geothermal area which is situated in the south of Lac Mweru rift zone to the south west of Kapisya has over 70 manifestations. It was the first site of geothermal power plant in Africa which produced 220 kw to supply a mining company in the early 1950s.

3. OVERVIEW OF CURRENT STATUS IN THE WB RIFT COUNTRIES

The development of geothermal energy in countries in the WB of Rift is at a very early stage of development (Table 1). The earliest known geothermal installed capacity was in DRC in the 1950's for a binary plant that is no longer functioning. Zambia has 200 KWe which is not operational.

Table 1: Status of Geothermal Development the WB Rift

Country	Recon studies	Surface studies	Drilling	Remarks
Burundi	X	-	-	Shared manifestations with Rwanda
DRC	X	-	-	No work done but shares the manifestations with Rwanda, Burundi & Uganda.
Malawi	X	-	-	Private sector interests
Mozambique	-	-	-	
Rwanda	X	X	-	
Tanzania	X	-	-	
Uganda	X	X	X	Shallow exploration wells drilling done by Iceland firm
Zambia	X	X		

From table 1 above, it is evident that geothermal development in the WB Rift is still at a very early stage of development. Most of the countries have not had predictable and adequate funding to carry out geothermal exploration and development. Most geothermal exploration initiatives have always been externally driven and in most cases there is no local input to sustain the programs.

The donor driven exploration approach is sometimes not aligned to national interests and making it difficult for geothermal to compete with traditional sources of power like hydro and oil fired generators. Since geothermal resources sometimes occur in rural areas which are far from the electricity grid but in areas sometimes endowed with mineral resources, geothermal energy can be developed for rural industries and mineral processing to spar economic development.

Apart from temperature gradient wells drilled in Uganda, detailed surface studies been carried in 3 geothermal areas of Gisenyi, Karismbi and Kinigi in Rwanda. Analysis of 1D resistivity sections parallel (Figure 10) and across (Figure 11) the Kivu Rift indicates that resistivity varies across and along the rift. This variation indicates the heterogamous and anisotropic nature of the rift structure. The high shallow resistivity is associated with recent lava flows and in some places exposed granitic intrusions and metasediments. The shallow high resistivity in some places is underlain by a lower resistivity zones which could be either due to hydrothermal alteration or sediments. The preferred interpretation close to the volcanic zone is hydrothermal alteration to clay minerals.

The Gisenyi, Karisimbi and Kinigi areas are associated with lower deep resistivity that may be linked in some places to semi molten material that could be the heat source. It would be desirable to: extend the available data to north of Kinigi into Uganda so as to evaluate the geothermal structure of the volcanic region, evaluate the resistivity and geological structure by deep drilling into the interpreted reservoir zone and extend the data into the rift in DRC to assist in developing a regional conceptual model. The Kabatwa area is the target for deep drilling to evaluate the geothermal potential of the southern slopes of the Karismbi Volcano which has aligned NE trending cones.

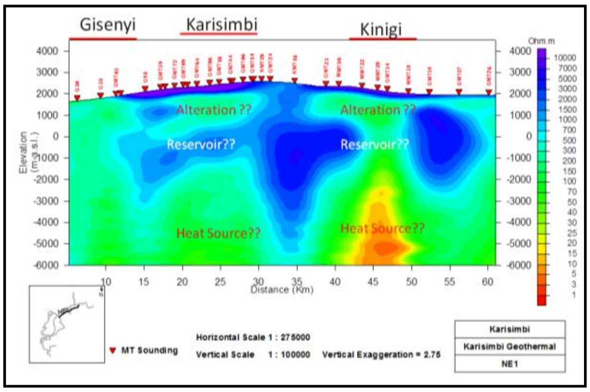

Figure 40: 1D resistivity section in the NE-SW direction parallel to the rift axis.

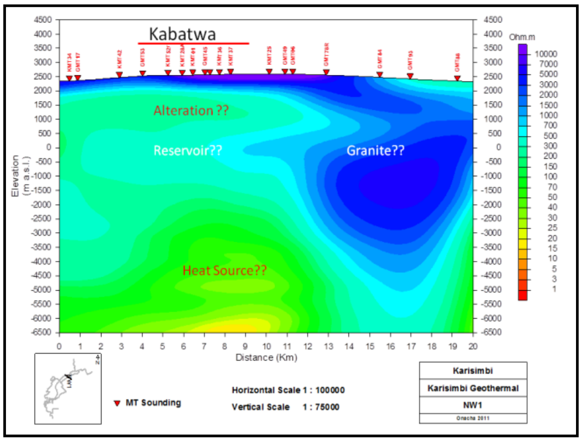

Figure 41: 1D resistivity section in the NW-SE direction on the southern slopes of Karismbi volcano that shows evidence of differentiation.

4. CHALLENGES

The challenges include the following:

i. Insufficient detailed information on most of the areas, on geothermal development potential which limits the inclusion of geothermal development in the Master plans for the countries in the WB of the Rift;
ii. Most of the geothermal resources may be shared across borders but there are no planned and coordinated programs to acquire data across borders to enhance conceptual modelling of the geothermal potential of the WB of the Rift. Detailed surface studies and exploration drilling would provide each of the countries with data to formulate the best and most economic development scenarios;
iii. The unique geological and tectonic setting of the Western Rift is sometimes not taken into account when evaluating the geothermal potential and also in most cases the exploration philosophy and conceptual modelling applicable in other countries is not applicable to the WB rift. Due to heterogeneity and anisotropy drilling of shallow wells might not yield sufficient information to evaluate the deeper structures. The shallow wells might yield misleading information thereby delaying or hindering further development of the geothermal resources;
iv. There is urgent need to build local and indigenous capacity to implement and manage geothermal development. This could include regional instrument pools and centres of excellence so that the countries can share information and quickly mobilize resources where and as required;
v. Incentives to promote geothermal energy exploration and development;
vi. The Governments should take more interest in reducing the risks associated with geothermal exploration;
vii. Financing of the geothermal projects and the role of private sector (establishing an industry/government partnership that would accelerate geothermal development); and
viii. Change perceptions - share information through workshops, conferences for policy makers and opinion leaders.

5. OPPORTUNITIES

The geothermal potential in the WB rift offers numerous opportunities for the private sector, public institutions, research institutions and Universities, electricity utilities, agricultural sector, mining sector and local communities to be actively involved in direct and indirect utilization of geothermal resources. The tourism sector in the WB rift could also greatly benefit from use of geothermal resources for recreational facilities. The opportunities are summarized in the table below

Table 2: Opportunities in Developing the Geothermal Potential of the WB Rift Countries

Opportunity	**Target Groups**
Generation of electricity	Public power utilities, private sector, local investors and communities. Generation could be for local communities who are far from the grid.
Industrial uses	Processing of agricultural products and minerals, cold storage of products, cosmetics and making of building materials
Heat pumps and smaller scale	Heating of houses, hotels, commercial buildings and ranches
Direct use	Green houses, fish farming etc
Geothermal tourism	Spas, saunas, indoor pools etc

6. DISCUSSIONS AND CONCLUSIONS

The WB of the Rift has a unique and tectonic geological setting which requires a unique and innovative approach to geothermal exploration and development. This challenge offers unique opportunities for the public sector, local communities, private sector, research institutions and universities as well as donors. The models applied to other countries in terms of resource evaluation may not be appropriate for the WB Rift. Due to heterogeneity and anisotropy, drilling of shallow wells may be inappropriate in providing information that can used to evaluate the geothermal potential.

There need for governments to play a greater role in facilitating accelerated geothermal development.

REFERENCES

Abeinomugisha, D. & Mugisha, F. 2004. Structural analysis of the Albertine graben, Western Uganda. Abstract, East African Rift System Evolution, Resources, and Environment Conference, Addis Ababa, June 2004.

Bahati, G., Natukunda. F. J., and Tuhumwire. J., Geothermal Energy in Uganda, Country Update Proceedings World Geothermal Congress 2010 Bali, Indonesia, 25-29 April 2010

Bahati.G., Vincent. K., and Catherine. N., Geochemistry of Katwe-Kikorongo, Buranga and Kibiro Geothermal Areas, Uganda Proceedings World Geothermal Congress 2010, Bali, Indonesia, 25-29 April 2010

DE Clercq F., Muchez P., Dewaele S. and Boyce A., 2008. The Tungsten Mineralization at Nyakabingo and Gifurwe (Rwanda): Preliminary results, Geologica Belgica (2008) 11/3-4: 251-258

Gíslason, G., K. Árnason, H. Eysteinsson, 2004. The Kibiro Geothermal Prospect. A Report on a Geophysical and Geological Survey. Prepared for the Icelandic International Development Agency and the Ministry of Energy and Mineral Development, Uganda. Unpublished report, June 2004. 109 pp.

Gíslason, G., K. Árnason, H. Eysteinsson, 2005. The Katwe and Kibiro Geothermal Prospects. A Draft Report on a Geophysical and Geological Survey. Prepared for the Icelandic International Development Agency and the Ministry of Energy and Mineral Development, Uganda.

Gíslason, G., K. Árnason, H. Eysteinsson and Ingvar T. Magnusson, 2008. The Katwe Geothermal Prospect. A Draft Report on a Geophysical and Geological Survey. Prepared for the Icelandic International Development Agency and the Ministry of Energy and Mineral Development, Uganda.

Jolie, E., (2010). Geothermal Exploration in the Virunga Prospect, Northern Rwanda. Proceedings of the World Geothermal Congress, Bali.

Kendall, J-M., Pilidou, S., Keir, D., Bastow, I.D., Stuart, G.W. & Ayele, A. 2006. Mantle upwellings, melt migration and the rifting of Africa: Insights from seismic anisotropy. In: Yirgu, G., Ebinger, C.J. & Maguire, P.K.H. (eds) Structure and Evolution of the Rift Systems within the Afar volcanic province, Northeast Africa, Geological Society Special Publications

Rogers, N. W., James, D., Kelley, S.P. and M. De Mulder (1998). The generation of potassic lavas from the Eastern Virunga Province, Rwanda. Journal of Petrology, 39, 1223-1247Stamps, D. S., E. Calais, E. Saria, C. Hartnady, J.-M. Nocquet, C. J. Ebinger, and R. M. Fernandes (2008), A kinematic model for the East African Rift, *Geophys. Res. Lett.*, 35, L05304, doi:10.1029/2007GL032781