Geothermal Development in Malawi – A Country Update

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ABSTRACT

Malawi, one of the poorest countries in Africa, has major electricity generating difficulties, due to limited conventional fossil fuel resources and an over-reliance on one form of electricity generation, viz. hydroelectricity, with consequent severe shortages during the dry season, and a significant gap between electricity supply and demand. Due to its location within the East African Rift System (EARS), one of the hottest geothermal zones in the world, it is endowed with significant potential geothermal energy resources. In recent decades, there has been major global growth in geothermal energy utilization, both in direct utilization applications and in electricity generation. However, despite its favourable location, Malawi has been slow in harnessing its potentially significant geothermal resources.

Geological investigations of the Malawi sector of the EARS indicate that the Malawi rift is controlled by N-S rift parallel normal faults, that also control upwards migration of the geothermal waters feeding hot springs, which occur along the length of the rift. The hot springs with most potential for electricity generation occur mainly in the northern half of the country and are thought to be sourced from porous sedimentary reservoirs at depth, either deeply buried young Neogene rift floor deposits or older Karoo sandstones, occurring in fault-bound basins within the Precambrian framework of the country.

A recent investigation to catalogue all of the hot springs in Malawi has led to the identification of 15 previously undocumented springs including the third hottest spring recorded in the investigation. This exercise has resulted in the delineation of 6 or 7 groups of springs with appropriate temperatures and geological settings that suggest a potential for electricity generation. These merit further more detailed surface geological, geophysical and geochemical exploration and monitoring, which should be undertaken, prior to any decisions on drilling. Other lower temperature hot springs in the country have the potential for utilisation for various direct applications, which could bring major benefits to local communities.

Major challenges hindering geothermal development in Malawi have been the absence of both technical and financial capacity, and the lack of government leadership in spearheading an assessment of the geothermal resources of the country. This has resulted in a spirit of individualism, coupled with an absence of collaborative cooperation between government agencies, research organisations and institutes of higher learning, which has led to failure to share information, consequent duplication of tasks and unnecessary waste of resources. However, a geothermal working group has recently been formed within the country, consisting of all the stakeholders from government, industry, research organisations and teaching institutes, and this body will chart the future progress in the development of Malawi's geothermal resources.

Malawi also needs to develop its technical capacity through specialised geothermal training programmes such as the United Nations University - Geothermal Training Program (UNU-GTP) in Iceland and the Postgraduate Certificate in Geothermal Energy Technology (PGCertGeothermTech) at the University of Auckland, New Zealand. With support from UNU – GTP and Government of Kenya, six Malawians have undergone a three week course in surface exploration of geothermal resources and one has been given a six month training fellowship to study geothermal and geological exploration.

1. INTRODUCTION

Malawi is one of the countries found among the hottest geothermal zones of the world. Its rift is to the southern end of the western branch of the East African Rift System (Figure 1). Its geothermal activities are guided by the tertiary faults of the Malawi Rift.

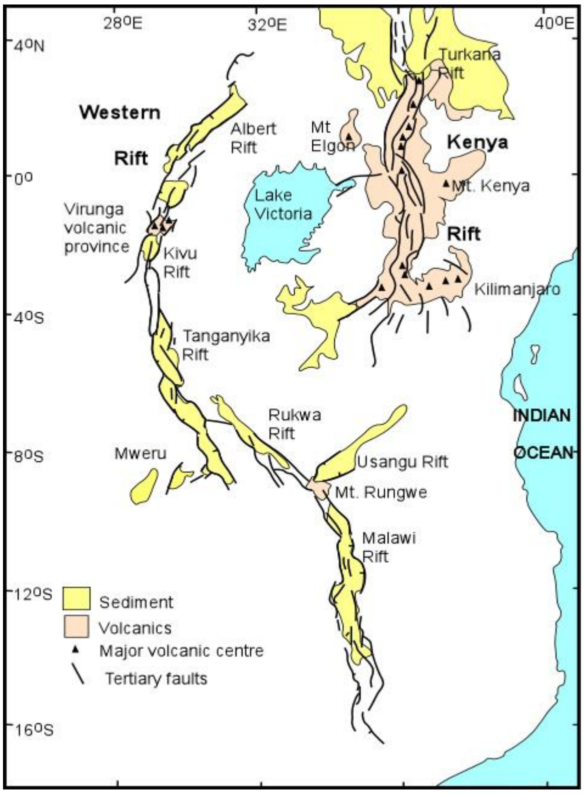

Figure 1: Map of the East African Rift System: Showing the Malawi Rift. ***Source Omenda, 2005***

The country is located between latitudes 8^{o}S and 18^{o} S and longitudes 32^{o} E and 36^{o} E. Tanzania neighbors it to the North and North-East, Zambia to the West and North-West and Mozambique to the East, South and South-West (Figure 2).

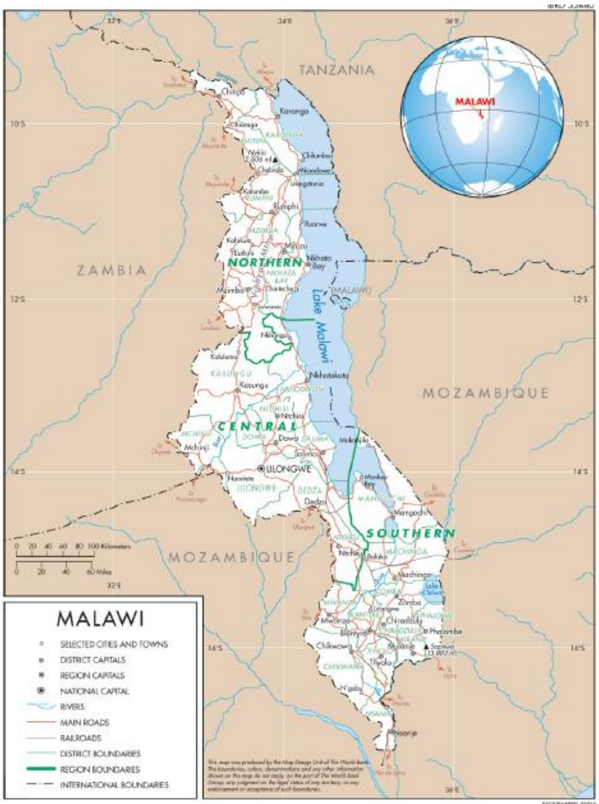

Figure 2: Map of Malawi and its World Location ***Source: World Bank, 2009***

Apart from private (off grid) generators, Malawi's electricity generation is basically 99% hydro with all the generating stations cascaded on the River Shire. Malawi is currently facing a series of serious power shortages and interruptions due to droughts, siltation and clogging of the hydro-electric power installation by vegetation and other debris during the rainy season. This has sometimes lowered the generation to as little as 50% of the total installed hydroelectric capacity of 284MW. The peak demand is estimated at 330MW.

The Electricity Supply Corporation of Malawi (ESCOM) is the only supplier of commercial electricity in Malawi. It has a monopoly over all generation, transmission and distribution of grid connected electricity.

By virtue of its location within the EARS, Malawi has abundant geothermal resources, some of which could be developed to generate electricity. The presence of numerous hot springs spread throughout the length of the country is a strong indication of this. However, despite having the great potential for geothermal exploitation, Malawi lacks the capacity both in personnel and resources to achieve this.
The government has constituted a Geothermal Technical Working Group to map the way forward in geothermal development.

2. STATUS OF ELECTRICITY GENERATION

Malawi is one of the countries where electricity supply is very unreliable. All the major hydro generation units are cascaded on the River Shire that flows from Lake Malawi. The only exception is the Wovwe mini-hydro power plant on River Wovwe in the Northern Region.

The dependence on one river renders Malawi very vulnerable to the effects of drought and other climate change effects.

Most industries have opted to use their own privately owned diesel powered generators due to frequent black-outs (and load shedding) that stands at an average of 66 days per year (World Bank, 2009).

2.1 Installed and Effective Generation Capacities

2.1.1 Installed Capacity

There has been a great variation in most documents as to what is the total installed capacity for electricity generation in Malawi.

According to the Department of Energy Affairs, there is a total installed generation capacity of 355.3MW (DoE, 2003). Electricity Supply Cooperation of Malawi (ESCOM) is responsible for 304MW while the remaining 51.3MW is controlled by private investors, and used as standby during the frequent blackouts of the ESCOM supply.

The other private power plant not included in the 51.3MW is the 10MW diesel power plant for Kayerekela Uranium Mine in Karonga. It became operational in 2007 and this brings the overall installed capacity to 365.3MW.

2.1.2 Effective Generation Capacity

The current generation capacity is 286MW and about 20% of it is lost as transmission and distribution losses (World Bank, 2011). However, ESCOM estimates the losses at 21%. Effectively there is a generation loss of about 57.2MW giving the effective generation at 228.8MW. This is far less than the current peak demand estimated at 330MW.

However, the Malawi Foreign Policy and Government Guide records effective generation capacity for ESCOM as 224MW as the figure for 2011. It continues to state that out of the 224MW, 214MW is from hydro and 10MW from diesel power plant.

At the time of writing this paper, information of the current status on the ground revealed that the total installed capacity for ESCOM is 302.9MW while the effective generation capacity is 286.45MW (284.4MW for grid and 0.75MW for Likoma Island). With a spinning reserve of 10MW the available generation capacity that is fed into the national grid is 274.4MW. Details on power plants and their capacities are presented in Table 1.

The privately owned generators have the total installed capacity of 61.3MW. Only the co-generation plants (18.5MW), the Kayerekera power plant (10MW) and the Lujeri Estates (0.84MW) plants operate on a regular basis. The rest of the 31.96MW is for standby supply.

2.2 Modes of Generation and their Contribution

Malawi's grid electricity generation is dominantly hydro with 94% of the total installed capacity and 99% of the effective generation capacity. The remaining percentage is supplied by fossil fuels (Table 1).

Table 1: ESCOM's Generation Units and Their Installed Capacities

Hydropower Generation Station			
Station Name	Installed Capacity (MW)	Effective Capacity (MW)	Comment
Wovwe	4.35 (3x1.45)	2.9 (2x1.45)	One unit faulty
Nkula A	24 (3x8)	24 (3x8)	
Nkula B	100 (5x20)	100 (5x20)	
Tedzani I&II	40 (4x10)	40 (4x10)	
Tedzani III	52.7 (2x26.35)	52.7 (2x26.35)	
Kapichira I	64.8 (2x32.4)	64.8 (2x32.4)	
Total	***285.85***	***284.4***	
Thermal Power Generation Units (All Fossil Powered)			
Chichiri	15	0	Not in Use
Mzuzu	1.3	1.3	Standby Use
Likoma	0.75	0.75	
Total	***17.05***	***2.05***	
TOTAL	**302.9**	**286.45**	

Fossil powered generation accounts for most of the privately owned off-grid generation. Table 2 and Figures 3 and 4 show that fossil fuels contribute 62% of the total installed capacity and only 34% of available generation. Biomass contributes only 36% of the total installed capacity but provides 63% of the available generation capacity. Fossil fuel powered plants are used for standby electricity supply only because of their low generation capacity compared to installed capacity.

Table 2: Private Generation Units and Their Installed Capacities

Station Name	Installed Capacity (MW)	Effective Capacity (MW)	Comment
Hydropower Generation Station			
Lujeri	0.84	0.84	
Biomass Generation (Sugar Waste)			
Dwangwa	7 (2x3.5)	7 (2x3.5)	
Nchalo	11.5	11.5	
Total	***18.5***	***18.5***	
Diesel Powered Generation Units			
Kayerekela	10	10	
Others	31.96	31.96	Standby Use Only
Total	***41.96***	***41.96***	
TOTAL	**61.3**	**61.3**	

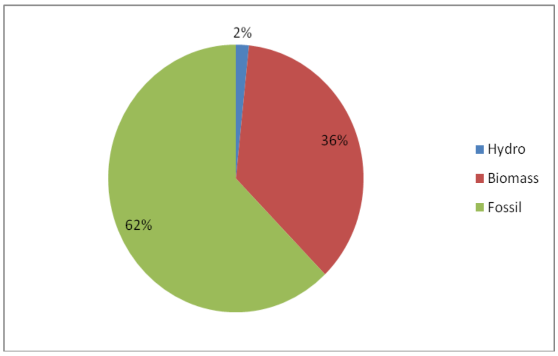

Figure 3: Share of Different Private Generators (Installed Capacity)

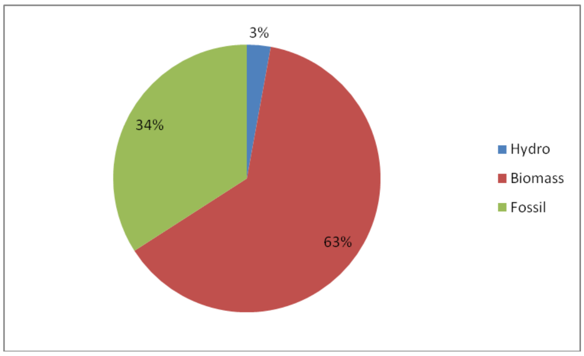

Figure 4: Share of Different Private Generators (Generation Capacity)

Apart from small solar PV and small wind systems, no additional sources other than those described in this section have been put to use in the electricity generation mix for Malawi.

2.3 Medium and Long Term Power Development Plan

According to the Malawi Growth Development Strategy 2, Malawi Energy Policy and the Vision 2020, Malawi is to become a technology-driven middle – income country by the year 2020.

To achieve this, the government aims at removing the difficulties in security and reliability of power supply due to the over dependence on the River Shire for all the electricity that is fed into the grid.

The Malawi Energy Regulatory Authority in its strategic plan (2009 – 2012) has highlighted the promotion of renewable energy sources. In general it intends to increase the electricity generation in the overall energy mix from the projected 10% in 2010 to 40% in 2050 for hydro and for the other Renewable Energy Technologies (RETs), from the projected 5.5% in 2010 to 10% in 2050 (MERA, 2009).

To offset the current power shortage, the government will develop a 300MW coal-fired power plant at Ngana in Karonga District, 1,300MW hydro, and 38MW from cogeneration plants at the two sugar companies (Dwangwa and Nchalo) as shown in figure 5 (MCA, 2009). Figure 5 presents the sites earmarked for hydropower development.

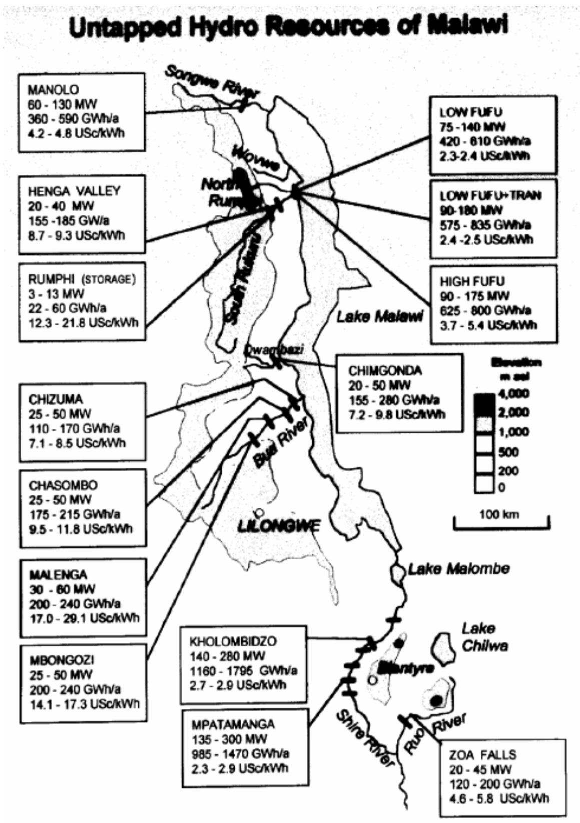

Figure 5: Sites Earmarked for Hydropower Development. ***Source: MCA-Malawi***

2.3.1 Role of Geothermal Energy in the Future Energy Mix of Malawi

Government has been reluctant to undertake geothermal development because of lack of sufficient data to quantify the resources and technical capacity. In his presentation at the 2003 meeting in Kenya, Kalindekafe (2003) stressed '*in the name of environmental protection and social economic development of Malawi efforts should **urgently** be made to start the process of geothermal resource exploitation in Malawi'.*

In the current Model for Energy Supply System Alternatives and their General Environmental Impacts (MESSAGE) study for the analysis of different supply options, geothermal energy has been envisaged to begin generating by the year 2021. The geothermal potential of Malawi is estimated at 200MW. In the Investor's Guide for the Clean Development Mechanism (CDM), it has been suggested that should there be potential investors in CDM a 30MW plant could be constructed at Nhotakota. The plant could later be upgraded to 100MW depending on the results of exploration drilling. The government of Malawi is committed to developing geothermal resources.

3. STATUS OF GEOTHERMAL DEVELOPMENT IN MALAWI

3.1Geological Setting

Malawi, situated within the southern part of the East African Rift System (EARS), is dominated by Lake Malawi, 580km long and with a maximum width of 75 km draining at its southern end into the River Shire, a tributary of the Zambezi. The northern part of the lake has a NW-SE trend but the central and southern parts of the lake define a N-S trend, which extends through the Shire lowlands and into the Urema Rift of Mozambique, the southernmost segment of the EARS. As shown in Figure 6, Malawi occupies the western side of the lake and the Shire Lowlands to the south.

Most of the country lies within the rift zone, which is up to 80 km in width, and has an elevation ranging from 37m.a.sl in the extreme south to just over 474 m.a.sl, the level of Lake Malawi. The rift trough, controlled by the N-S rift fault system, contains Lake Malawi and rift lowlands bordering Lake Malawi and the River Shire. The rift trough is bounded by plateaus and highlands rising to a maximum of 2700m.

Malawi is predominantly underlain by crystalline Precambrian (Palaeo-Neoproterozoic) metamorphic and igneous rocks which constitute most of the plateau and highland areas of the country. Permian to early Jurassic Karoo sedimentary sequences occupy a number of small fault bounded basins within this Precambrian framework, mainly in the North and South-West of the country. The rift lowlands along the shores of Lake Malawi and in the Shire valley are floored by Quaternary-Recent alluvial and lacustrine sediments. No Neogene volcanism has affected Malawi, but a very localised sequence of Neogene tuffs just inside the northern border with Tanzania (Ray, 1975),is correlated with an explosive eruption within the last 10,000 years of one of the active volcanoes of the Rungwe Volcanic Province of the Rukwe Rift, just north of the border in SW Tanzania (Harkin, 1960; Fontijn et al, 2009). Similar tuffaceous deposits have been identified in borehole cores of sediments from northernmost Lake Malawi (Williams et al, 1993; Barry et al, 2002).

Structural control of the Lake Malawi Rift is dominated by a series of segmented N-S rift controlling normal faults. Lake Malawi has been subdivided into three linked half graben basins: the Karonga, Nkhotabay and Nkhotakota sub-basins, that alternate in polarity along the axis of the lake (Ebinger et al, 1984; 1987; Specht & Rosendahl, 1989**)**, each controlled by a major bounding fault system.

Drilling of the sediment fill at two sites in the Nkhatabay and Karonga sub-basins and associated seismic reflection profiling of the Lake Malawi sediment sequence (Ebinger et al, 1987; Scholz & Rosendahl, 1989; Scholz et al, 2005), suggests a sediment thickness of the order of 1.8km in the Nkhatabay sub-basin, indicating a depth to basement below the lake surface of the order of 2.5 km. Taken together with the 2.2km of topography to the west of the lake, this represents ~ 4.7 km vertical offset across the Nkhatabay Fault. Furthermore, much of the 1.8km of sediment thickness in the Nkatabay Basin, probably consists of material eroded from the rising basin margin so a total vertical throw of perhaps 6km or more may have occurred on the Nkhatabay Fault over the last ~8.6 Ma, the estimated age of initiation of rifting of the Lake Malawi Basin (Delvaux, 1995).

A similar, but slightly lesser throw of the order of 4-5km may have occurred on the Livingstone Fault, bounding the adjacent Karonga Basin. Earthquakes in December 2009 and January 2010 on faults bordering the Karonga and Nkhotakota sub-basins indicate that the rift-controlling fault system of the Lake Malawi trough is still active. The magnitude of movements on these rift-controlling faults suggests that significant thicknesses of Neogene deposits could exist in the rift lowlands bordering Lake Malawi, so aquifers may occur at considerable depth.

Geothermal gradients in the EARS will vary along the length of the rift system depending on degree of crustal thinning and volcanic activity. In the volcanically active southern part of the Eastern Rift of the EARS, geothermal gradients of 200°C/km have been estimated on the basis of heat flow measurements (Whieldon et al, 1994). In a relatively inactive rift such as the Rhine Rift, where volcanic activity ceased 16 Ma ago, present day geothermal gradients ranging from 30-140°C/km are indicated from borehole measurements (Rybach, 2007). As volcanic activity in the Rukwe Rift adjacent to the northern border of Malawi, is still continuing, geothermal gradients of at least 100°C/km might be expected in the northern sector of the Malawi Rift.

3.2 Geothermal Resource Investigation

The geothermal resources of Malawi have been investigated and catalogued as the first step in assessing their potential for geothermal power generation. Indicators of such resources are mainly the presence of hot springs, representing the rapid migration of geothermal waters from depth to the surface via fault conduits. Early documentation of Malawi's hot springs by Dixey (1927), Kirkpatrick (1969), and in four Malawian Geological Survey Department bulletins (Bloomfield, 1965; Bloomfield & Garson, 1965; Harrison & Chapusa, 1975; Ray, 1975) recorded them mainly out of interest rather than as resources, although some temperature and hydrochemical parameters were presented. More recent documentation (Kalindekafe, 2003; Dulanya, 2006) emphasised their geothermal potential, but supplied no new data, only reproducing the information given in the four bulletins listed above. However, Dulanya (2006) supplied UTM coordinates for many of the previously recorded hot springs. In the most recent investigation, over 55 hot springs have been visited and catalogued, 15 of which were previously undocumented, and temperatures and where possible, flow rates and other hydrogeological parameters were measured. Samples were also collected for chemical analysis, although many of the springs were contaminated by human usage. In particular, detailed notes of their geological settings were made, as this is the key to assessing their potential for geothermal power production and for further detailed investigations.

Geothermal resources are a function of a heat source, a reservoir and a carrier fluid, generally subsurface water or steam. Since Malawi has experienced no recent volcanism its geothermal resources are non-volcanic. With the heat source as the temperature of the rock units at depth, a function of the geothermal gradient, the reservoirs are the porous geological units and structures, and the carrier as the heated groundwater circulating in the subsurface. Thus they are controlled by the disposition of aquifers, and the fault structures intersecting them which allow the upwards migration of geothermal waters. The temperature of hot springs is a function of the depth of the source, the geothermal gradient and the degree of inter-mixing of the geothermal waters with cooler shallower groundwater during upwards migration. In Malawi, the critical parameters are the presence of porous sedimentary horizons at depth, limited to the small fault-bounded Karoo Basin sediments and the young Neogene rift floor deposits, and to the degree of inter-mixing with shallow groundwater.

3.2.1 Results of Investigations

Most of the hotter springs in Malawi occur in the northern part of the country adjacent to the Karonga and Nkhotakota Basins (Figure 6). Although, the Nkhatabay Basin is the deepest of the Lake Malawi sub-basins, its polarity is such that the rift bounding Nkhatabay Fault, forming its western margin, downthrows to the East, bringing Precambrian crystalline rocks in its footwall up against the lakeshore, with no deposition of rift sediments to the west of the lake. Although numerous hot springs exist in the Viphya Mountains adjacent to the lake, the crystalline Precambrian rocks are devoid of porous rock formations to act as geothermal reservoirs, so the geothermal waters must reside in fault zones at depth with limited storativity. The Karonga and Nkhotakota sub-basins are of opposite polarity, with broad rift lowlands composed of Neogene rift sediments to the west of the lake.

A number of the hot springs can be clearly linked to rift parallel normal faults, which have brought crystalline Precambrian rocks into juxtaposition with young Neogene sediments. Two of these, Chiwi and Ngara, are located on the lake shore, and are likely to have been significantly cooled by the lake waters and very shallow groundwater with which they are in continuity. Other hot springs, e.g. the Chiweta and the Mwankenja springs have Karoo reservoirs. The Mwankenja springs lie on the rift parallel Rukuru Fault which brings Precambrian rocks into juxtaposition with Karoo sediments. These springs are located within and on the banks of the River Rukuru, and are also probably significantly cooled by surface and shallow groundwater. The Chiweta springs, the hottest springs in Malawi (79-84°C), issue into the E-W Mphisi stream over a stretch of 150m, a few hundred metres from Lake Malawi. The upwards migration of these geothermal waters is apparently controlled by an E-W fault, but this appears to intersect within a kilometre, a major rift parallel fault which bounds the Precambrian Nyika Plateau, bringing it into juxtaposition with Karoo sediments. This fault may be the primary fault conduit for these geothermal waters.

3.2.3 Further investigations

Six groups of hot springs, each apparently associated with rift parallel faults and potential porous sedimentary reservoirs at depth, merit further more detailed investigations. Most of these springs exhibit surface temperatures in excess of 60°C, but in some cases are in the 50-60°C range. In addition, the Nkhotakhota group of springs, traditionally regarded as the hottest springs in Malawi, and the only springs to have been captured for exploitation, should also be investigated further, although they appear to be surrounded by Precambrian rocks, and no clear fault structure controlling their location was determined. Further investigations of all the selected springs should include geophysical surveys to delineate the precise orientations of the fault conduits bringing the geothermal waters to the surface, together with continuous monitoring of temperature, discharge and various hydrochemical parameters over a period of a year to determine the seasonal fluctuation of these parameters in order to estimate the degree of intermixing of the geothermal waters with surface waters. Further sampling of these springs for chemical and isotopic analyses should also be undertaken and geothermometric calculations conducted to determine temperatures of the source reservoirs, in an attempt to estimate the depth of these reservoirs. Although Dulanya (2010) recently undertook such an exercise on some of the Malawi springs, his calculations are based on the chemical data reported in the Malawi Geological Survey

Dept bulletins published 50 years ago, and only involved two of the selected springs.

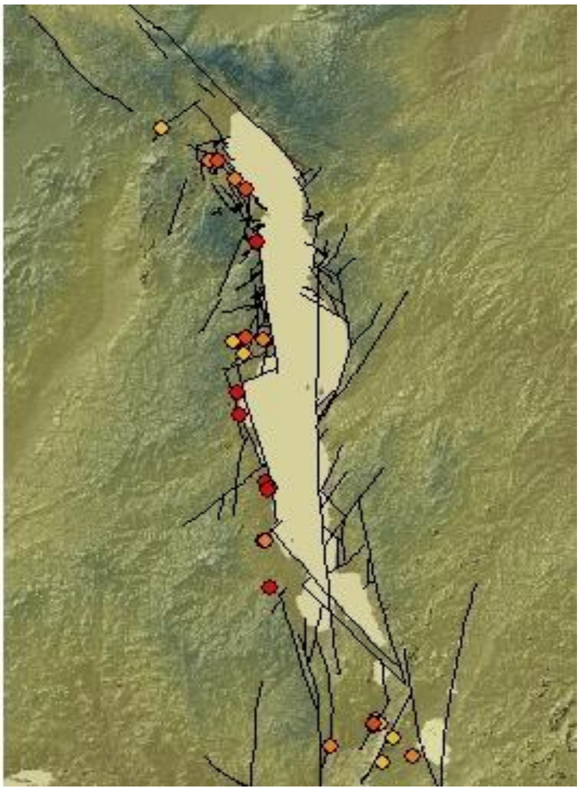

Figure 6: Location of hot springs of Malawi. Symbols: red >60°C; brown 50-60°C; orange 40-50°C; yellow 30-40°C.

In the light of these further investigations, it should be possible to assess which of the groups of springs have sources with the greatest potential to generate electricity and on that basis could be graded in terms of priority for exploration drilling. Drilling sites and estimated depths to the source reservoirs should also be indicated by the geophysical and geochemical results. Borehole core data, plus downhole geophysics and pumping tests will allow hydrogeological parameters such as temperature, hydraulic conductivity, transmissivity and storativity of the source reservoirs to be determined. On the basis of these parameters, the suitability of any of the delineated geothermal reservoirs to generate electricity will ultimately be determined.

4. INVESTMENT OPPORTUNITIES

The key to the continued investigation and development of the geothermal resources of Malawi is sustained investment by the Malawian government, development aid agencies and lending institutions, rather than by private investment in order to ensure an ordered long term scientific approach to the exploration process. A short term profit-driven approach is more likely to lead to short cuts and potential failures.

It must however be pointed out that the government is working on possible ways of attracting private investors in electricity generation. It is believed that the geothermal working team will strategize on the incentives that would attract investors.

5 . OUTLOOK AND CONCLUSIONS

Although Malawi, due to its location within the EARS, has potentially significant geothermal resources, to date little effort has been made to assess and develop them. This, despite the fact that the electricity generating capacity of the country is limited, with an over-dependence on hydroelectricity which is affected by climatic fluctuations leading to frequent blackouts and a demand that outstrips supply.

Analysis of the geological characteristics of the Malawi rift system and the geology of the country indicates that those hot springs with greatest potential for electricity generation are mainly located in the northern half of the country, are associated with rift parallel faults which have facilitated migration of the geothermal waters to the surface, and have as their source reservoirs, deeply buried Neogene rift floor deposits or Karoo sandstones in small fault bounded basins.

Further detailed investigations of selected groups of springs with suitable temperatures and geological settings, should firstly involve geophysical surveys, hydrochemical and isotopic studies, and a monitoring programme to delineate seasonal temperature and hydrogeological parameters, prior to any drilling.

A geothermal working group consisting of all stakeholders should be established to direct the investigation and development of the geothermal resources of the country.

Sustained funding by government, development aid agencies and lending institutions should be made available to finance the development work.

It is critical that the technical capacity of the local Malawians be built through specialised trainings in both exploration and utilisation of geothermal energy resources.

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