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Exploration for Sedimentary Basin Hosted Low-Enthalpy Geothermal Systems in Zambia

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ABSTRACT

While there has been historic work in Zambia relating to geothermal energy, including the building of a pilot power plant on the Lake Tanganyika fault, there was no economic imperative to follow-up due to an abundance of low cost large scale hydroelectric power. In response to the changing dynamics that the new hydroelectric power is no-longer low cost and the challenge of meeting escalating domestic and industrial/mining demand, alternative sustainable energy has become a priority both in Zambia and Africa generally.

Sedimentary basins which occur in regions of active extensional tectonics provide a geological setting conducive to geothermal systems. The Karoo era basins within Zambia which have regionally extensive normal faults are now being found to contain geothermal systems that justify exploration.

As a private company operating within defined permit timelines and with an elective right to target development, a range of exploration techniques are being undertaken to define those most effective in identifying preliminary drill targets at one specific site within the Kafue Trough. These include ground magnetics, radiometric, gravity, resistivity, geo-botany and soil temperature profiles. From this work a preliminary drill programme confirmed the presence of a hydrothermal system produced from >150^{O}C up-flow along deep faults in the Proterozoic basement, with outflow along shallow permeable zones within the basin fill. The system is overlain by Karoo sediments forming the thermal cap rock. Exploration work is ongoing and further drilling is planned; the objective is to commence a pre-feasibility study in the next year. The system model and most effective exploration techniques are being rolled out to other targets within the sedimentary Basin. Meanwhile research suggests direct applications of geothermal energy could play important roles in rural energy, industrialisation and food security programmes; a Community Investment Programme is trialling water filtration to produce potable water in response to the Millennium Challenge.

1. INTRODUCTION

The Zambian economy has traditionally been based on mining and particularly copper, powered by two major hydroelectric dams, Kariba and Kafue. Historically there has been no perceived need to diversify energy sources; however surges in mine production, industrial investment and domestic demand have put pressure on the current installed generating capacity and led to both a challenge to diversify production and a shift to cost reflective tariffs in order to redress the prevailing power production deficit. It has long been recognised that Zambia hosts geothermal systems that may have potential for power production or direct applications. Indeed one of Africa's early binary power plants was installed in 1986 on the thermal springs within the Lake Tanganyika fault zone. This initiative was not followed up due to geotechnical challenges and more fundamentally the then low cost and surplus capacity of large scale hydroelectric power. However, with increasing demand for power and growing concerns as to the long term viability of hydroelectric power, the Zambian Government is encouraging the private sector to develop additional diversified power generating capacity. In 2011 a private company, Kalahari GeoEnergy Ltd entered into an agreement with the Zambian Government to research and if justified explore and subsequently develop geothermal energy.

While there has been a significant amount of work in connection with the geology of the mineralisation, particularly in the Copperbelt, there has been very little that has any relevance to geothermal energy. Preliminary research by Kalahari GeoEnergy identified two distinct hosts of geothermal systems: deep convection within fault fracture zone structures as found at the Lake Tanganyika hot springs, and those associated with Karoo era sedimentary basins, of which there are a number that appear to have been developed by similar forces and extend from the Kafue Trough into Eastern Africa. Of these basins, the Kafue Trough in southern Zambia is the focus of ongoing exploration. This basin has been determined to be in a previously highly active tectonic zone at the intersection of major thrust faults and shear zones on the margin of the Kalahari Craton; there is evidence of significant extensional normal faults desirable for geothermal systems.

The Kafue Trough is some 210km east to west and up to 100km north to south; its surface is the Kafue River flood plain. The basement within this graben structure includes Paleoproterozoic granites, gneisses, carbonates, amphibolites, quartzites and Katangan limestones; the regional geophysics suggests there are a number of buried faults which could be significant in the context of a basinal geothermal system. The basin infill, which may be up to 2,000m thick, consists of Lower Karoo mudstones and siltstones overlaid by the Upper Karoo conglomerate, sandstone, mudstone and basalt. Evidence suggests that the Lower Karoo mudstones acts as an aquiclude; however the sandstone sequences of the Upper Karoo can act as shallow aquifers. Geothermal fluid has been located in the basement/Lower Karoo unconformity. The entire sequence would act as a cap or thermal cover to a geothermal system within the Basin.

On the periphery of the Kafue Trough, on the contact between the Karoo and basement rocks, four groups of hot thermal springs have been identified. All have been investigated and while one group on the northern flank of the Basin appears to derive fluids from a geothermal system within the Hook of Granite, the rest have similar characteristics and discharge fluids that appear to derive from within the Basin. The focus is on the Bwengwa River area on the southern boundary of the Basin, which contains the Bwanda, Gwisho and Namulula hot springs near Lochinvar Lodge, where an ongoing extensive exploration programme is being conducted and which has included the drilling of two slim, shallow wells. Results suggest a $Na\text{-}SO_4$ thermal fluid with a temperature indicated by geothermometers of >150^{O}C moving from within the Basin close to the unconformity at the basement/Lower Karoo contact; geothermal gradients of 10^{O}C/100m and greater have been recorded in the wells. The ongoing task is to better understand the geothermal system, and to target the up-flow path at an economically viable depth/temperature.

2. ZAMBIA - BACKGROUND

Zambia has a surface area of 752,618km^2; a population of 13.01 million (2010 census), giving a density 17.2/km^2, which is anticipated to rise threefold to 45 million in 2045. Zambia's nominal GDP is $20.5 billion (2012 estimate); its primary economic focus remains copper mining, producing 976,218 tonnes in 2013 (Bank of Zambia Annual Report 2013), with a Government expectation of a 50% increase by 2017; agriculture plays an increasing role in the economy. Mining and most industrial activity are owned and financed by the private sector.

Power production is currently in deficit, with increased and diversified production being stated priorities of the present government. Total installed generating capacity has this year increased from 1,880MW to 2,350MW of which 99% is produced by large scale hydro electrical power. In spite of this increase, domestic access to electricity is believed to be 23% and power production remains in deficit to suppressed demand which is believed to be 2,800MW. While additional hydroelectric and thermal coal plants with a cumulative capacity of some 1,000MW are planned to come into production over the next 3 years, demand is growing at a rate of >6% per annum with significant increases sought by new mines and smelter capacity, industrial investment and rise in domestic consumption; thus production is likely to remain in deficit without additional capacity being built. Zambia has the legislation in place, and working precedent, for private power generation (Lunsemfwa Power Co), distribution (Copperbelt Energy plc and North-Western Energy); Open Grid access has been effective from 2013 and there are no restrictions on counter-parties to off-take agreements. Regional distribution is a reality within the Southern African Power Pool ("SAPP"). The power tariff is currently US$0.07 kWh; however, the Government, the Energy Regulation Board, and the Zambian Electricity Supply Company ('ZESCO') all recognise this as being unrealistic and a move to a cost reflective tariff has commenced. A Renewable Energy Feed-in Tariff under review with proposed rates due in late 2014; meanwhile a precedent has been set at $0.11kWh for privately generated hydroelectricity and $0.12kWh for the 300MW still in construction Maamba Coal fired thermal plant. Current Government policy is to diversify the energy mix to include both thermal and Renewable Energy, so reducing reliance on large scale hydroelectricity due to implications of climate change; Kalahari GeoEnergy's research infers a 2^{O}C temperature rise and 8-10% decrease in rainfall since 2010. The circumstances create an environment in which there is a tangible opportunity for private sector power production, particularly utilising sustainable energy that is not susceptible to the effects of climate change or variations beyond the plant operator's control

Geothermal exploration is managed by the Department of Energy, Ministry of Mines, Minerals and Water Development on behalf of the Zambian Government; the terms and conditions of the agreements are based upon the mineral exploration licencing format. Kalahari GeoEnergy has an agreement with the Government of Zambia which defines the exploration area and sets criteria for exploration, rights to develop targets, extensions to the agreement and reporting. The current agreement gives Kalahari exploration rights to the Kafue Trough, a Karoo era sedimentary basin in Southern Province, south-west of Lusaka.

There has been historic geothermal exploration and attempted development including a nationwide reconnaissance survey in 1970's (Legg 1974) and the establishment of a geothermal binary plant of 220KW consisting of two Turboden Organic Rankine Cycle turbo generators on shallow wells at Sumbu, Lake Tanganyika in 1987 (Zambian – Italian Geothermal Project 1985-1987). There are no reports of any other subsequent exploration.

3. THE TECTONIC SETTING OF THE KAROO SUPERGROUP WITHIN CENTRAL AFRICA

It is very apparent in a regional context that the Kafue Trough and associated hot springs occur in close proximity to a previously highly active tectonic zone close to the north-western margin of the Kalahari Craton (Figure 1). The Kafue Trough lies at the intersection of the Zambezi mobile belt, as defined by a zone of prominent east-west trending and southward verging thrust faults, and the dominant feature of this diagram, the major ENE-trending Mwembeshi Dislocation Zone or shear zone, showing a dextral sense of displacement, separating the Kalahari and Congo Cratons (Daly, 1986). However, during the later Phanerozoic period, which includes the Karoo depositional event, it is suggested (Daly et al 1987) that the Mwembeshi was reactivated but with a sinistral sense displacement.

The Mwembeshi Shear Zone is a regional transfer fault which transfers movement from a series of thrust belts (Daly et al, 1984 and Daly, 1986). It is evident that Kafue and the Lower-Zambezi basins are associated with Mwembeshi shear zone and the Mzarabani shear zone respectively. These represent pre-existing lines of structural weakness associated with the late Pan-African tectonothermal event that were reactivated during Karoo rifting (Kasolo and Forster, 1991 and Unrug, 1987). It has also been suggested that the coalescence of the mid-Zambezi, Lower Zambezi and Luangwa rift zones represents a failed Karoo-aged paleo-triple junction (Oesterlen and Blenkinsop, 1994).

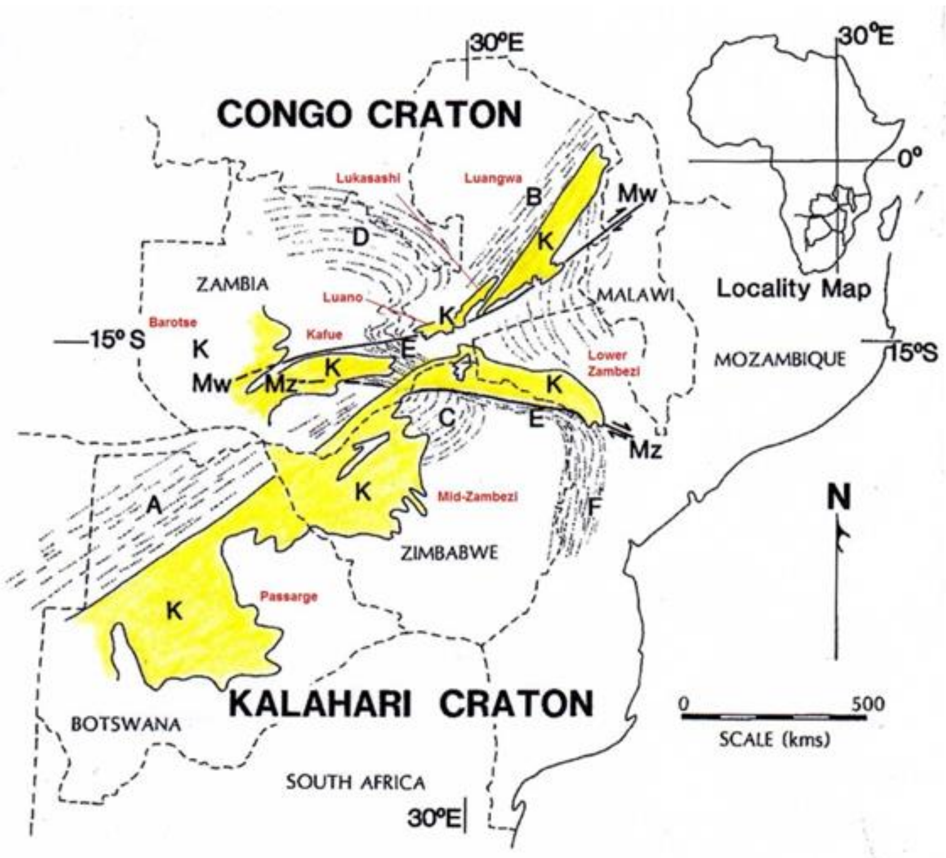

Figure 1. Sketch map showing the mobile belts of Central Africa and the distribution of Karoo Basins (from Orpen, 1989 modified after Coward and Daly, 1984). Mw=Mwembeshi shear zone, Mz=Mzarabanzi shear zone, K=Karoo basins, A=Damaran belt, I=Irumide belt, C=Magondi belt, D=Lufilian Arc, E=Zambezi belt , F=Mozambique belt.

4. THE DISTRIBUTION AND BASINAL SETTING OF THE KAROO IN ZAMBIA

The Karoo sequence in Central and Eastern Africa were deposited within two different basinal settings either side of a dividing line which roughly follows the present watershed of the Congo River (Catuneanu et al, 2005). To the east of the dividing line deposition occurred in an extensional regime within intra-continental rifts, whilst to the west of the dividing line deposition occurred within sag basins.

The Karoo era rift system commences with the Kafue Trough and the mid-Zambezi basin in the south, passing successively into the Luano-Lukasashi Basin and Luangwa Basin in eastern Zambia and ultimately extending into East Africa (Unrug, 1987 and Catuneanu et al., 2005). All these basins were typical intracratonic rifts (Catuneanu et al, 2005). All these successions show a remarkable similarity, indicating that their development was controlled by similar forces. Due to the specific structural history of these basins, the older Karoo deposits were laid down and preserved within the oldest graben structures, most of which occupy the deepest parts of the basins today (Catuneanu et al, 2005). As the rifts expanded, younger sedimentary sequences progressively overstepped onto domino-style tilted horsts and younger grabens (Catuneanu et al, 2005). Thus, almost continuous sedimentation took place within the deep parts of the rifts whereas the successions on the rift shoulders were interrupted by hiata and erosion evidenced by unconformities and reduced sections.

The Kafue Trough, a graben, is located to the west of Lusaka and extends westward into the Barotse Basin. It has a surface area of some 14,000km^2, being some 210km from east to west and up to 100km from north to south; it's surface forms the flood plain of the Kafue River known as the 'Kafue Flats', which is now controlled by the Itezhi Tezhi and Kafue Gorge dams. The mean elevation is 1,000m ASL.

5. THE KAROO STRAIGRAPHY IN THE KAFUE TROUGH

Exposure of the Karoo rocks within the Kafue Trough is extremely poor, being masked by recent alluvium and/or Kalahari sands. Nowhere is the outcrop continuous enough for a definitive succession to be established and the sporadic outcrops are generally confined to the margin of the Basin. The stratigraphic succession based on surface exposures and the sparse diamond core holes is shown in Table 1.

Lithology	Formation	Series	System
Basalt	Batoka Basalt		
Sandstone with mudstone and siltstone bands. Basal conglomerate which is unconformable on Basement/Katanga	Sandstone above the Escarpment Grit	Upper Karoo	Stormberg
	Escarpment Grit		
Mudstones with limey horizons	Madumabisa Mudstone	Lower Karoo	Lower Beaufort
Coal Measures	Gwembe Coal Formation		Ecca
Buff sandstone and maroon mudstone and tillite	Siankondobo Sandstone		Dwyka

Table1. Correlation of the lithological units from the south-eastern margin of the Kafue Trough with those from the Mid-Zambezi Valley (highly modified from Barr and Brown, 1968)

The Upper Karoo rocks comprise conglomerate, sandstone and mudstones, overlain by basalt (Barr and Brown, 1968 and Brown, 1966). The conglomerates occur in coarse-grained sandstones of the Escarpment Grit close to the unconformable contact with the basement. Sandstone, which is the dominant lithology in the Upper Karoo, forms most of the outcrops which vary from fine-grained to coarse grained; they are usually coarse-grained and gritty close to the margin of the area of Karoo outcrop and become finer grained towards the centre. The sandstones are massive, planar bedded or cross-bedded, well sorted to poorly sorted, and are generally red to pink in colour. The reddish mudstones and siltstones occur as thin bands interbedded throughout this sandstone succession, but are more prolific in the lower half of the sequence; green and grey colours are not common.

The Madumabisa Mudstones of the Lower Karoo comprises massive, laminated, and ripple cross-laminated grey and more rarely green chloritic, siltstone and mudstone. Pale blue-grey argillaceous limestone occurs at the top of the Madumabisa mudstone within the Monze embayment (Brown, 1966). The Gwembe carboniferous mudstones and coal measures have been intersected below the Madumabisa mudstones. The lowermost tillite has been intersected in some historic boreholes in the Monze embayment to the south-west of Bwengwa River, but often this lowermost sequence appears to be missing.

It is not uncommon to find the Upper Karoo, whose base is defined by the unconformity at the base of the Escarpment Grit, overstepping or overlapping the Lower Karoo to lie directly on the Basement rocks at the margins of the Kafue Trough as in the vicinity of the Mpandza Mission, Lochinvar Lodge and the village of Magoye.

6. GEOLOGICAL SETTING OF BWENGWA RIVER HOT SPRINGS

The hot springs deliver their water in close proximity to but on the basin side of the steeply dipping normal fault marking the boundary between the Karoo and the Basement (Katangan and Paleoproterozoic) on the southern margin of the Kafue Trough (Figure 2 attached). The alteration along the fault is characterized by chalcedonic silica filling vugs and veins, as well as a matrix in the breccias, which may largely seal the fault zone. This is typical of the post-Karoo aged faults seen elsewhere in Zambia where the Karoo rocks are in faulted contact with older rocks. The amount of and direction of displacement across this bounding fault remains uncertain, however it would appear that there is a component of lateral movement in addition to the vertical movement.

The only outcrop of the Karoo at surface is developed at Sebenzi Hill between the Bwanda and Gwisho springs, and comprises sandstones and pebbly sandstones which can be correlated with the Escarpment Grit; these sandstones have been strongly silicified adjacent to the fault.

The Basement/Katangan rocks strike northwest-southeast and intersect the bounding fault almost at right angles; they dip to the northeast at moderate to shallow angles (24° to 41°). The Basement lithologies comprise quartz-mica schist, augen gneiss, quartzite and amphibolite. The Katangan rocks comprise limestone and biotite schist. The interleaved nature of the Katangan and Paleoproterozoic basement at Lochinvar Lodge indicate that some of the contacts are thrusts resulting in the development of a regional thrust stack within the Basement rocks. The southern limit of this stack is marked by the Mzarabani shear zone, which represents the boundary of the Zambezi mobile belt. It also marks the southern limit of the Katangan carbonates on the southern margin of the Kafue Trough (Figure 1) Surface mapping has indicated dips within the Karoo of between 17° and 30° north-westwards into the Basin. Karoo sediments dip at around 30° in Kalahari GeoEnergy’s Well LOCH 02 and the section through this well indicates that the Basement-Karoo contact also dips at 30° parallel to the bedding.

The Lochinvar Lodge hot springs are developed sporadically along the strike, but on the basin side of the fault over a distance of some 7km and abut against different Basement rocks; at Bwanda it is quartzite, at Gwisho it is limestone, and at Namulula it is quartz-mica schist. Multiple mounds and eyes occur at each of these localities. The spring apron at surface is marked by sodium sulphate.

7. EXPLORATION TECHNIQUES EMPLOYED

Interpretation of Aster images

Structural geological mapping

Hot spring fluid sampling – Laboratory analysis for Anions, Cations and Isotopes (δD and δ^{18}O)

Magnetics (GEM Systems magnetometers, model GSM-19T((Readings were taken every 25m on lines 100m apart)

Resistivity – Magnetotellurics (‘MT’) and Vertical Electrical Soundings (‘VES’) along 1Km spaced lines (Zonge GDP32II Measured 2 electrical fields in x axis on 250m dipole, 1 electrical field in the y axis on 50m dipole)

Gravity (CG-5 Scintrex gravity meter) (Readings every 250m on lines 1Km apart)

Radiometric (GF Instruments multi-channel Gamma Surveyor v1.2) (Readings every 10m on lines 100m apart)

Soil temperature surveys (Geotron (Pty) SA drill and probe assembly with temperature sensor at 2m depth) (Readings every 250m on line 1Km apart)

Diamond drilling and core logging of slim wells (Wells LOCH 01 and LOCH 02, inner diameter 47.6 mm Drilled by BluRock Mine Services, Kitwe, Zambia)

Measurement of clay alteration (Methylene Blue test for Smectite)

Down-well temperature surveys (Kuster K10 P&T Tool)

Magnetic susceptibility (readings taken at 1m intervals along the core)

Radiometric (readings taken at 1m intervals along the core)

Geo-botany –investigating the distribution of thermophile plants and algae

8. RESULTS OBTAINED FROM THE EXPLORAION PROGRAME

Water samples taken at the surface spring eyes at Bwanda are in the range 58-92^{O}C. From the analysis of the anions and cations they are categorised compositionally as being Na-SO_4 waters the equilibrium temperatures indicated by the Na-K geothermometer are 179-184^{O}C, the SO_4-F geothermometer are 152-153^{O}C, the K-Mg geothermometer are 141-157^{O}C and silica geothermometer temperatures are 143-146^{O}C. The surface temperatures, chemical composition and geothermometers are broadly similar at Gwisho. The chemical analysis suggests the fluids have moved through Basement rocks. The oxygen and hydrogen isotopes indicate that the geothermal waters have been derived from meteoric water.

The bounding fault mapped at surface is well defined on the ground magnetic survey, the MT resistivity profiles and the gravity survey (Figures 3-4). The Karoo sediments, mainly the Madumabisa mudstones and siltstones are conspicuous by their low resistivity on MT sections when compared to the more resistive Basement (Figure 4). The MT sections indicate that the southern bounding fault is most probably steeply dipping and that the Karoo sediments form a wedge off it that dip shallowly to the northwest (Figure 4).

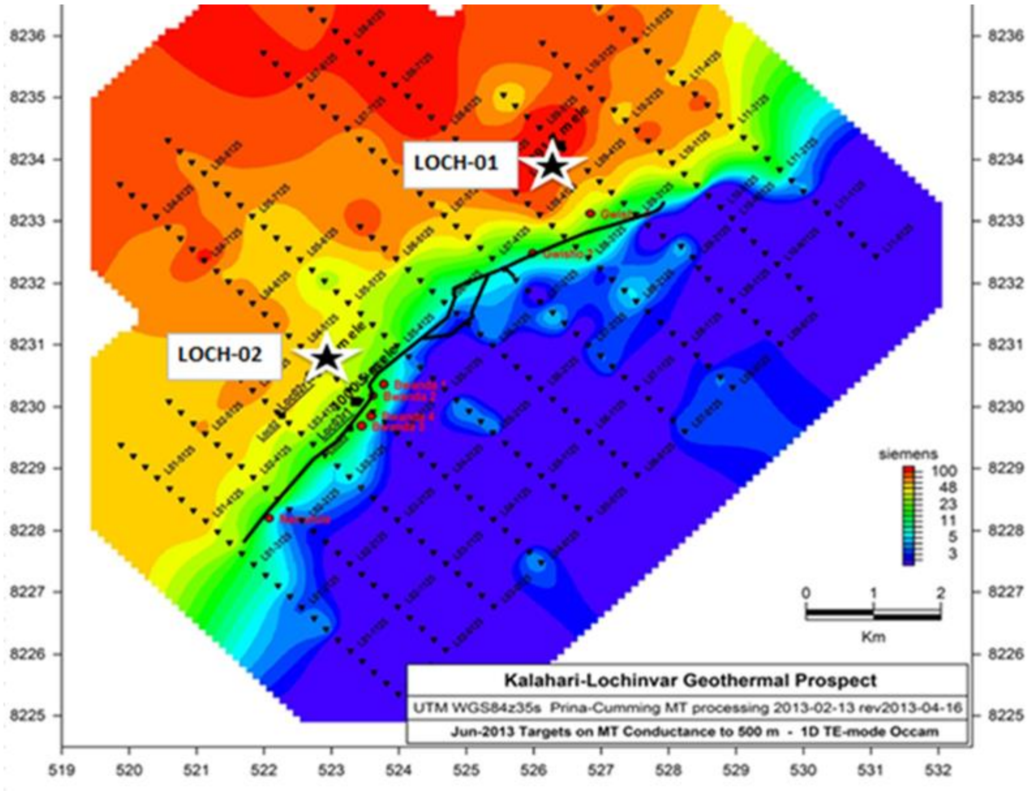

Figure 3: Bounding fault at surface, hot springs and Well locations on MT Conductance to 500m

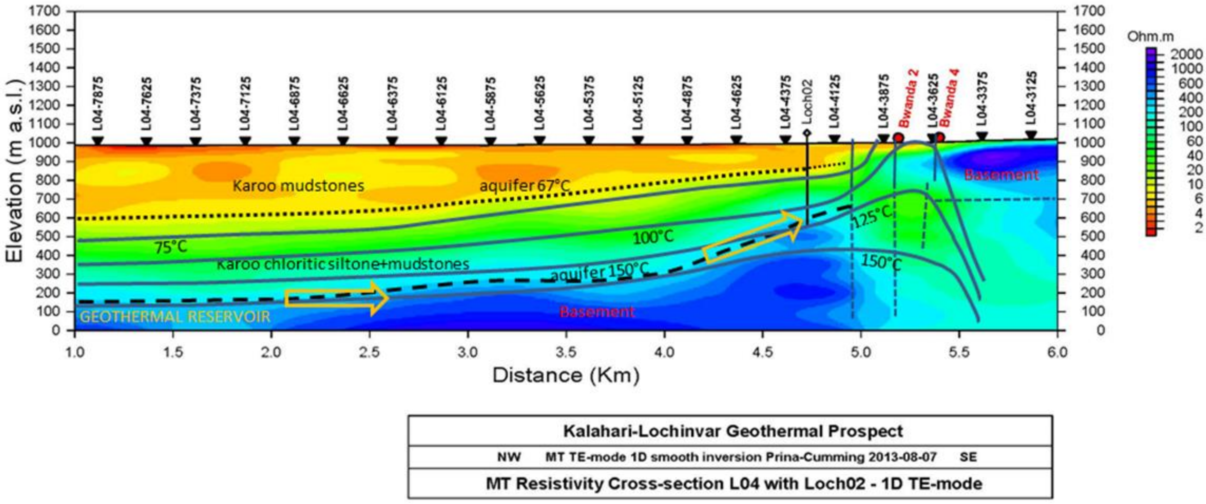

Figure 4: MT Resistivity Cross Section through Well LOCH 02. The cross section is annotated with the key lithology, aquifers and temperature isobars as determined from Well LOCH 02, the total depth of which is 440m.

The results of the ground radiometric survey in the vicinity of the Bwanda springs indicate that there are two distinct and spatially separate uranium anomalies. One anomaly encompasses the Bwanda springs themselves, extending from the bounding fault basinwards into Karoo sediments to close to the collar of borehole Loch 02. The other is located further to the south over the Basement rocks immediately adjacent to the bounding fault. It is thought that these anomalies are the surficial expression of the geothermal fluid that has leached small amounts of uranium and thorium from the Basement rocks during its passage through them; this would correlate with the hydro-chemical analysis.

Recent, but still to be completed, soil temperature surveys indicate the presence of anomalous temperatures further than 10km basinward of the bounding fault at Bwanda – this survey will be extended to cover the gravity and MT survey areas.

Well LOCH 02 indicated that a major aquifer is developed at the base of the Karoo on the Basement contact. This is associated with strongly fractured rocks below the coaliferous zone; poor core recoveries were also encountered at this depth. It would therefore, appear that there has also been some movement along the basal contact of the Karoo parallel to Basement-Karoo contact. Although structurally disturbed, this cannot be the fault mapped at surface because the MT indicates that this fault dips very steeply and in addition, this zone shows no silicic alteration so typical of the main bounding fault at surface (Figure 4). It is apparent that the impermeable Madumabisa siltstones and mudstones have acted as thermal barrier or cap to the geothermal fluids.

The drilling also indicated that additional aquifers could be developed within the Upper Karoo. The upper aquifer is associated with intraformational breccias in the upper portions of the Madumabisa mudstone sequence. The Karoo sediments within both aquifers are typically reddened and oxidized.

The temperature in the aquifer within the unconformity at the base of the Karoo intersected by well LOCH 02 was 101^{O}C. The well has artisanal pressure of 39 psi. Multiple samples have been taken of the fluid from LOCH 02 and analysed over a six month period. Fluid source temperatures indicated by the Na-K geothermometer are 202-228^{O}C, and the relatively fast acting silica (quartz adiabatic) geothermometer is >150°C which is supported by the other cation geothermometers. Although the cation geothermometers are not as applicable or reliable in this situation, they support the conclusion that the source of the Bwengwa thermal waters is >150°C.

An initial interpretation of the plot of temperatures taken with the down-the-well Kluster tool against the geological and geophysical logs of well LOCH 02, has indicated that there are significant geothermal gradients of 10^{O}C/100m or greater both above the upper aquifer at 160m within the Upper Karoo sandstone, and between that aquifer and the lower one believed to be in the unconformity on the Karoo/basement contact; the temperature remains fairly constant with increasing depth in both the upper aquifer/magnetic depletion zone as well as in the lower magnetic depletion zone, fractured zone and Basement lithologies (Figure 5).

The Well LOCH 02 magnetic susceptibility readings are low until just above 100m, below which there is a marked and sharp increase which coincides with the depth at which there is a prominent thin resistivity high on the MT profiles throughout the area and which was associated with the Escarpment Grit/ Madumabisa contact in well LOCH 01. The readings are low in the vicinity of the upper aquifer indicating that the magnetic component may have been leached or oxidized by fluids. The readings increase at base of chloritic siltstone, but then drop in the vicinity of the fractured zone close to the Basement contact as with the upper aquifer, indicating that the magnetic component may have been leached or oxidized by fluids. The readings are extremely low over the coaliferous zone near base of the hole as well as in the carbonaceous mudstone unit further up-hole. The highest readings are associated with the Basement meta-quartzites and may be the partial cause of the magnetic high on the original ground survey – well Loch 02 is collared in this magnetic anomaly. Alternatively, the high may be reflecting a buried mafic-ultramafic intrusion.

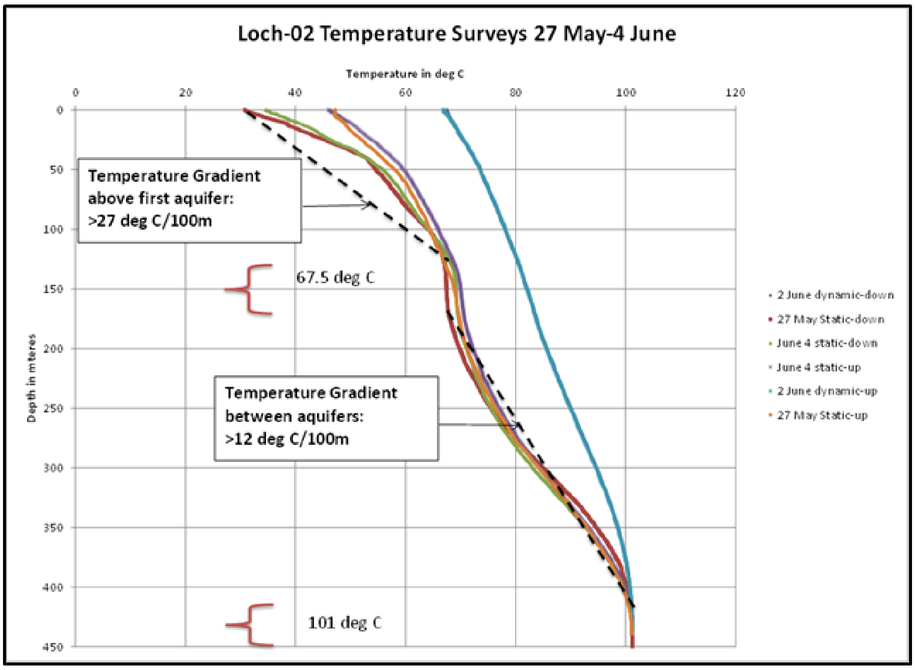

Figure 5: Temperature gradient in Well LOCH 02

Observations at both the Bwengwa River springs and also some hot springs within Zambia indicate that a small perennial bush, tentatively identified as *Pluchea dioscoridis* (L.) DC grows in close proximity to hot water and not observed elsewhere. Stakeholders including herdsmen are being trained in the plant's recognition. It is of interest that this plant has high tolerance to saline soils and is considered to be an excellent insecticide and has wide usage by herbalists (Shaltout and Slima, 2007)

9. DIRECT APPLICATIONS

Direct applications of geothermal are considered to have potentially significant implications for energy applications and food security in developing countries such as Zambia where utilities in rural areas are often rudimentary. In the area of Bwengwa River the only water available is brackish and often undrinkable. Kalahari is conducting trials of locally made filtration units with objective of providing potable drinking water and thus add to the impetus to achieve the Millennium Challenge of increasing access to potable water. Follow-on research is to investigate using geothermal as the energy source for forward osmosis membranes. The Kafue Trough is a traditional cattle grazing region for an estimated 250,000 head of cattle. Preliminary discussions concerning pasteurisation of dairy products are being held with stakeholders.

10. NEXT STEPS

A detailed review of all existing data including a reinterpretation of geophysics based on the slim well data is being undertaken with the objective of targeting the 150^{O}C up-flow (Figure 4). Subject to the detailed findings of the review, additional slim well(s) are to be drilled. Subject to the results this will lead to deep drilling, a pre-feasibility and ultimately, Feasibility Study. Concurrently, exploration of the areas of other spring groups within the Kafue Trough is underway.

11. CONCLUSIONS

There have been sporadic investigations of geothermal energy in Zambia since 1970's, however until recently such work was largely academic as there was no imperative to develop alternative sources of energy. Recent growth in the mining and industrial sectors together with a rapidly growing population has led to a power deficit on the one hand and on the other, technical concerns as to the long term viability of dependence on hydroelectricity has led to a policy of diversification. This creates a tangible opportunity for private sector as there are already the relevant statutes and precedent for independent private power production, access to the grid, distribution and sales. A cost reflective tariff and a renewable energy feed-in tariff are anticipated in 2014.

The extensional faulting along previously formed older Proterozoic structures in the Kafue Trough, one of a series of Karoo-era basins that extend from western Zambia into East Africa has been proven to host geothermal systems. The Kafue Trough is of significant size and is in-filled with Lower Karoo rocks in the deeper basin and is overlain by those of the Upper Karoo which can overlap the Basement. The Lower Karoo contains silt and mudstones and can be considered to be an aquiclude, whilst the sandstones of the Upper Karoo can, as has been discovered, host aquifers. The Karoo in-fill sequence can be seen as an effective thermal cap rock to any geothermal system within the Basin.

Several sets of thermal springs have been located on the basin side of the contact between the basement and the Karoo on both the northern and southern margins of the Basin. Of these, those at Bwengwa River have been the focus of extensive exploration to determine the characteristics of the source of the geothermal fluids. Hydrochemistry at Bwengwa River from both the hot springs and well LOCH 02 suggests that the source of the Na-SO_4 rich geothermal fluids is in the Basement within the Basin and that the fluid moves towards the edges of the Basin in, or close to, the unconformity along the Karoo/Basement contact under a thinning thermal cap; this is supported by geophysics and geological observations. The geothermometers including silica suggest the source temperature of the fluids in the aquifer at the Karoo / Basement contact at Bwanda to be > 150°C. The geothermal gradients calculated in Well02 are greater than 10°C/100m between the two aquifers encountered. This is seen as significant.

The temperatures derived from the geothermometers and the geothermal gradients are considered to be in the range for low-enthalpy commercial geothermal power production and the source is likely to be at a realistic depth within the Basin. Additionally, the fact that the Bwengwa thermal waters (Bwanda and Gwisho Springs and wells) appear to have a common source suggests a larger reservoir than if they were separate sources. Again this is considered significant.

Potential direct uses of geothermal energy either on a stand-alone basis or as part of a geothermal power plant are seen has having significant applications with regard to food security and rural energy and industrialisation and agro-industry. The Bwengwa River is within a traditional cattle ranching area so applications related to dairy farming are already being studied. However, the immediate focus during the ongoing exploration phase is the provision of fresh drinking water to local communities thereby making a contribution to the global Millennium Challenge of universal access to potable water.

Current results justify further exploration at both Bwengwa River and at other targets in the Kafue Trough.

REFERENCES

Barr, M.W.C. and Brown, A.G. (1968). Karoo rocks of part of the Kafue Trough between Mpanza Mission and Ndundumwense. Records Geol. Surv. Zambia, 11, p.29-51.

Brown, A.G. (1966). Karoo deposits of the Kafue Trough. Records Geol. Surv. Zambia, 10, p.25-29.

Catuneanu, O., Wopfner, H., Eriksson, P.G., Cairncross, B., Rubidge, B.S., Smith, R.M.H. and Hancox, P.J. (2005).The Karoo basins of south-central Africa.Journal of African Earth Sciences, vol. 43, p.211-253.

Coward , M.P. and Daly, M.C. (1984). Crustal lineaments and shear zones in Africa: their relationships to plate movements. Precambrian Research, vol.24, p.27-45.

Daly, M.C., Lawerence, S.R., Kimuna, D. and Binga, M. (1991). Late Paleozoic deformation in Central Africa: a result of distant collision? Nature 350, p.605-607.

Daly, M.C., Chorowicz, J. and Fairhead, J.D. (1987). The reactivation of steep basement shear zones and their influence on rift basins in Africa. In: Williams, G. and Cooper, M.A. (eds). Inversion tectonics. Geol. Society Spec. Publ., no.29. Blackwell, Oxford.

Daly, M.C. (1986). Crustal shear zones and thrust belts: their geometry and continuity in Central Africa. Phil Trans. R. Soc. London, A317, p.111-128.

Daly, M.C., Chakraborty, S.K., Kasolo, P., Musiwa, M., Mumba, P., Naidu, B., Namateba, C., Ngambi, O. and Coward, M.P. (1984). The lufilian arc and the Irimudie belt of Zambia: results of a geotraverse across their intersection. Journal of African Earth Sciences, vol. 2, No. 4 p.311-318.

Geological Survey of Zambia (1983). Coal exploration Zambia. 80pp.

Kasolo, P.C. and Foster, R.P. (1991). Fluid channeling and gold mineralization within the late Proterozoic Mwembeshi shear zone, Zambia. In: Ladeira, E.A. Brazil Gold '91: the economics, geology, geochemistry, and genesis of gold deposits. Balkema, Rotterdam, p.673-679.

Legg, C.A. (1974). A reconnaissance survey of the hot and mineralized springs of Zambia. Economic Report of the Geological Survey of Zambia, No.50, 80pp.

Nyambe, I.A. (1999). Tectonic and climatic controls during the deposition of the Sinakumbe Group and Karoo Supergroup in the mid-Zambezi Valley Basin, southern Zambia. Jour. African Earth Science, vol. 28, No.2, p.443-463.

Oesterlen, P.M. and Blenkinsop (1994). Extension directions and strain near the failed triple junction of the Zambezi and Luangwa rift zones, Southern Africa. Journal of African Earth Sciences, vol. 18, No. 2, p.175-180.

Orpen, J.L., Swain, C.J., Nugent, C. and Zhou, P.P. (1989). Wrench-fault and half-graben tectonics in the development of the Paleozoic Zambezi Karoo basins in Zimbabwe – the Lower Zambezi and "Mid-Zambezi" basins respectively – and regional implications. Journal of African Earth Sciences, vol. 8, No. 2/3/4, p.215-229.

Shaltout K H and Slima D F (2007) The Biology of Egyptian Woody Perrenials, Pluchea Dioscoridis (L) DC. Assiut University, Egypt, Bull. Environ. Res. Vol 10 No 1, March 2007

Unrug, R (1987). The tectonic position of the Karoo basalts, Western Zambia. American Geophysical Union.

Figure 2. The geology around the Bwanda, Gwisho and Namulula hot springs south of Lochinvar Lodge (after Legg, 1974)