# COUNTRY UPDATE REPORT FOR ZAMBIA

**Peter Vivian-Neal[1], Peter Harrison[2] and Abel Chavula[3]**
[1] Kalahari GeoEnergy Ltd, Lusaka, ZAMBIA, peter.vivian-neal@kalaharigeoenergy.com
[2] Pretoria, SOUTH AFRICA, peter@dunkelly.co.za
[3] ZESCO, Lusaka, ZAMBIA achavula@zesco.co.zm

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## ABSTRACT

Zambia hosts a number of geological structures that are recognised as being prospective for geothermal energy. Historic work has included regional reconnaissance and the installation of a geothermal pilot power plant. The Country's current move to diversify from near total reliance on hydro-power, and concurrently both increase generating capacity to redress a significant power deficit and increase power distribution, together with a favourable regulatory environment, has created the opportunity to further investigate the Country's geothermal potential. At a National level, systematic geothermal resource mapping and exploration is being advocated, but which requires capacity building. Meanwhile, Kalahari GeoEnergy Ltd, a private company has conducted extensive exploration at Bwengwa River, which lies within the Kafue Trough, Southern Zambia, where a medium-low enthalpy geothermal energy resource of 10-20MW has been established, which has the characteristics of a technically viable geothermal power production resource. Results indicate that similar structures elsewhere in the basin are prospective for additional geothermal resources similar to that at Bwengwa River.

## 1. INTRODUCTION

This paper looks at a) the status and challenges of Zambia's power generation capacity, the historic geothermal work, the rational for a fresh approach and the contribution of ZESCO to a national evaluation of geothermal energy together with appropriate capacity building, and b) the progress of a private company, Kalahari GeoEnergy Ltd, which is engaged in ongoing exploration of geothermal targets within the Kafue Trough, a non-volcanic, seismically active, sedimentary basin located to the west of Lusaka, for which the initial exploration programme was discussed previously at ARGeo-C5 by Vivian-Neal (2014).

Results obtained by Kalahari GeoEnergy during 2015 provide further confidence that Bwengwa River has a geological setting conducive for geothermal hydrothermal systems. Calculations provide a consistent estimated usable resource capacity in the range of 10-20MW. Further work is being conducted in 2016 both to add confidence to the resource and extend the size of the resource area.

## 2. ENERGY AND REGULATORY MARKET

Zambia and the surrounding countries are currently facing severe power deficits, which within the SADC Region amounts to -8,000MW (July 2016). Zambia has an installed power generating capacity of 2,448MW of which 95% is large scale hydro-power. Low rainfall in the catchment areas in the last two years has led to reduced energy storage in the major dams, leading to a national power deficit of some 900MW (July 2016). This has resulted in widespread load management (load shedding) affecting both industry and domestic consumers and thus reducing economic productivity with severe socio-economic consequences. The Zambian Government has already taken measures to mobilise both the public and private sectors to diversify the energy mix and both increase generating capacity and distribution.

Additional generating capacity and distribution is considered essential for both Zambia and the region to achieve its development goals. The Zambian Government and other relevant institutions are taking determined measures to engage the private sector and diversify the power industry. It is recognised that the necessary regulatory frame-work is in place and there is precedent, for private sector generation (including geothermal), transmission and sale of electrical power in Zambia; there are ongoing initiatives to adopt cost reflective tariffs.

## 3. GEOTHERMAL ENERGY IN ZAMBIA

Historic work by Legg (1974) identified a significant number of surface manifestations indicating widespread geothermal resource areas in three different geological settings: non-volcanic Karoo (Permian) extensional basins, hot Katangan (Late Proterozoic) granites and in the north, part of the East African Rift System, which are all now recognised as being prospective for geothermal energy.

In the 1980's a Zambian-Italian joint venture followed up earlier reconnaissance work with a drill programme at several targets -which culminated in a 200KW geothermal pilot plant being erected at Kapisya near N'sumbu on the Lake Tanganyika Rift structure in the 1980's. This was designed to use a total of 15 shallow exploratory and production wells, four of which had submersible pumps installed. The plant which has two Organic Rankine Cycle (ORC) Turboden turbo-generators was designed to operate at temperature of 95˚C. It never became operational as the resource temperature was found to be too low, no power evacuation line was built, and there was no imperative to resolve the challenges due to the then excess power within the Country.

Subsequent assessments for potential of the N'sumbu geothermal resource by KenGen in 2006 suggested the potential of generating more than 2MWe; a re-assessment by ICEIDA in 2014 was rather pessimistic and suggested the resource had limited potential for power generation. While this has dampened the momentum for further work on the Kapisya project, both KenGen and ICEIDA recommended exploratory drilling.

## 4. ZESCO

### 4.1 Strategy

At the National level, ZESCO's strategy is to undertake a review of the inventory of all known geothermal occurrences across the country and to establish their potential for electricity generation or other direct uses. With advancing technology, further exploitation and development of geothermal resources, it may be possible to find suitable sites for power generation or other direct uses overlooked in previous reviews. It is ZESCO's intention to engage technical consultants to carry out this work as capacity is built. This is now justified by the results obtained by Kalahari GeoEnergy Limited, which has established a geothermal resource in the Kafue Trough with promising prospects for power generation.

### 4.2 Challenges

ZESCO's geothermal strategy will require external financial support to build capacity. While key technical staff have had training opportunities including short courses and workshops with KenGen and the UNU-GTP, a significant investment would be required to build a national geothermal development group that would work alongside the private sector which is already active in the Country's geothermal and power sectors. It is also pertinent that the statutory authorities are also actively seeking to build regulatory capacity specific to geothermal.

## 5. KALAHARI GEOENERGY LTD

The Company's privately funded exploration work has included the drilling of five temperature gradient holes totalling 1,980m, which was supported by geological mapping, geophysical surveys (ground magnetic, AMT, gravity and radiometric), surface geochemical surveys (sampling of springs), soil temperature surveys and stable isotope studies, all of which is conducted in accordance with geothermal industry standards and best practice. It has also conducted preliminary exploration including systematic geophysics at other identified targets within the Kafue Trough.

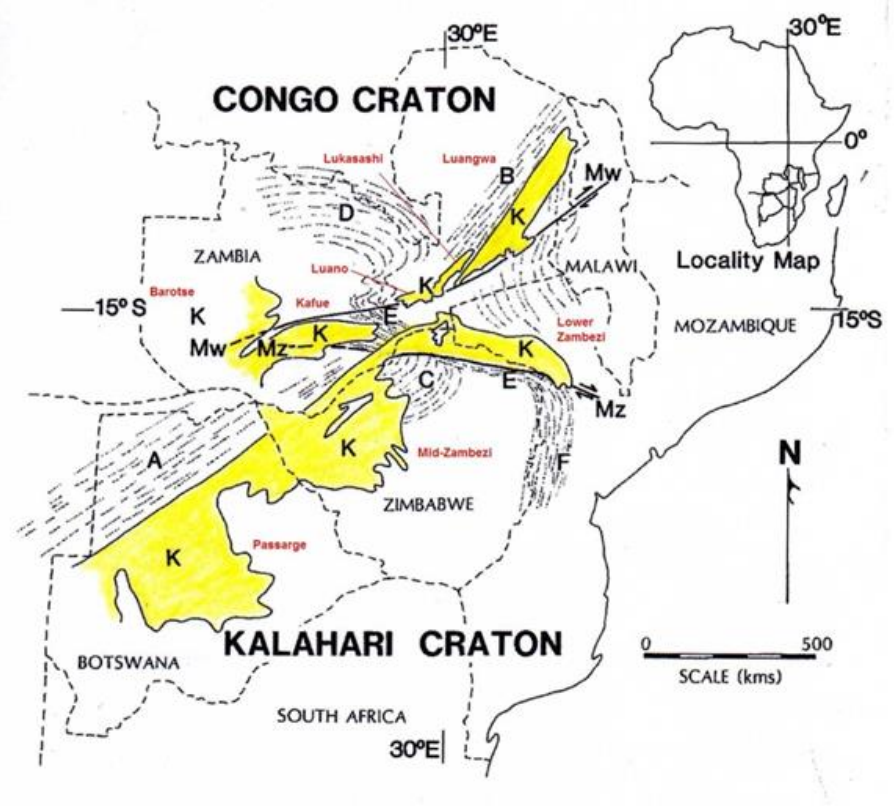

**Figure 1. Sketch map showing the mobile belts of Central Africa and the distribution of Karoo Basins (from Orpen, 1989 modified after Coward and Daly, 1984). Mw=Mwembeshi shear zone, Mz=Mzarabanzi shear zone, K=Karoo basins, A=Damaran belt, I=Irumide belt, C=Magondi belt, D=Lufilian Arc, E=Zambezi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

### 5.1. Kafue Trough

The Kafue Trough lies at the intersection of the Zambezi mobile belt and the Mwembeshi Shear Zone (Figure 1).The latter 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 Trough is associated with Mwembeshi dislocation zone, a pre-existing line of major structural weakness associated with the late Pan-African tectono-thermal event (Kasolo and Forster, 1991 and Unrug, 1987). The Karoo basins developed as a result of sinistral shear along the reactivated Mwembeshi Shear Zone (Figure 2). Pull apart basins developed from strike slip when the basin was located in the shear (Kafue Trough and Luano Rift in Zambia, Ruhuhu in Tanzania and Manaimba in Mozambique) and grabens developed where the basins were at angle to the shear zone (South-, Mid- and North-Luangwa Rifts, Lower and Mid-Zambezi Rifts and the Lukuakasi Rift). The pull apart basins were probably initiated by a strike slip fault couplet along the Mwembeshi and sub-parallel lateral thrust ramps. Continued subsidence then took place through tensional block faulting and sag – these look like a normal interior fracture tensional grabens.

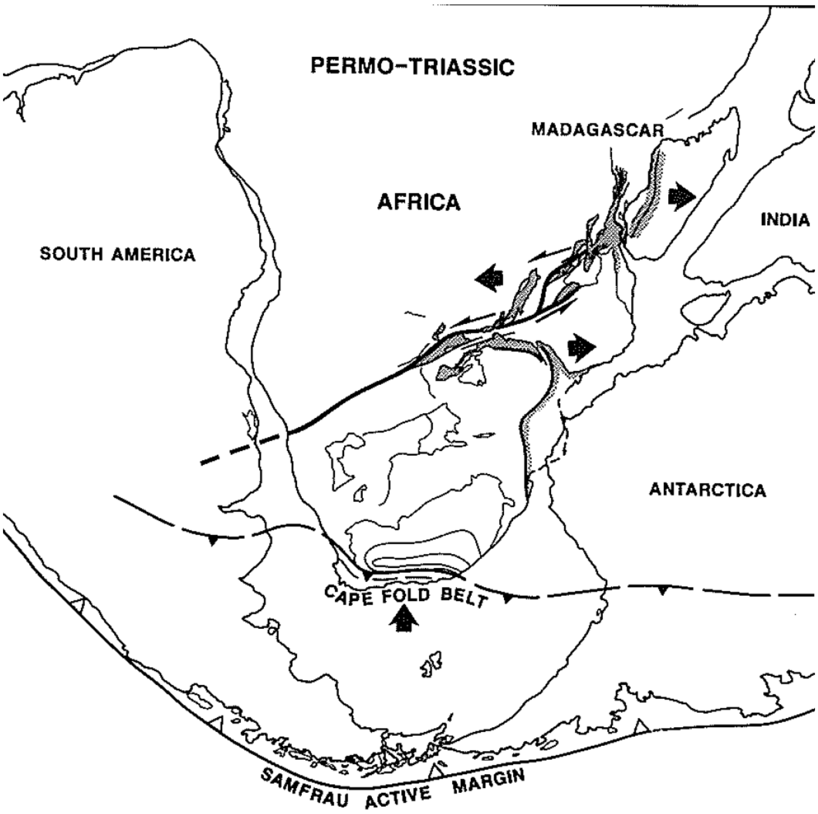

Figure 2. Tectonic model to explain the contemporaneous development of Karoo rift basins of Central Africa and the foreland Karoo basin associated with the Cape fold and thrust belt of South Africa (from Coward et al, 1987)

### 5.2. Structural Setting of the Bwengwa River Prospect

The surface manifestations of the Bwengwa River Geothermal Resource Area include three clusters of geothermal springs that extend over 6km and lie on the southern bounding fault (SBF) of the Kafue Trough, which marks the boundary between the Karoo and the Basement (Katangan and Paleoproterozoic) on the southern margin of the Kafue Trough. The Basement/Katangan rocks form a thrust stack which strikes northwest-southeast and intersects the bounding fault almost at right angles; the stratigraphic layers dip to northeast at moderate to shallow angles and are displaced by the SBF. The mapped SBF is well defined on the ground magnetic and gravity surveys and is characterized by a noticeable gradient in the conductivity data from the AMT survey.

Mapping and interpretation indicates that the SBF is a steeply dipping ($70^{0}$-$80^{0}$N), ENE-WSW trending, oblique dip slip fault, which also has a prominent right lateral (dextral) strike slip component. The fault trace shows a noticeable change, or bend, in strike, which is convex outwards, between the southern and northern groups of springs. In this area where the strike changes the fault bifurcates and duplexes are developed (strike slip component). The dip of the stratigraphic units within the Karoo steepens to $30^{0}$N in the vicinity of the SBF as a result of downward drag down along the fault plane (normal slip component).

A prominent basement fault which parallels the SBF has been defined at depth some 500m basin-ward of the SBF. In addition, ground magnetics identified some weak cross faults paralleling the trend of the bend in strike of the SBF down dip of the springs. These add further credence to the existence of a major fault zone which would be essential for hosting a significant thermal reservoir. The hot springs exhibit a strong structural control with respect to the SBF in that they are located close to the major intersections at either end of the anastomosing fault zone.

The importance of fault bend and duplex (or relay ramp) models as favourable structural settings for the location of geothermal systems within intracontinental rift zones are well known. Geothermal systems most commonly occur in belts of intermeshing, overlapping, or intersecting faults. Step-overs (relay ramps), terminations, intersections, and accommodation zones in normal fault systems correspond to long-term, critically stressed areas, where fluid pathways would more likely remain open in networks of closely-spaced, breccia-dominated fractures (Faulds et al 2011, Faulds 2013, and Faulds and Hinz 2015 (Figure 3).

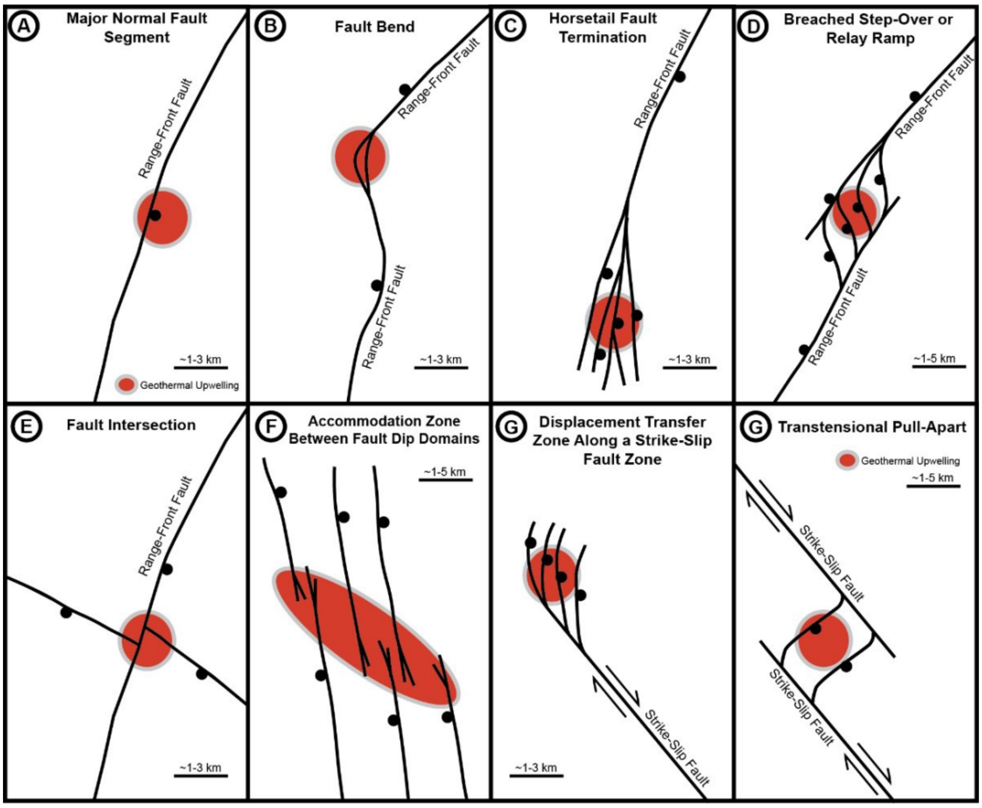

Figure 3: Characteristic structural settings for geothermal systems in the Great Basin region. Areas of upwelling geothermal fluids are shaded in red. A. Major normal fault. B. Bend in major normal fault. C. Fault tip or termination with main fault breaking into multiple strands or horse tailing. D. Fault step-over or relay ramp between two overlapping normal fault segments with multiple minor faults providing hard linkage between the two major faults. E. Fault intersection. F. Accommodation zone, consisting of belt of intermeshing oppositely dipping normal faults. G. Displacement transfer zone, whereby major strike fault terminates in array of normal faults. G. Trans tensional pull-apart in major strike-slip fault zone. (Faulds et al, 2011 and Faulds and Hinz, 2015).

## 5.3. Geothermometers

The temperature gradient holes indicate that the high temperatures are located within the fractured Basement rocks below the Lower Karoo Gwembe Coal Formation comprising siltstones and mudstones with minor coal seams which together act as a seal or cap rock.

Temperature logs, hydrology, fluid chemistry, and lithology from the five temperature gradient holes also suggest that temperatures observed in springs (approximately boiling) and spring chemistry extend westward from the SBF. Loch-02 and Loch-05 encountered maximum temperatures of 104 $^{0}$C at 440 and 564 m, respectively More importantly, the temperature gradients observed in these holes (>100 $^{0}$C/1,000 meters (m)) exceed typical regional temperature gradients in fault-hosted geothermal systems in the Great Basin, Western United States (>70 to 90$^{0}$C/1,000 m). These high temperature gradients can be extrapolated to indicate that temperatures of up to 150 $^{0}$C can occur at 1,000 m.

Chemical geothermometers (estimated temperatures at with the thermal fluids equilibrated with rock based on fluid chemistry) applied to Bwengwa River spring and well waters indicate that a range of geothermal reservoir temperatures, but all within the range of commercial geothermal power generation. The geothermal fluid observed in springs and wells is most likely flowing up the fractured zone which makes up the SBF from a higher (>$130^0$ to $150^0$ C) temperature reservoir below. The quartz-based geothermometers appear to the most reliable for the conditions at Bwengwa River (Table 1).

Table 1. ESTIMATED RESOURCE TEMPERATURES FROM GEOTHERMOMETERS (in degrees C)

| Location | **Quartz (conductive)**[1] | **Quartz (adiabatic)**[2] | **Na/K**[3] | **K/Mg**[4] | **Na/Li**[5] |
|---|---|---|---|---|---|
| Loch-02[6] | 150 | 143 | 202 | 141 | 178 |
| Loch-05 | 137 | 130 | 181 | 121 | 167 |
| Bwengwa South | 151 | 143 | 184 | 140 | 164 |
| Bwengwa North | 141 | 134 | 164 | 124 | 160 |

1-based on $SiO_2$ and equilibrium with quartz with no boiling between reservoir and surface (Fournier, 1973)
2-based on $SiO_2$ and equilibrium with quartz with boiling before sampling (Fournier, 1973)
3-based on equilibrium with feldspars (Fournier, 1981)
4-based on equilibrium with feldspars and clay alteration (Giggenbach, 1988)
5-empirical geothermometer for sedimentary-based systems (Fouillac and Michard, 1983)
6-analysis of most recent sample

Temperatures estimated from chemical geothermometers suggest that the geothermal reservoir is at least $30^0$C to $50^0$C higher in temperature than measured temperatures in both springs and wells (Table 1). In addition to indicating that the source of the geothermal fluids observed in the wells and springs are hotter than measured temperatures, the chemistry of the fluids from these wells and the springs is sufficiently similar to suggest that the hotter system supplying the wells and springs extends over an area of several square kilometres marked by the two springs and the two wells. Elevated shallow (2m) temperature anomalies are observed proximal to the SBF, which are likely related to shallow westerly outflows from the SBF fracture system. When the shallow and gradient hole temperatures are combined into a temperature model, a reservoir volume is projected which can be used to estimate resource capacity (Figure 4).

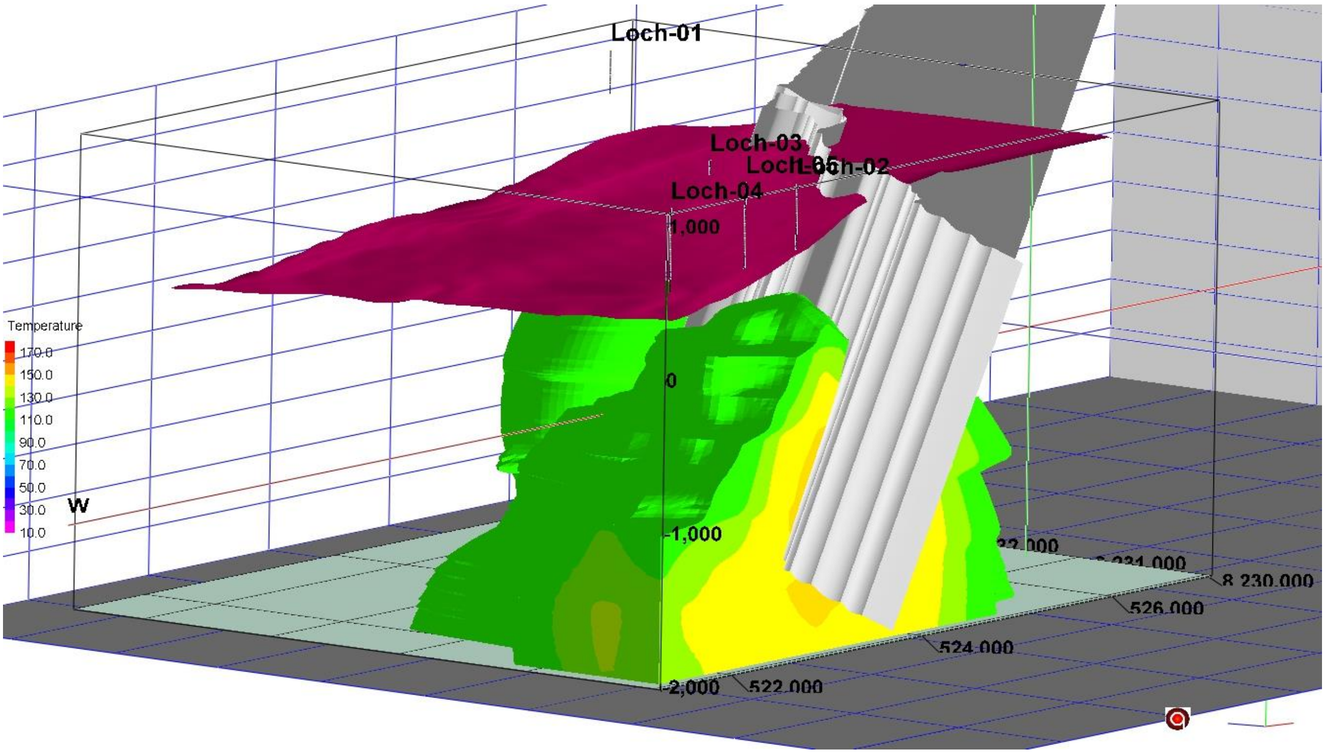

Figure 4. 3D Temperature model of the Bwengwa River Geothermal System using temperatures from gradient holes, hot springs and shallow surveys. The dark red surface is the top of the Proterozoic metamorphic basement; the grey surface is the Southern Bounding Fault. The temperature contours are colour coded according to the legend: the lowest temperature contoured is 110 $^0$C (bright green). The volume at 110 $^0$C is 10.8 km$^3$, at 120 $^0$C 7.5 km$^3$, 140 $^0$C, 4.0 km$^3$ and at 150 $^0$C the volume is 1.25 km$^3$. Spatial coordinates (x,y,z) in meters (WGS84).

## 5.4. Water

The presence of numerous hot springs and shallow aquifers suggest that water is sufficiently abundant in the Bwengwa River area to support a hydrothermal system and related development. During drilling of the temperature gradient holes, several highly productive aquifers were encountered.

Stable isotopic studies of the Bwengwa River thermal and non-thermal waters indicate that the source of the geothermal fluids is local meteoric waters suggesting high rates of recharge. Isotope plots typically indicate a marked variation in $\delta^{18}$O combined with the lack of variation in $\delta$D. This is generally interpreted as the exchange between rock and water at high temperature.

## 5.5. Geothermal Resource Capacity

Geothermal resource capacity has been estimated in several ways during the exploration phase. These have include: a) Monte Carlo simulations of the heat in place models for geothermal resource capacity (e.g. Nathensen, 1975, a, b, Garg and Combs, 2010, 2015), b) power density with Monte Carlo simulation (Wilmarth and Stimac, 2015; Cummings et al., 2016), and c) heat flow (or heat loss) (Richards and Blackwell, 2002; Wisian et al, 2001). The Bwengwa River Resource capacity estimates (Haizlip 2016) are summarized in Table 2 below.

Table 2. The Bwengwa River Resource Capacity estimates

| | **Reservoir Area** | **Reservoir Temperatures** | **MW** | | | |
|---|---|---|---|---|---|---|
| | km$^2$ | $^0$C | P90 | P50 | P10 | % confidence |
| Heat-in-Place | 2 to 10 | 130$^0$C to 170$^0$C | 7 | 16 | 32 | Assumes thermal conversion factor of 0.08-0.2 |
| Power Density | 2 to 10 | 130$^0$C to 170$^0$C | 6 | 19 | 57 | Power density of 2MW to 9 MW/km2 |
| Heat Flow | 7.45 | - | 23.5 to 26.5 | | | Based on temperature Gradients: reservoir capacity MW electrical =10xMWthermal |

The most commonly used method for estimating geothermal resource capacity for power generation is the heat-in-place model with power density as a common back-up. Heat flow or heat loss provides an important additional measure of potential heat. Similarities between the MW estimates at 50% confidence from heat-in-place and power density and the heat flow estimates provide strong reassurance that the Bwengwa River Geothermal Area contains sufficient heat to support at least a small to moderate sized geothermal power generation project. Additional exploration drilling will be required to confirm that the heat can be extracted by water at commercially reasonable rates.

### 5.6 Future Work Programme

In order to test the conceptual geothermal reservoir model for the Bwengwa River Geothermal Resource Area, further characterize the geothermal reservoir temperature, permeability, size and confirm initial estimates of reservoir capacity, the Company will drill up to four additional exploration holes. This drilling programme, which is to be undertaken this year, is planned to raise this to a Proven and Probable reserve for use in the intended feasibility study. These holes will be designed as slim wells and will be targeted to encounter 130°C to 150°C geothermal fluids near the top of the reservoir. If the wells and subsequent testing are successful, the results will be used in a feasibility study that could be completed by July 2017.

The Kafue Trough and environs are also highly prospective for additional geothermal resources similar to Bwengwa River; it is therefore considered realistic that ongoing exploration may well significantly increase the current estimated resource capacity. The most prospective of these are the Longola springs, which are evident along a strike length of 3.25km in a similar position along the northern margin of the Kafue Trough and are essentially a mirror image of the Bwengwa River springs.

## 6. SOCIO-ECONOMIC IMPACT

The only current application of geothermal energy within Zambia is artisan salt production. However any commercial development of geothermal power would create the opportunity for the integration of direct heat applications of thermal energy rejected by the power plant. Kalahari GeoEnergy is currently investigating such applications in the dairy industry that would have a positive impact on the pastoral, Bwengwa River community and on regional food security.

## 7. CONCLUSIONS

Zambia, while not previously recognized as a likely host to geothermal systems suitable for commercial power production should now being re-evaluated in light of Kalahari GeoEnergy’s work and results. The Bwengwa River Geothermal Resource Area contains compelling evidence of the three key elements required for hosting a hydrothermal system: temperature, permeability and water. Evidence for minimum reservoir temperature from 130°C to more than 150°C is provided by both the fluid chemistry and temperature gradient holes. Permeability is confirmed by the discharge of the hot springs along the regional bounding fault and the associated geologic structures. The reservoir is in fractured basement rocks at a shallow to medium depth adjacent to the bounding fault. The source of water is local meteoric water that is plentiful.

Results obtained during 2015 provide further confidence that Bwengwa River has a geological setting conducive for geothermal hydrothermal systems. Heat-in-place, power density and heat flow methods used, provide a consistent estimated usable resource capacity in the range of 10-20MW, which under the Australian Geothermal Resource and Reserve Code, would be currently defined as “Indicated”. There is a strong probability of a medium-low enthalpy geothermal resource that can support a power generation project of at least 10MW. The current indication of a 10MW, or greater, power project, to be generated using binary technology, represents a positive step towards the Company’s objective of producing geothermal power. Ultimately, geothermal power may provide a valuable component in Zambia’s drive to increase generation capacity and distribution.

The ongoing results from Bwengwa River provide the impetus for Zambia to develop the capacity to evaluate other geothermal targets as a part of its drive for energy diversification and increased generating capacity.

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