Proceedings, 7th African Rift Geothermal Conference
Kigali, Rwanda 31st October – 2nd November 2018

Aero-Magnetic Surveys for Geothermal Exploration in Malawi

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Keywords

Curie Depth, magnetic, heat flow, aero-geophysics

ABSTRACT

The geologic setting of Malawi shows potential of geothermal resources. However, information of the country's potential geothermal resources is limited. Malawi is on the western branch of the East African Rift System (EARS) and does not show any volcanism except at the northern tip where the rift is older. Here, the work reviews countrywide aeromagnetic data, its usage in geothermal exploration and how to estimate the Curie point depth (CPD). CPD is an isothermal surface at which magnetic minerals lose their magnetization and as such outlines an isotherm of about 580 °C. Spectral analysis is applied to the aeromagnetic data to estimate the CPD spatial distribution and findings used to explore for geothermal resources.

The calculated curie point depth of the Malawi Rift ranges from 17.8 to 27.5km. The estimated heat flow values range between 52 and 81 mWm^{-2}. In the northern part of the country, there are elevated heat flow values of > 75 mWm^{-2} due to partial melt of mantle fluids.

1. Introduction

In a bid to find more information on the geothermal resources of Malawi, in 2016, a geochemical reconnaissance study was conducted on 50 geothermal manifestations in Malawi by Electroconsult and the Malawi government. Chiweta and Kasitu prospects, found in the Northern part of Malawi, recorded the highest surface temperature of 79°C and 73.3°C respectively and further geophysical studies have been conducted on them by Electroconsult (2017). Although this work has advanced the knowledge of the resources in the country, there is still need for further studies.

Geothermal exploration is a multidiscipline process that integrates geology, geophysics, and geochemistry. By using the aero magnetic data, further information can be deduced to give a regional overview of the geothermal prospects of the country in relation to its geological characterisation in a cost-effective way. It is important to note that magnetic data analysis is just one component in the geothermal exploration. For more concrete results, information obtained from magnetic data analysis must be coupled with other geophysical studies like gravity and seismicity.

According to Njinju (2016), aeromagnetic data collected by the Government of Malawi between 1984 and 1985 through E-W transects with 1 km line spacing, 10 km tie lines, and 120 m terrain clearance. The magnetic data from the airborne geophysical data was merged into a total magnetic intensity grid and this was obtained from Council of Geosciences. The total magnetic intensity map shows much more detailed geological features.

This paper will consider how geophysical exploration methods, with concentration on magnetic data, obtained from aeromagnetic surveys has been used for geothermal exploration in Malawi. We will look at calculated Curie point depths and heat flow that were derived from aero-geophysical survey data acquired in 1984 acquired by the Malawi government and how we can use the same principle and apply them to new data.

2. Geological Setting of Malawi

Malawi lies almost entirely within the late Precambrian to early Palaeozoic Mozambique Orogenic Belt (MOB) Carter & Bennet (1973). In the northern part of the country, it falls within the triple junction of mobile belts, namely the Usagara belt to the NE, the Ubendian belt to the NW and the Irumide belt to the SW (Fig. 1). The Mozambique orogenic belt (MOB) is one of the intercratonic regions affected by the Pan-African (± 500 m.y.) thermo-tectonic episode and at its climax, produced high grade granulites and migmatites in some localities. Successively, during late Paleozoic and Mesozoic periods, some extensive basins were formed and filled with sediments, known as the Karoo System. According to Delvaux (1995), tectonic activities and rifting continued to recent times and formation of basins and ranges took place, including the formation of Lake Malawi as the southward propagation of the East African Rift.

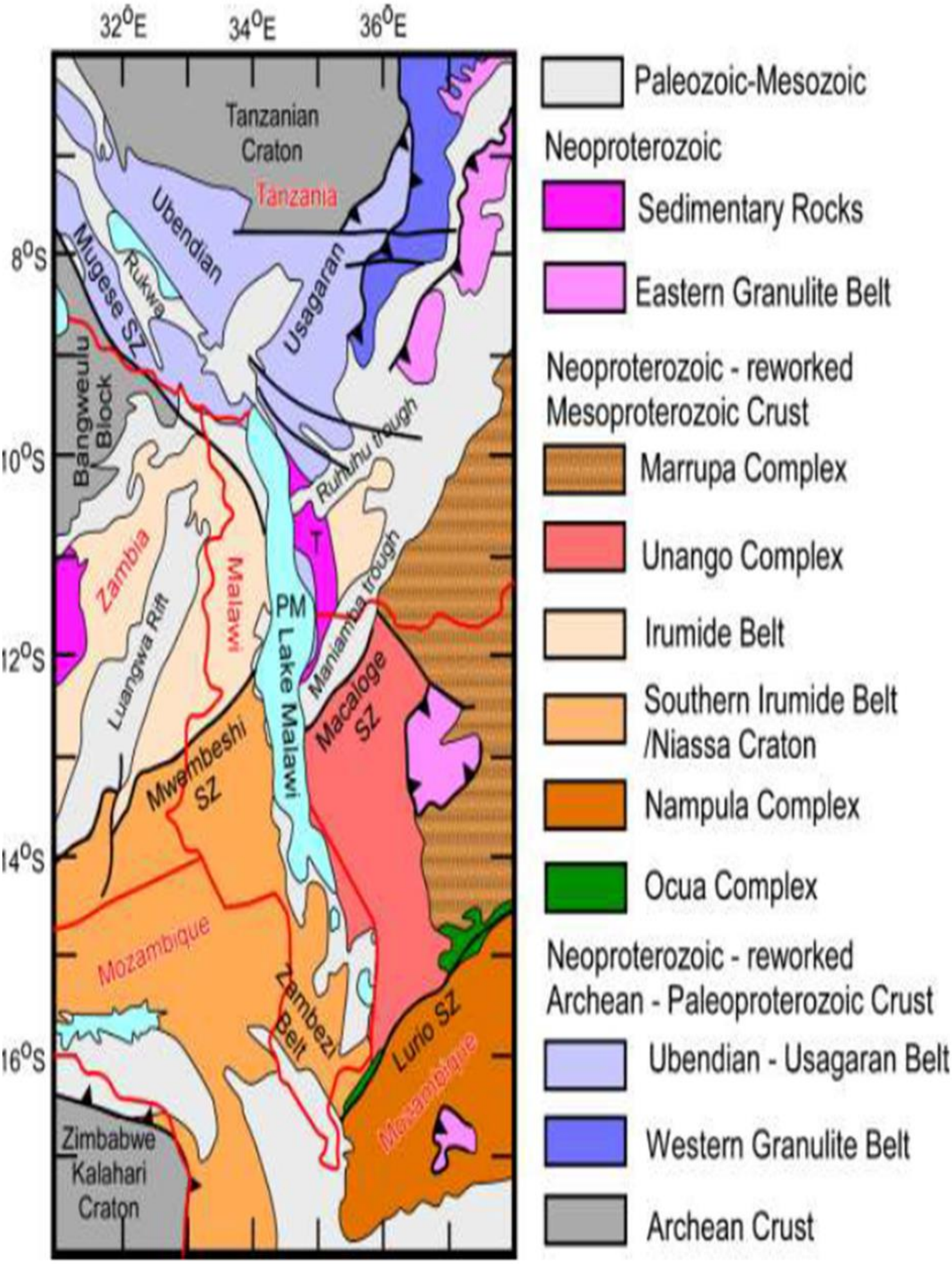

Figure 1 Tectonic map showing the exposures of the Precambrian and Paleozoic-Mesozoic units around the Malawi Rift. (Njinju 2016)

3. Structural Setup

The Western branch of the EARS lies in Malawi and Tanzania. According to Chorowicz (2005) It extends over 2100 km from Lake Albert in the north, to Lake Malawi in the south, Chorowicz(2005). It comprises several segments: the northern segment includes Lake Albert, Lake Edward, and Lake Kivu basins, turning progressively in trend from NNE to N–S; the central segment trends NW–SE and includes the basins of lakes Tanganyika and Rukwa; the southern segment mainly corresponds to Lake Malawi and small basins more to the south. Most of the great lakes of Eastern Africa are in the rift valleys, except notably Lake Victoria whose waters are maintained in a relative low area between the high mountains belonging to the eastern and western branches.

The Malawi Rift, is a southern extension of the western branch of the East African Rift system as illustrated in Fig. 2. It extends for about 900 km, from the Rungwe volcanics in southern Tanzania to the Middle Shire River. The rift structures extend for a further 600 km to the south by the Urema graben and Dombe trough in Mozambique. The Malawi Rift, which is largely occupied by Lake Malawi, consists of a series of half grabens. The extensional basins of the Western Rift show distinct and highly elevated rift flanks. Ebinger (1989), each half-graben is associated with a clearly defined deposition center and a highly uplifted footwall flank; the ramping side of the basins show less topographic elevation. The topography generally rises to over 2 km. on the footwall side of the basins adjacent to the border faults, whereas the elevation difference on the ramping sides amounts to some hundreds of meters, enhancing basin asymmetry.

Earlier work by Fairhead and Stuart (1982), Bungum and Nnko (1984) ton the continuity in topographic and seismicity trends support that the seismically active Malawi rift is a southern extension of the Western Branch of the EARS. Furthermore, Studies of g the seismicity byNolet and Mueller (1982) and gravity data by Fairhead and Reeves (1977) and Brown and Girdler (1980) show that the crust beneath the Western Branch has been thinned. In contrast to the characteristic of the Kenya rift system in the eastern branch?? t, volcanism in the Malawi Rift is restricted to alkali volcanics at the northern end of lake Malawi, Harkin (1960). The Precambrian ductile deformations, as observed in the basement metamorphic rocks are important, since their rejuvenations brought about important younger structures, which may have important bearings in the search for geothermal systems according to Ring (1994).

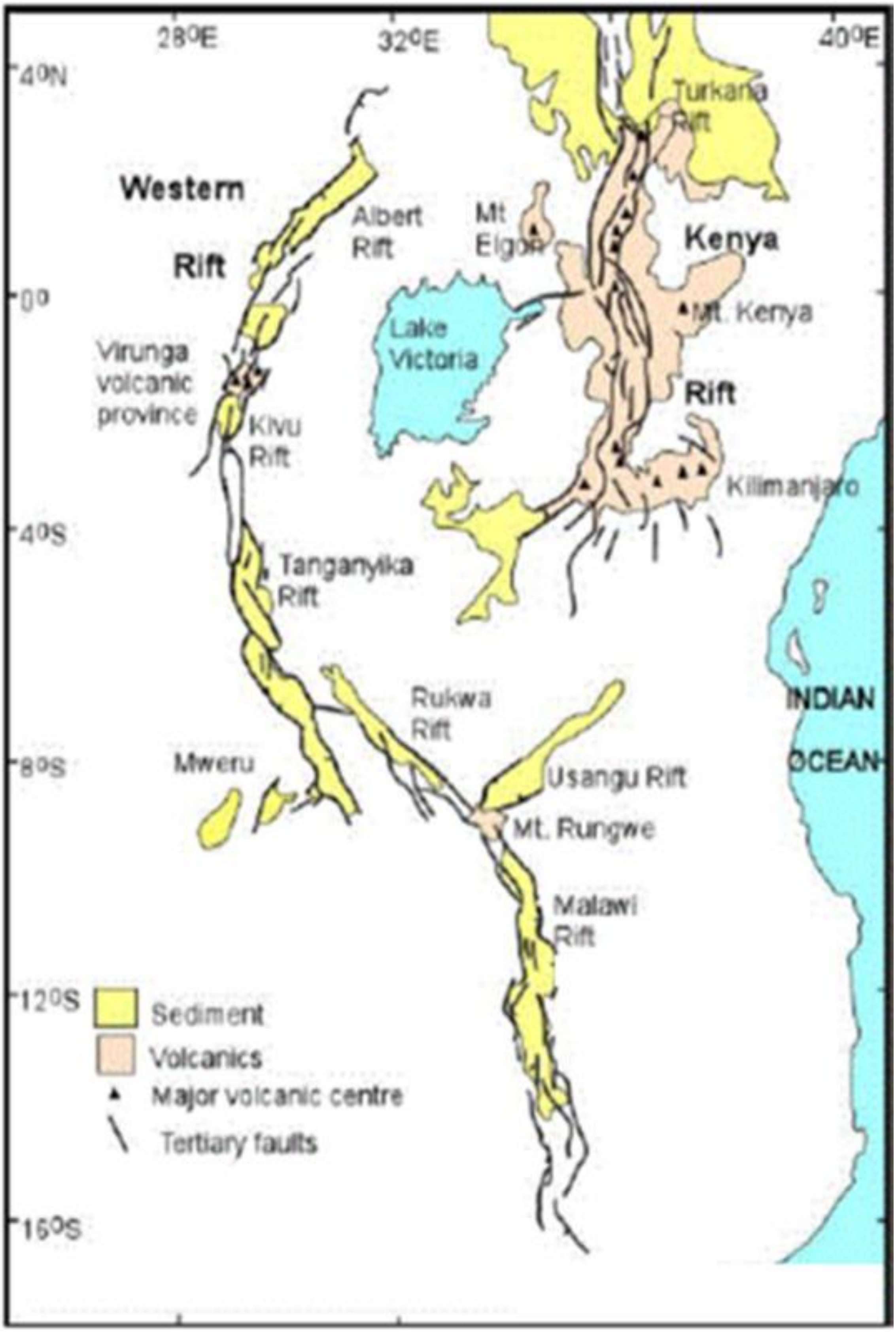

Figure 2: Map showing the Western Branch of the East African Rift Valley System (Omenda, 2010)

3. Methodology

3.1 Magnetic Survey

Hinze and Frese (1990) state that the application of the magnetic method to geothermal exploration is aimed at locating subsurface intrusive bodies, finding areas with reduced magnetisation which can be caused by thermal activity and possibly estimating their depth, tracing buried dykes and faults. The process requires a multiple step process involving data acquisition, data reduction, anomaly isolation, and geologic interpretation. In the data acquisition phase, considerations must be given to observing the data at a detail and a precision which allows for an appropriate interpretation. The data must be acquired over a broad enough region so that the anomalous features can be isolated from the background magnetic signatures.

3.2. Curie Point Depth and Heat flow

Curie temperatures are used to estimate the subsurface temperatures. The Curie point depth (CPD) is the depth at which materials within the crust and upper mantle, reach their Curie Point or temperature at which magnetic minerals lose their ferro-magnetization to become paramagnetic. According to Ross et al. (2006) The recorded temperature is at 580 ºC for magnetite. The CPD is related to either heat flow or geothermal gradient, or to the thermal properties of the lithosphere.

It is important to note that temperature increases with depth due to the local geothermal gradient and therefore, curie depth will reflect the local geothermal gradient. Curie temperatures can show the state of geothermal without drilling and other direct exploration methods. The variation in the CPD will also provide information of the geological boundaries based of the variation in signature and inform on different mineralogy of the rocks.

Spector and Grant *(*1970) and Tanaka et al., *(*1999) state that the CPD can be estimated using a statistical method which relates the 2D radially average power spectrum of magnetic anomalies to the depth of the magnetized sources in the magnetic data. This is a preferred method for regional data manipulation.

Previous studies [e.g., *Okubo et al.,* 1985] showed from the calculated 2D radially averaged power spectra, that the CPD values can be estimated by:

(1) Determining the depth to the top (Zt) of the magnetized crust by plotting (ln [Power spectrum]) against the wavenumber (*k*) and calculating the slope of the linear fit at the higher wavenumber portions of the curve;

(2) Determining the depth to the centroid (Zc) of the magnetized crust in a similar fashion by plotting (ln [power spectrum/|*k*|]) against *k* and calculating the slope at the lower wavenumber portions of the curve.

The CPD or depth to the base of the magnetized crust, Zb is given by:

$$Zb = 2Zc - Zt$$

The geothermal gradient (dT/dz) between the Earth's surface and the CPD (Zb)was defined by Tanaka et al (1999) as:

$$dT/dz = 580\ °C / Zb;$$

4. Results

Njinju (2016), calculated Curie point depth beneath the Malawi Rift to be between 17.5 and 27.5 km and the heat flow values range between 59 and 81 mWm-2. This is illustrated in figure 2 and 3.

From the Fig. 3 and 4, there is a NE high heat flow (70-81 mWm-2) that extends beneath the rift centre, to the Ruhuhu and Maniamba troughs in Tanzania and coincides with CPD values of 18-20km. There is a region of high heat flow (70-81 mWm-2) beneath the Rungwe Volcanic Province at the northern tip of the rift but with no surface geothermal manifestation. Further south, near the Lurio shear zone, heat flow ranges between 65- 67mWm-2

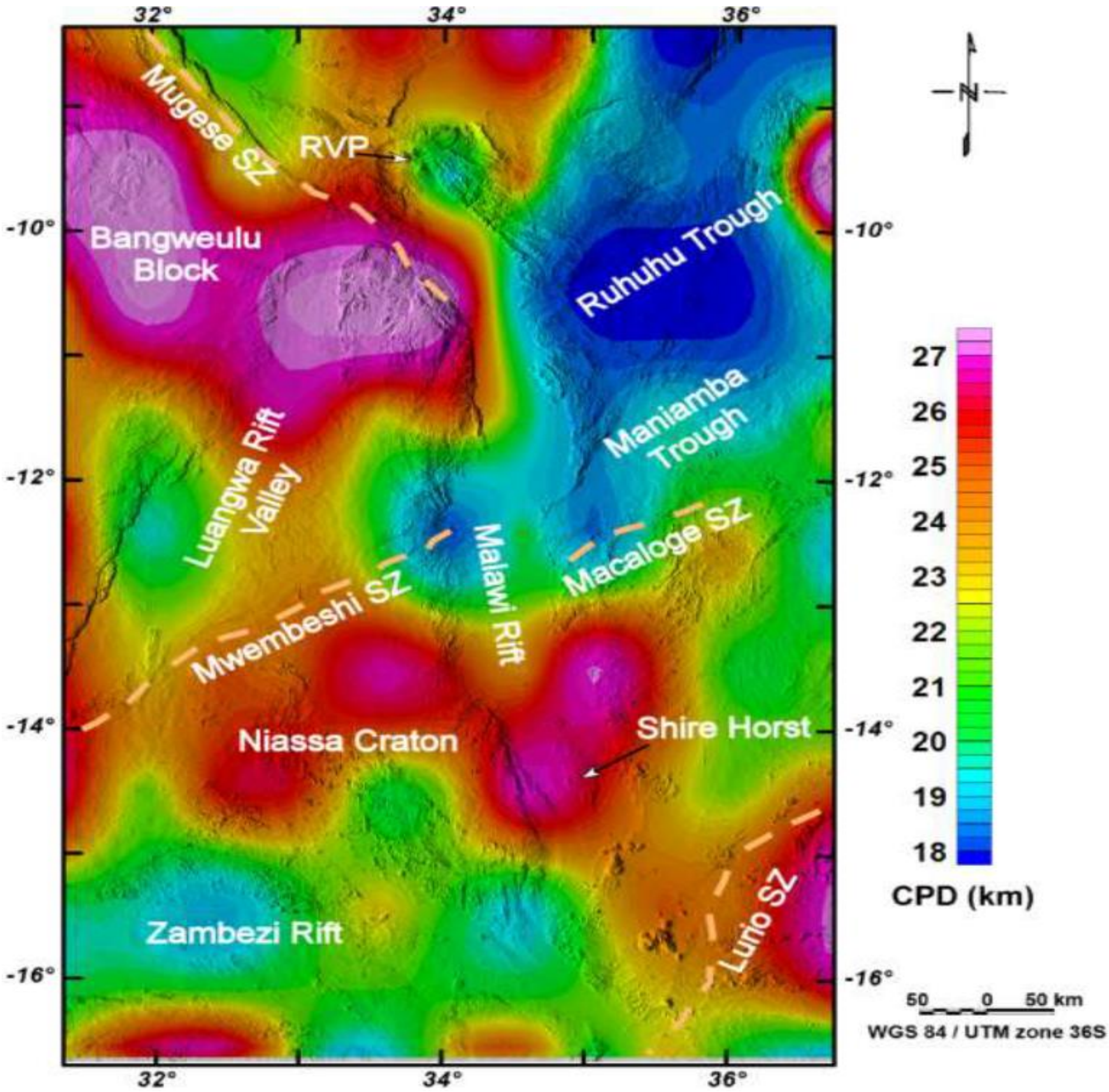

Figure 3: Curie Point Depth Map of Malawi and surrounding areas. (Njinju, 2016)

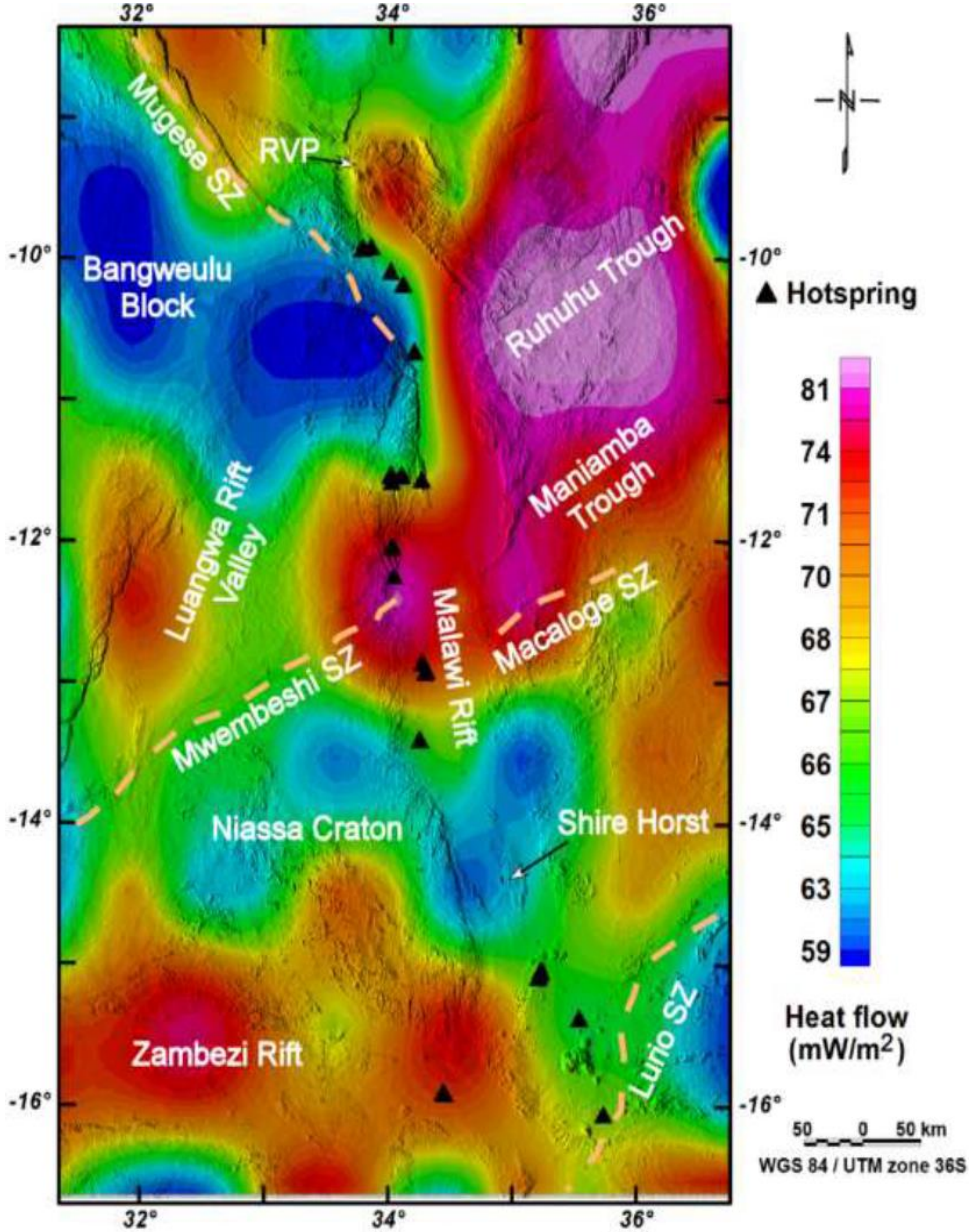

Figure 4: Heat flow and hot spring location map. (Njinju,2016)

4. Discussion

Shallow CPDs (18- 21km) identified, are in areas of border faults of the Malawi rift. The geothermal manifestations in Malawi exist along the rift boundaries as stated by Ebinger et al. (1989). Therefore, there is a reasonable evidence that one of the main controlling factors in the formation of some geothermal systems are major fault systems. Such faults zone creates permeable routes through which hot fluids may migrate around.

According to Njinju (2016) regions of high heat flow are coincident with the Karoo-aged rift basins. Literature on the Karoo Supergroup of Malawi states that it is composed of terrigenous epicontinental sediments dating from the Permian to the Upper Triassic (300–200 Ma) deposited unconformably on the basement complex. In Malawi, the Karoo sediments occur in two distinct areas: in the far north and in the far southeast of the country. This is true for the geothermal prospects with highest temperatures found in Malawi as observed in the Heat flow map as shown in Figure 3. The Chiweta prospect is found NE of the Mugese shear zone in a Karoo environment with mudstones and sandstones. The same applies to the hot springs found at the southern tip of the Malawi rift.

5. Conclusion

Malawi has made progress in geothermal resource exploration. However, there is a lot of work that needs to be done for more feasible information. The new high resolution airborne geophysical (2013) was acquired by Sanders Geophysics Limited and can be processed for more specific CPD values along the Malawi rift system to verify and add on to the works done at regional level along the western branch of the EARS. There is need for the Geological Survey Department to dedicate resources to acquire software that can run extension MAGMAP filters that are used to calculate CPD. By calculating the curie depths for geothermal prospects on a local scale, the country will have taken a step closer in the development of geothermal energy. There is also a need to dedicated drilling programs or advanced technologies for geothermal reservoir characterizations for low temperature systems as supported by previous work.

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