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Malawi Geothermal Potential

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ABSTRACT

The Government of Malawi (GoM) through the Ministry of Natural Resources, Energy and Mining (MoNREM),received funding from the International Development Association (IDA) of the World Bank to support the implementation of the Malawi Energy Sector Support Project (ESSP). The objective of the project is to increase the reliability and quality of electricity supply in Malawi, since the country's power generation derives almost exclusively from hydro projects exploiting the resources of the Shire River, located in the southern region of the country, and the Wovwe River in the northern region. The ESSP is expected to build capacity in the electricity generation subsector by bringing about diversification in the use of alternative sources of energy for power generation, including the possibility of generating power from wind, solar, thermal (using coal), biomass obtained through sugar, tea and timber processing and from geothermal sources. Regarding the latter potential sources, some 25 sites of geothermal manifestations have been reported in Malawi in the past. This paper gives highlights of current geochemistry and geophysics surveys that have been conducted on geothermal manifestations in Malawi. It also highlights development of human capital working in the geothermal sector

1. INTRODUCTION

To stimulate the geothermal development in Malawi, Ministry of Natural Resources Energy and Mining (MoNREM) started work to re-evaluate geothermal resources in August 2014. In February 2016 the contract between the Ministry of Natural Resources, Energy and Mining (MoNREM), on behalf of the Government of the Republic of Malawi, and ELC-Electro-consult was signed and work begun to assess the Geothermal Resources in Malawi.

Following an analysis of all the available technical documentation, all the thermal manifestations of the country were visited in order to get a general assessment of their geological setting and to collect water samples, which would provide indications on the origin of the fluids and on the underground temperatures. At conclusion of this stage, rank was assigned to these manifestations according to the probability that the manifestations are the surface expressions of a geothermal system. Ranking was based on technical grounds, but also took into account non-technical factors, such as morphology, accessibility, land use, environmental and social framework and distance from the national grid.

In accordance with the established ranking, 6 prospects were then selected, to be covered by more detailed investigations, which included remote sensing studies, geological mapping and geochemical sampling of waters and gases. A new ranking was defined at the conclusion of the investigations, taking again into account, besides the technical aspects, also non-technical ones. Through the combination of these aspects, two prospects were then singled out for more detailed efforts for their assessment.

The two singled out prospects were subjected additional geoscientific investigations, which include detailed geological and geochemical survey and more specifically geophysical (magnetotelluric/transient electromagnetic (MT/TEM) and gravimetric) surveys. These prospects are what will be discussed in this paper.

2. GEOLOGICAL SETTING OF MALAWI

Malawi lies almost entirely within the late Precambrian to early Palaeozoic Mozambique Orogenic Belt (MOB). To the north, it falls within the junction of three mobile belts, namely the Usagara belt to the north east, the Ubendian belt to the north west and the Irumide belt to the south west. The interaction of these mobile belts forms a complex system of structures and control the lithological configuration of Malawi. The MOB is one of the intercratonic regions affected by Pan-African (± 500 m.y.) thermo-tectonic episode and at its climax produced granulites and migmatites in some localities. Successively during late Paleozoic and Mesozoic periods, some extensive basins were formed and filled with continental sediments, known as the Karoo System. 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.

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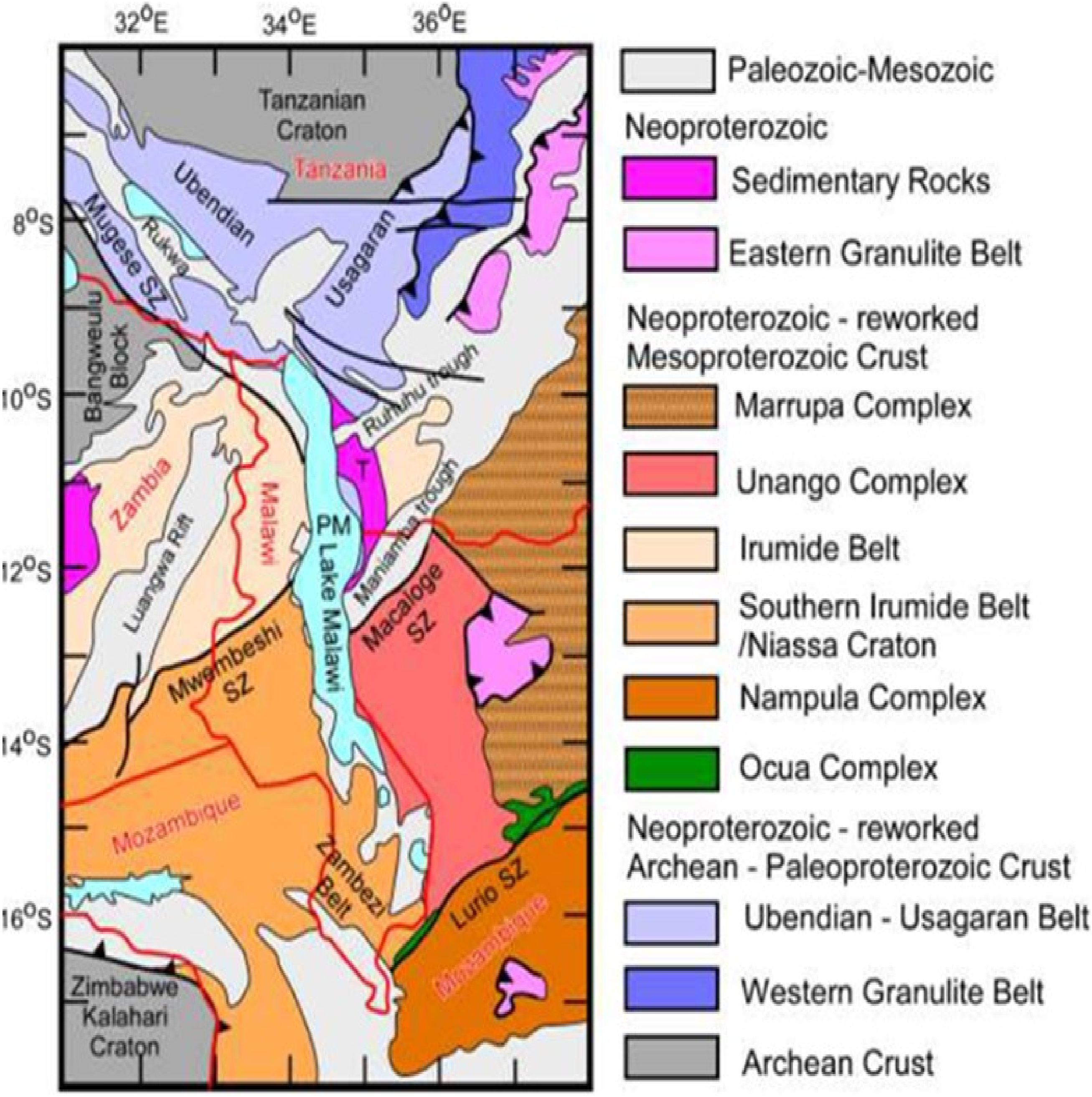

Figure 1: Position of Malawi on the regional geological map

3. STRUCTURAL SET-UP

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) on 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 the seismicity by Nolet 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, 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).

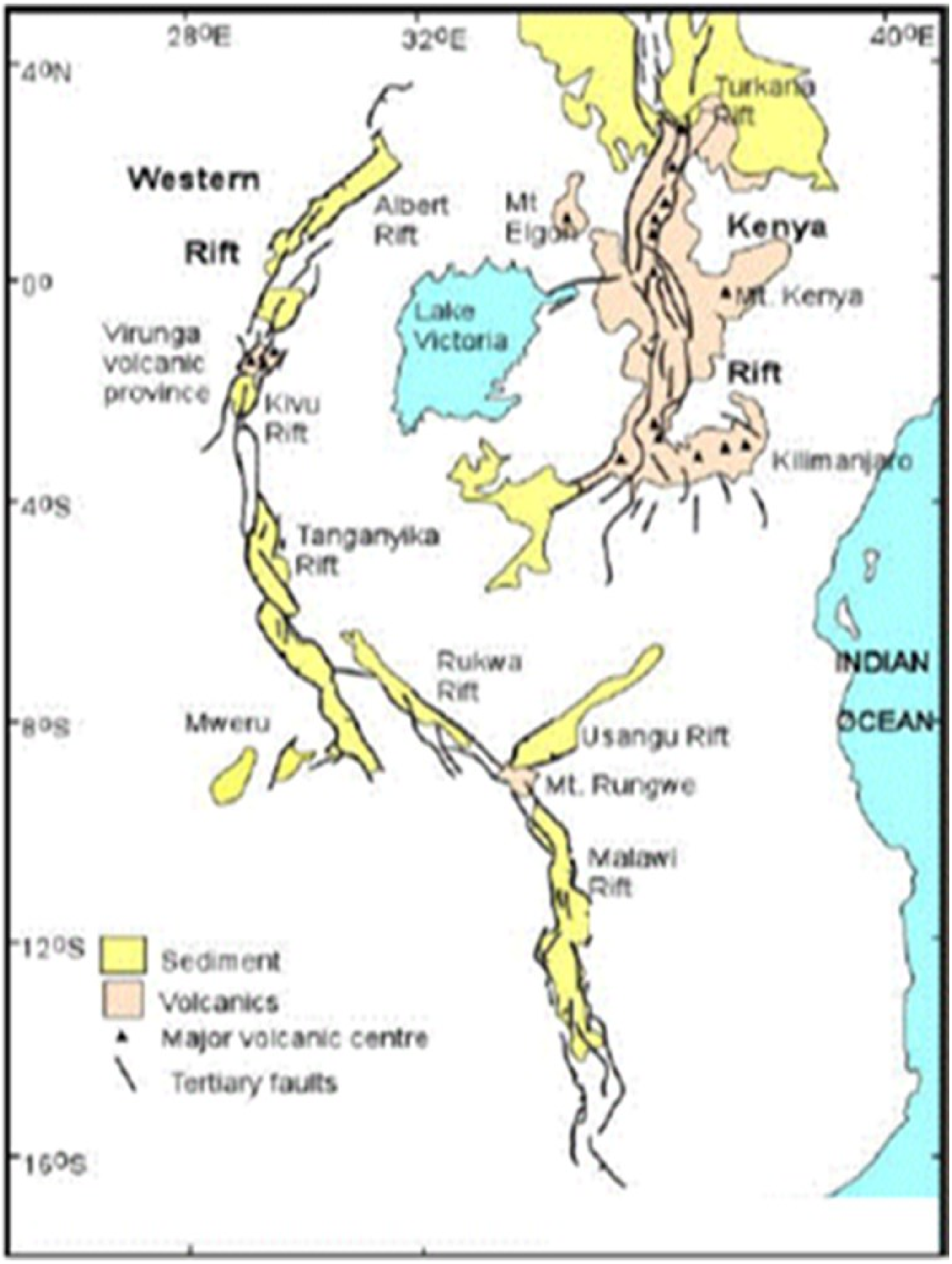

Figure 1: Map showing the Western Branch of the East African Rift Valley System (Omenda, 2010)

GEOCHEMICAL STUDIES ON CHIWETA AND KASITU PROSPECTS

The Chiweta prospect is located in the Rumphi district in the Northern Region of Malawi. For the Chiweta prospect a total of six samples were collected from two hot springs and a stream for geochemistry studies. Temperature, pH, Eh, total alkalinity and electrical conductivity were measured in the field by means of portable instruments. Below are tables that show saturation temperatures with hydrothermal minerals and geothermometers of Chiweta and Kasitu prospects.

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Table 1: Saturation temperatures with hydrothermal minerals for Chiweta prospect (Chiweta Assessment Report, 2017, page 35)

Sample	Name	Outlet Temp	Chalcedonay	Quartz = Albite	K-Faldspar	Illite	Beidellite-Ca	Paragonite	Clinozoisite	Clinochlore
		°C	°C	°C	°C	°C	°C	°C	°C	°C
MLW-7A	Chiweta-1	79.4	109	136	145	146	135	133	159	-
MLW-7B	Chiweta-2	70.1	103	131	141	141	129	128	151	-
MLW-51	Chiweta-1	79.1	102	130	139	135	130	129	123	139
MLW-52	Chiweta-1B	79.2	104	132	140	135	132	131	127	120
MLW-53	Chiweta-2	78.8	99	128	138	134	120	121	131	-
MLW-54	Chiweta stream	64	91	122	135	126	107	110	131	-

Table 2: Geothermometers of Chiweta prospect (source: Chiweta Assessment report, 2017, page 33)

Sample	Name	Sampling Date	T chal	T SiO_2	T qz	T K-Mg	T Na-K,F	T Na
			°C	°C	°C	°C	°C	°C
MLW-7A	Chiweta-1	30/04/2016	115	124	141	128	174	192
MLW-7B	Chiweta-2	01/05/2016	110	119	137	129	175	192
MLW-51	Chiweta-1	04/09/2016	107	115	134	174	171	189
MLW-52	Chiweta-1B	04/09/2016	109	117	136	187	169	187
MLW-53	Chiweta-2	04/09/2016	108	116	135	132	173	191
MLW-54	Chiweta steam	04/09/2016	106	114	133	136	181	198

Table 3: Saturation temperatures with hydrothermal minerals for Kasitu prospect (Kasitu Assessment report, 2017, Page 8)

Sample code	Name	Outlet Temp	Chalcedony	Albite Quartz	Clinozoite	Beidellite-Ca	K-Feldspar	Paragneiss	Illite
		°C	°C	°C	°C	°C	°C	°C	°C
MLW-20A	Kasitu-1	73.3	77	111	114	112	114	115	123
MLW-20B	Kasitu-2	75.1	82	114	87	120	118	121	130
MLW-47	Kasitu-1	74.5	66	104	103	96	111	102	112
MLW-48	Kasitu-2	76.2	72	107	91	102	112	107	118

Table 4: Geothermometers of Kasitu prospect (Kasitu Assessment report, 2017, Page 8)

Sample code	Water point name	Outlet Temp	T Chal	T SiO_2	T qz	T K-Mg	T Na-K, F	T Na-K,G
		°C	°C	°C	°C	°C	°C	°C
MLW-20A	Kasitu-1	73.3	100	108	128	90	114	135
MLW-20B	Kasitu-2	75.1	98	106	126	95	128	148
MLW-47	Kasitu-1	74.5	99	107	127	103	126	146
MLW-48	Kasitu-2	76.2	99	107	127	88	119	140

The hot springs of Chiweta represent the discharges of a thermal circuit, which is partly hosted into the fractured rocks of the crystalline basement and partly developed in the overlying sedimentary rocks of the Karoo System. The saturation temperature with several hydrothermal minerals indicates reservoir temperatures between 130 and 159°C for the Chiweta geothermal system. These temperatures are consistent with the highest apparent equilibrium temperatures given by the H_2-Ar and H_2-N_2 gas geothermometers as well as with other qualitative evidences, such as the presence of an oxygen isotope shift, though small, and the high CO_2/N_2 ratio of dissolved gases. These characteristics make Chiweta unique among the thermal waters of Malawi and a potential to develop the sight for energy production.

GEOPHYSICAL STUDIES ON CHIWETA AND KASITU PROSPECTS

The gravity and electromagnetic surveys were conducted on the Chiweta and Kasitu to study the subsurface conditions. For the gravity survey, a total of 95 gravity stations were setup for Chiweta and 97 for Kasitu, within the focal area, arranged over a rectangular grid with nominal station inter-spacing of 0.8 km and covering a surface of about 50 km^2. Stations were located with a 60 m tolerance from the ideal position. There was care taken to collected usable data by having a quality control system of the equipment. The gravity meter was switched on and reached the working temperature (50.4 °C) three days before the start of the survey. It was maintained at the working temperature without any interruption during all the survey. During car transfers, the meter was always carried on the knees of the operator to reduce vibrations. During transfers by feet, the meter was carried in a sack on the shoulder of the operator. During each measurement, the meter was protected from sun direct exposition. The global navigation system was calibrated to account for differential static measurements.

CONCEPTUAL MODEL OF THE CHIWETA PROSPECT

On the base of the results derived from the geological, geochemical and geophysical investigations, the geothermal model of the Chiweta and Kasitu prospect can be constructed.

The tectonic setup of the Chiweta prospect is dominated by the presence of major NW-SE trending faults, which extend for tens of kilometres and control the formation of the basin filled by the Karoo products, together with the transversal NNE-SSW system, which delimits the basin to the north-west and determined the development of a graben-horst pattern within the basin. This structural setting favours the deep circulation of waters, which tend to infiltrate in the highlands and to flow in a general SE direction towards the Malawi Lake. In the area proper of the manifestations a small graben (Chiweta graben) can be recognized, oriented in accordance with the regional NW-SE trend. The NE border of the graben is associated with the manifestations and the SW one (poorly visible on surface) with important sinter deposits, witnessing the rejuvenation of the tectonic and hydrothermal activity. A similar indication is provided by the density of the lineation, exhibiting concentrations along the major fault belts, in particular in correspondence of the manifestations zone.

The tectonic setup of the prospect is dominated by the presence of major N-S faults related to the Malawi Trend, which extend for several kilometres and are spaced on average 2-3 km. These faults are of normal type with a high dip angle and eastern downthrow, causing a progressive lowering of the Basement Complex towards Lake Malawi, which on its turn represents the central portion on the Malawi Rift.

The Chiweta and Kasitu geothermal system, are located within a continental rift in a region of active tectonism, belong to the convection-dominated play category. According to Moeck the extensional domain (Fault-controlled) play acts on the Chiweta and Kasitu. In this case, the mantle is elevated due to crustal extension and thinning, thus providing the principal source of heat for geothermal systems associated with this play type. The resulting high geothermal gradient facilitates the heating of meteoric water circulating through deep faults or permeable formations.

The geological study conducted in the course of the present project found no surface evidence of the existence of an adequate heat source which might be related to either magmatic or plutonic activity. In fact, the closest recent volcanic activity recognized in the area occurs in the Rungwe Volcanic Province, located in the southern portion of Tanzania, some 150 km NNW of Chiweta.

Under this situation, the Chiweta and Kasitu prospect can be classified as extensional domain play, that is a play where the principal source of heat is provided by the elevated mantle. Extensional domain plays can be either fault controlled or fault-leakage controlled which is the case of the Malawi prospects. In purely fault controlled play systems, convection occurs along the fault and is commonly combined with infiltration of meteoric water along the fault. In fault-leakage controlled play systems, the fluid leaks from the fault into a permeable concealed layer expanding laterally. It may be observed that in the fault-controlled play temperature is gradually increasing at well site, whereas in the fault-leakage controlled one a temperature reversal is encountered below the reservoir horizon.

CAPACITY BUILDING

Geothermal development requires a multi-disciplined approach for serious development to be achieved. The major technical competences or disciplines that are required for geothermal development include geology, geochemistry, geophysics, reservoir engineering environmental science, geothermal engineering finance and management. Malawi through the United Nations University - Geothermal Training Program (UNU-GTP) and Kenya's geothermal fraternity has managed to train scientists and engineers in the geothermal energy field. By 2019, Malawi has managed to send 18 engineers and scientist to Kenya for training in geothermal surface exploration and from the, 4 have gone further with the 6 months specialized training in geothermal utilization and geology at UNU-GTP in Iceland. Malawi needs to develop its technical capacity through specialized geothermal training programmes. With the increased number of those trained, more work is being done to increase the information on the geothermal resources of Malawi even though the development is affected by no access to processing computer software.

CONCLUSION

From the results presented on the geological, geochemical and geophysical studies, it is recommended that Malawi should explore Low- Temperature geothermal power. Low temperature geothermal power uses resources below 149°C to generate electricity, usually through the use of a secondary fluid. The use of low temperature is gaining popularity as it is more accessible being close to the surface than high temperature reservoirs and relies on natural geothermal gradient. However, the equipment used to drive this power is more costly than that of high temperature power generation. There is also need for the Malawi government and partners to plan for a drilling project that will develop real time data of temperatures deep in the earth's crust at the Chiweta and Kasitu prospect.

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