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Results of 1-Meter Soil Temperature Survey Conducted at Butajira Geothermal Prospect, South Ethiopia

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ABSTRACT

This paper presents the result of near surface (1 meter) soil temperature measurements carried out at Butajira Geothermal prospect, which is about 150 km south of Addis Ababa and about 20 km southeast of Butajira town, on the Marginal plane of Main Ethiopian Rift called Ashute. Hot springs and mud pools with a maximum measured temperature of 98 °C are the surface geothermal manifestations of the survey area. Measurements were carried out in vicinity of the manifestations, enclosing a 2.3 km x 3.5 km area. Results from the soil temperature distribution of the area shows anomalies with a general direction of NE-SW; while deep insight into the temperature profile distinguishes about three structures that are oriented to the NE-SW, NNE-SSW and N-S directions. These striking directions coincides with the direction of the main Ethiopian rift margin and Debrezeyit - silti active tectonic lineament. The alignments of the temperature anomalies are in line with the direction of the geothermal manifestations. This implies that the presence of a hidden fault associated with the general NE-SW rifting direction, along the flat plain Ashute area.

1. INTRODUCTION

Measuring the near surface soil temperatures in the early stages of geothermal exploration can increase the efficiency of a geothermal exploration program by locating thermal anomalies at an early stage of exploration, mapping thermal aquifers, and by reducing the number of gradient wells needed, thereby reducing costs (Sladek. et al., 2007).

Butajira geothermal prospect is the newly discovered prospect among the 23 geothermal prospects that are found throughout the Ethiopian rift system, as a result, it is under the first stage of surface exploration.

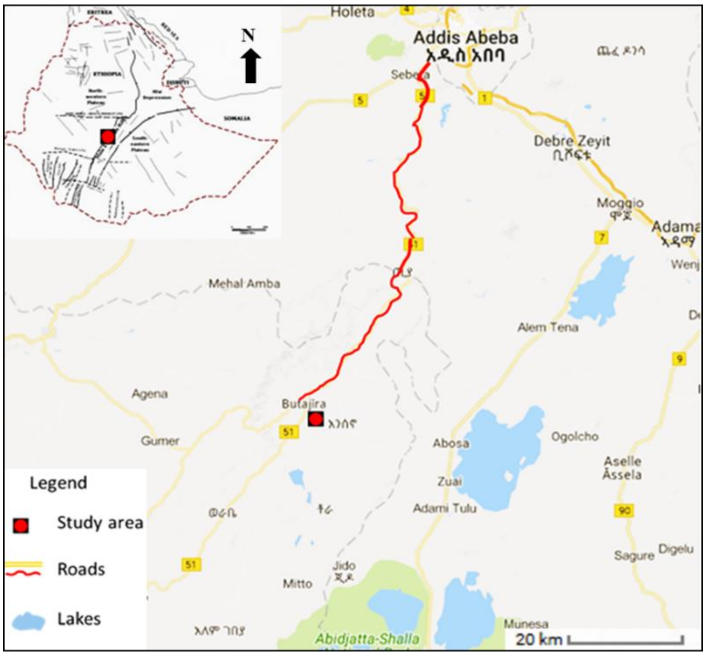

Figure 1: Location map of Butajira Geothermal Prospect area.

Butajira geothermal prospect is located on the western margin of the main Ethiopian rift system. Butajira town is about 150 km south of Addis Ababa and the prospect area is about 20 km southeast of Butajira (figure 1). The prospect lays on the area called Ashute, which is the lowest flat plain surface in the area, with an elevation between 1819 and 1846 m above sea level.

The area is thermally active, and the surface hydrothermal manifestations are limited to hot and warm springs and mud pools (figure 2) with temperatures reaching up to 98 °C. There is also occasionally a voluminous geyser interacting with mud, and erupts following raining (figure 2). The plain of Ashute study area is covered by fertile soil, calcium carbonated soil, and grassy swamp where the manifestations are situated. Hydrogeologically, it is very rich in groundwater resources that drain from the Guraghe highland to the plane area in the major aquifers of pyroclastic deposits, and older fractured volcanic rocks of rhyolites and basalts of the escarpment (MOWR, 2008).

Figure 2. Pictures showing thermal manifestations; mud pools and geyser on the survey area.

The aim of the survey was to conduct 1 meter temperature measurement on and around the manifestation area in order to outline thermal anomalies in the early stages of exploration, to roughly delineate structures and their relationships with the existing exposed structures, and to sweep the way for the next stage of geothermal exploration.

2. GEOLOGICAL BACKGROUND

The onset of the Main Ethiopian rift system dates back to Miocene time (eg. Wolfenden et al., 2004; Chernet et al., 1998; WoldeGabriel et al., 1990). During Pliocene, it progressively deepened forming intense volcanism and a sequence of half graben, from both margins, continuing to Quaternary. The recent activity on the Main Ethiopian rift system is characterized by the NNE-SSW trending en-echelon normal faults, and the Wonji Fault Belt that obliquely cuts the axial zone/rift floor (eg.Ebinger and Casey, 2001; Boccaletti et al., 1998).

The rift margins are characterized by tertiary volcanic rocks, except for some locations where it associated with Precambrian basement and Mesozoic sediments, as in the western rift of Kella horst (WoldeGabriel et al., 1990). The floor of the Main Ethiopian rift is dominated by younger basaltic fields, silicic domes and calderas interlayered and covered with Plio-Quaternary fluvio-lacustrine sediments (e.g. Chernet et al., 1998; WoldeGabriel et al., 1990).

The Eastern margin of the Main Ethiopian rift is marked by the high-angle, W-dipping, and segmented border faults, with an overall direction of strikes about NE-SW (Boccaletti et al., 1998) and is well developed in the western margin.

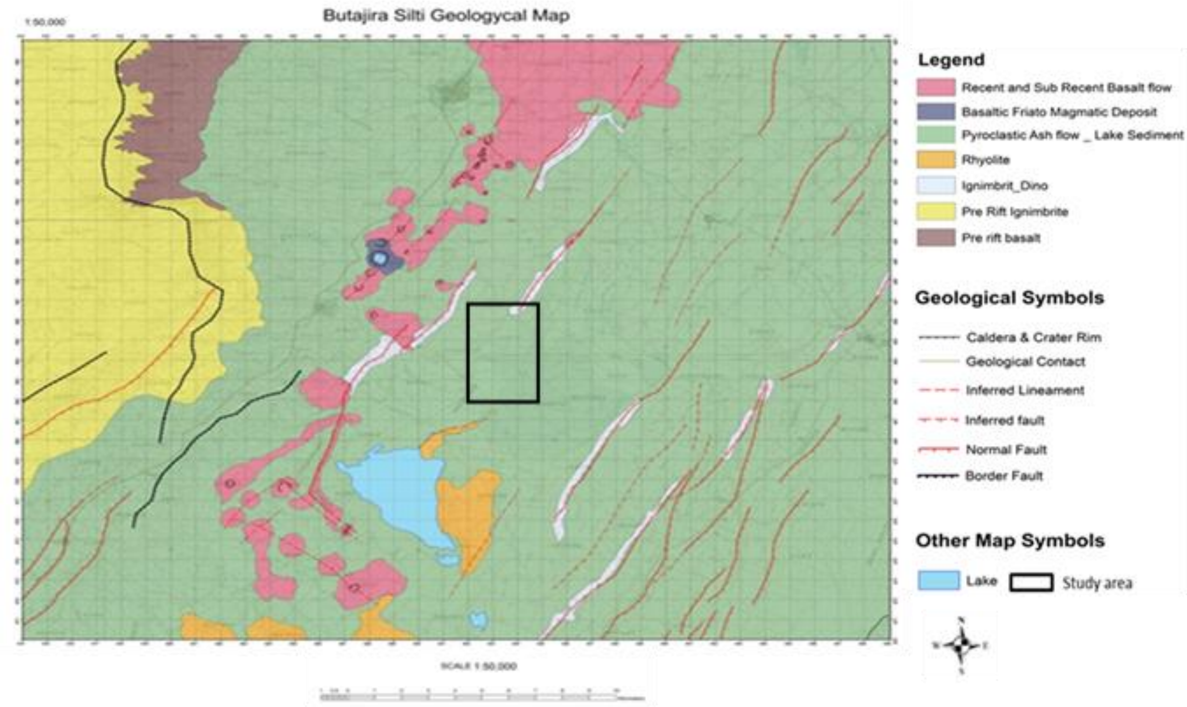

Figure 3. Geological Map of Butajira area (modified from GSE, 2017).

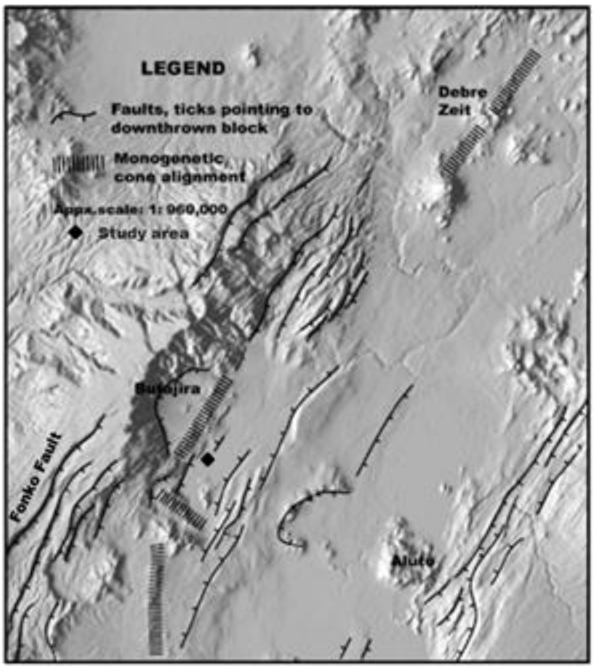

Figure 4. Western margin of the Main Ethiopian Rift shows Faults and clusters of cinder cone along the off-axis belts (Abebe et al., 2007).

The Western boundary is oriented to the general direction of NE-SW with transverse faults of different orientation (figure 4). Butajira volcanic area is part of the central sector of the main Ethiopian rift system, situated near to the western boundary. The marginal graben at Guraghe fault escarpment, close to Butajira, is formed during late Miocene by 9.7 Ma (WoldeGabriel et al., 1990); and is mainly defined by a few, but large, high angle normal faults (Agostini et al., 2011b; Boccaletti et al., 1998; WoldeGabriel et al., 1990), with spacing of about 5 km and vertical offset up to ~700–1000 m (Agostini et al., 2011b). The Guraghe fault escarpment is a narrow deformation belt marked by SE-dipping step faults and minor NW-dipping transverse faults (Agostini et al., 2011b). Northeast of this, between Ziquala and Kessem valley, faults are trending N-S and also NE-SE (Boccaletti et al., 1998), while the southern portion of the western margin is defined by wider N-S oriented W-dipping subparallel normal faults of the Fonko fault (figure 4; Agostini et al., 2011b; Boccaletti et al., 1998).

Lithologically, the Western rift margin is characterized by minor outcrop of Precambrian basement rocks, Late Miocene–Pleistocene pyroclastics, Oligocene-Miocene flood basalt, Pliocene–Pleistocene trachytic lava flows, and plateau pyroclastic deposits (figure 3). Down from the western escarpment, it is mainly characterized by secondary products of the escarpment; talus deposits, fan deposits, alluvial and colluvial deposits mixed with some lacustrine deposits (MOWR, 2008).

This is defined by the presence of NNE–NE aligned cinder cones and lacustrine deposits (MOWR, 2008). These are affected by active late Quaternary–Holocene activity of the off-axis belts (figure 4); as in the Wonji Fault Belt of the eastern rift margin (Abebe et al., 2007; Agostiniet al., 2011b). this is defined by the presence of NNE–NE aligned cinder cones and maars along the narrow Butajira belt (Abebe et al., 2007), which separates the Guraghe escarpment from the Kuntane-Inseno-Kela plain (MOWR, 2008). Down to the east from the western escarpment, the Kuntane/Ashute plain, that comprises part of the temperature survey area is characterized by loam soil, weathered volcanic ash, and lacustrine sediments (MOWR, 2008). From a geothermal point of view, the late Quaternary–Holocene activity of the off-axis belts of Butajira volcanic zone is valued activity, regarding its young geothermal and tectonic activity.

3. METHODOLOGY

Temperature measurements can be categorized three ways, depending on the depth below the surface at which the temperatures are measured: surface measurements, measurement at depth of 0 to 20 m, and measurements at depths > 20 m (Sladek et al., 2007). Temperature measurement at depth of 0 to 20 m in an early stage of geothermal exploration is an effective and efficient way of exploration. Shallow (1-3 m) temperature surveys are important to identify and delineate geothermal outflow zones (Zehner et al., 2012), for much lower costs, prior to temperature gradient drilling and other exploration techniques. The survey is also used to locate and map thermal anomalies in an early stage of exploration, and to map thermal aquifers in detail (Sladek et al., 2012). According to Sladek et al., 2007, shallow temperature measurements (2 meter) can be performed, mapping the thermal aquifers located approximately 70 m below surface.

Shallow temperature surveys are cost effective, portable, quick, and potential; though the equipment has limitations in that the rods cannot penetrate harder grounds or bedrocks. Temperature at depths of 0-20 m can also be affected by daily and seasonal temperature cycles (weather influence, variations in solar radiation and air temperature) at the earth's surface, plus soil moisture and elevation (Sladek et al., 2012). Weather effects have little influence at depth greater than 0.5 m and can be corrected by performing long-term base station data

Figure 5. Tools used during soil temperature measurements.

The equipment used for the one meter temperature measurement includes steel rod, auger with a metal joint and bit to drill harder ground, GPS to take location of points, measuring temperature device (NT Logger thermometer) to record temperature from the inserted rod, and also hand hammer (figure 5). The equipment we used originally was designed for two-meter surveys however, it also allowed us to perform one-meter temperature survey. The technique was performed by inserting steel rods into the hollow ground, after drilling by auger (figure 5), or directly pushing the steel using the hand hammer, depending on the hardness of the ground. The measuring temperature device is then inserted in to the steel rod and temperatures are recorded after it equilibrates, usually taking 5 minutes.

The soil temperature measurement at Butajira geothermal area was carried out at 1 m depth, on and around the geothermal manifestation area. The survey included 188 measurement points, distributed along a 2.3x3.5 km grid with an interval of 200 m. To better understand the extent of the anomalies, the 1 m survey was also conducted with a 100 m interval on and around the manifestation area.

Before the commencement of this study, there was a hot ground water blowout at the time of drilling for drinking water purpose, on May 2014. The blowout was caused by highly pressurized geothermal fluid. The fluid was projected up to 60 m above the surface and made a small, about 30-40 m wide pond, on the surface around the well (figure 6). The fluid had flowed from the feed zone located between 234-255 m deep, with an estimated down hole temperature of about 200-250 °C. This activity attracts the geoscientists to go through further geothermal investigations.

Figure 6. Picture showing the blowout well during drilling in May 2014.

4. RESULTS AND DISCUSSION

During the survey, both hot/ warm springs and mud pools have been measured and their temperature range was 27 - 98 °C. The mud pools are mostly small in number and size (figure 2), relative to the hot springs. The measured 1 m temperature record ranges from 20.04 to 101.3 °C. The temperature map produced from the survey data (figure 7) shows the highest anomaly is concentrated on two zones of the area; identified as area 1 and area 2. The surface geothermal manifestations are structurally controlled and can be correlated with the direction of the lineament ‘A’ and ‘B’ as shown on figure 7. The manifestations themselves are likely to occur parallel to the NE, to the direction of the rift.

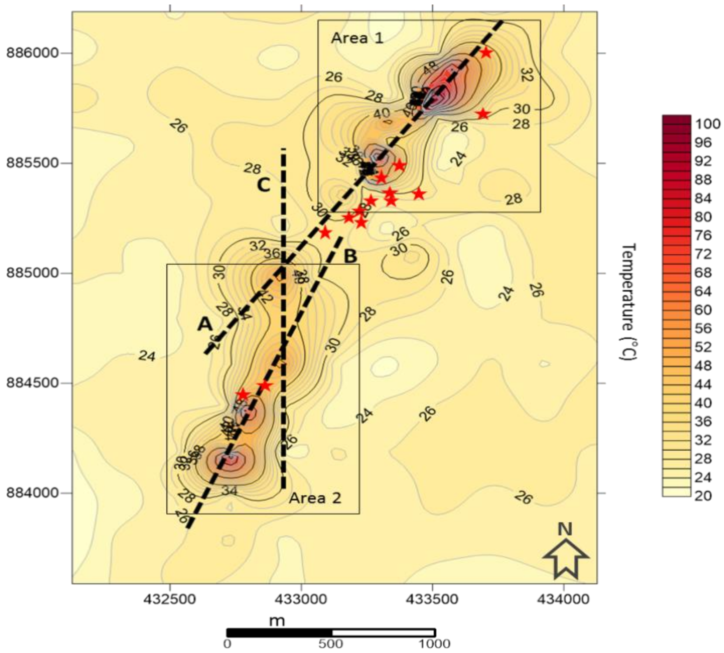

Figure 7. Soil Temperature distributions Map at Butajira Geothermal Prospect area. Red stars represent measured geothermal manifestations, dotted lines are structural lineaments indicated by temperature, and boxes; Area 1 and 2 are anomalous zones.

The rough interpretation of the anomalies indicates the presence of a NE-SW trending structure, while the detailed study of the map can define two to three structures/ lineaments that seems to coincide with the local, as well as, regional structures. On the temperature map bellow, dotted lines ‘A’ and ‘B’ shows a respective NE and NNE trending lineaments as the general direction of the rift margin, including Guraghe fault escarpment. Both lineaments are also in line with the local faults called Dobo-Sabola Fault zone (from MOWR, 2008) and other unnamed faults (see figure 8 & 9). They are also parallel with the youngest geological feature of the area, a series of cones that represent the active effort of the geology of the area. The other lineament, line ‘C’ seems to align on N-S direction which might follow the regional structures that are located to the south and northeast of Mt. Guraghe, that are characterized by N-S orientation (e.g. Boccalleti et al., 1998).

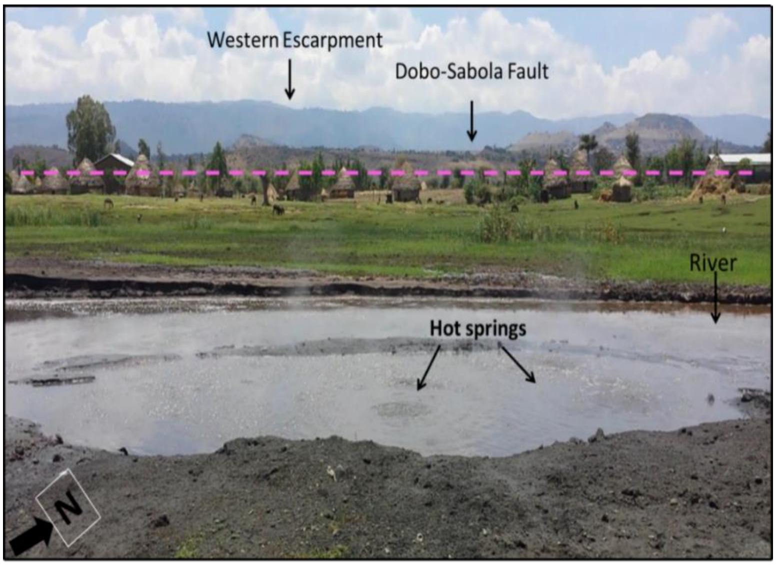

Figure 8. Part of the survey area, showing hot springs together with the western escarpment and the Dobo-Sabola Fault. zone and cinder cones.

This appearance of temperature lineaments, together with the manifestations, led us to realize the presence of a hidden fault along the flat plain Ashute area, which is parallel to the general NE-SW direction of the main Ethiopian rift margin and its associated graben and faults.

Most hydrothermal manifestations are controlled by tectonic activities. The central part of the study area, which is topographically low, does not show any structure on the surface, while it is the only place with a significant hydrothermal manifestations. However, interpretation of near surface temperatures revealed the existence of hidden fault systems along the flat plain area. Apart from this, the magnetic survey carried out on this area coincides with results of the temperature survey. According to Wondifra 2018, the magnetic data interpretation revealed the presence of locally buried structures along the central part of the area, and about three structures that are oriented to the NE-SW, NNE-SSW and N-S directions are located on the area.

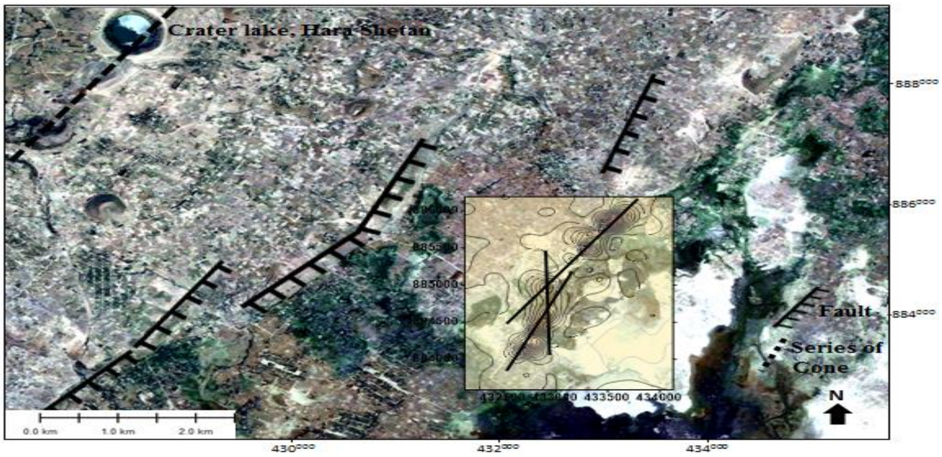

Figure 9. A sketch on the Spot 5 image represents correlation of structures between result of the soil temperature and surface local structures at survey area.

5. CONCLUSIONS

The extent of the temperature record of the survey reaches from 20.04 to 101.3 °C.

The measured 1 m temperature survey in Butajira prospect, depicts two areas with higher temperature anomaly that tend to be aligned NE-SW and NNE-SSW, which is the local and regional tectonic stress directions.

The structural lineament and geothermal manifestations are parallel with the structural lineaments outlined from the temperature anomaly. This advocates the presence of hidden structure associated with the general NE-SW direction of the main Ethiopian rift along the flat plain Ashute area.

The priority target areas for future exploration by drilling could be within the perimeter of the two identified areas, targeting to the identified fault systems.

It is recommended to conduct further detailed exploration studies of geology, geochemistry and geophysics on the area.

REFERENCES

Abebe, B., Acocella, V., Korme, T., Ayalew, D., 2007.Quaternary faulting and volcanism in the Main Ethiopian Rift.J. Afr. Earth Sci. 48, 115 –124.

(Agostini et al., 2011b).(Agostini, A., Bonini, M., Corti, G., Sani, F., Mazzarini, F., 2011b. Fault architecture in the Main Ethiopian Rift and comparison with experimental models: implications for rift evolution and Nubia–Somalia kinematics. Earth Planet. Sci. Lett. 301, 479 –492).

Boccaletti, M ., Bonini, M., Mazzuoli, R., Abebe, B., Piccardi, L., Tortorici, L., 1998. Quaternary oblique extensional tectonics in the Ethiopian Rift (Horn of Africa).Tectonophysics 287, 97–116.

Chernet, T., Hart, W.K., Aronson, J.L., Walter, R.C., 1998. New age constraints on the timing of volcanism and tectonism in the northern Main Ethiopian Rift-southern Afar transition zone (Ethiopia). J. Volcanol. Geotherm. Res. 80, 267–280.

Ebinger, C.J., Yemane, T., WoldeGabriel, G., Aronson, J.L., Wal ter, R.C., (1993). Late Eocene- Recent volcanism and faulting in the Southern main Ethiopian rift. *Geological society of London*, 150, 99-180.

Geological Survey of Ethiopia, Geology of Butajira Silti area, 2017. (Unpublished Internal Report).

Ministry of Water Resources, 2008. Butajira – Ziway areas development study.

Sladek C., Coolbaugh M.F., Zehner R.E, 2007.Development of 2-meter Soil Temperature Probes and Result of Temperature Survey Conducted at Desert Peak, Nevada, USA. GRC Transactions 31, 363-368.

Sladek, C., Coolbaugh, M.F., Penfild, R., Skord, J., and Williamson, L., 2012, The influences of thermal diffusivity and weather on shallow (2-meter) temperature measurements: Geothermal Resources Council Transactions, v. 36, p. 793-797.

WoldeGabriel, G., Aronson, J.L., Walter, R.C., 1990. Geology geochronology and rift basin development in the central sector of the Main Ethiopian Rift. Geol. Soc. Am. Bull. 102, 439–458.

Wondifra, T. T., (2018). Magnetic Geophysical Surveys over Butajira Ashute Geothermal prospect, Ethiopia. 7thAfrican Rift Geothermal Conference, 1-10. https://www.geothermal-energy.org/pdf/IGAstandard/WGC/2010/0155.pdf

Zehner, R.E., Tullar, K.N., and Rutledge, E., 2012, Effectiveness of 2-meter and Geoprobe shallow temperature surveys in early stage geothermal exploration: Geothermal Resources Council Transactions, v. 36, p. 835-841.