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Magnetic Geophysical Surveys over Butajira Ashute Geothermal prospect, Ethiopia

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ABSTRACT

The magnetic method involves the measurement of the earth's magnetic field intensity. Typically the total magnetic field and vertical magnetic gradient is measured. Measurements of the horizontal or vertical component or horizontal gradient of the magnetic field may also be made. Magnetism is, just like gravity, a potential field. Anomalies in the earth's magnetic field are caused by induced or remanent magnetism. Induced magnetic anomalies are the result of secondary magnetization induced in a ferrous body by the earth's magnetic field. The shape dimensions, and amplitude of an induced magnetic anomaly is a function of the orientation, geometry, size, depth, and magnetic susceptibility of the body as well as the intensity and inclination of the earth's magnetic field in the survey area.

For the exploration of geothermal energy, ground magnetic work can be used to investigate the presence of a geothermal resource in combination with gravity. From the magnetic maps several of the anomalies can often be correlated with surface expressions of volcanism such as craters, domes or cones, localised basaltic lavas or plugs. From these maps most of the basaltic centres tend to lie in areas with magnetic highs (positives). Sometimes a superimposed magnetic low (negative) exist; but this is generally weak or zero.
Butajira Ashute geothermal field is a new prospect area under investigation for a possible power generation project, based on its proximity to national electric power grid and the level of study compared to other geothermal prospects. Geophysical survey using magnetic method was carried out in Ashute area between April 10 and May 27, 2017.

The aim of a magnetic survey was to investigate subsurface geology on the basis of the anomalies in the earth's magnetic field resulting from the magnetic properties of the underlying rocks. The NNE fault found within Ashute geothermal field, splits inner caldera, and most of the geothermal manifestations are found at around this fault system.

Keywords: Geothermal energy, Butajira, Anomalies, Susceptibility

1. Introduction

The Butajira, Ashute geothermal field was start geophysical survey by using magnetic method in Ashute area the survey was completed between April 10 and May 27, 2017raw data were acquired according to the survey specification on the given time. Geophysicists have been able to develop a mathematical model for the earth's magnetic field, i.e., its shape and intensity across the surface of the earth, Magnetometer surveys indicate that there are many unexpected variations in this model, called "magnetic anomalies". A magnetic high anomaly is where the measured field strength is higher than the value predicted by the global model, and a magnetic low is where the measured field strength is lower than the value predicted by the global model.
The objective of the magnetic survey to identify and locate geothermal features such as buried craters, caldera faults/lineaments and fractures and map lithological contacts, altered zones in the earth's magnetic field are caused by induced or remanent magnetism. Induced magnetic anomalies are the result of secondary magnetization induced in a ferrous body by the earth's magnetic field.

Possible causes for magnetic highs include the presence of magnetically charged rocks in the subsurface. Magnetic prospecting looks for variations in the magnetic field of the earth that are caused by changes in the subsurface geologic structure or by differences in the magnetic properties of near-surface rocks. The inherent magnetism of rocks is called the magnetic susceptibility.
Data acquisition instruments are a state of the art and during data acquisition, no interferences such as magnetic storms, pipelines, electric lines, buildings, track traffic were encountered that may affect data quality. Data processing and plotting were conducted daily after fieldwork and discussions were made with field geologists on survey results to get general view of the source of geophysical anomalies.
Data reduction, processing and interpretations were performed using appropriate software.
There is no previous magnetic method work in this area only to do work as priori information from the area except gravity method and surface geological investigations in quarter scale.

1.1 Location and Accessibility of the area

Butajira, Ashute geothermal field is located in the Southern Nations Nationalities Regional State southwestern part of the main
Ethiopian Rift Western margin, about 180 km south east of Addis Ababa in the low plain of Ethiopian rift and nearby towns are Butajira and Kebet in Silti Wereda.

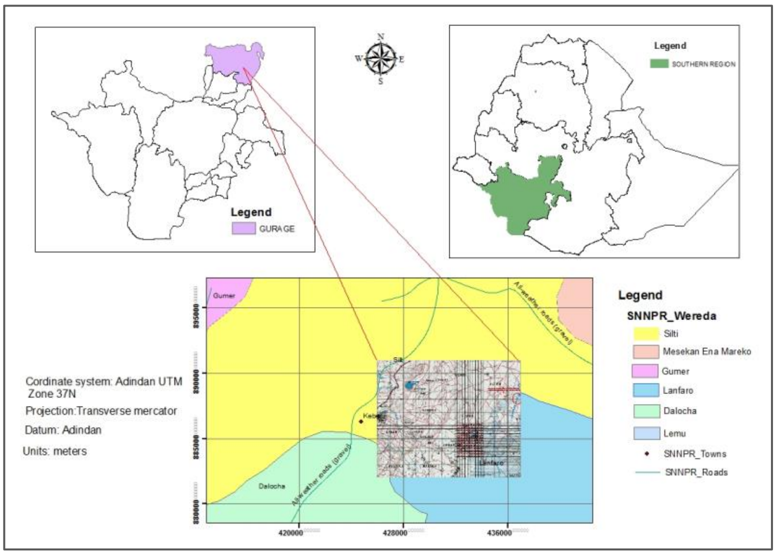

Figure1: Location map of Butajira Geothermal Prospect area

2. Tectonic and Geological Settings

The geology of Butajira area and Hosanna map sheet have been described in regional geology and geophysics. The onset of the main Ethiopian rift system dates back to Miocene time
by various authors, few among these are Chernet et al., 1998; WoldeGabriel et al., 1990) Basalfew Zenebe et al (2012); and detail geological studies by Zelalem Abebe, Yared Sinetibeb and Andualem Eshetu (2017) reviewed the Previous geological studies of Butajira area and Geothermal prospect area summary of these detail works is presented here to serve as a background to the interpretations of magnetic data, in hosanna map sheet they have to do gravity survey.

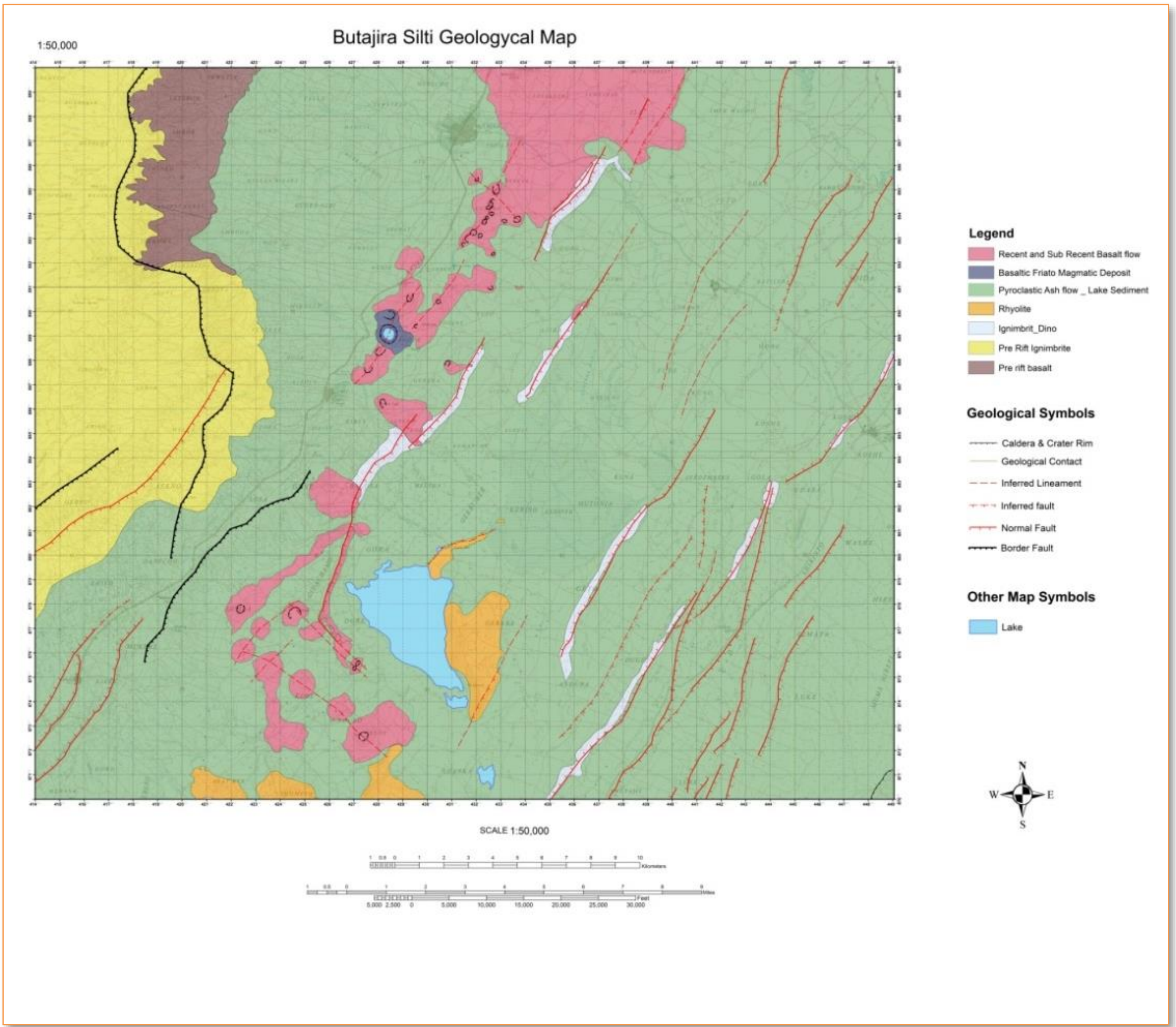

Figure 2: Geological Map of Butajira area (modified from GSE, 2017)

The rift margins are characterized by tertiary volcanic rocks except for some location 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 than the western margin. Butajira volcanic area is part of the central sector of main Ethiopian rift system situated on the western boundary. The Western boundary is oriented to the general direction of NE-SW with transverse faults of different orientation (FIGURE 2.1). The marginal graben, at Guraghe fault escarpment close to Butajira said to be form during late Miocene by 9.7 Ma (WoldeGabriel et al., 1990) and is mainly defined by few but large high angle normal fault (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).

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 margins defined by wider N-S oriented W-dipping sub parallel normal faults of fonko fault (Agostini et al., 2011b; Boccaletti et al., 1998).

Lithologically, rocks of the western rift margin characterized by Late Miocene-Pleistocene Pyroclastics Oligocene flood basalts, basement rocks, Pliocene–Pleistocene trachitic lava flows and plateau pyroclastic deposits(FIGURE 2.1)(Agostini et al., 2011b). Down from the western escarpment, it is mainly characterised by secondary products of the escarpment: talus deposits, fan deposits, alluvial and colluvial deposits mixed with some lacustrine deposits (MOWR, 2008).

From Geothermal point of view, the late Quaternary–Holocene activity of the off-axis belts of Butajira volcanic zone is unvalued activity regarding means of heat source and permeability; as they are basic requirements in the selection of geothermal field. This young activity also increases the geothermal activity in the area.

3. Instrumentation

A magnetometer is a more complex instrument which measures both the orientation and strength of a magnetic field. When the magnetic field of a rock sample is measured, the result is actually a measure of the field as it is being affected by the earth's magnetic field, as well as any other large bodies of magnetic rock which are nearby. Magnetometer surveys measure small, localized variations in the Earth's magnetic field. Magnetometers are highly accurate instruments, allowing the local magnetic field to be measured to accuracies of 0.002%. There are several types of instruments on the market. The common ones used for commercial applications are the proton precession, fluxgate, and caesium vapour and gradiometer magnetometer systems. The systems operate on broadly similar principles utilizing proton rich fluids surrounded by an electric coil. A momentary current is applied through the coil, which produces a corresponding magnetic field that temporarily polarizes the protons. When the current is removed, the protons realign or precess into the orientation of the Earth's magnetic field. The precession generates a small electrical current in the surrounding coil, at a frequency directly proportional to the local magnetic field intensity. Gradiometers measure the magnetic field gradient rather than total field strength, which allows the removal of background noise. Gradiometers measure the magnetic field gradient rather than total field strength, which allows the removal of background noise.

FIGURE 3.2: Proton Precession magnetometers. (a) Geometrics G-856(photo by Andarge Mengstu)

4. Magnetic Survey and Data Processing

The magnetic surveys were conducted over most of the Western margin of the centeral main Ethiopia Rift close to Butajira, Ashute area, covering an area of 6 Km2. However, for this report magnetics observations of the surrounding areas of Ashute are included. Geophysical surveying was carried out to accurately position observation points, both laterally and vertically. Figure 5.2 presents the survey lay out Within the Ashute basaltic area. The total field magnetic data were acquired at 250 meters profile spacing and at every 250 meter station separation for magnetic survey reading with the length varying from 3 to 4.5 kilometres. The sensor was monted on horizontal and set always in North direction. Before field survey execution, diurnal characteristic in the area was measured for one day at a station; Based on the diurnal variation curve, data acquisition time was set between 8:00AM and 11:30 PM when diurnal change assumes straight line. For diurnal variation correction of the field data reading were taken at the beginning and end of the survey at a chosen base station every survey day, which is located outside the survey grid at UTM location 428840E, 887262N and Elevation 2039, Adindan map datum. Base station value is 35246nT. Steel and other ferrous metals such as belt buckels were avoided during operations. The measurements at field stations were then corrected by assuming a linear change of the field between repeat base station readings. Diurnal corrected data was gridded and contoured using the Geosoft Oasis Montaj software.

Interpretation of geology from magnetic data is difficult near equator, which is typical of the present survey area. The analytic signal of the total magnetic field simplifies interpretation of the total field magnetic data near the equator. It is useful in locating the edges of magnetic source bodies, particularly where remanence/ low magnetic latitude complicates | interpretation (OASIS montaj release 4.3, 1999).

The analytic signal is the square root of the sum of the sum of the squares of the derivatives in the x, y and z directions.

$$|A(x,y)| = \sqrt{\left(\frac{dT}{dx}\right)^2 + \left(\frac{dT}{dy}\right)^2 + \left(\frac{dT}{dz}\right)^2}$$

Where:
/A(x, y)/ is the amplitude of the analytic signal at (x, y), T is the observed magnetic field at (x, y).
The analytic signal map is generated using the Geosoft Oasis Montaj software.

4.2 Data Reduction

Diurnal magnetic variations and non-dipolar broad variations of the magnetic field arising from the earth's core are of external and internal origins, respectively, which are unrelated to the Earth's crust. It is thus essential to remove these variations in order to obtain observations due to the earth's crust only. Correction for diurnal variations was performed during the data acquisition stage by monitoring the variation on a daily basis using a base station. The non-dipole core

4.3 Data Processing

Data collected at a closely spaced, regular, square grid adequately samples the magnetic survey without loss of any information content. Thus the first step is gridding of the field acquired data using minimum curvature method in order to interpolate the magnetic data on to a regular, square grid. The chosen grid cell size is 1/4th of station interval; in this case,
Cell sizes are 65 meters for magnetic survey. As a next steps a smoothing Handing filter (3 by 3) was applied before performing any filtering, in order to remove random errors. Various filters in wave number domain were applied to enhance anomalies of interest after applying Fast Fourier Transform.

Magnetic fields were obtained by employing band pass filters, with wavelengths from 2100 to 200 meters.
A low pass filters using wavelengths above the highest wavelengths of the band Pass filters were used to generate data of magnetic fields.
In employing Tilt angle derivative filters were applied to obtain solutions of depth and location of sources (such as faults, lineaments, etc.), using structural indices (0.5, 1& 2). Furthermore, the magnitude of horizontal gradient field was calculated for locating lateral mass in homogeneities. Maximum gradient magnitudes were automatically picked and the plotting the locations of the peak values delineates lithological or structural boundaries.

5. Magnetic Anomaly Description and Interpretation

At the early stage of data processing, total magnetic field maps were prepared to serve as a basis for further processing. After applying the various filters as pointed out above, several maps were produced. Few among others, which are found useful for interpretation, analytical signal and Tilt angle derivative depth plot of a fault model maps and structure they are selected for Interpretation.(Figure5.1),the total field magnetic map, reveals high magnetic features elongated in the north south direction.
These north south elongations of the features appear due to low latitude effect on the total field of magnetic data .This can be recognized from the analytic signal map produced from the total field magnetic data (Figure 5.2). The features in the total field magnetic map cannot be readily correlated with the geological map of (Figure 2.1), however, the area of the rock type has high magnetic responses. Geological units are better described in the magnetic analytical map (Figure 5.2).
The analytical signal map reveals low magnetic features in the southern part of the area. There are high magnetic anomalies in the western and northeast, revealed roughly by circular high values and North West extending bodies.The high values are clearly depicted in the Tilt angle derivative map generated from the analytic signal map (Figure 5.3)

The overlapped rock contact on the analytic signal map revealed that rock types produced the most intensive magnetic anomaly in the area. These high value anomalies extend in the western and northeast direction
With very high picks on Lines 01N, 02N, 03N, 04N, 05N and 06E in the western area and on Lines 07W and 08W in the north. Low magnetic values characterize areas of acidic volcanic, pyroclastic ash flow and lake sediment rocks, whereas ignimbrite rocks are mapped by medium magnetic values. The southern end low magnetic feature striking northeast- southeast could indicate, Pyroclastic ash flow and lineament possible area for the Geothermal prospect indicate Suchlike, mud pool and hot spring.

Tilt angle derivative map revealed lineaments/fault zones, These are shown in the Tilt angle derivative map of (Figure 5.3).Pyroclastic ash flow occurrences shown in the geological map of (Figure 2.1),track these lineaments in the NE-SW and central parts of the area. Some recent and sub recent basalt flow occurrences are over high magnetic responses or around their contacts and intersection of lineaments, particularly in the north direction.
The magnetic field distribution of the study area shows structure with a general direction of NE-SW; but our study area in to the magnetic profiles lay out about three structures oriented to the NE-SW, NNE-SSW and N-S directions. The striking directions are coincides with the direction of the main Ethiopian rift margin and its associated graben and different local faults. The alignment of the geotharmal manifestations are also in line with the structural lineaments outlined from the magnetic anomaly. This implies the precence of normal fault associated with the general NE-SW direction of the main Ethiopian rift along the flat lain Ashute area.

Generally, magnetic data revealed possible, pyroclastic ash flow and lake sediment rocks characterized by low magnetic responses, connected with the destruction of magnetite in the southern end, which is possible geothermal area .Structural features/lineaments and high magnetic responses are possible recent basalt flows area.

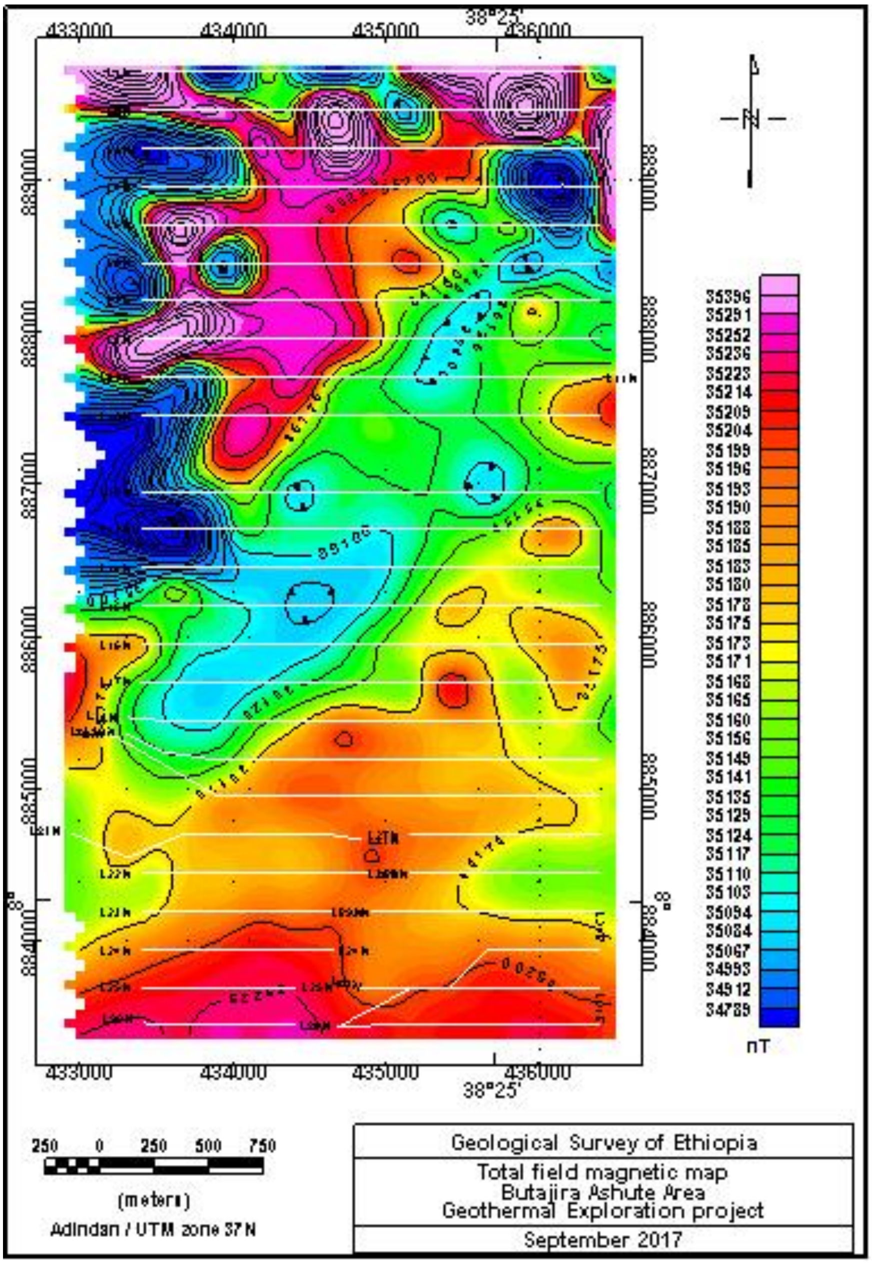

FIGURE 5.2: Total Field magnetic map

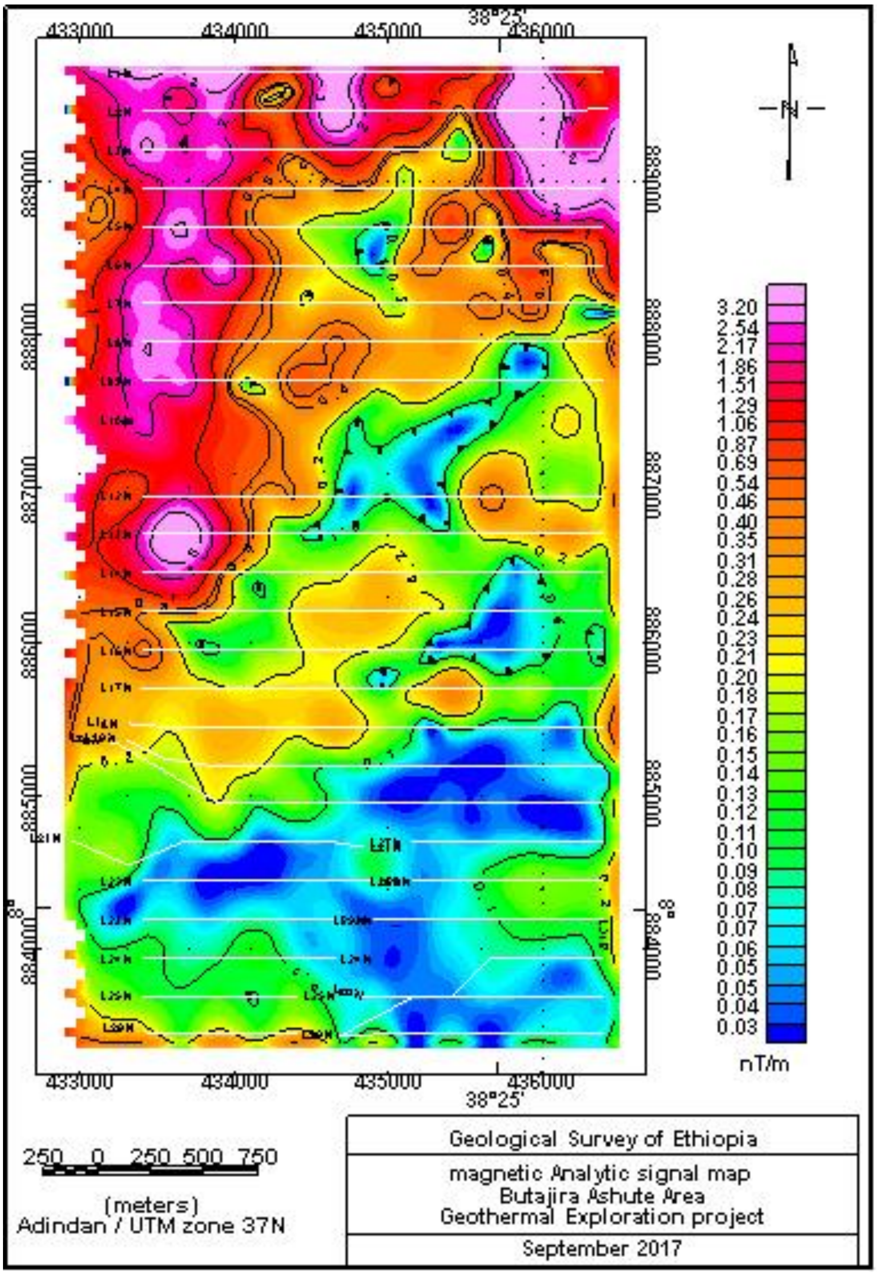

FIGURE 5.3: Magnetic Analytic signal map

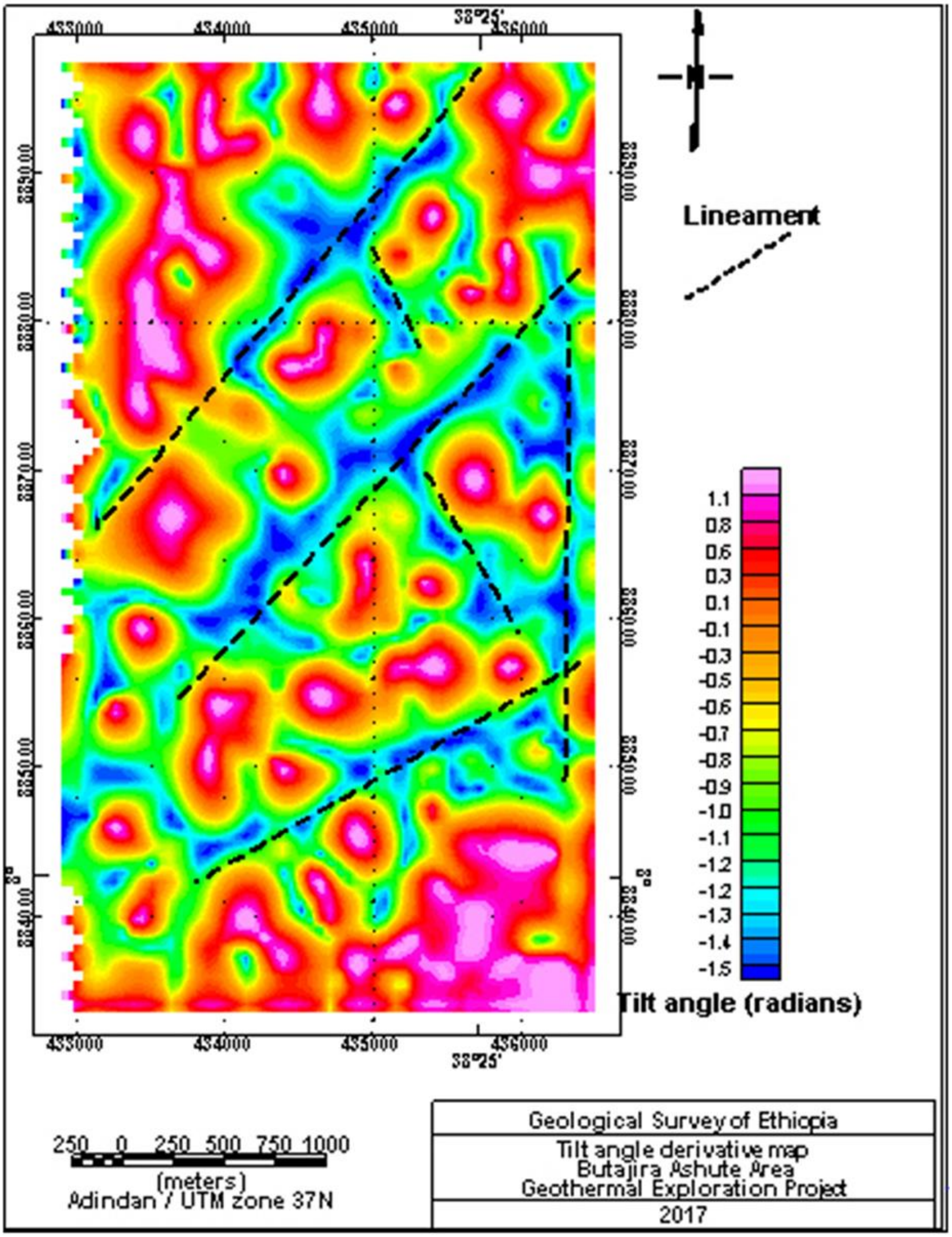

FIGURE 5.4: Tilt angle derivative map

6. Conclusions and Recommendations

From the magnetic anomaly description and interpretation dealt in the present sections, the following conclusions can be drawn the numerous craters, and vents revealed by the magnetic surveys are consistent with geothermal structures.The analytic signal magnetic field survey in Butajira Ashute, prospect areas with low magnetic anomaly that tends to be aligned NE-SW and NNE-SSW, which is the local and regional tectonic stress directions and as wel as , The measured 1 m temperture survey in Butajira prospect depicts two areas with higher temperture anomaly that tends to be aligned NE-SW and NNE-SSW, which is the local and regional tectonic stress directions.The extent of the temperature record of the survey riches from 20.04 to101 °C.

In a geothermal environment, due to high temperatures, the susceptibility decreases. It is not usually possible to identify with certainty the causitive lithology of any anomaly from magnetic information alone.

In general, the survey data have met their objectives, and the results of these surveys can be used as framework for future studies, Such that structural features and anomalous zones indicating geothermal area were indicated. The integrated geophysical data are found important in different features and indicating prospecting parts of the area. From magnetic data analysis, analytic signal is effective in outlining lineaments/faults. Possible Pyroclastic ash flow occurrence areas and ignimbrite, and also lake sediment that indicate geothermal area. Magnetic survey could be more useful in accurately mapping structural features if line interval was narrower than 250 meter.

Based on the integrated results test drilling is recommended on the NE-SW and NNE-SSW, anomalies continuing the magnetic survey toward the north and south are highly recommended.

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