

Magnetic and Gravity Survey of Gedemsa Geothermal Prospect Area-Main Ethiopian Rift

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Key words: Gedemsa, Gravity, Magnetics

ABSTRACT

The main important parameters for geothermal resource exploration are identification of the heat source, reservoir rock, impervious caprock and recharge to the system.

The physical properties of a magnetic source structure that can be determined from a grid of magnetic data include its shape (plan), location of its edges, depth to top edges, dip, and rock susceptibility contrast. The problems to be overcome in data enhancement are to identify and map (a) subtle anomalies attenuated in the dynamic range due to the presence of high amplitude magnetic anomalies, (b) the continuity of individual bodies where there are lateral changes in susceptibility and/or depth of burial, and (c) the edges of structures by adequately accounting for the nature of the rock magnetization. Rock magnetization is a vector quantity that can consist of both remanent and geomagnetically induced components. The presence of the remanent component can adversely affect the shape of the magnetic field response and result in spurious derivatives, if one has assumed that only the induced component is present.

Density increases downward within the crust and varies laterally to enable gravity mapping a useful tool for Earth science studies. The density variations create gravity anomalies due to presence of inhomogeneity in the subsurface. Gravity method maps the structures volcanic centers and surface & subsurface geology based on gravity field variations arising from density differences.

Randomly spaced gravity data and about 600 magnetic data points within 17 profiles on Gademsa areas were collected and analysis is made to assist the Geothermal Exploration activities. The magnetic anomaly map and analytic signal of the magnetic anomaly map and Bouguer gravity anomalies were further processed to enhance the different parts of the data in order to extract important information. This was achieved by producing different maps for qualitative interpretations of the magnetic and gravity data. The different component of the magnetic and gravity data were enhanced using derivative, continuation, high-pass low-pass and band-pass filters in Fourier domain. Trend surface and filters in space domain were also applied to see their effect.

Major structural features revealed by the magnetic and gravity anomalies in the Gademsa and the vicinity areas include the eastern rift marginal up-rise, the subdued rift floor, the volcanic centers, Wonji & transverse faults, etc. Interesting for geothermal exploration are areas where the two faults intersect. Analytic signal, derivative and residual maps indicate the faults and their intersections except where they are obscured by their own erupta.

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Based on the preparation and selection of suitable regional and residual maps qualitative interpretation is made using analytic signal of magnetic anomaly map and bouguer gravity map.

Depending on the qualitative interpretation of the maxima or peak of the magnitude of analytic signal and tilt derivative are shown in the figure. These peaks could probably represent the magnetic contacts between igneous intrusions and the surrounding basement rocks within the area, the boundaries between different lithologic unit, faults, lineaments and fractures.

The bouguer anomaly map corresponds effect of volcanic covers of the Gedemsa plateaus with deep seated high temperature gradient underlying the area. And the power spectra map of the gravity anomaly shows the high density material is located relatively at shallower depth of 1.5Km beneath the volcanic centers of the caldera (Getachew.B).

1. INTRODUCTION

The Gedemsa geothermal prospect is located about 150 km south east of Addis Ababa (Figure 2) in Oromia Regional State, north-eastern Shoa zone, south-west of Adama town close to Koka hydro power station and the national grid system. It is found in the northern portion of the Main Ethiopian Rift (MER) between 515000m and 531000m and 920000m and 935000m UTM coordinate.

Tectonically the Gedemsa Area is characterized by the presence of central volcano, whose summital portion is affected by a calderic structure almost 7-10 km in diameter. The erupted products are strongly differentiated up to a peralkaline rhyolitic (74% of SiO_2). The volcanic activity following the calderic collapse is characterized by product of similar composition. While the collapse occurred between 0.1 and 0.2 MY, The silicic post calderic activity is 0.1 MY. The whole area is presently affected by a strong tensional tectonic activity, with associated fissural basaltic eruption.

The fault segments are trending 20°00' Northwards with respect to the NE-SW direction of the rift escarpment and starting from eastern shore of lake Ziway, extending up to Gedemsa, leaving an open structures of 0.5 to 1.0 kilo meters width (Eletroconsult Report, 1987). Normal faults (NW-SE) cut the rift floor forming confined grabens (known as "a rift in the rift structure") and several horsts in the area (Kazmin et al., 1980, Mohr,1960,Barberi et al., 197 and Dipola, 1970).

Gravity and magenetics surveys were conducted to study and map geological structures (fault, fractures, fissures, contacts, graben) and to locate bodies that could be possible heat sources in gedemsa geothermal prospect. The gravity survey was conducted using a Lacoste and Romberg model 1105 G gravimeter having a reading accuracy of 0.01mGal. The position and elevation of the survey stations were obtained using Garmin etrex GPS receiver. A proton precession magnetometer G-856AX Memory-MagTM was used to measure the total magnetic field having a reading accuracy of one gamma.

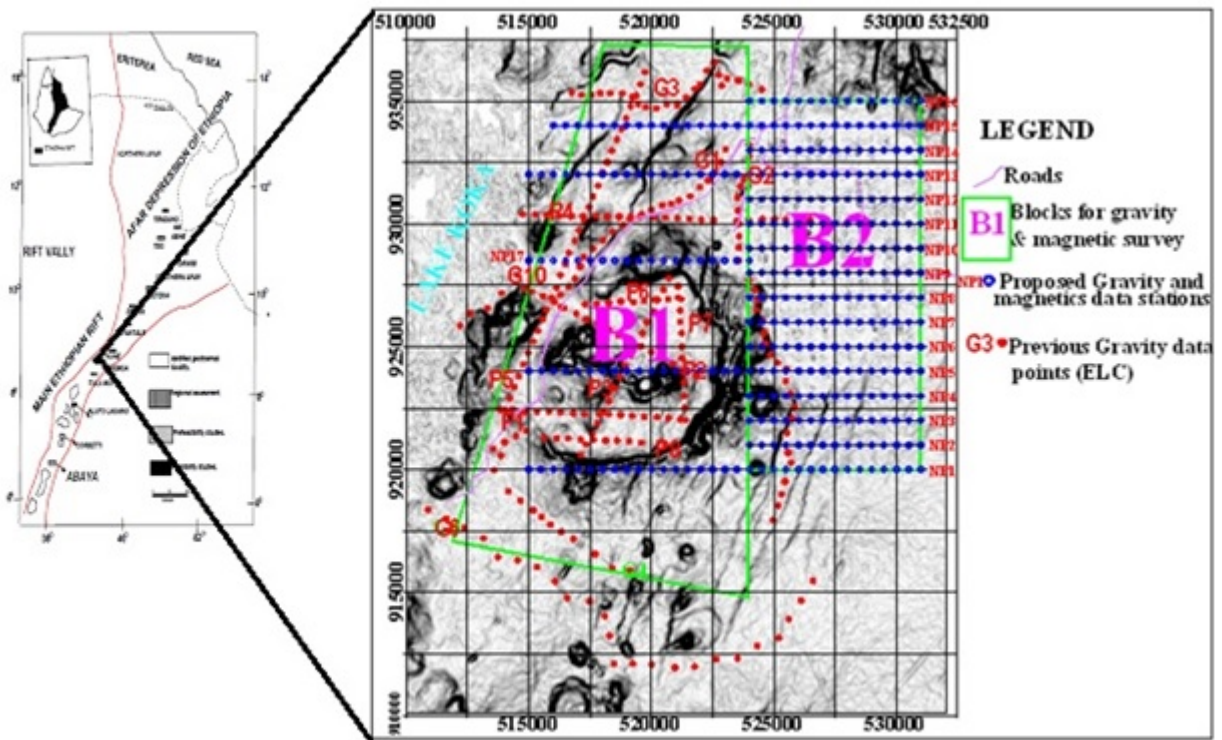


Figure 1: Location map of Gedemsa Geothermal prospect area.

2. REVIEW OF PREVIOUS WORK

2.1 Geologic and Tectonic Setting

The Gedemsa geothermal prospect area is found in the northern subdivision of the MER near the water shed between Awash river and lake Ziway, close to the large rift marginal faults constituting its eastern escarpment, in the rift floor (figure 1.0), which is totally affected by two volcano-tectonic series of Naziret and Wonji Fault Belt systems (Mohr 1971, Meyer 1975, Kazimin 1970, Di Poala 1970).

Naziret group (ignimbrites, unwelded tuffs, pumice of peralkaline affinities, etc) is the lower most out cropping unit in the area. Old rhyolitic lava domes and flows, lacustrine sediments and paleosol sometimes intercalated with in pyroclastic units and fissural basalts (Bofa basalt, scoria, etc) are found on top of the Naziret group. The area is dominantly covered by pyroclastic deposit of peralkaline silicics, such as ignimbrites, tuffs, pumice and also with minor lava appearing in the fissures (basaltic and rhyolitic lava flows).

The tectonic system of the Wonji Fault Belt (WFB) revealed itself as "en echelon" form with densely spaced normal fault segments trending NNE-SSW, NE-SW, rarely to the N-S. These segments are of variable lengths (80 to 120 kilometers length, DI Poala, 1970) and are formed during quaternary volcano-tectonic activities

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Gedemsa Caldera is the largest caldera in the area with 8 kilometers of diameter and is dissected by Wonji fault belt, both at its internal floor and outer flanks, and shows presently active tectonic remains of recent basaltic flows and cones in its vicinity. The silicic domes inside caldera are elevated to 200 meters above the floor. Rhyolitic flows in the caldera walls form the oldest rock. A peralkaline rhyolitic ignimbrite sheet forms the top most unit overlying the peralkaline rhyolitic greenish-grey pumices. Post caldera activities are the eruptions of pumice through the ring faults and the formation of Ittisa hills (Electroconsult report, 1987).

All the inner floor of Gedemsa is covered by lacustrine and subordinated alluvial deposits intercalated with reworked loose pyroclastic products (mainly ashes). This fact can be well seen in the easter side, where normel faults with several meters of vertical throw are present.

Fluvio-lacustrine deposits are found also outside the caldera all around it. They are considered to be 0.1 MY old as this is the age suggested by laury and Albritton(1975) for the higheast level reached by a large lake occupying in the past all the central part of the Ethiopian Rift. As these sediments, which are at places found some tens of meters above the present caldera floor, partly cover Ittisa products, post-caldera activity is inferred to be between 0.2 and 0.1 MY. Its real age could be even younger, since the interaction of magma with the water of the lake, is well preserved and not covered by sediments (Bigazzi et al., in press).

The final eruptive phase of Gedemsa is quite different from the preceding ones, being characterized by basaltic effusions. Two scoria cones are found inside Gedemsa, a bigger one on its NE part and a very small one on its SW part. These basalts are related to the strong tensional tectonics which affected the caldera structure. The NE cone which is located close to the rim has been successively cut by the same fault from which magma rose up. It lies over and is associated with a series of thin cross laminated ‘‘wet surges’’ deposits with black basaltic lapillis and pisolites . this deposit (up to 20m thick) covers the caldera rim fault and part of the outer flanks toward Alem Tena. It has been generated by the explosive activity terminated probably when the vent become insulated from the water by accumulation of surge deposits; at that moment a purely magmatic activity (strombolian) began forming the scoria cone.

Several eccentric volcanic vents are found around Gedemsa caldera. The most conspicuous one is cheka cone located between the outer Eastern flank of gedemsa and wonji plantation. It is constituted mostly by mugearitic lava flows overlain by pyroclastic deposits (falls and surges). Many obsidian and perlite domes are found on the shore of koka lake SW and NW of Gedemsa; lava are peralkaline rhyolites similar to those of the caldera. On the prolongation out of the caldera rim of the fault originating the NE inner scoria cone, several similar basaltic vents are found up to the bridge on Awash river.

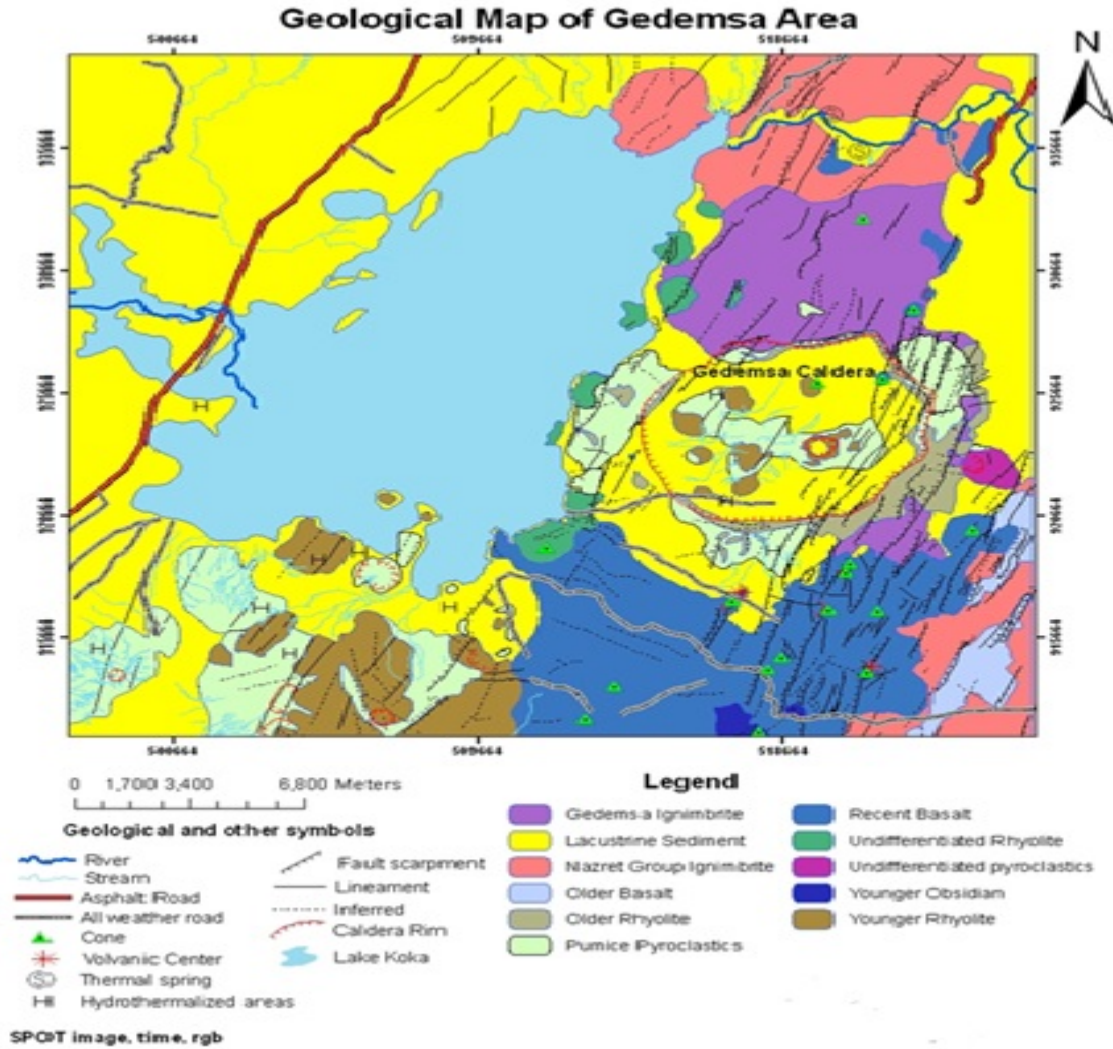


Figure 2: Geological map of Gedemsa geothermal prospect area. (After Electroconsult, digitized by Selamawit Worku, supervised by Tadese Mamo)

2.2 Previous Geophysical Work

Regional and semi-detailed geophysical studies have been carried out in the Gedemsa geothermal prospect area and inside the Gedemsa caldera, with the aim to investigate the deep structures and to delineate possible geothermal reservoir and heat source. The methods include, Vertical Electrical Sounding (VES), Magnetics and Gravity survey (e.g. ELC 1987) among others but the magnetic survey was not conducted around Gedemsa caldera.

ELECTROCONSULT (ELC), between 1985 and 1987, conducted geo-electrical and gravity surveys around the Gedemsa and Tulu Moyo volcano. Sixty-nine Vertical Electrical Sounding (VES) observations were carried out in the Gedemsa area (inside and outside the caldera). Three hundred and four gravity stations were measured covering an area of 400 km² and extending from the southern limit of the map sheet (joining Tulu Moyo survey area) up to Awash River.

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The Vertical Electrical Sounding (VES) data, presented as geoelectric section, was used to understand the stratigraphic sequence of the Gedemsa area. The stratigraphic sequence of the area, from the youngest to the oldest (from the top to the bottom) is presented as follows.

- Alluvium and recent basaltic flows (about 100 m thick);
- Post- caldera pumice and rhyolites, only present inside the caldera and west of it (thickness of up to 100 m);
- Pre – caldera rhyolite with average thickness of 200m;
- Ignimbrite mainly attributed to the Nazret Group (500 – 800 m thick).
- Basalts of the rift floor, constituting the basement of the area.

The resistive basement, with its depth ranging from 1000 to 1700m, is characterized by undulating surface. The marked up rises were interpreted as due to intrusive and or the up pushing of a shallow magma chamber. The resistivity survey also delineated faults that have surface expressions step like forming horst and graben. The Gravity modeling of Gedemsa caldera has identified three density layers and interpretation has indicated a collapse structure of the caldera.

3. THE FOLLOWING PROCEDURE WAS ADOPTED FOR THE STUDY

Measurement was made along the proposed 17 lines in the east and north-east of Gedemsa Caldera, inside the caldera and on the rim of the caldera guided by GPS. The lines were oriented east-west direction that intersects the north-east south-west regional strike direction, the so called the Wonji Fault Belt. Nevertheless due to raggedness of the area especially inside and on the rim of the caldera we didn't keep the straightness of the lines but almost all the proposed stations are reached except inside and on the rim of the caldera.

(i) The Gedemsa magnetic intensity map was digitised and reproduced using Geosoft software package.

(ii) The regional magnetic field was determined by fitting a 2 dimensional first degree polynomial surface to the total field data using the least square method. This was achieved using Trend analysis which is an Oasis Montaj program based on the least squares technique.

(iii) The residual magnetic field was obtained by subtracting the regional field values from the total magnetic field values at grid cross points.

(iv) Analytic signal technique was applied to the residual magnetic intensity field data in the space domain by calculating the horizontal gradient by finite difference method in the first step and then based on the role of FFT the vertical derivative was calculated by FFT of horizontal gradient and formulated as the analytic signal. This was achieved using MAGMAP program based on analytic signal technique.

(v) The resultant analytic signal map was interpreted qualitatively

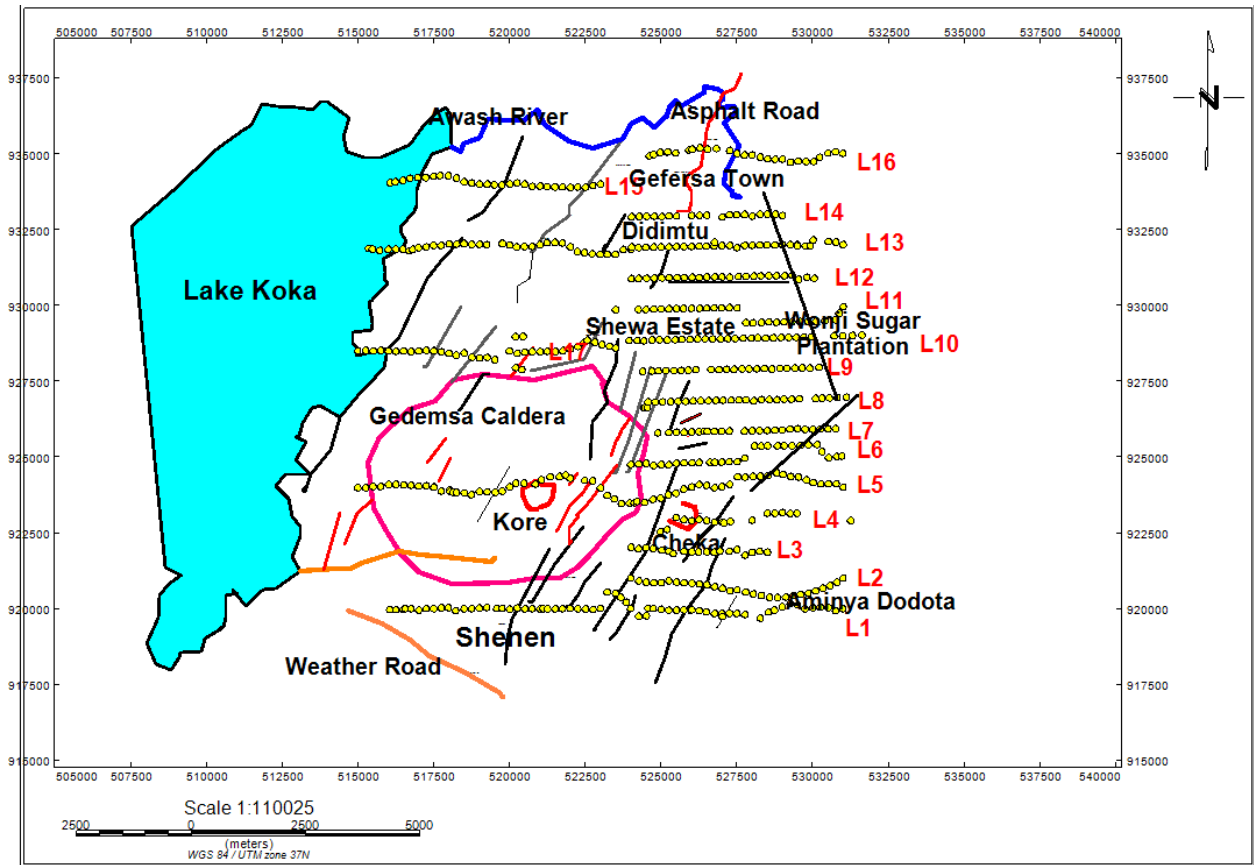


Figure 3: Base map of the study area and the blue dots are magnetic data points with 17 profiles(L1 – L17)

4. RESULT AND DISCUSSION

Total magnetic field map

From the total magnetic field map Figure 3 three main anomaly regions are outlined. These regions named as, high magnetic anomaly region with amplitude greater than 35600 nT, region low amplitude less than 35100 nT and an intermediate region between the range of 35100 and 35600 nT are observed and distributed within different parts of the surveyed area.

The positive anomaly region can be classified as high magnetic anomaly that could possibly be the responses from rocks which have low susceptibility because we are at minimum inclination (on the equator) the response should be opposite. This high magnetic anomaly zone is trending in the SW to NNE direction following the regional fault pattern, and covers most of the rim of the Gedemsa caldera, North and North-East of the Gedemsa caldera that is covered by sugar plantation. The second zone is of relatively low magnetic anomaly of less than 35100nT and this may arise due to rocks of high magnetic susceptibility. This region covers partly the Northern and Eastern portion of the map which is the area around the base of the Gedemsa Caldera and a transition region between the positive high responses and the negative low responses. The third region which have an intermediate value is observed at the center of the gedemsa caldera and most of the Eastern part of the map which is the Wonji sugar plantation cover in large extent.

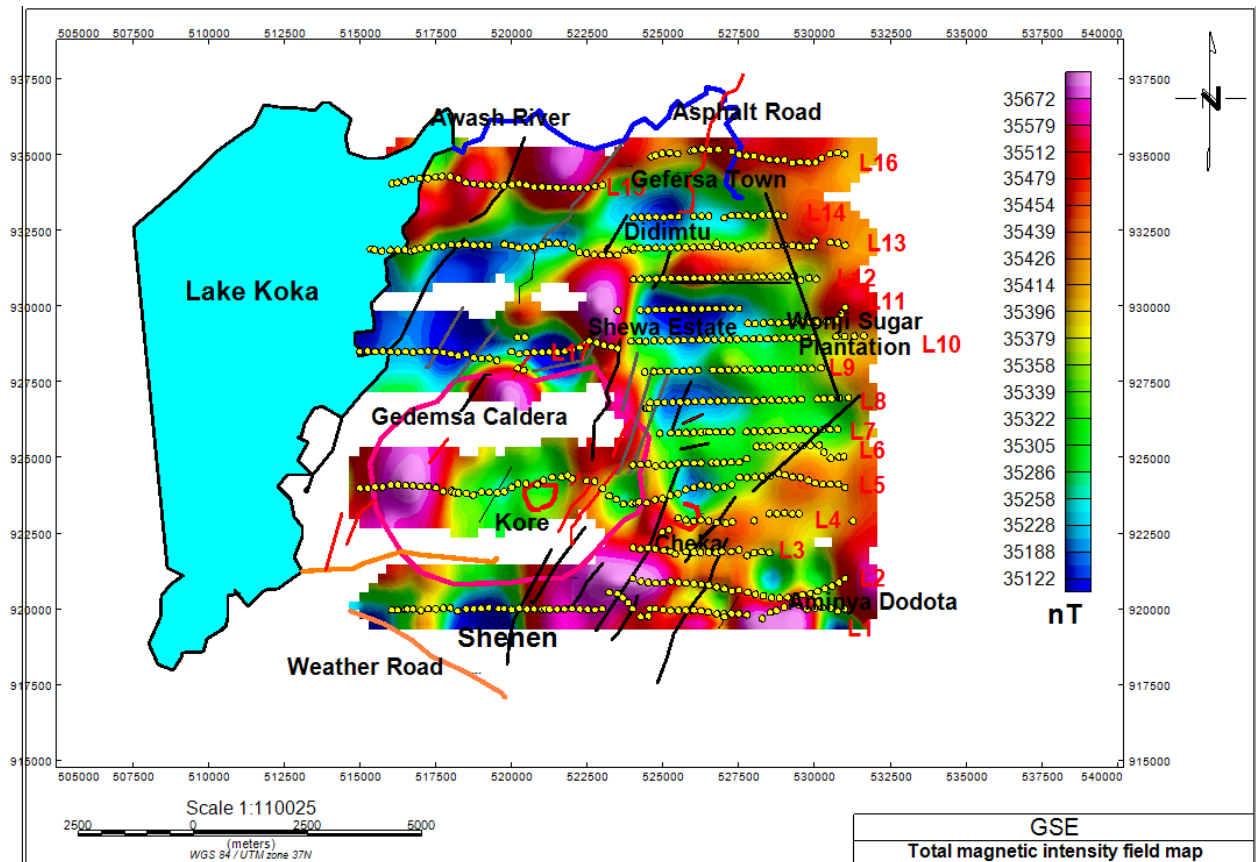


Figure 4: Total magnetic intensity map of Gedemsa geothermal prospect area.

Analytic Signal map

The interpretation of magnetic field data at low magnetic latitudes is difficult because the vector nature of the magnetic field increases the complexity of anomalies from magnetic rocks. The magnitude of the analytic signal of the total magnetic field produces maxima over magnetic contacts regardless of the direction of magnetization and is always positive.

The magnetic contacts could result from differences in magnetic susceptibility between an intrusive rock and a country rock, between geologic contacts and across a fracture zone due to the oxidation of the magnetite or infilling of the fracture zone by magma thus forming intrusive bodies whose magnetic susceptibility is different from the host rock or in geothermal area the fractured zone is filled with geothermal fluid.

From the geology map of Gedemsa area (figure 2) the high analytic signal or low magnetic intensity region is correlated with Gedemsa ignimbrite at the south east and most of the northern parts of the Gedemsa caldera. Low analytic signal or/and high magnetic intensity region is correlated with lacustrine sediment and covers most of the north east and east (sugar plantation) of Gedemsa caldera and inside the caldera. Intermediate value of magnetic intensity and analytic signal is correlated with pumice pyroclastics and younger rhyolite which are found at center of Gedemsa caldera, south and north east of this caldera.

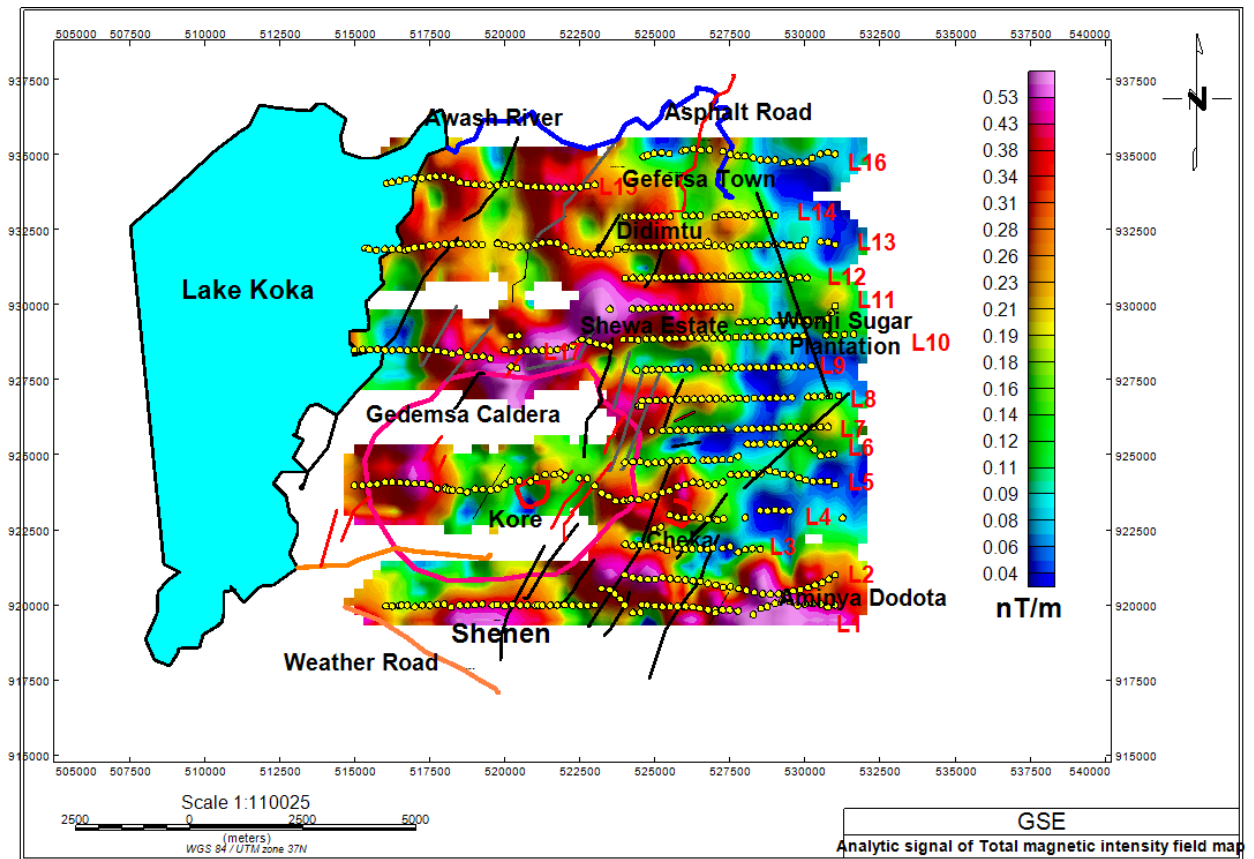


Figure 4: Analytic Signal of Total magnetic intensity map of Gedemsa geothermal prospect area.

Tilt derivative

The Tilt derivative option in MAGMAP calculates the tilt derivative of a grid and optionally, the total horizontal derivative of the tilt derivative grid. The tilt derivative and its total horizontal derivative are used for mapping shallow basement structure (Geosoft manual, 2007).

The tilt angel of a residual magnetic field enhances weak magnetic anomalies, otherwise over shadowed by stronger structures. The tilt derivatives vary markedly with inclination within an amplitude range of $\pm\pi/2$. For inclinations of 0 and 90°, the zero crossing is close to the edges of the model structures.

The tilt derivative is similar to the local phase, but uses the absolute value of the horizontal derivative in the denominator.

$$TDR = \tan^{-1} \left[\frac{VDR}{THDR} \right]$$

where VDR and THDR are the first vertical and total horizontal derivatives, respectively, of the Total magnetic intensity. While VDR can be positive or negative, THDR is always positive. For profiles in the x direction.

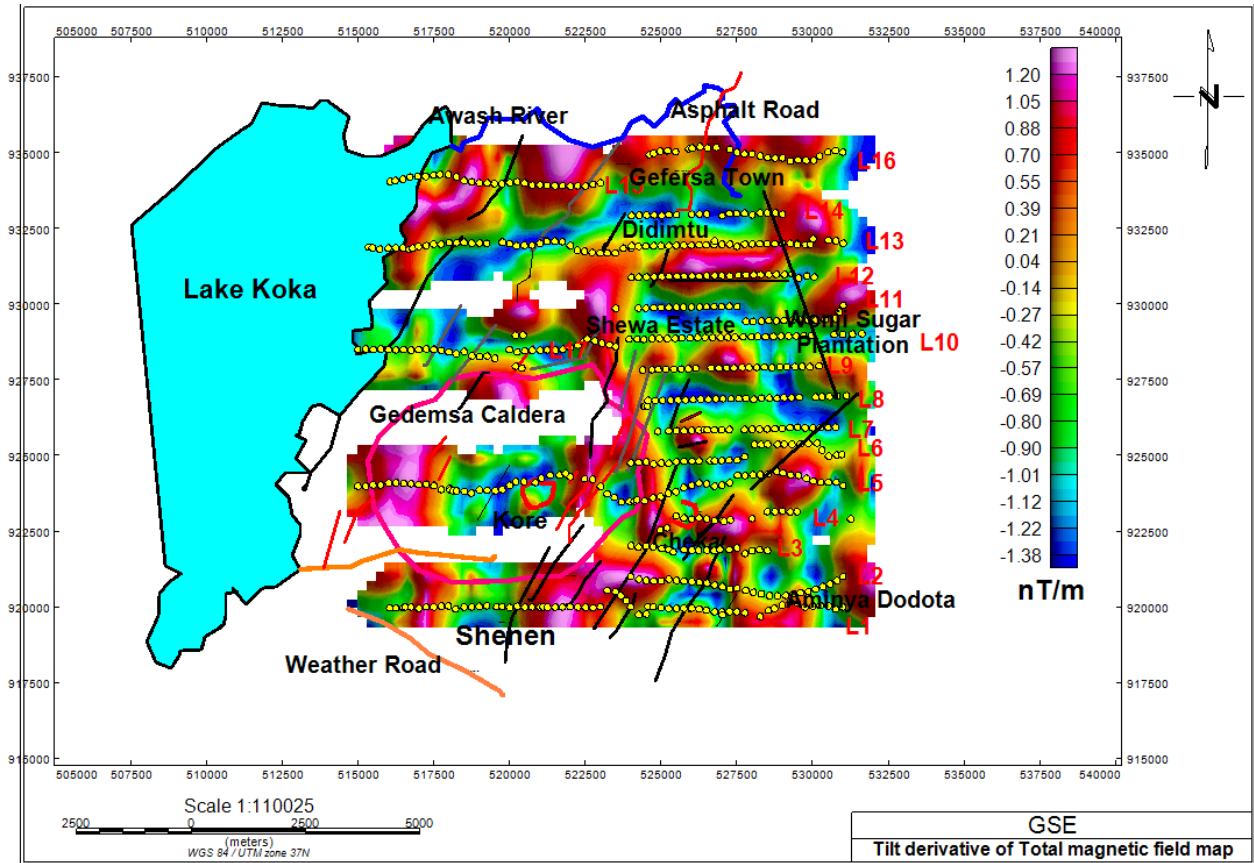


Figure 6: Tilt derivative of Total magnetic intensity map of Gedemsa geothermal prospect area.

Bouguer Anomaly Gravity Map

The Bouguer map displays high gravity anomalies mainly constrained within the Gedemsa Caldera and lows between Koka and Wonji sugar plantation. While intermediate Bouguer values are observed around the periphery of the Gedemsa Caldera. Generally, high Bouguer values are obtained over high elevated areas. However, there are areas detected by high Bouguer values and high elevations which may indicate that the areas are under-compensated. Compared with geology, it has revealed that these local anomalies correspond to areas of basaltic flows, in which case the basaltic material might be buried underneath the overlying sediment. This Bouguer anomaly corresponds to the effects of volcanic covers of the Gedemsa Plateaus with deep-seated high temperature gradients underlying the area. Hence, the Gedemsa gravity highs could be ascribed to the complex fissure eruptions, volcanoes, and basaltic flows which resulted in the deposition of the Wonji series rocks (Meyer et al., 1975). The result indicated in the power spectrum map shows that high-density crustal material is located at a relatively shallow depth of 1.5 km beneath the major volcanic centers of the caldera.

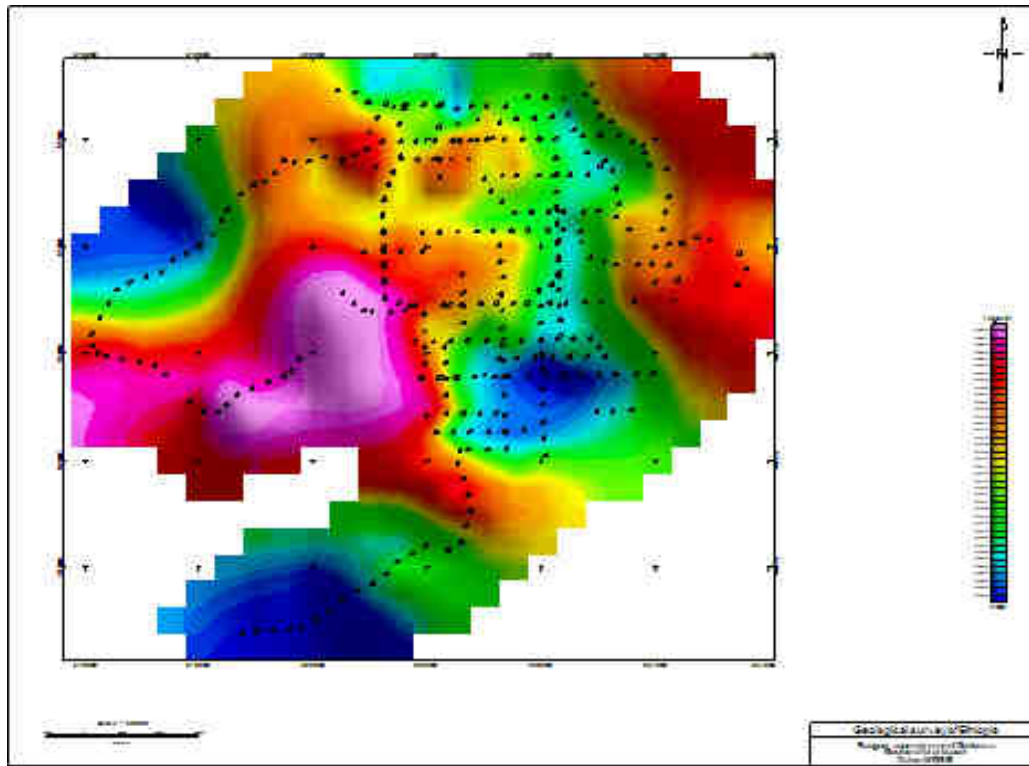


Figure 5: Bouguer Anomaly map of Gedemsa Geothermal prospect area.

CONCLUSION

Analytic signal and derivative techniques has been applied in the frequency domain to the total and residual magnetic field of Gedemsa area. The magnitude of analytic signal within the study area depends on the magnetic susceptibility contrast between deep-seated (1-3km) basaltic intrusion and the Older Basement rocks. The results revealed peaks that could probably represent the magnetic contacts between igneous intrusions and the surrounding basement rocks within the area; and fractures. The probable igneous intrusions in the study area could be basaltic intrusions (dykes) which form structural features of the volcanic Complex and are shallow heat source rocks for thermal activity in the study area.

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REFERENCES

- Ayele, A., Teklemariam, M., and Kebede, S. (2002): Compilation report Geothermal resource exploration in the Abaya and Tulu moye-gedemsa geothermal prospects, main Ethiopian Rift.
- Bigazzi G., Bonadonna F.P., Di Paola G.M., Giuliani A. (1981): “New k-Ar and fission track age of the last volcano-tectonic phase in the Ethiopian Rift Valley (Tullu moye area)” – Proc. 1st Int. Symp. On crustal movement in Africa, U.N.E.C.A., 21pp., in press by UN.
- ELC, (1987). Geothermal Reconnaissance study of selected sites of the Ethiopian Rift System,(Geophysical report), Milano, Italia.
- G.M. Di PAOLA, 1970 Geological-Geothermal Report on the central part of the Ethiopian Rift.
- Geosoft, (2007). Oasis Montaj, Mapping and filtering software. Toronto, Canada, Geosoft incorporated.
- Gylfi Pall Hersir, Alex Bjornsson, (1991): Geophysical exploration for geothermal resources principles and application UNU G.T.P., Reykjavik, Iceland, report 15, (1991).
- Meseret Teklemariam, Kibret Beyene., Yiheyis Amdeberhan, Zewde Gebregziabher, (2000). Geothermal development in Ethiopia. *proceedings world geothermal congress*. Kyushu-Tohoku, Japan Mohr. P.A., (1971): the geology of Ethiopia university college of Addis Ababa. Addis Ababa- Ethiopia.
- Nabighian. M.N., (1972). The analytic signal of two-dimensional magneticbodies with polygonal cross section: its properties and use for automated anomaly interpretation. *Geophysics*, **37**, 507-517.
- Telford, W.M., Geldart, L.P. and Sheriff, R.E., (1990). Applied Geophysics, 2nd Edition. Cambridge University Press, Cambridge, UK. Pp 6-48, 522-562.
- Tigistu Haile, Ranieri, G., Tamiru Alemayehu. (2003). Application of Geophysical methods for the evaluation of thermal centers and their structural controls in Boku, Nazareth, Main Ethiopian Rift. *Near Surface Geophysics*.