SPECTRAL ANALYSIS OF GROUND MAGNETIC DATA IN MAGADI AREA, SOUTHERN KENYA RIFT

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ABSTRACT

The area surrounding Lake Magadi in the southern Kenya rift is characterized by hot springs that issue from fractures distributed along the shores of the lake. Presence of earthquake swarms that cluster in northern margin of Lake Magadi strongly indicate magmatic activity in the area. This study was done as a follow-up to investigate depth to the heat source possibly causing high seismic activity and high heat flow in the area. A ground magnetic survey was conducted to investigate geothermal potential of the area and a magnetic anomaly contour map prepared. Spectral analysis involving determining power spectrum was applied to magnetic data along selected profiles cutting through discerned anomalies. Spectral analysis results suggest that the Curie-point isotherm depth under Magadi ranges from 5.20 km to 8.30 km. Estimated vertical temperature gradients along the profiles ranges from 111.53˚C/km to 69.92˚C/km. The high-temperature gradients and relatively shallow Curie point depths indicates high heat flow which suggests presence of a hot magmatic intrusion.

INTRODUCTION

Magadi area, as illustrated in figure 1, is in the southern part of the Gregory Rift, bounded by latitudes 1˚ 40′ S and 2˚ 10′ S, and longitudes 36˚ 00′ E and 36˚ 30′ E an active continental rift that is part of the East African Rift System. The Gregory Rift is of continental rift type (Gregory 1921); it extends from the Magadi –Natron basin in the south to Baringo and Suguta grabens in the north and is a complex graben bisecting the Kenya domal uplift. Lake Magadi is located in a broad flat depression that occurs at the lowest point in the southern Kenya Rift Valley.

Hot springs are distributed along the shores of Lake Magadi issuing from the base of fault scarps. This study was carried out with a view to understanding the subsurface structure of the greater Magadi area by investigating possibility of presence of bodies that may be heat sources. Previous geophysical works done in the area reveal high seismic activity in the subsurface. During one of the first micro-earthquake surveys in Kenya, Molnar and Aggarwal (1971) found the Magadi Rift to be seismically the most active section of the Kenya Rift. Later, as part of the Kenya Rift International Seismic Project (KRISP 94), a temporary seismic network around Lake Magadi recorded more than 200 events in a period of two weeks. A seismotectonic and crustal structure study by Ibs-Von Seht et al (2001) revealed an earthquake cluster north of Lake Magadi, beside little Magadi as illustrated in figure 2. The cluster represented 75 percent of observed events in the area, other events being distributed over the rift floor.

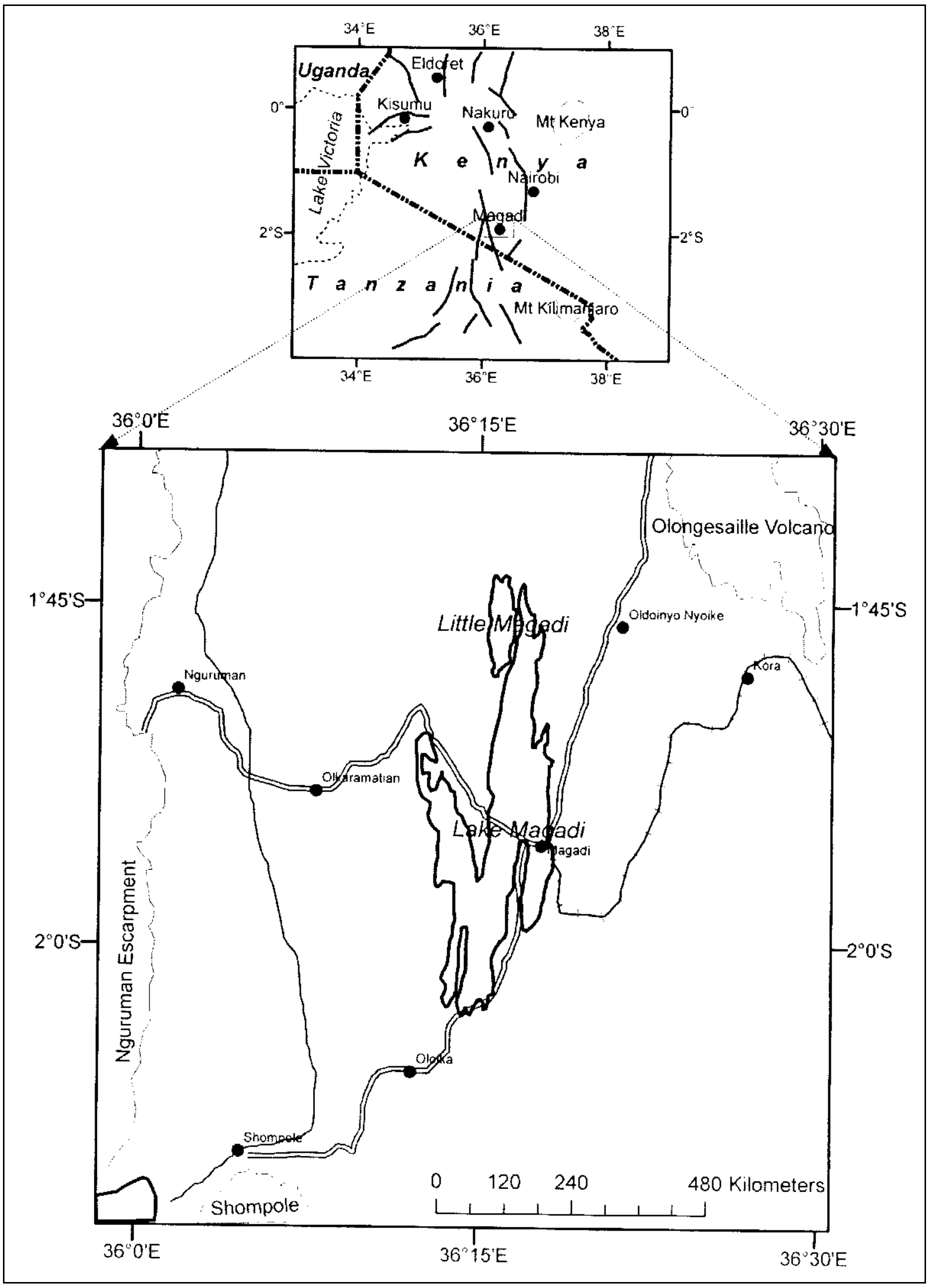

Figure 1: Location map of the study area (after Ibs-Von Seht *et al.* 2001).

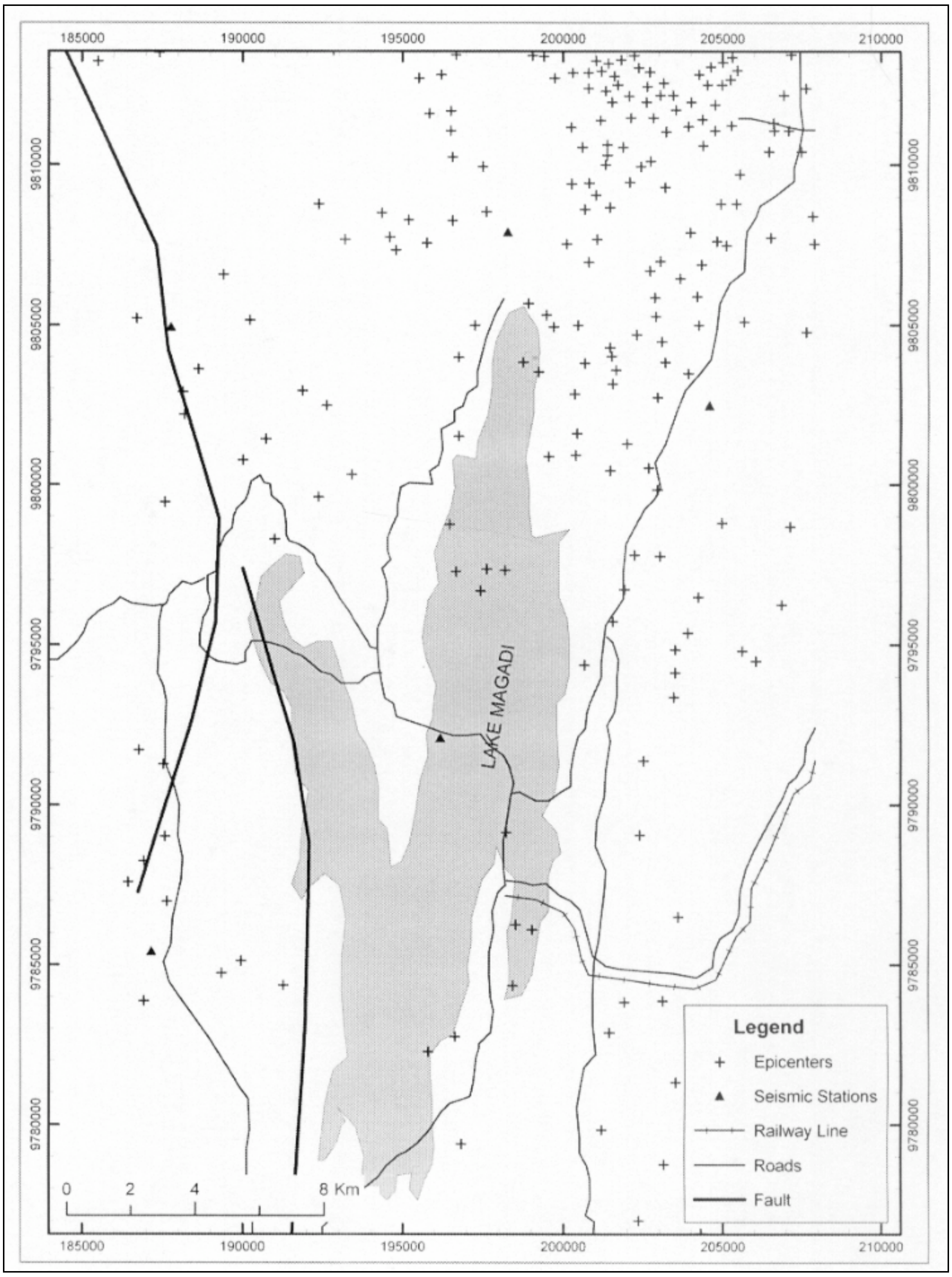

Figure 2: Distribution of earthquake epicentres in Magadi (after Ibs-Von Seht *et al*. 2001).

Geology

The broader Magadi area is largely covered by Holocene sediments that overlie extensive Pleistocene trachyte lavas. The trachyte lava overlies Pliocene olivine basalts and nephelinites, which, in turn rest on the Archean basement. A dense network of grid faults affects the area. These faults, especially the north-south trending fault scarps, control the occurrence of geothermal manifestations (Riaroh and Okoth 1994)

The Magadi area was classified into three formations by Baker (1958, 1963) namely Precambrian metamorphic rocks, Plio-Pleistocene volcanics, the Holocene to Recent Lake and fluvial sediments. The basement rocks consist mainly of regular banded schist, gneisses and muscovite-rich quartzite. The most extensive volcanic activity in the area occurred between 1.4 and 0.7 Ma (Crossley 1979). During this activity the Magadi plateau trachytes series were formed. The study area is on the rift floor region dominated by Magadi plateau tachytes and Lacustrine fluviatile sediments as displayed in figure 3.

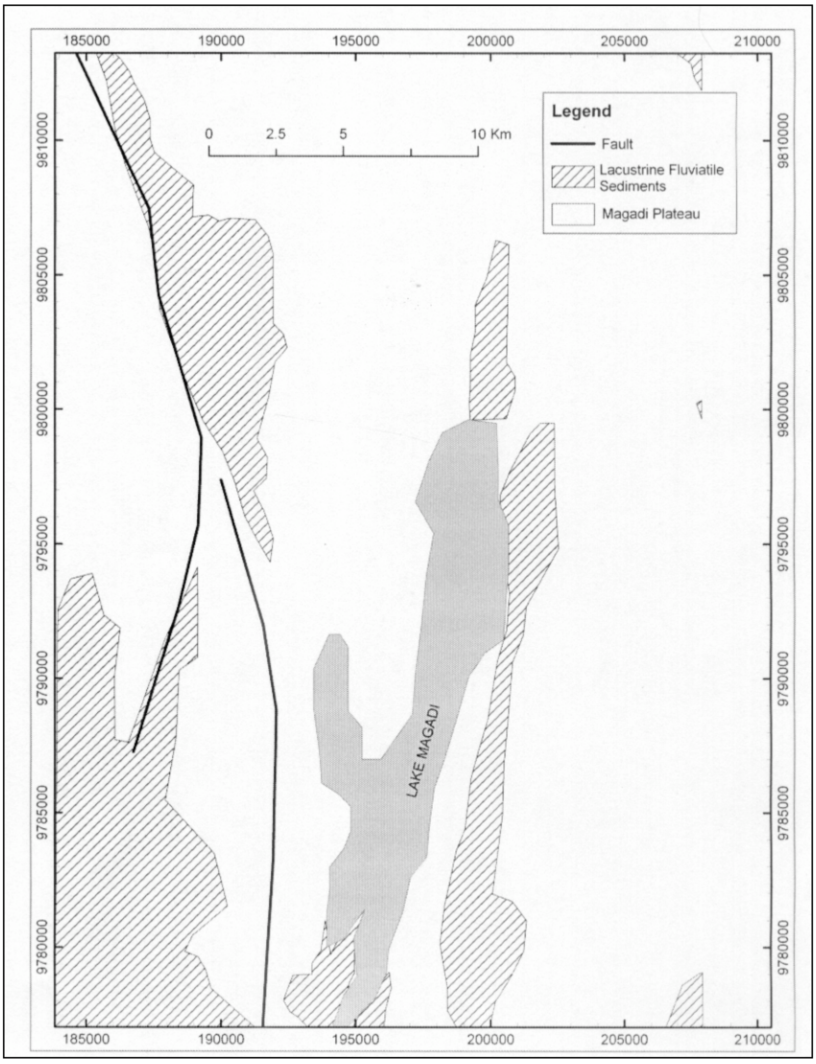

Figure 3: Geological map of Magadi (simplified from Baker 1958, 1963).

MATERIALS AND METHODS

Field Procedure, Reduction and Analysis

Establishing and positioning of magnetic stations including base stations was done using a Global Positioning System model Garmin 45. A total of 58 magnetic stations were established. The total magnetic field intensity was measured at each station using a proton precession magnetometer model Geometrics G-856 with an accuracy of 0.1 nT. A single proton precession magnetometer was used in the survey and therefore a base station was chosen at the beginning of a day's work and reoccupied after about every two hours and diurnal variations carried out. Normal geomagnetic corrections were neglected in this study as the survey area was considered small relative to geological features of interest. The residual total magnetic field intensity map was prepared with contour intervals of 25 nT as displayed in figure 4. Solid contours in this contour map were used to represent magnetic highs while hachured contours represent magnetic lows. Profiles were selected from the total intensity magnetic map passing through the discerned anomalies.

Estimation of Curie-Point Depth by spectral analysis

According to Okubo *et. al* (1985), the basal depth of a magnetic source was considered to be the Curie point depth. In this study, Fast Fourier Transform (FFT) was applied to reduced to the pole (RTP) magnetic profile data. The pole-reduced data software was sampled at an equal spacing of 0.125 km. The forward FFT was done using Origin Pro software version 7. The input data consisted of two columns with profile distance sampled at a spacing of 0.125 km against the corresponding RTP magnetic data. The sampling intervals of 0.125 km used in all the magnetic profiles correspond to a maximum frequency of 4 cycles/km equivalent to 8π radians/km. Therefore the FFT estimated Fourier components between zero frequency and the Nyquist limit of 4cycles/km.

The Curie point depth was estimated as suggested by Bhattacharyya and Leu (1975) and Okubo *et al.* (1985). The first power spectrum was obtained by plotting a log of square root of power per absolute wave number against absolute wave number. These variables are related as in equation;

$$Ln\left[\frac{P^{\frac{1}{2}}}{|S|}\right] = LnA - 2\pi|S|z_0 . \qquad (5)$$

Equation 5 can simplify to the form as

$$LnQ = LnA - 2\pi z_0 X , \qquad -(6)$$

where $Q = \frac{P^{\frac{1}{2}}}{|S|}$, $X = |S|$ which represents the absolute wave number, P is the power spectra of the anomaly and A is a constant. The depth to the centroid z_o of the magnetic source was determined from the slope of the longest wavelength part of the power spectrum as expressed in equation 6. Another power spectrum of logarithm of square root of power against the wave number was plotted for the same profile. Equation 7 relates the variables for the spectrum. Both the first and second spectrum for each profile was fitted using the five point adjacent averaging smoothing method.

$$Ln\left[P^{\frac{1}{2}}\right] = LnB - 2\pi|S|z_t \qquad (7)$$

Equation 7 can be simplified to

$$LnR = LnB - 2\pi z_t X , \qquad (8)$$

Where B is a sum of constants independent of the wave number X. The depth to the top boundary z_t was obtained from the slope of the second longest wavelength of the spectral segment of the second spectrum. The basal depth Z_b which was assumed to be the Curie point depth (Okubo *et a*l. 1985) was calculated from equation 9 for profiles AA′, BB′, CC′, DD′, EE′ and FF′ and the results are displayed in table 1.

$$z_b = 2z_0 - z_t \tag{9}$$

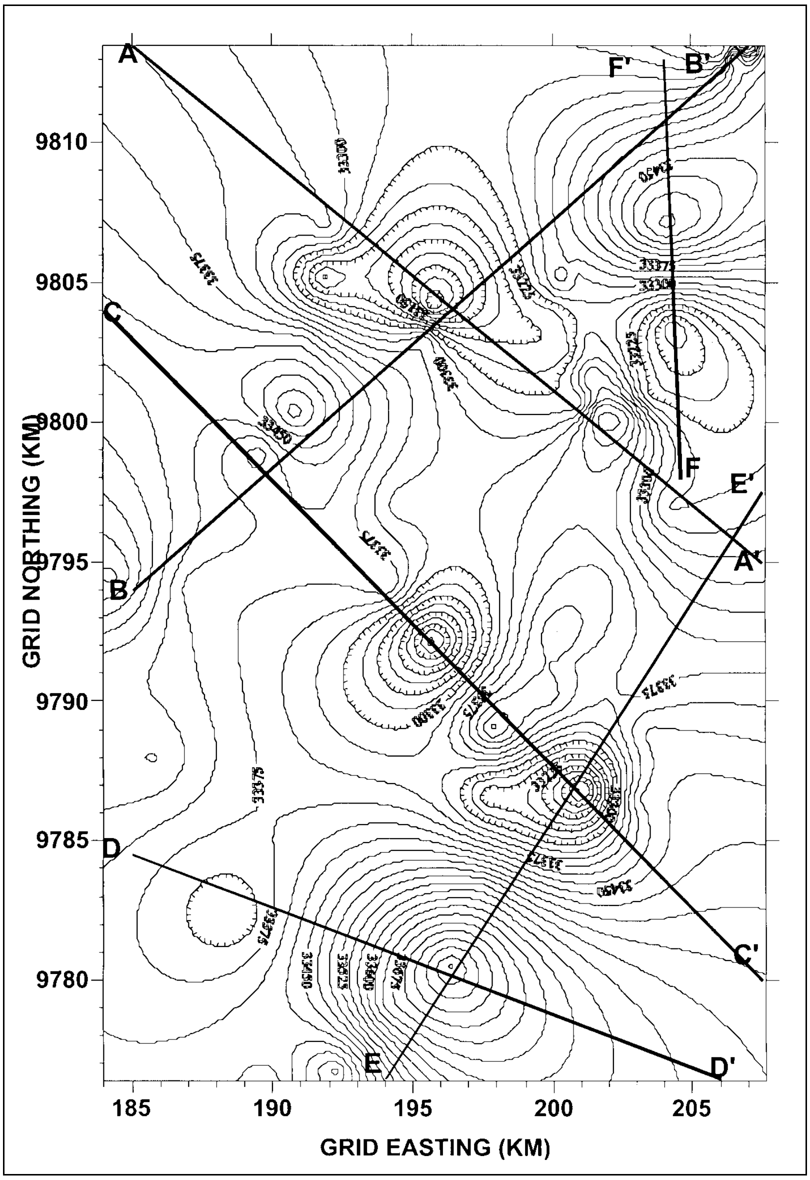

Figure 4: Magnetic intensity contour map.

Table 1: Curie-point depth estimate along selected profiles.

Profile	**Z_o (Km)**	**Z_t (Km)**	**Z_b (Km) (Curie-Point depth)**
AA'	2.700	0.200	5.200
BB'	3.860	0.170	7.550
CC'	3.600	0.160	7.040
DD'	4.200	0.105	8.295
EE'	3.200	0.140	6.260
FF'	3.200	0.320	6.080

Figure 5 illustrates the depths described in equation 9 in a parallelepiped subsurface body.

The power spectra described by equations 6 and 7 of the profiles AA′, BB′, CC′, DD′, EE′ and FF′are displayed as figures 6, 7, 8, 9, 10 and 11 respectively.

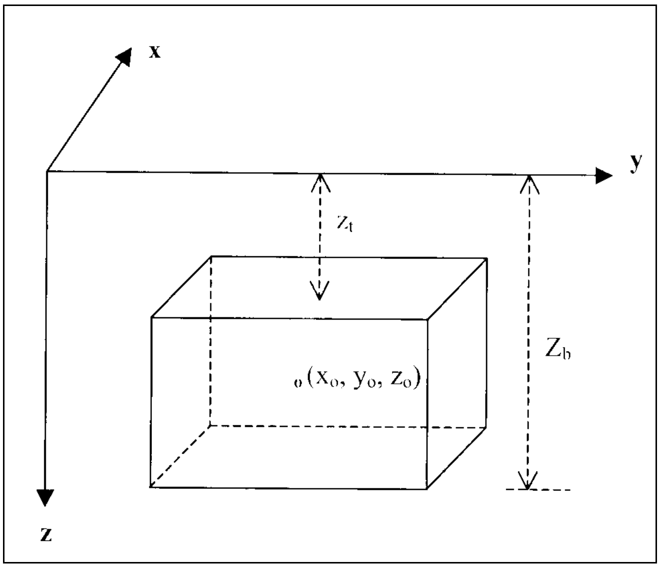

Figure 5: Illustration of Curie point depth in a parallelepiped body.

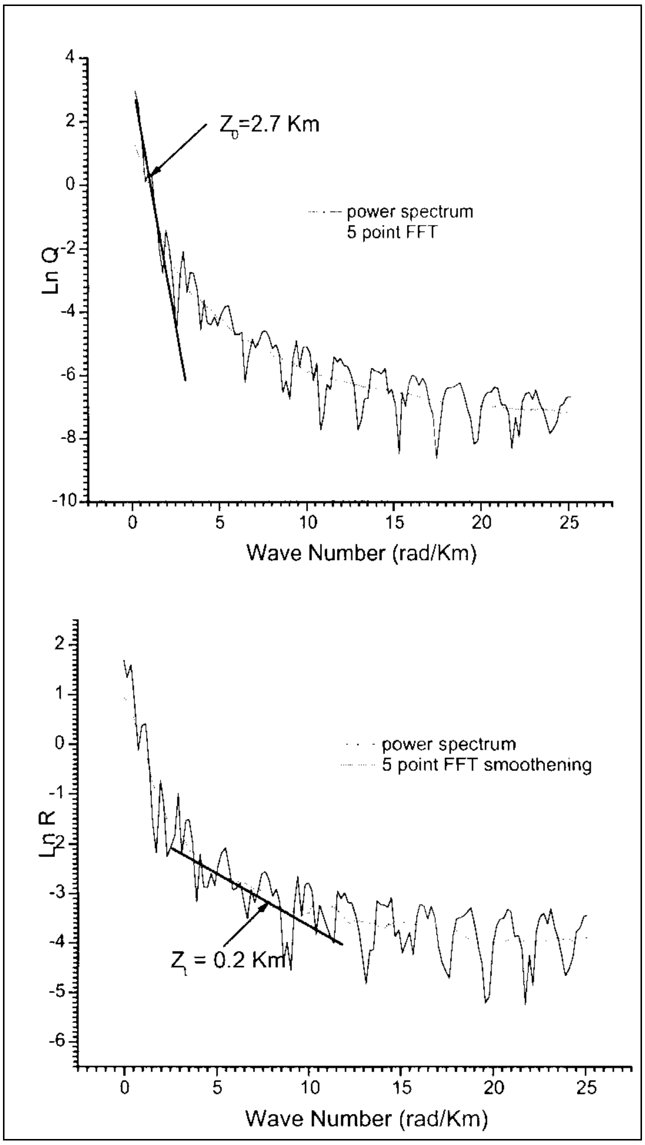

Figure 6: Power spectrums of LnQ and LnR against wave number for profile AA

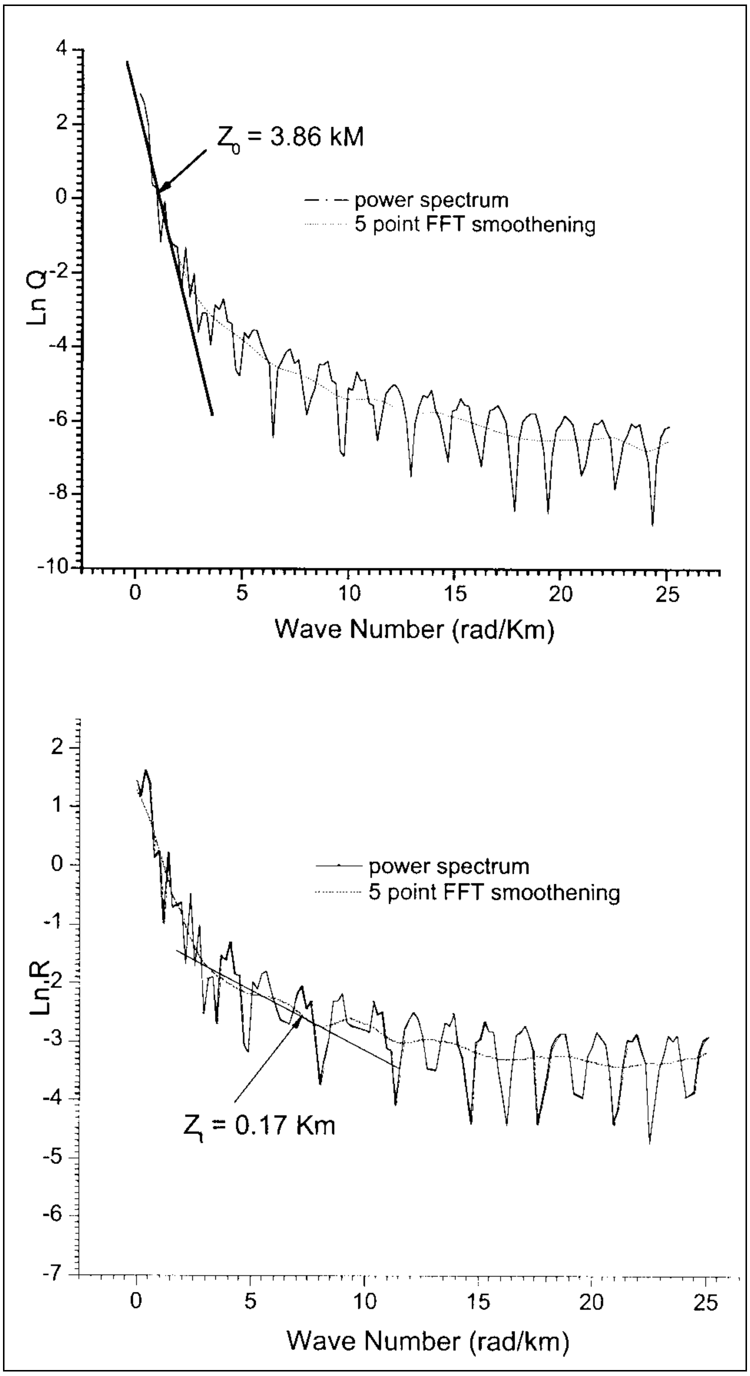

Figure 7: Power spectrums of LnQ and Ln R against wave number for profile BB′.

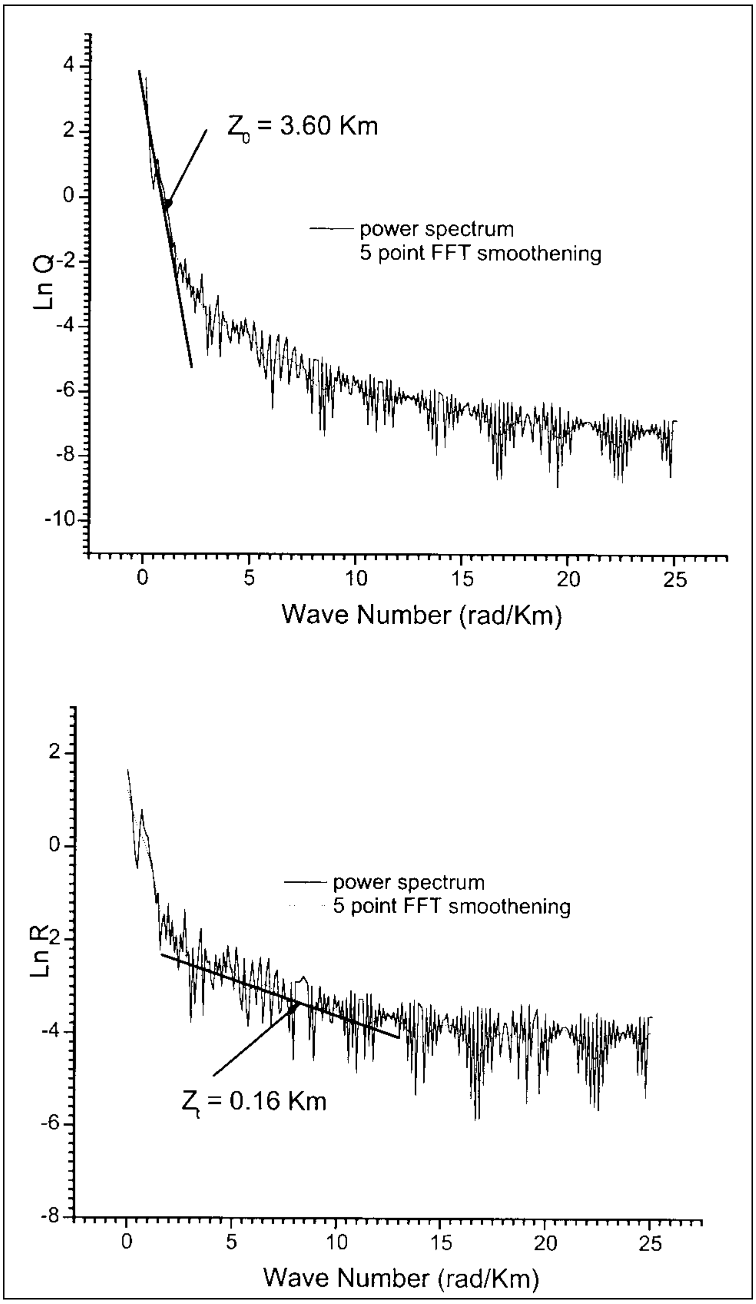

Figure 8: Power spectrums of LnQ and LnR against wave number for profile CC′.

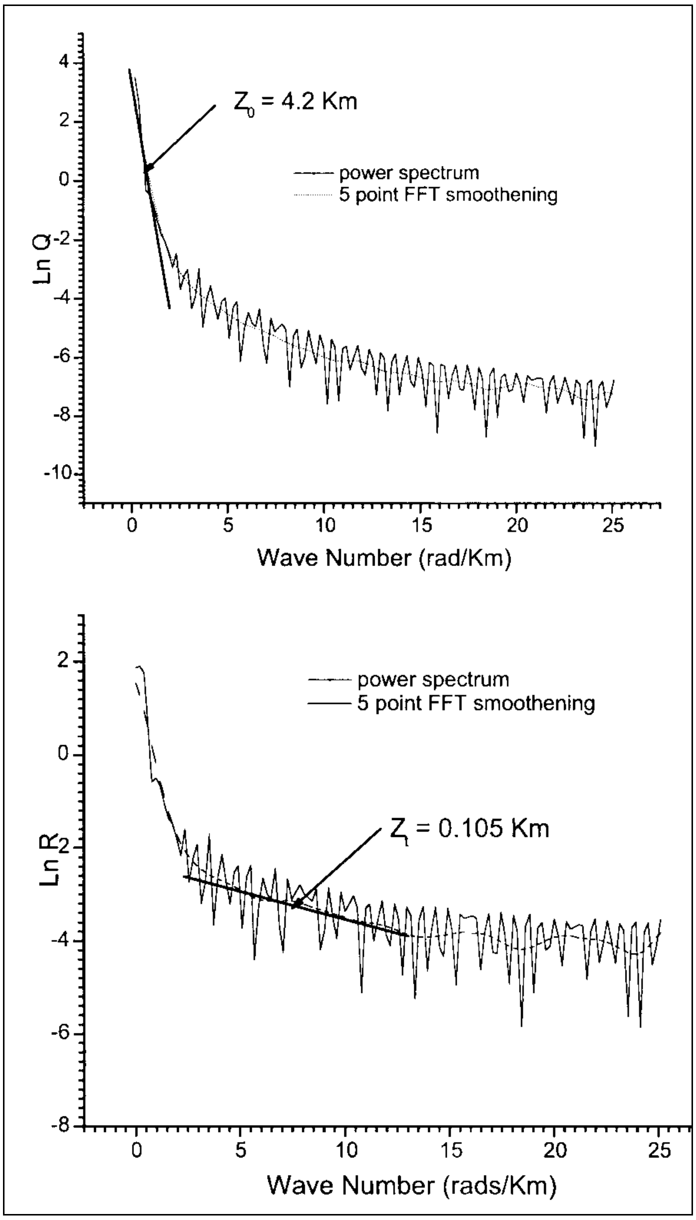

Figure 9: Power spectrums of LnQ and LnR against wave number for profile DD′.

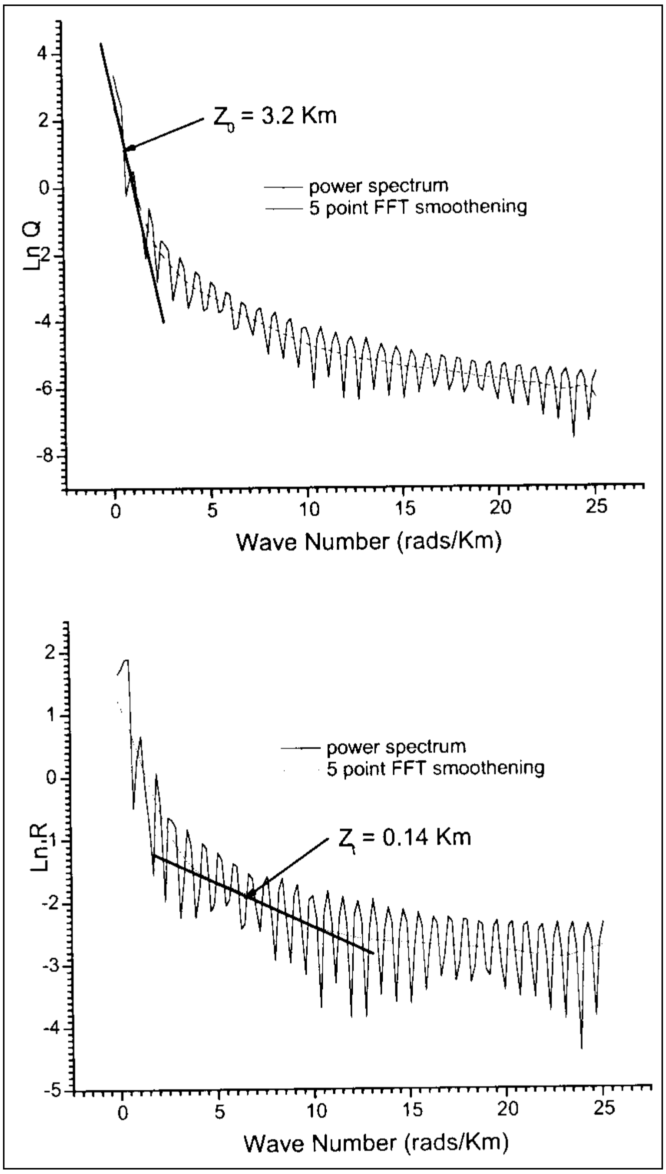

Figure 10: Power spectrums of LnQ and LnR against wave number for profile EE′.

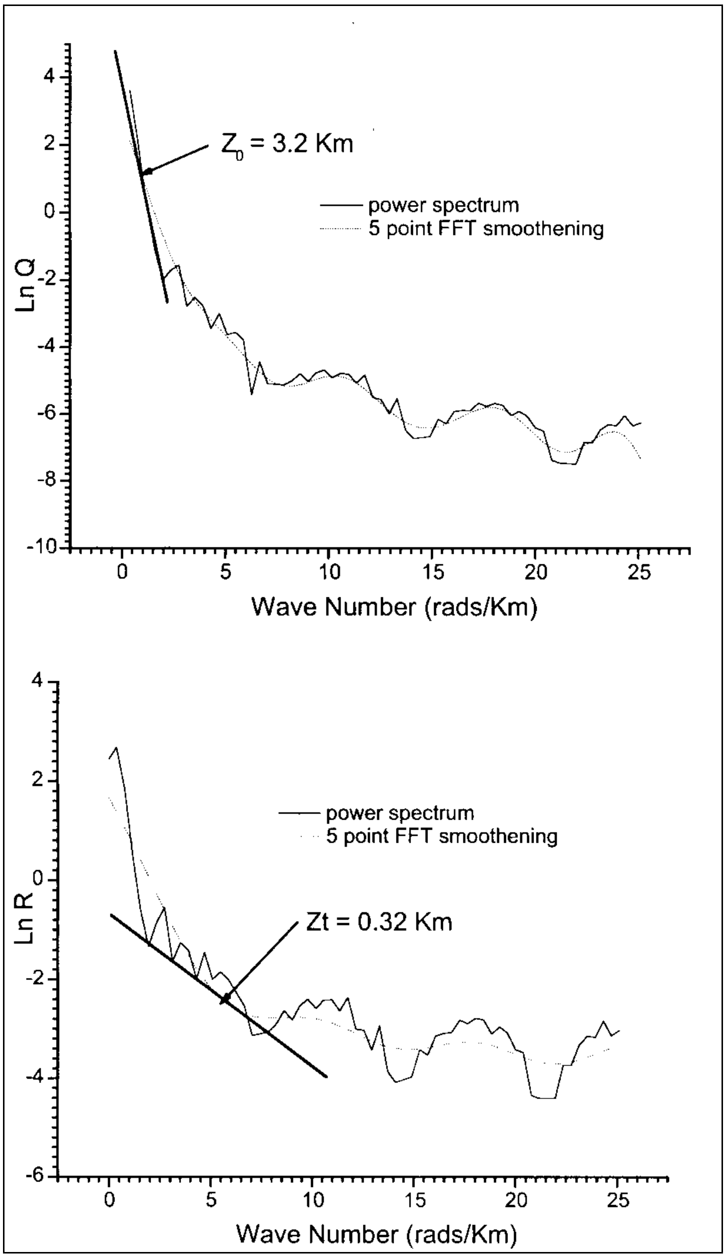

Figure 11: Power spectrums of LnQ and LnR against wave number for profile FF′.

DISCUSSION AND CONCLUSIONS

The depth Z_t computed using the power spectrum method Spector and Grant (1970) and modified by Okubo *et al.* (1985) is the thickness of the sediments overlying the volcanics. The sediments depth Z_t determined along profiles AA′, BB′, CC′, DD′, EE′ and FF′ were 0.2 km, 0.17 km, 0.16 km, 0.105 km and 0.14 km respectively. The Curie point depths calculated were 5.20 km along profile AA′, 7.55 km along BB′, 7.04 km along CC′, 8.29 km along DD′, 6.26 km along EE′ and 6.08 km along FF′ as displayed in table 1. The Curie point depths were considered shallow and are located within the crust. The shallowest depths are on profiles AA′ and FF′ which traverse along the northern part of the study area. This may indicate presence of the thermal anomaly responsible for the earthquake swarms in the northern region near the little Lake Magadi. The previously determined Curie point depth was used to estimate temperature gradients in the crust. Thermal gradient of each profile was calculated by assuming that rocks are dominated by magnetite which has a Curie temperature of 580˚C. Therefore by dividing the temperature by the depths, the estimated vertical temperature gradients along profiles AA′, BB′, CC′, DD′, EE′ and FF′ are 111.53˚C/km, 76.82˚C/km, 82.38˚C/km, 69.92˚C/km, 92.65˚C/km and 95.39˚C/km respectively.

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