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Near Surface Anomaly Depth Estimation Using Downward Continuation

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Abstract: *Depth estimation in gravity survey is very important in mineral prospecting. It does not only inform the choice of the optimal point for mineral exploration but also very important in analyzing economical viability of the mines. A number of depth determination techniques ranging from empirically derived formulae to modern automated analysis of gravity data have been developed. In this study, downward continuation filtering technique has been used to filter the near surface perturbations on the gravity field which are suspected to be as a result of minerals. The measured total magnetic field data of Migori greenstone belt was first subjected to cleaning process to remove the effects which are not of geophysical interest, and later enhanced by removing long wavelength anomalies which are as a result of regional magnetic trend. The complete Bourguer anomaly was then subjected to downward continuation at depths of 0 m, 500 m, 1000 m and 1500 m. The near surface features seem to be filtered at a depth of 1500 m, leaving the deeply seated features. This result with the available geological information is a good indicator of the possible depth of the near surface anomaly causative bodies. The result was further improved by integrating it with the geochemical analysis of rock samples. Shallow gravity structures are mapped from the surface to a limiting depth of approximately 1,500 m. These structures agree well with the geochemical results that shows presence of minerals and known geology of the area.*

Keywords: *Gravity, Anomalies, Migori Greenstone belt, Continuation, geochemical analysis.*

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I. Introduction

1.1 Analytic continuation

An important consequence of the fact that the anomalous masses below the plane can be replaced by an anomalous layer of surface density $\Delta g(x, y)/ 2\pi G$ is as follows;

The anomalous mass of a volume element of the layer is $\delta(x, y)dv$. But if dS is a surface element,

$$\delta(x, y)dv = \delta(x,y)hdS$$

$$= \sigma(x,y)dS$$

$$\delta(x, y)dv = \frac{\Delta g(x,y)}{2\pi g}dxdy \quad \ldots\ldots 1$$

$$V = \int \frac{G\rho}{r}dv \quad \ldots\ldots 2$$

From equation 2, we get the gravitational potential V at any point D(x, y, z) above the earth as

$$V = \int_{y=-\infty}^{\infty}\int_{x=-\infty}^{\infty} \frac{\Delta g(x,y)}{2\pi Gr}dxdy \quad \ldots\ldots 3$$

Where $r = [(x - x^1)^2 + (y - y^1)^2 + (z - z^1)^2]^{\frac{1}{2}}$ is the distance of D from the surface element dx^1dy^1.

Thus the potential at D can be found solely from knowledge of $\Delta g(x^1, y^1)$ on the ground surface. If the positive z axis is in the downward direction then, the gravity at the point D will be given by dV/dz. Then from Equation 3

$$\Delta g(x, y, z) = -\frac{z-z^1}{2\pi}\iint \frac{\Delta g(x^1,y^1,z^1)}{[(x-x^1)^2+(y-y^1)^2+(z-z^1)^2]^{\frac{3}{2}}}\,dx^1dy^1 \quad \ldots\ldots 4$$

If we chose the origin of coordinates to lie on the ground surface we can put $z^1 = 0$. The z coordinate of D will then be $-H$ if H is the height of D above the surface. Hence

$$\Delta g(x, y, -H) = -\frac{H}{2\pi}\iint \frac{\Delta g(x^1,y^1,0)}{[(x-x^1)^2+(y-y^1)^2+H^2]^{\frac{3}{2}}}\,dx^1dy^1 \quad \ldots\ldots 5$$

This procedure of calculating the field at a higher or lower level when it is given on the ground surface is known as upward or downward analytic continuation (Telford *et al*, 1990). The theory of upward continuation is used in the process of filtering the regional trend in order to obtain the residual anomaly.

II. Methodology

2.1 Data acquisition

Ground gravity data was collected from 425 stations established over an area of approximately 200 km^2 bounded by the latitudes 34˚15'E -34˚40'E and longitudes 0˚55'S – 1˚12'S in Migori, Macalder and Kehancha areas (Figures 2.1 and 2.2), with station and profile spacing of approximately 300 m and 1 km respectively. Gravity measurements were taken using Gravity meter prospect W45. Variations in the earth's gravity which did not result from the differences in density of the underlying rocks were corrected from the ground survey data. This includes instrumental drift, free air variation, Bourguer slab, latitude and terrain effects. Drift correction was done by having a base station which was preoccupied periodically in the day. A drift curve was plotted and readings made in other stations assumed to have a linear drift as fitted base readings. Using the drift rate each reading was corrected to what it would have read if there were no drift (Kearey *et al*, 2002)

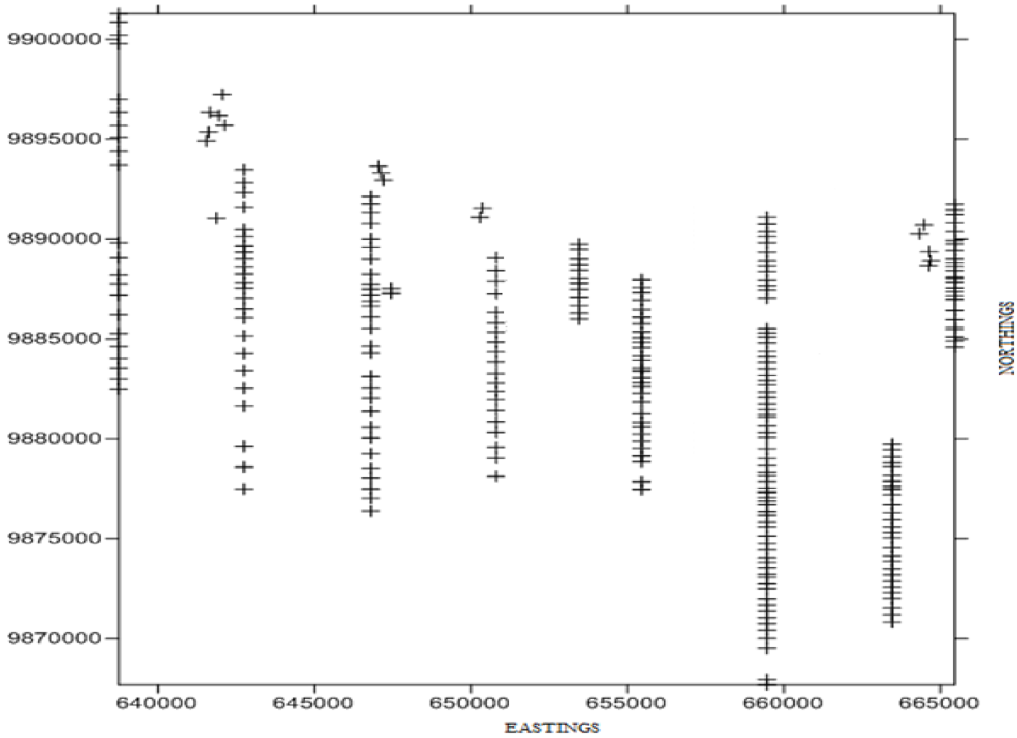


Figure 2.1: Station locations

Gravity varies with latitude because of the non-spherical shape of the earth, with polar radius shorter than equatorial radius. The theoretical value of gravity ($g_\emptyset$) at given latitude ($\emptyset$) was calculated using gravity formula (World geodetic system, 1984)

$$g_\emptyset = 9.7803267714\ 1 + 0.00193185138639 sin^2\emptyset / \sqrt{1 - 0.00669437999013 sin^2\emptyset}\ \text{ms}^{-2} \ldots\ldots 2.1$$

and it was subtracted from or added to the measured value to isolate latitude effect. As one moves away from the center of the earth, gravity decreases, the rate of decrease can be deduced by assuming spherical earth. From

$$g = GM/r^2 \ldots\ldots 2.2$$

$$\delta g/\delta r = -2\,g/r = -0.3086\Delta h \ldots\ldots 2.3$$

Where g is gravity, G is the universal gravity constant, r is the distance from Centre of the earth, M is the mass of the earth and h is the altitude. For the sites which were above the reference point, free air correction was added to the observed gravity value. For the sites which were below the reference point, free air correction was subtracted from the observed gravity value. Bouguer correction ($g = 2\pi G\rho\Delta hg$) where ρ is the average crustal density, was done to remove the effect of attraction of a slab of rock present between the observation point and the datum. Terrain correction was also conducted to remove the effect of a hill or a valley at the vicinity of a station, which ultimately reduces the gravity value.

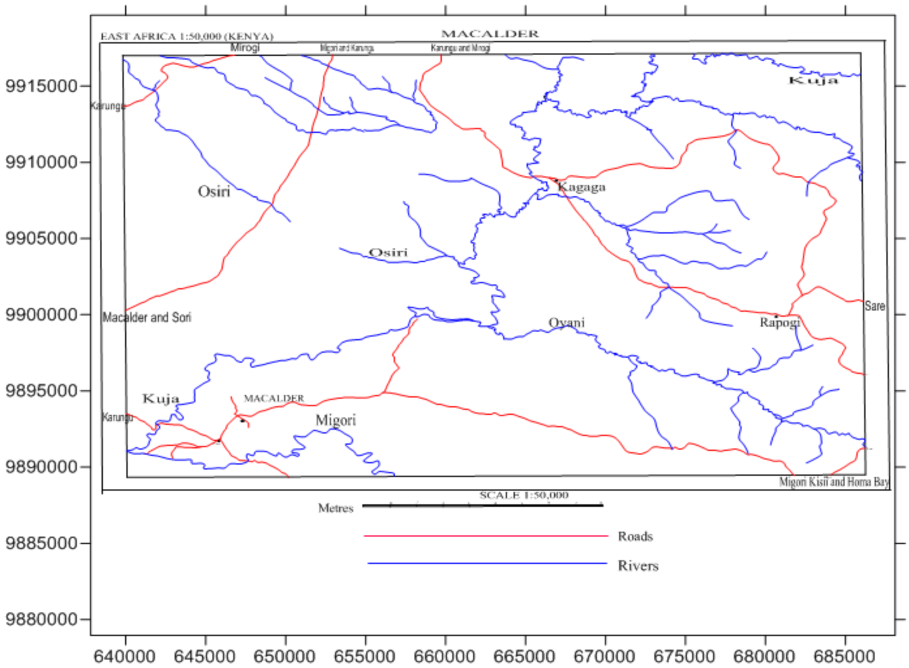


Figure 2.2: Digitized map of Macalder showing drainage features

2.2 Gravity Data Analysis

Shaded colour contour map of the complete bourguer anomaly (Figure 2.3) was drawn using Geosoft Oasis Montaj program. The colour shaded contour map delineates a high gravity anomaly trending ESE-WNW, the localized gravity anomalies caused by rocks are superimposed on the regional trends. Power spectral analysis of geologically constrained gravity field data was then conducted, in order to obtain the limiting depth of the anomaly causative bodies.

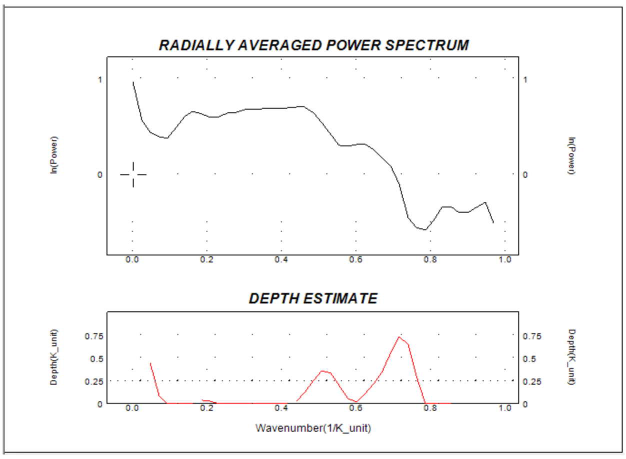


Figure 2.3: Computed power spectrum of the gravity anomaly

The computed power spectrum of the magnetic anomalies (Figure 2.3) gives a depth of approximately 750 m as the limiting depth of the causative bodies, with some anomalies featuring at shallow depths of about 100 m. The same application software was used to generate the gravity field strengths at 0 m, 500 m, 1000 m and 1500 m (Figure 2.4) in an attempt to determine the depth extent of the near surface anomalies. The gravity field intensity reduces remarkable at a depth of 1500 m, an indication of the approximate end to the effects of near surface features. Shallow causative body depths of between 500 m to 1,500 m were therefore obtained. The depth obtained by the downward continuation is comparable to the power spectral analysis.

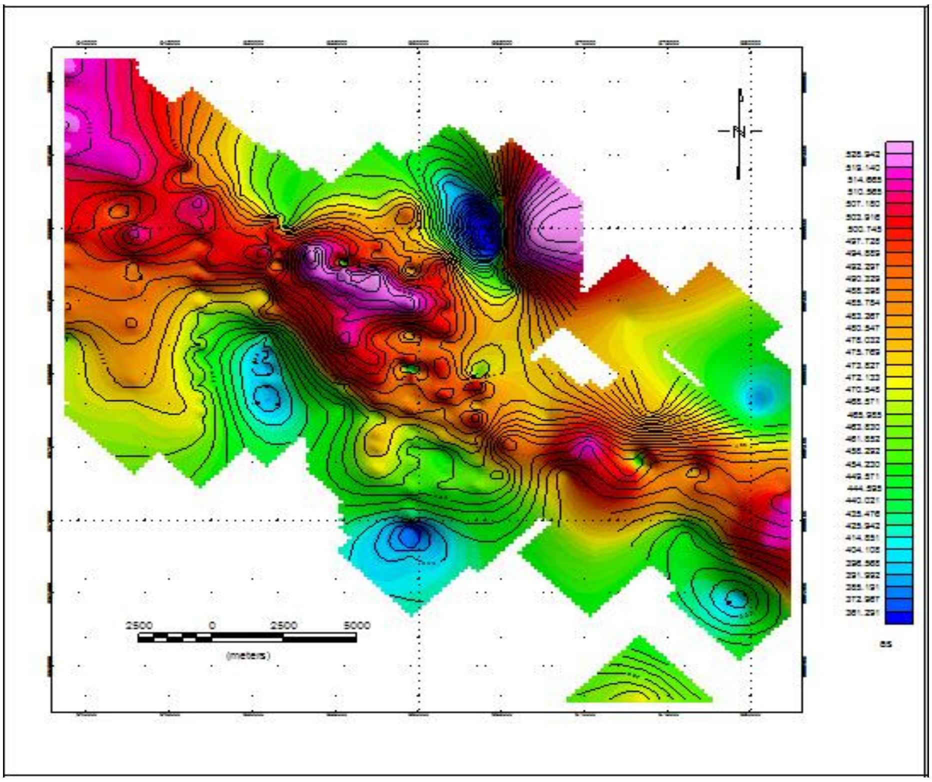
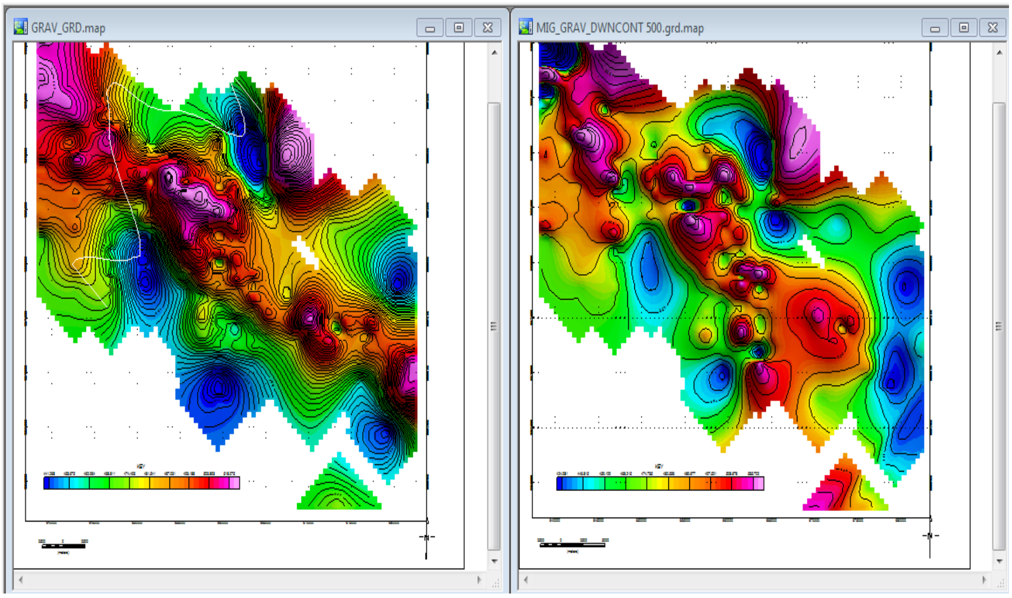


Figure 2.4: Shaded colour relief of the complete Bouguer anomaly

The near surface anomalies filtered at about 1500 m leaves the relatively deeper long wavelength anomalies. Near surface anomalies are significant in this study since they are associated with minerals while the long wavelength anomalies are as a result of deeper intrusive bodies. The result shows possible presence of minerals from the ground surface up to a depth of about 1500 m.



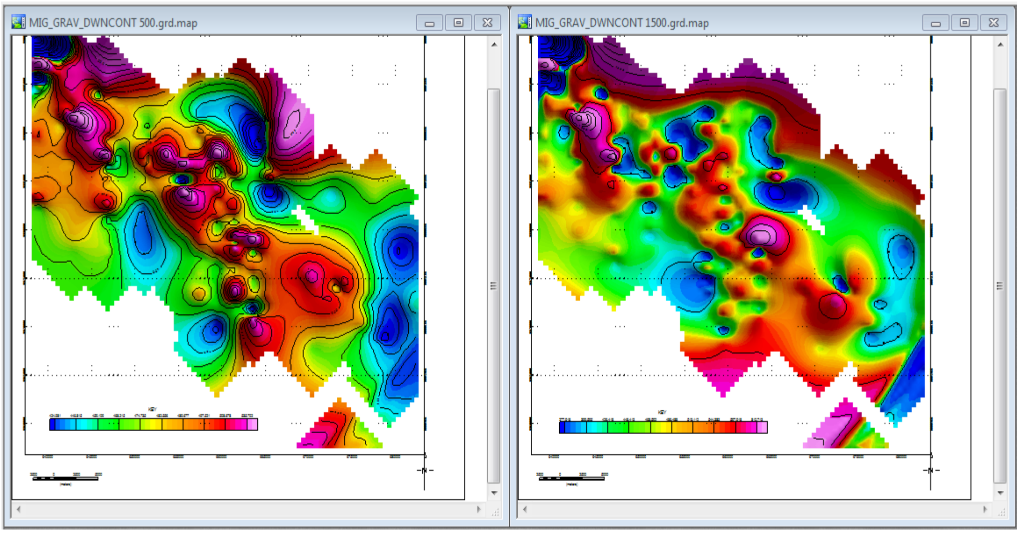


Figure 2.5: Colour shaded contour maps at depths of 0 m, 500 m, 1000 m and 1500 m

2.3 Geochemical data analysis

Geochemical analysis of 20 rock samples was conducted using wavelength dispersive X-Ray fluorescence spectrometry (XRF). This method is applicable for determination of major, minor and trace elements given that its emission spectrum is simple and orderly, coupled with the fact that its sample preparation and analysis is fast and not labour intensive. It suffers from spectral overlaps and sample inhomogeinity which might affect its accuracy, precision and sensitivity. The analysis was conducted at the Ministry of mining and natural resources laboratories in Kenya. The rock samples were taken at depths of about 20 m from open mines. Good presence of silicate was noted with traces of arsenic. Fe, Zn, Cu, Au, Ag are some of the minerals present in the rock samples. The presence of precious metals at low values is otherwise good given their economical value.

III. Discussions and Conclusion

The gravity data of Migori greenstone belt delineates high gravity anomalies of amplitude of up to 525 mgal. The structures trends ESE-WNW from Kenya-Tanzania border through Kehancha, Masaba, Nyanchabo, Migori, Mukuro, Masara, all through to Macalder. The anomalies peak at Kehancha, Masara and Macalder regions. These regions have witnessed a lot of artisan mining using opencast method (Ichangi, 1993). The Downward continuation filtering technique maps these dense structures from the ground surface to depth of about 1,500 m. The gravity highs are sandwiched by the high gravity gradients that are interpreted as fault lines. The causative structures are associated with granitic intrusive characterised by banded iron formations that also act as a host for other minerals. These results of this study agree well with the computed power spectrum depth interpretation techniques (Odek, *et al*, 2018) and known geology of the area (Shackleton, 1946).

Recommendation

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