Journal of Applied Sciences

ISSN 1812-5654

Journal of Applied Sciences 5 (10): 1858-1866, 2005
ISSN 1812-5654

Contribution to the Investigation of Structure and Origin of a Rift Valley System by Gravimetry

[1]Tondozi keto, [1]Liu Tianyou and [2]Zana Ndotoni
[1]Faculty of Geophysics, China University of Geosciences, Wuhan 430074, China
[2]Faculty of Sciences, University of Kinshasa, Kinshasa 190, Congo

Abstract: Geophysical data have real interest only after a series of treatments; prior to be more useful, the diurnal, annual, semi annual and secular variations must be at least eliminated from the magnetic data. The same way for gravity data, they become particularly significant after a series of corrections, where the latitude, altitude, topographic and tidal influence of the sun and moon, all have been eliminated. After undergoing these corrections commonly called data reductions, the data are located with respect to geoid. These reductions processes need first to adopt the work frame hypothesis concerning the mode of calculation and the depth compensation. For our investigation measurements have been done in the East of Democratic Republic of Congo including the graben region from the parallel joining Goma city and Mahagi city, the region between Albert and Aka lakes and the route from Aba to Kinsagani. During the surveys the density of recording points has been selected according to the importance of anomalies. In this way, the offset was 1 km where the disturbance was high in Goma city and 20 km have been sufficient along the route from Aba to Kinsagani. The compensation hypotheses used are: Pratt 113.7,80 and 50 km, Airy 60, 40, 50 and 20 km.

Key words: Gravity anomaly, data reductions, compensation, offset, isostasy

INTRODUCTION

Geophysics as its name indicates has to do with the physics of the Earth and its surrounding atmosphere. Gilbert's discovery that the Earth behaves as a great and rather irregular magnet and Newton's theory of gravitation may be said to constitute the beginning of geophysics. Mining and the search of metals date from the earliest times, but the scientific record began with the publication of a famous authoritative work on mining[1]. The initial step in applying geophysics to the search for minerals probably was taken in 1843, when Von Wrede pointed out that the magnetic theodolite, used by Lamont to measure variations in the Earth's magnetic field, might also be to discover bodies of magnetic ore. However this idea will be acted on later. The Thomson-Thalen instrument furnished the means of locating the strike, dip and depth below surface of magnetic dikes.

The continued expansion in the demand for metals of all kinds and the enormous increase in the use of petroleum products since the turn of the century have led to the development of many geophysical techniques of ever-increasing sensitivity for the detection and mapping of unseen deposits and structures. Advances have been especially rapid since World War II because of major improvements in instrumentation and the widespread application of the digital computer in the processing and interpretation of geophysical data. Because the great majority of ore deposits are beneath the surface, their detection depends on those characteristics that differentiate them from the surrounding media.

Methods based on variations in the elastic properties of rocks have been developed for determining structures associated with oil and gas, such as faults, anticline and synclines several kilometers below the surface. The variation in electrical conductivity and natural currents in the earth, rates of decay of artificial potential differences introduced into the ground, local changes in gravity, magnetism and radioactivity, all these provide information about the nature of the structures below the surface, thus permitting geophysicists to determine the most favorable places to search for the mineral deposits they seek. Several of the devices used by geophysicists were derived from methods used for locating gun emplacements, submarines and aircraft during the two world wars. Attempts were made to locate artillery batteries during the World War I by measuring the arrival times of the elastic waves generated in the earth by their recoil; this led directly to the refraction method of seismic prospecting.

Corresponding Author: Tondozi Keto, Faculty of Geophysics, China University of Geosciences, Wuhan 430074, China
Tel: ++00862767885909

Submarines were located by transmitting sound pulses underwater and measuring the interval between the emission and the return of reflected pulses; knowing the velocity of sound in seawater, one can calculate the distance to the reflecting objects. Sonar is now used widely for navigation in marine geophysical surveys. Radar developed during the World War II, utilized radio pulses in a similar manner to track aircraft and ships, submarines and mines were also detected in both wars by their magnetic properties. It should be pointed out that geophysics techniques can detect only a discontinuity, that is, where one region differs sufficiently from another in some property. This, however, is a universal limitation, for we cannot perceive that which is homogeneous in nature; we can discern only which has some variation in time and/or space. Geophysicists deal with all aspects of the physics of earth, its atmosphere and space. Geophysical measurements were made by the men who landed on the moon and the atmospheres, magnetic fields and other properties of planets are studied using geophysical data obtained by unmanned spacecraft.

POTENTIAL DERIVATIVES

Quantities useful in gravity analysis may be obtained by differentiating the potential in various ways. We already know that the vertical gravity is given by g = -∂/∂z. This is the quantity measured by gravimeters. The first vertical derivative of g is:

$$\begin{aligned}\frac{\partial g}{\partial z} &= -\frac{\partial^2 U}{\partial z^2}\\ &= -U_{zz}\\ &= \gamma\rho \iiint_{XYZ} [\frac{1}{r^3} - \frac{3z^2}{r^5}] dx\, dy\, dz \qquad (1)\end{aligned}$$

where subscripts indicate derivatives of U. Measurements occasionally are made of the vertical gradient.
The second vertical derivative is

$$\begin{aligned}\frac{\partial^2 g}{\partial z^2} &= -\frac{\partial^3 U}{\partial z^3}\\ &= -U_{zzz}\\ &= 3\gamma\rho \iiint_{XYZ} [\frac{5z^3}{r^7} - \frac{3z}{r^5}] dx\, dy\, dz \qquad (2)\end{aligned}$$

This derivative frequently is employed in gravity interpretation for isolating anomalies and upward and down continuation. Derivatives tend to magnify near surface features by increasing the power of the linear dimension in the denominator. That is, because the gravity effects vary inversely as the distance squared, the first and second derivatives vary as the inverse of the third and fourth powers, respectively (for three dimensional bodies). The derivatives of g along x and y axes give us the components of the horizontal gradient of gravity:

$$\begin{aligned}U_{xz} &= -\frac{\partial g}{\partial x}\\ &= 3\gamma\rho \iiint_{XYZ} [\frac{xz}{r^5}] dx\, dy\, dz \qquad (3)\end{aligned}$$

and similarly for the y component U_{yz}. The horizontal gradient can be determined from gravity profiles or map contours as the slope or rate of change of g with horizontal displacement. The horizontal is useful in defining the edges and depths of bodies. The differential curvature (or horizontal directive tendency, HDT) is a measure of the warped or curved shape of the potential surface, already we know

$$U_{xx} = \gamma\rho \iiint_{XYZ} [\frac{3x^2}{r^5} - \frac{1}{r^3}] dx\, dy\, dz \qquad (4)$$

Other components are U_{yy} and U_{xy}. The differential curvature (HDT) is given by

$$\begin{aligned}HDT &= \left[(U_{yy} - U_{zz})^2 + (2U_{xy})^2\right]^{1/2}\\ &= 3\gamma\rho \iiint_{XYZ} [\frac{(x^2+y^2)}{r^5}] dx\, dy\, dz \qquad (5)\end{aligned}$$

It is not possible to measure U_{xx}, U_{yy}, U_{xy} or HDT directly. Differential curvature can be obtained from torsion-balance measurements[2].

MIDDLE AND EAST AFRICAN GRABEN

Geological and geophysical mapping have demonstrated typical rift basin block faulting with sequences of reservoir quality sandstone exposed in the graben. This African graben is a Mesozoic-Cenozoic rift basin formed and developed on the Precambrian orogenic belts of the African Craton. The graben trends NE-SW through to most of its length and forms the northern most part of the western branch of the East African Rift System (EARS). Each of the rift basins in this graben is bounded by steep border normal faults and broad uplifted flanks that are predominantly Precambrian basement composed of metamorphosed rocks such as gneisses quartzite, gneisses and varying amounts of mafic intrusions. The Paraa and Kibiro oil seeps have a similar source type based on the similarities in the biomarkers, mostly a fresh water lacustrine environment with an appreciable algal input. The Kibuku oil seep is from a different freshwater terrestrial source rock of fluviatile, lacustrine-deltaic or lacustrine environment consisting mainly of land plant material (angiosperm-rich) of late Cretaceous or younger age. The diahopane/(diahopane+ hopane) ratios suggest a mid-mature source for the Paraa and Kibiro oil seeps (0.65-0.85% Ro), while the Paraa oil seep is early mature(0.60% Ro). Interpreted from present data of outcrops and drilled wells, the reservoir rocks are well developed with good porosity and permeability in the sands and conglomerates.

The fractured and weathered basement rocks may also act as favorable reservoirs. Since the reservoir potential rock composition is mainly quartz, more than 75% in content, their resistance to compaction is relatively strong. This contributes to preservation of primary porosity and therefore provides a good reservoir potential for oil and gas. Several rifting movements formed relatively large scale structural traps in the graben such as drape anticlines, fault blocks, rollover anticlines and buried hills. Facies changes and unconformities in the graben also provide for stratigraphic and/or lithologic traps. The eastern part of the graben was the favorable area for oil and gas migration and accumulation, where there are several heights. The source rocks and basin wide clays are also the seal in the central part of the graben[3].

GRAVITY ANOMALIES AND STRUCTURES

When we turn to gravity anomalies of smaller extent, we find that we are dealing with the effects of variation in density closer to the earth's surface. In many cases, these involve juxtaposition of rocks of known type, so that interpretation depends upon some knowledge of the average densities of rocks. Porosity is usually low and the rock density is a weighted average of the densities of the constituent minerals; but for sedimentary rocks, porosity is a controlling factor and the density of a given rock type will vary with depth of burial. It is possible only to list ranges of density for representative rocks. Gravity measurements have been used to study a great many types of geological structure, ranging in scale down to the dimensions of ore bodies. It is possible here to discuss only a few examples, which appear to have significance on a global scale. Some of the most striking types of gravity anomalies are the long, narrow strips of negative anomaly discovered by Vening Meinesz and known as to be associated with oceanic trenches and island arcs.

The values of the acceleration of gravity, g, include the effects of all masses within the Earth. The geometry figure of the Earth, the unevenness of it surface, as well as its composition and geological structure are responsible for the fact that the acceleration of gravity differs from place to place on its surface. In particular in the Earth's crust. However, the effects of these masses on the values of the acceleration of the gravity are obscured by the effects due to other factors. In applied geophysics, in order to emphasize the gravity effects of the irregular distribution of masses, we look at the gravity anomalies, generally defined as the difference between the actual acceleration of gravity (observed at the Earth's surface) and its computed theoretical value. All the figures below have been drawn with data gathered in the surveys area well-defined in the footnotes. Figure 1 shows how the upward continuation of gravity is done and Fig. 2a and b shows respectively the gravity map and the anomaly map after 0.05 Low Pass Filter at latitude H_2.

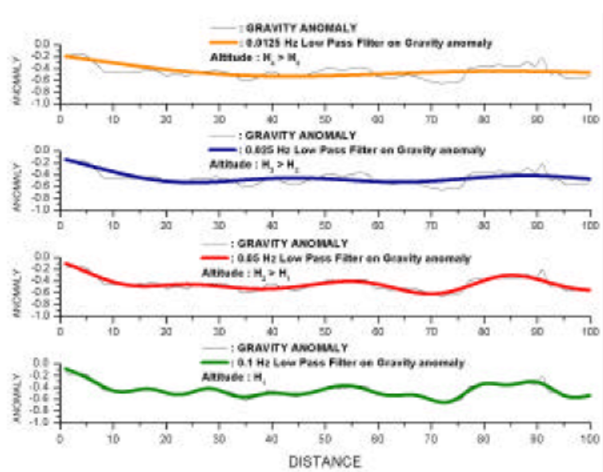

Fig. 1: Upward continuation of gravity anomaly field

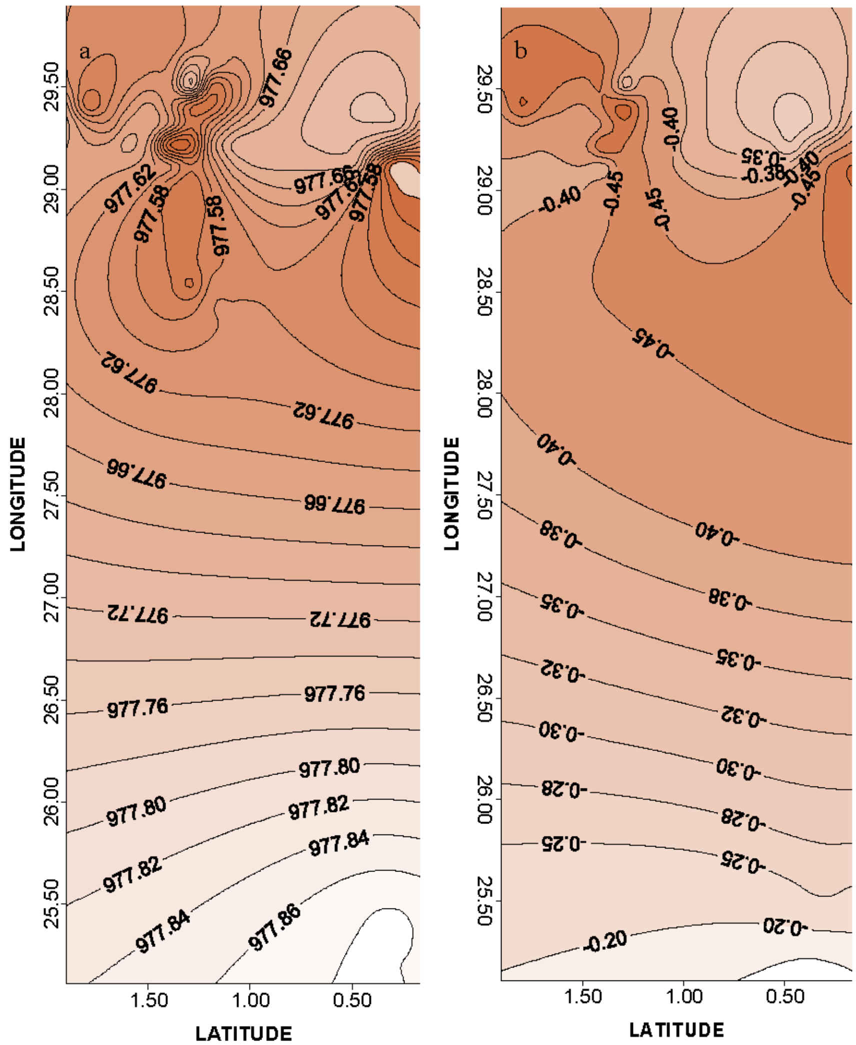

Fig. 2a: Gravity map

b: Gravity anomalies map at a latitude H_2

BOUGUER ANOMALIES AND STRUCTURES

The type of anomaly most frequently used in gravimetry and in research into the structure of the Earth's crust is the Bouguer anomaly which expresses the effects of anomalous masses, as well as the effect of "remote" topographic masses and all of the compensating masses. The effect of compensating masses and remote topographic masses is mostly constant over a small area and, together with the effect of more remote anomalous geological masses; it can be included in a regional component of the gravity field. We can calculate the Bouguer anomaly without topographic correction by subtracting not only the effect of the normal ellipsoid at a given point P from the acceleration of gravity, g, observed there, but also the effect of the normal masses which are located or which are assumed to be in the horizontal layer (Bouguer layer) between the normal ellipsoid and the level of point P. Bouguer anomalies without topographic correction (provided the curvature of the Earth is neglected), therefore express the gravity effects of not only the anomalous masses but also the normal masses which are located above the level of point P, or which we have assumed to be below this level, above the topographical surface of the Earth.

The Bouguer reduction does not eliminate the effect of masses which are located above the Bouguer plate but below the topographical surface and which diminish the anomaly. Also we should subtract the effect of any non existent masses between the upper surface of the Bouguer plate and the topographical surface. The acceleration of gravity g is usually observed above (or, exceptionally, below) the surface of reference ellipsoid (on the real Earth's surface). In order to be able to calculate the gravity anomaly both quantities must be referred to the same height. Relation between spatial scale and depth of the source – large spatial scale features are generally assigned to deeper depths, though this is not guaranteed. Conceptually we know that upward continuation produces a smoother field, so smoother fields are generally associated with deeper features.

RELATION BETWEEN GRAVITY ACCELERATION AND GEOLOGY

In addition to the types of gravity anomalies defined on the amount of processing performed to isolate geological contributions, there are also specific gravity anomaly types defined on the nature of the geological contribution. To define the various geologic contributions that can influence our gravity observations, consider collecting gravity observations to determine the extent and location of a buried, spherical ore body. The gravity anomaly expected over such a geologic structure is well known. Density is defined as mass per unit volume. For example, if we were to calculate the density of a room filled with people, the density would be given by the average number of people per unit space and would have the units of people per cubic root. The higher the number, the more closely spaced are the people. Thus, we would say the room is more densely packed with people. The units typically used to describe density of substances are grams per centimeter cubed; mass per unit volume. In relating our analogy room to substances, we can use the point mass described earlier as we did the number of people. Consider a simple geologic example of an ore body buried in soil. We would expect the density of the ore body, d2, to be greater than the density of the surrounding soil, d1. The density of the material can be thought of as a number that quantifies the number of point masses needed to represent the material per unit volume of the material just like number of people per cubic foot in the example given above described how crowded a particular room was.

Thus to represent a high-density ore body, we need more point masses per unit volume than we would for the lower density soil. In this discussion we assume that all of the point masses have the same mass. Now let us qualitatively describe the gravitational acceleration experienced by a ball as it is dropped from a ladder. This acceleration can be calculated by measuring the time rate of change of the speed of the ball as it falls. The size of the accelerated ball will be proportional to the number of close point masses that are directly below it. We are concerned with the close point masses because the magnitude of the gravitational acceleration varies as one over the distance between the ball and the point mass squared. The more close point masses there are directly below the ball, the larger its acceleration will be. We could, therefore, drop the ball from a number of different locations and, because the number of point masses below the ball varies with the location at which it is dropped, map out differences in the size of the gravitational acceleration experienced by the ball caused by variations in the underlying geology. A plot of the gravitational acceleration versus location is commonly referred to as a gravity profile.

SEPARATING LOCAL AND REGIONAL ANOMALIES

Because Regional Anomalies vary slowly along a particular profile and Local Anomalies vary more rapidly, any method that can identify and isolate slowly varying portions of the gravity field can be used to separate Regional and Local Gravity Anomalies. The methods generally fall into three broad categories:

1 Direct estimates: There are estimates of the regional anomaly determined from an independent data set. For example, if your gravity survey is conducted within the continental US, gravity observations collected at relatively large station spacing are available from the National Geophysical Data Center on CD-ROM. Using these observations, you can determine how the long-wavelength gravity field varies around your survey and then remove its contribution from your data.

2 Graphical estimates: These estimates are based on simply plotting the observations, sketching the interpreter's estimate of the regional gravity and subtracting the regional anomaly estimate from the raw observations to generate an estimate of the local gravity anomaly.

3 Mathematical estimates: These represent any of the wide variety of methods for determining the regional gravity contribution from the collected data through the use of mathematical procedures. Examples of how this can be done include:

- Moving Average: In this technique, an estimate of the regional gravity anomaly at some points along a profile is determined by averaging the recorded gravity values at several nearby points. Averaging gravity values over several observations points enhances the long-wavelength contributions.

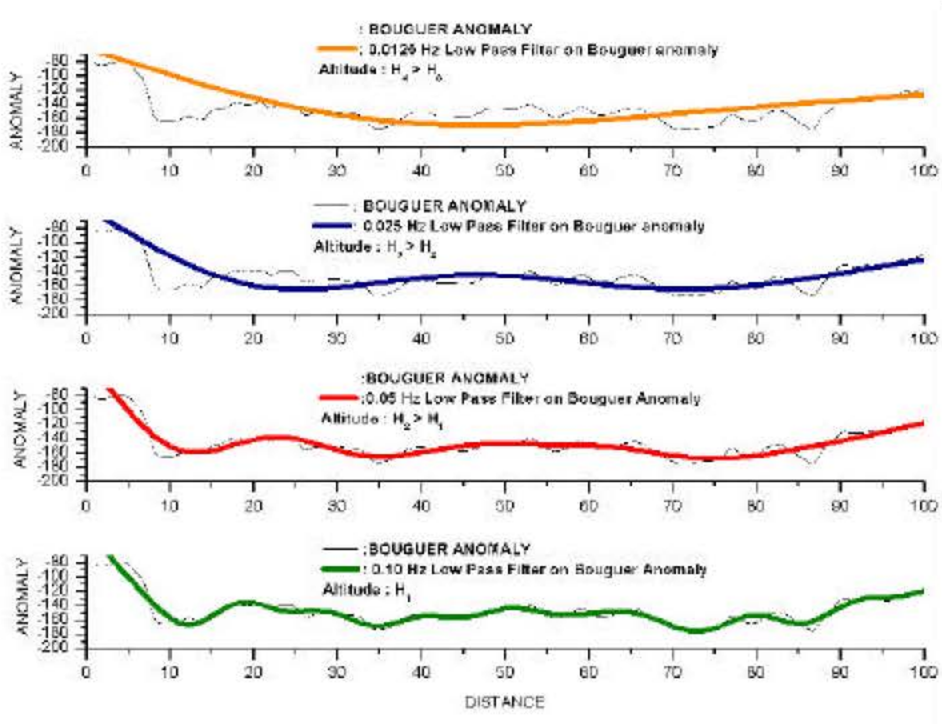

Fig. 3: Upward continuation of Bouguer Anomaly field

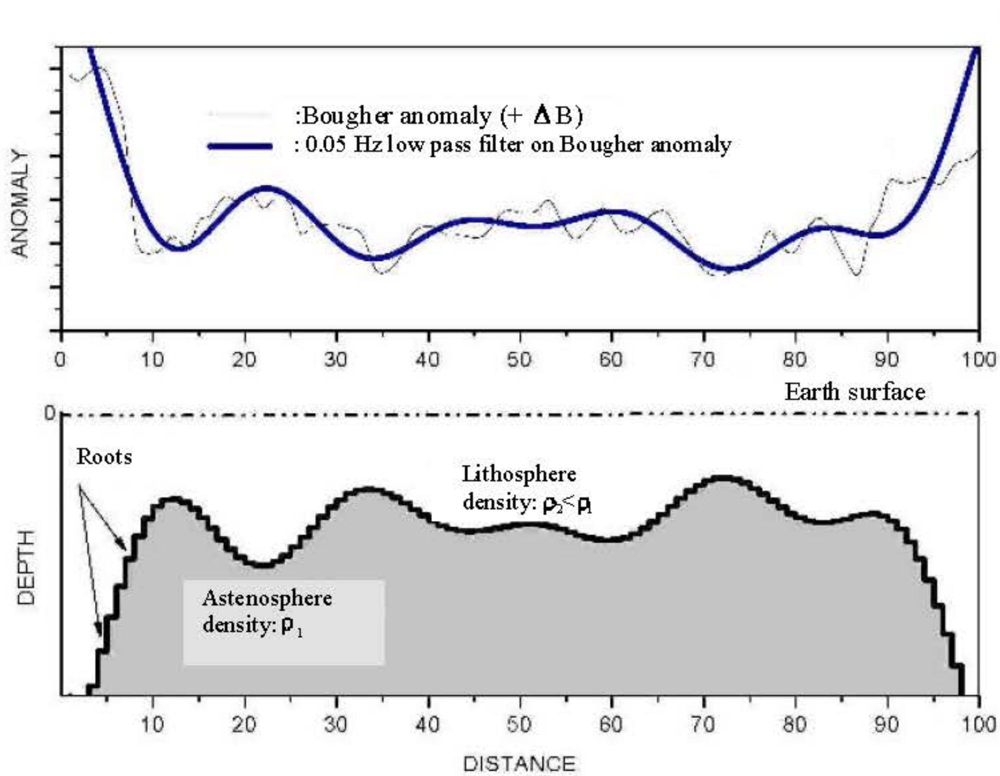

Fig. 4: Expected model for 0.05 Hz Low Pass filter

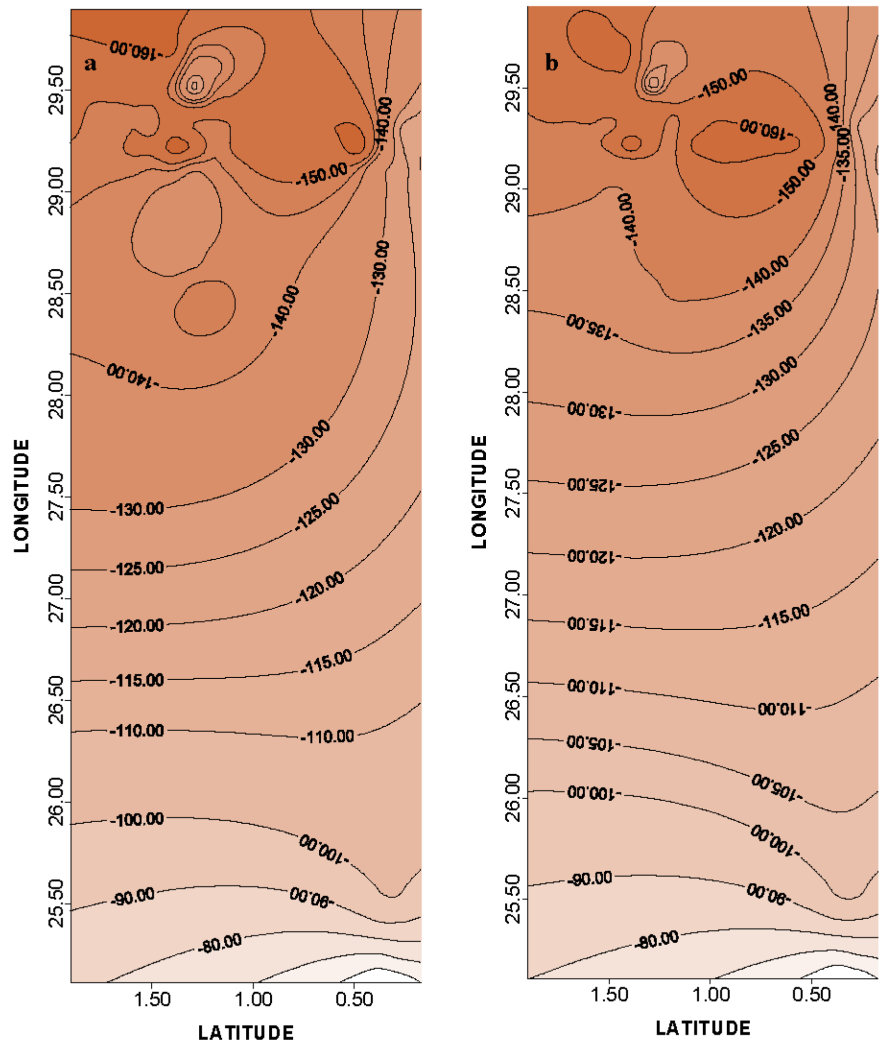

Fig. 5a: Anomalies map at altitude H_1
b: Anomalies map at altitude H_2

- Function fitting: In this technique, smoothly varying mathematical functions are fit to the data and used as estimates of the regional gravity anomalies. The simplest of any number of possible functions that could be fit to the data is a straight line.
- Filtering and Upward continuation: These are more sophisticated mathematical techniques for determining the long-wavelength portion of a data set. Those interested in finding out more about these types of techniques can find description of these in any introductory geophysical textbook[4].

Figure 3 shows the enhancement of regional Bouguer anomalies with the upward continuation technique by eliminating the residual Bouguer anomalies.

Because a Bouguer map shows horizontal differences in the acceleration of gravity, only horizontal changes in density produce anomalies. Purely vertical changes in density produce the same effect everywhere and so no anomalies result. Gravity field is a superposition of anomalies resulting from density changes (anomalous mass) at various depths. Some anomalous masses lie at depths in the zone of interest, some result from deeper masses and some from shallower ones. As the source of anomaly deepens, the anomaly becomes more spread out and its amplitude decreases. The smoothness (or apparent wavelength) of anomalies is generally roughly proportional to the depth of the lateral density changes. The depth range we wish to emphasize, depends on the objectives of the interpretation. Shallow anomalies are of

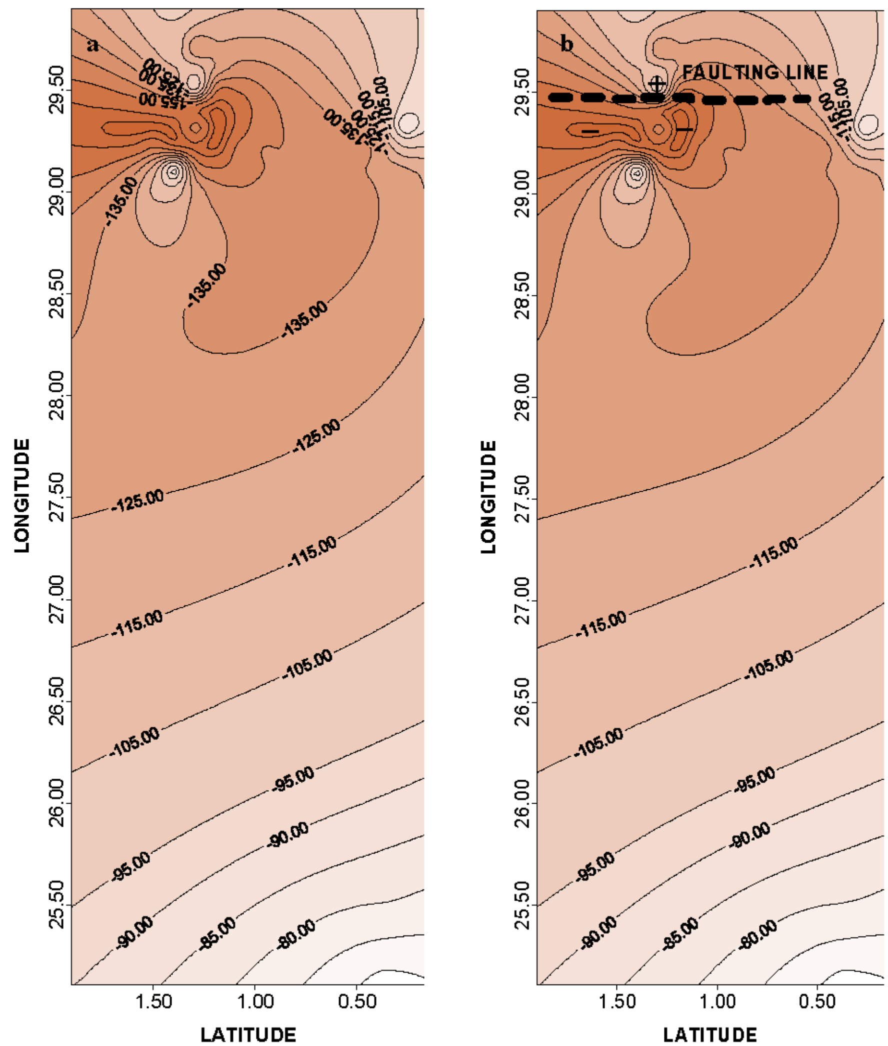

Fig. 6a: Anomalies map at altitude H_3
b: Fault line

interest in mineral exploration but are usually regarded as undesirable noise in petroleum exploration. As in any geophysical technique, the most useful factor in interpretation is knowledge of the local geology.

Whereas it is possible for a distributed anomalous mass to give an anomaly that appears to originate from a more concentrated deeper mass, a concentrated mass cannot appear to originate deeper. The horizontal smooth extent of an anomaly is therefore usually a measure of the depth of the anomalous mass and this property can be used to partially separate the effects of anomalous masses that lie within a depth zone of interest from the effects of both shallower and deeper masses. The effects of shallow masses (near-surface noise) are usually of short wavelength. They can be removed largely by filtering out (smoothing) short wavelength anomalies. The effects of deeper masses are called regional.

Figure 4 shows an example of the probable expected model in the case of 0.05 Low Pass Filter on Bouguer anomaly field.

The gravity field after near surface noise and the regional has been removed is called residual; it presumably represents effects of the intermediate zone of interest. The major problem in gravity interpretation is separating anomalies of interest from the overlapping effects of others features; usually the main obscuring effects results from deeper features. Residualizing attempts to remove the regional effects and by that emphasize the residual effects. However, the separation is not usually complete; both regional and residual are distorted by the effects of each other. Residualizing can also be thought of as predicting the values expected from deep features and then subtracting them from observed values, so as to leave the shallower effects. The expected value of the regional is generally determined by averaging values in the area surrounding the station. There are methods to remove the unwanted effects of regional[5]. Figure 5a and b show, respectively the Bouguer anomalies map corresponding to reference field at latitude H_1, where commonly the field value is set equals zero and with the upward continuation we have the Bouguer anomalies map at latitude H_2.

Figure 6a and b show, respectively the Bouguer anomalies map at latitude H_3 and one of the probable faults locations.

ACKNOWLEDGMENTS

I would like to thank Professor Zana Ndotoni who provides us the gravity data used in our investigation and professor Liu Tianliu whom is always prepared to supervise and support suitably motivated researchers on nearly any topic of mutual interest.

CONCLUSIONS

Data from gravity surveys are more subject to ambiguity in interpretation than with seismic surveys; because any gravity field can be accounted for equally well by widely different mass distributions. Additional geophysical or geological information over a gravity anomaly will reduce the ambiguity and increase the usefulness of the gravity data.

Volcanic activity of this graben is mainly limited to the southern part of the graben and becomes mild northwards. Magnetic activity has been localized in the fault-bounded basins where chains of active volcanism are aligned along tips of some border fault segments and along oblique-slip transfer faults crosscutting the rift valley.

Existence of hot springs indicates the thinning of the crust and the closeness of the mantle plumes to the surface, which has facilitated a relatively higher geothermal gradient in the graben. Lacking significant volcanic fill, the western branch consists of narrow, deep and stratified lakes that have been accumulated organic rich sediments. Lake Albert covers the central part of the graben and in some parts it extends to the western escarpment of the graben in Democratic Republic of Congo.

A high degree of petroleum potential is revealed by the large sediment thickness (5000 m), the numerous oil seepages, the potential oil source and good reservoir rocks outcropping in the graben. Geochemical analyses and correlation of the three oil seeps in the graben (Paraa, Kibiro and Kibuku) are poor in steranes relative to hopanes, which is suggestive of a non-marine source.

REFERENCES

1. Agricola, G., 1956. Mining and mineral resources exploration. Treatise De Metallica, 1: 30-31
2. Telford, W.M., L.P. Geldart and R.E. Sherrif, 2004. Gravity Data Processing. Applied Geophysics, 2nd Edn., 1: 26-33.
3. Tarney, J., 2003. Lecture 3 on Geology: Wilson cycle. Plate Tectonics GL 209, 3: 3-5.
4. Hammer, S., 2003. Separating regional and local anomalies. Geophysics, 4: 184-194.
5. Garland, D., 1979. Gravity Anomalies and Structures. Intr. Geophysics (Mantle, Core and Crust), 2nd Edn., 1: 88-200.