Contribution to the Investigation of Structure and Origin of the East African Graben by Gravimetry

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ABSTRACT For our investigation we have 235 measurements done in the east part of Democratic Republic of Congo by P. Herrinck during a magnetic survey 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. For the topographic and isostatic reductions only one cartographic document has been chosen that was the international map of the scale 1/1 000 000 which presents a certain characteristic of homogeneity.

KEYWORDS gravity anomaly; data reductions; compensation; offset; isostasy

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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 in 1956 of the famous treatise De re metallica by Georgius Agricola, which for many years was the authoritative work on mining. 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 was not acted on until the publication in 1879 of professor Thallen’s book titled: on the examination of iron ore deposit by magnetic methods. The Thomson-Thalen instrument furnished the means for locating the strike, dip, and depth below surface of magnetic dikes.

The continuous 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, detection of them 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 differ-
ences 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 need. Several 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.

Submarines were located by transmitting sonar 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 such thing which is homogeneous in nature; we can discern only something 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.

1 Summary of gravity types

Gravity prospecting involves measurements of variations in the gravitational field of the earth. One hopes to locate local masses of greater or lesser density than the surrounding formations and learn somewhat about them from the irregularities in the earth’s field. It is not possible, however, to determine a unique source for an observed anomaly.

We have now described the host of corrections that must be applied to our observations of gravitational acceleration to isolate the effects caused by geologic structure. The wide variety of corrections applied can be a bit intimidating at first and has led to a wide variety of names used in conjunction with gravity observations corrected to various degrees. Let’s recap all of the corrections commonly applied to gravity observations collected for geophysical exploration surveys, specify the order in which they are applied, and list the names by which the resulting gravity values go.

Observed gravity ($g_{obs}$) Gravity readings observed at each gravity station after corrections have been applied for instruments drift and tides.

Latitude correction ($g_{n}$) Correction subtracted from $g_{obs}$ that accounts for the earth’s ellipsoidal shape and rotation. The gravity value what would be observed if the earth were a perfect (no geologic or topographic complexities), rotating ellipsoid is referred to as the normal gravity.

Free air corrected gravity ($g_{fa}$) The free-air correction accounts for gravity variations caused by elevation differences in the observation locations. The form of the free-air gravity correction, $g_{fa}$, is given by:

$$g_{fa} = g_{obs} - g_{n} + 0.3086 \times h \text{ (mGal)}$$

where $h$ is the elevation of the gravity station, which is above the elevation datum chosen for the survey (this is usually sea level).

Bouguer slab corrected gravity ($g_{b}$) The Bouguer correction is a first-order correction to account for the excess mass underlying observation points whose elevation is higher than the elevation datum. Conversely, it accounts for the mass deficiency at observations points below the elevation datum. The form of the Bouguer gravity correction, $g_{b}$, is given by:
\[ gb = gobs - gn + 0.308 \times 6 \times h - 0.04193 \times \rho \quad \text{(mGal)} \]

where \( \rho \) is the average density of the rocks underlying the survey area.

Terrain corrected Bouguer gravity \((gt)\) The terrain correction accounts for variations in the observed gravitational acceleration caused by variations in topography near each observation point. The terrain correction is positive regardless of whether the local topography consists of a mountain or a valley. The form of the terrain corrected Bouguer gravity correction, \( gt \), is given by:

\[ gt = gobs - gn + 0.308 \times 6 \times h - 0.04193 \times \rho + TC \quad \text{(mGal)} \]

where \( TC \) is the value of the computed terrain correction.

Assuming that these corrections have accurately accounted for the variations in gravitational acceleration, any remaining variations in the gravitational acceleration associated with the terrain corrected Bouguer gravity, \( gt \), can now be assumed to be caused by geologic structure. Another way of summarizing the situation now is that the corrections discussed here are removing the effects which we already know about, and the resulting terrain corrected Bouguer gravity is the effect of the unknown component of the geology. Finally (here) it is important to remember that the observation stations have not moved.

We have removed the effect of topography, and the mass making it up, but the gravity anomaly which results in the gravitational acceleration caused by density anomalies in the subsurface, measured at the observation points. This will be an important point in detailed modeling of anomalies. Corrections might better be called "reductions", because, except for the drift correction, they imply no deficiency in the data observed and would be applied with equal validity to perfect data collected with a perfect instrument and perfect observers.

2 Gravity data processing

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 from. 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 that we wish to emphasize depends on the objectives of the interpretation. Shallow anomalies are of 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 extent smoothness 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.

The gravity field after near surface noise and the regional has been removed is called residual which 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 result from deeper features. Residualizing attempts to remove the regional effects and then
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 several methods to remove the unwanted effects of regional [1].

3 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 most of its length and forms the most northern 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 / (diaphane + hopane) ratios suggest a mid-mature source for the Paraa and Kibiro oil seeps (0.65%-0.85%), while the Paraa oil seep is early mature (0.60%). As 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. The source rocks and basin wide clays are also the seal in the central part of the graben [2].

4 Gravity anomaly and structures

When we turn to gravity anomalies of smaller extent, 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 the 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.

Since these regions are essentially at the sea level, the effect is evident on all types of anomaly. They must result from fairly shallow strips
of mass deficiency, and Vening Meinesz concluded that they were expressions of a symmetrical down buckle of a light crust into the denser mantle. More recently it has become apparent that interpretation of gravity anomalies is not independent of the structure determined seismologically, because of the relation between density and velocity. This relation has been used, for example, in the study of the Tonga Trench to produce a combined interpretation which attributes much of the negative anomaly to a thick accumulation of sedimentary material at the top of the Ocean crust. Still more recently, attention was been called to the broad positive anomaly which is always associated with the negative strip, and this was interpreted on the assumption of a dense plate of the lithosphere, descending several hundred kilometers into the mantle. Fig. 1 and Fig. 2 display the Bouguer and gravity anomaly of the survey area; Fig. 3(a)-3(b) and Fig. 4(a)-4(b) display the Bouguer anomaly and gravity anomaly map.

![Fig. 1 Bouguer anomaly smoothing](image1)

![Fig. 2 Gravity anomaly smoothing](image2)

5 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. Magmatic 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 (5 000 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.
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