Satellite gravity data as a tool for kimberlite exploration – insights from southern Africa

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Abstract

The geological exploration for kimberlite bodies which are common hosts for diamonds has benefited over the years from the use of geophysical data sets. However, little innovation has been observed in the use of different methods and especially for the re-observation of familiar methods such as gravity. Regarding this, we use two sets of data derived from satellite gravity missions to examine the regional framework of the southern part of the African continent where a myriad of kimberlites are observed, some of them being diamondiferous. By examining these data we observe that the kimberlite fields have similar disposition to that of features observed in the complete Bouguer anomaly and the vertical gradient of the gravity field as measured by satellites. However, some regions are not consistent with the trends observed in these data. Our observations from satellite gravity data are consistent with geophysical features observed in support data as satellite magnetic data, maps for the Lithosphere-Asthenosphere boundary and changes in the thickness of the crustal pile. These conjunct interpretation point out that the long-wavelength data from satellite gravity surveying has potential to aid in the interpretation of the regional architecture of regions hosting kimberlites. That can lead to insights on the regional distribution of the kimberlites and, potentially, to the observation of patterns in the distribution of those endowed in diamonds worldwide.

Introduction

The geological exploration for kimberlites, rocks which are plausible hosts for diamonds, has taken advantage from geophysical methods for long for the detection of the target host rocks[1]. Their targeting has been made through different approaches[1,2]. One is to target for small scale geophysical anomalies that could be the manifestation of the presence of kimberlite bodies. Alternatively, explorers have used regional data to target loci of potentially favorable structural settings to host kimberlites or sets of bodies, like districts. In any case, practical exercises of exploration have evolved from the regional approach to the more localized inspection of the terrane with indirect geophysical data[3].

The use of potential field data is widespread in this context, with airborne magnetics playing a major proxy in the identification of the kimberlites ad associated rocks given its large common contrast to their host framework[2]. Ground gravity data have also been used as a major constraint on the regional framework of the host terranes. However, the exams have been concentrated over similar acquisition methods over time, with little innovation in terms of geophysical prospecting techniques[1–3]. A possible novel approach is the use of satellite gravity data as an alternative to the regular gravity datasets. Such data have the potential to represent the major gravity framework of the host terranes, being exempt of short frequency signals that relate to cover sequences or to the kimberlites themselves. That is of interest to investigate the deep crustal framework of the host terranes to the kimberlites as a media to evaluate the possible existence of structural elements involved large-scale processes in their collocation in the crust throughout the deep lithosphere (e.g., magma plumbing, interference between regional structures for permeability)[4,5].

The southern part of the African continent is acknowledged as one area of high interest for kimberlite prospecting historically[4]. The region hosts a vast number of intrusions formed in different ages which are variably endowed in diamonds. The area has also been used as a test site to evaluate the context in which diamond and related alkaline intrusive rocks form in the continental crust[4,5]. The formation of the diamonds and the rocks that carry them to the surface depends on the mantle composition and structure, with the cratonic lithosphere presenting the best potential for its formation and conservation[4,5]. However, for their transfer and collocation in the crust, the mineral system depends on the architecture of the crust during the incidence of the magmatic activity.

In this contribution, we present partial results on the use of geophysical products derived from satellite gravity datasets to investigate the architecture of the southern African continent. We interpret two sorts of gravity information derived from satellite data to obtain information on the density structure over the region along the middle- to lower-crust and below as a proxy for major discontinuities that could relate to the spatial distribution of the kimberlites in the region. We interpret a Complete Bouguer Anomaly map derived from the Gravity Observation Combination (GOCO) satellite gravity model version 05 (GOCO05s)[6], and the vertical gradient of the gravity field (Tzz) derived from the Gravity field and steady-state Ocean Circulation Explorer (GOCE) mission[7]. To support our interpretations we use data from global seismic tomography data[8], a vast compilation on crustal thicknesses determinations and satellite magnetics data[9].

Our observations over the satellite gravity data point out to the presence of large-scale changes in the gravity signal as observed in the Complete Bouguer Anomaly on the Congo Craton and the southern bounds of the Kaapvaal Craton. The gravity field gradient shows that many of the kimberlite fields align with the highest gradients in the region, especially along the southern Kaapvaal and the Tanzania Craton, whereas districts trend oblique to the gravity gradients in the Congo Craton. The texture observed in the gravity maps has parallels with the trend observed in the magnetic satellite data, which is also coincident with the major axes of the kimberlite fields. The changes in the Complete Bouguer Anomaly and gravity gradients also have parallels to the changes in the crustal thickness along the subcontinent, with kimberlite districts running parallel to the changes in the crustal thickness. A map for the Lithosphere-Asthenosphere Boundary is relatively inconclusive, with kimberlites occurring in regions of both thickened and thinned lithosphere, and also along regions of gradients in the thickness. We observed that both regions of concomitant homogenous LAB depth and gravity gradients, and of gradients in both the LAB and gravity are particular interest for hosting kimberlites.

Method

Data from the GOCO05s model[6] where taken as the gravity over the ellipsoid at 6,000 m height above the sea level) and truncated at degree/order 250 and stored in a 0.02-degree mesh. The data was then reduced from the normal gravity in its closed-form[10] and the calculation of the simple Bouguer anomaly (reference density of 2670 kg/m^3). Posterior forward modeling of the gravity effect of the rocks contained at the topographic surface (from the ETOPO1 model[11] lead to the topography effect and its removal from the simple Bouguer anomaly led to the Complete Bouguer Anomaly map. The processing pipeline is as in the previous publications[12,13]. The resulting Complete Bouguer Anomaly map and other data were interpreted qualitatively as maps. Location of kimberlite rocks come from worldwide compilations[14]. The satellite gravity gradients, magnetic and tomography plus passive seismology data were taken as from the original publications.

Example

The complete Bouguer Anomaly map (Fig.1a) shows that the Congo, Tanzania and Kaapvaal cratons in the southern African subcontinent have an indistinct signature in the gravity data. The kimberlite fields have an overall spatial coincidence with regions of low- to medium-values (up to 50 mGal) in the complete Bouguer anomaly, and predominantly overlie regions of the lowermost values (e.g., in the Tanzania Craton, Fig. 1a). However, it is observed that the kimberlites, in general, are disposed of in parallel to regions of increased change of the gravity anomaly (e.g., in central-southern Congo Craton, and the southern Kaapvaal Craton, Fig. 1a). The Tzz map (Fig. 1b) shows an indistinct characteristic for the cratons, similar to the complete Bouguer anomaly. However, features in the Tzz map are not observed to transpose between the different cratonic cores. Tzz values are, in general, disposed of in N-S regions of alternating low and high values. It is observed in the Tzz map that the kimberlites occur mostly along regions of medium- to high- gradients (from 0,0 to 0,31 E) in the Kaapvaal Craton and Tanzania Craton (Fig. 1b). The kimberlite fields tend to trend along the form lines in the Tzz value. Contrastingly, the main kimberlite cluster in the Congo Craton is indistinct to the Tzz value and are disposed of in an oblique trend about the high-gradient zone observed traversing the craton (Fig. 1b).
The magnetic scalar anomaly map (Fig. 2) has two main trends in the distribution of the signal. One is an overall NE-SW trend which is mostly observed along the southern-eastern Congo Craton and extended to the Tanzania and Kaapvaal cratons (Fig. 2). Secondly, a roughly E-W fabric of coalescing high-anomaly regions are observed from the central to the northern parts of the Congo Craton (Fig. 2). A roughly NW-SE trend is observed in the western part of the Kaapvaal Craton, In any case, the overall trend forms are given by discontinuous features of alternating regions with high- and low- anomaly values. The kimberlites tend to follow the main trend directions observed in the magnetic anomaly especially in the southern Congo Craton and the Kaapvaal Craton (Fig. 2). They notably cluster along the marked discontinuities of the magnetic trends, especially where there is an intersection of trends of different directions (e.g., extreme south Kaapvaal Craton and central Tanzania Craton, Fig. 2).

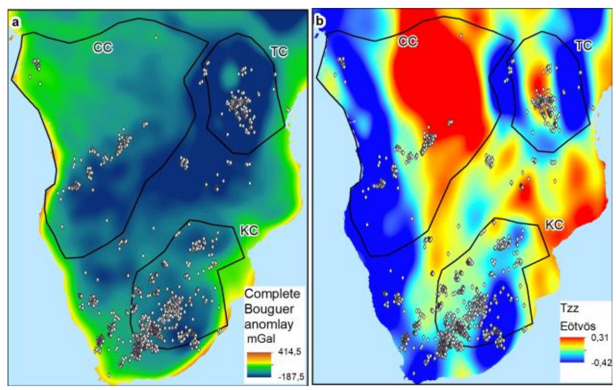

Figure 1 – A) Complete Bouguer anomaly map for southern Africa. B) Tzz map for the study area. Dots for kimberlite location. CC – Congo Craton, TC – Tanzania Craton, and KC – Kaapvaal Craton. Craton outline from literature[4].

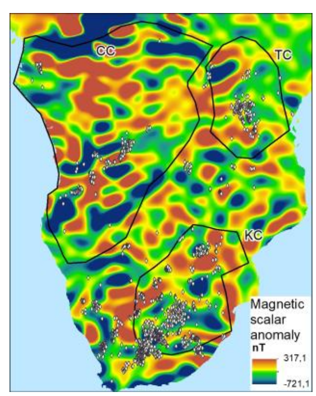

Figure 2 – Magnetic scalar anomaly map. Dots for kimberlite location. CC – Congo Craton, TC – Tanzania Craton, and KC – Kaapvaal Craton. Craton outline from literature[4].

The figure 3a shows the distribution of the kimberlites in the region and the depth for the Lithosphere-Asthenosphere Boundary (LAB) and Moho discontinuity (Fig. 3b) in the area. It is observed that the LAB depth does not relate immediately to the limits of the craton cores (Fig. 3b), with irregular shapes. However, it is observed that thicker lithosphere exists in most of the Congo and Kaapvaal cratons, with a more complicated pattern of the thinner lithosphere in the Tanzania Craton. The Moho depth (Fig. 3b) is in general larger far from the limits of the cratons in a parallel fashion to its major axis. There is some relation between the thicker lithosphere and concomitantly thicker crustal pile (e.g., central Kaapvaal, Fig. 3a,b). The kimberlites are observed mostly along regions of simultaneously thicker crustal pile and lithosphere (e.g., central Kalahari, and southern Congo craton Fig 3). The kimberlites often occur along regions of prominent gradients in the LAB (e.g., eastern Kalahari and eastern Tanzania cratons).

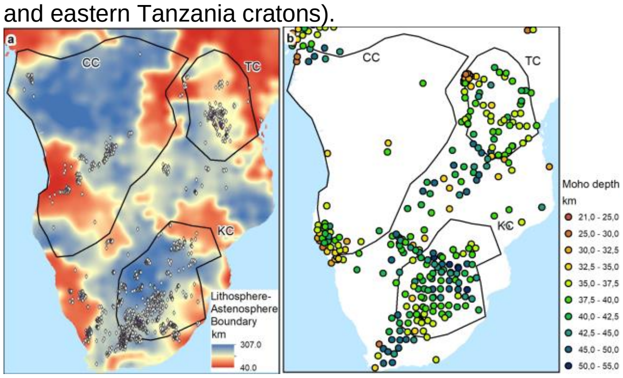

Figure 3 – A) location of the kimberlites and fields. B) Information from seismology surveying – the Lithosphere-Asthenosphere Boundary (LAB) depth and determinations for the Moho depth.

Conclusions

From our observations, it is evident that the satellite gravity presents features that distribute similarly to other geophysical methods. That indicates that the gravity anomaly depicted by those data can be of realistic world objects. The similarities between the fabrics observed in satellite gravity and magnetics are most convincing that both are tracking the response of crustal features.

There is also an agreement between the trend directions observed in the potential field satellite data and those observed in seismology data. That points out that the satellite data are capable of tracking changes in the physical property of the whole lithosphere since trends observed in the gravity are fairly coincident with the distribution of the LAB depth. A similar interpretation would be that the structural coupling along the lithosphere would allow the different datasets to depict similar trends.

The kimberlites in the area are observed to follow trends imaged in all the datasets consistently. An important observation is that kimberlites align with trends observed in the satellite gravity data in the Kaapvaal and Tanzania cratons, with the Congo Craton presenting less clear relationships. A prominent relation from the trend directions in the Tzz map and the trend directions of the kimberlite clusters has been observed.

From our observations in the southern African continent, it is evident that interpretations over the long wavelength information of the satellite gravity data have similarities to other geophysical datasets. Such synergies have been capable of tracking the possible regional framework of the region consistently. The overall relation between trends observed in the geophysical data and the trend direction and different concentration of the kimberlite locations point out that further evaluation of such data could cast light in the relationships between lithospheric structure and the distribution of kimberlite bodies and fields in regional terms.

Acknowledgments

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