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3D modelling of Trompsburg Complex (in South Africa) using 3D focusing inversion of gravity data

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ABSTRACT

The Trompsburg complex is a huge layered mafic igneous rock that is located near the town of Trompsburg in the Free State Province, South Africa that does not outcrop on the surface. Here, we construct 3D model of Trompsburg intrusion using 3D focusing inversion of gravity data. The inversion of gravity data is one of the most important topics in the quantitative interpretation of practical geophysical data. Focusing inversion can produce compact solution and recover the sharp boundaries between intrusive body and host rocks. In focusing inversion of Trompsburg gravity data we set focusing parameter equals 0.02. According to the geological information, lower density bound set to −0.1 g/cm^3 and upper density bound set to 0.5 g/cm^3. The results of 3D inversion in this study indicate that the Trompsburg Complex is a deep bowl-shaped intrusion which is extended to 33(km) below the surface. It is like an oval in horizontal plane sections with major axis of nearly 50 km in west- east direction and north- south minor axis about 30 km. The obtained results confirms that this complex could be related to intraplate magmatism.

1. Introduction

The Trompsburg complex is a huge layered mafic igneous rock that is located in the Free State Province, South Africa. This complex does not outcrop on the surface, therefore it was localized by geophysical investigations. The main part of this geological structure is composed of mafic igneous rocks but granite rocks located in the center of the complex. The main composition of the granite resembles that of the Villa Nora area of the Bushveld complex (Ortlepp, 1959).

The range of mafic igneous rocks is coarse-grained gabbro, anorthosite and mafic pegmatoid. The above mentioned structure has a roughly circular cross section in horizontal plane with the diameter of about 50 km (Ortlepp, 1959; Buchmann, 1960; Reynolds, 1979). In 1946–1949 seven boreholes were drilled by the Transvaal Orangia Ltd. Near the west of the town of Trompsburg penetrating some 1050 m of Karoo sedimentary cover before intersecting a mafic igneous rocks (Ortlepp, 1959). Briefly, the Trompsburg intrusion rocks share some compositional, lithologic aspects with the Bushveld Complex (Maier et al., 2003). The existence of the important source of platinum-group elements (PGE), chromite (Cr), and vanadium (V) deposits is the main goal of mining activities in this area (Reynolds, 1979), also the Trompsburg intrusion could be a resource for platinum group metals (Anhaeusser, 2004). There are some similarities between the satellite image of Bushveld and Trompsburg igneous complex which previously led to the thinking that the Trompsburg intrusion constitutes part of the Bushveld igneous complex. However, the isotope study of the Trompsburg intrusion (Maier et al., 2003) showed that crystallization age of two gabbroic samples was 1915 ± 6 Ma (Anhaeusser, 2004; De Waal et al., 2001; Tankard et al., 1982; Von Gruenewaldt et al., 1988; Maier et al., 2003) while the minimum age of Titanite sample of the Bushveld Complex was about 2058.9 ± 0.8 Ma (Buick et al., 2001). In the other word, Trompsburg intrusion is not directly related to the Bushveld structure. Maier et al. (2003) also showed that origin of Trompsburg intrusion is upper mantle that is related to a super-plume event. Nguuri et al. (2001) showed that crustal thickness in the study area is 32–35 km using seismic data.

Cooper (2006) used wavelet transform and Euler deconvolution of Trompsburg gravity data to estimate depth of the source of the

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gravity anomaly in the region. He showed that source of the Trompsburg gravity anomaly is located at a depth 20–40 km. Maré and Cole (2006) were as pioneer researchers that tried to present a three dimensional model for the Trompsburg Complex using aeromagnetic and gravity data. They used forward strategy for modelling of potential field data and their result showed a large, circular layered intrusion with a feeder extending to more than 16 km below the surface. The layers appear to dip in towards the center of the Complex in the north-western edges, but the most of the layers in the middle seem to be nearly horizontal. As the available boreholes were located to the northwestern part of the Complex, therefore the rest of the model was not as well constrained as in the northwestern part (Maré and Cole, 2006). There was a large difference between the calculated and observed magnetic data compared with the gravity field clearly where the magnetic rocks are shallow. On the other hand, the residual between the calculated and observed gravity data was 5 (mGal) which represents 5% acceptable error for a model of this scale. Forward modelling of potential field data is extremely ambiguous, and similar results can be achieved using different models. Therefore, it was suggested other modelling techniques and geophysical data are demanded to create a better model (Maré and Cole, 2006).

The inversion of gravity data is an important topic in the quantitative interpretation of practical data, since construction of density contrast models could increase the amount of information that can be achieved from the gravity data (Li and Oldenburg, 1998). One of the most interesting geological framework for gravity and magnetic data interpretation regards the detection of sharp boundaries between geological target and host rocks. Therefore, an algorithm producing compact solutions, such as the focusing inversion (Zhdanov, 2002) is the natural choice (Marchetti et al., 2014; Glegola et al., 2015). Focusing inversion is an inversion method based on Tikhonov regularization theory. The Tikhonov cost function consists of a misfit functional and a stabilizing functional. The misfit functional measures the misfit between original data and predicted data from produced model. The stabilizing functional can incorporate information about the properties of the type of models used in the inversion. For example this functional helps generating a sharp and focused inverse model in focusing inversion method (Portniaguine and Zhdanov, 2002).

As inversion approach has not been used for 3D modelling of Trompsburg intrusion. In this study, a three dimensional model of Trompsburg intrusion is created using gravity data and a 3D focusing inversion algorithm coded up by the authors of this paper.

2. Material and methods

2.1. Forward modelling

The vertical attraction of gravity, g_i, in Cartesian coordinates for a 3D model can be obtained as Eq. (1) (Blakely, 1996).

$$g(x_i, y_i, z_i) = -\gamma \int_{z'} \int_{y'} \int_{x'} \rho(x', y', z') \frac{(z - z')}{r^3} dx'dy'dz' \quad (1)$$

where, $\rho(x', y', z')$ is the density of a point mass located at (x', y', z'), γ is the Newton's gravitational constant, and r can be computed as Eq. (2).

$$r = \sqrt{(x - x')^2 + (y - y')^2 + (z - z')^2} \quad (2)$$

To perform inverse modelling, it is required to discretize the subsurface under the survey area into rectangular prisms of known sizes and positions. Here, the formula given by Plouff (1976) has been used to compute the gravity response of each prism, after discretization of subsurface by rectangular prisms. If the observed gravity anomalies are caused by n subsurface rectangular prisms, the gravity anomaly at the field point i (g_i) is given by

$$g_i = \sum_{j=1}^{n} G_{ij}\rho_j, \quad i = 1, 2, ..., m \quad (3)$$

where, G is the kernel matrix which has elements that compute at ith data point of a unit density in jth prism (Fig. 1) and ρ_j is density contrast of jth prism.

In Fig. 1, padx and pady denote the number of cells of padding used to extend the model domain in x and y directions which avoid possible distortion in the produced model along the boundaries (Boulanger and Chouteau, 2001). In the matrix notation Eq. (3) can be written as

$$G\mathbf{m} = \mathbf{d}, G \in R^{m \times n}, \mathbf{d} \in R^m, \mathbf{m} \in R^n \quad (4)$$

Here, $\mathbf{m}$ denotes the vector of unknown model parameters and $\mathbf{d}$ is data vector that is given by measurements (Li and Oldenburg, 1998). Measurement data are corrupted with some error that is assumed to be uncorrelated and have Gaussian distribution, so

$$G\mathbf{m} = \mathbf{d} + \mathbf{e}, \mathbf{e} \in R^m \quad (5)$$

where $\mathbf{e}$ is vector of data error and $\mathbf{d}_{obs} = \mathbf{d} + \mathbf{e}$ is vector of observed data (Rezaie et al., 2017a). The main objective in the gravity inverse problem is to find a geologically plausible density model ($\mathbf{m}$) that predicts measured data ($\mathbf{d}_{obs}$) at the noise level.

2.2. Focusing inversion

The gravity inverse problem is usually ill-posed and suffers from non-uniqueness. Therefore, the solution of this problem can be obtained by the minimization of the Tikhonov parametric functional (Zhdanov, 2002)

$$P^{\alpha}(\mathbf{m}) = \phi(\mathbf{m}) + \alpha S(\mathbf{m}) \rightarrow \min \quad (6)$$

Because of the linear relationship between prisms density and the prisms gravitational attraction, the misfit functional $\phi(m)$ is defined as

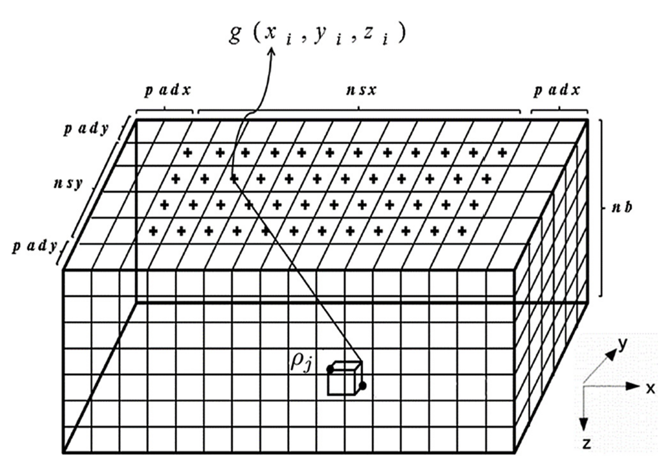

Fig. 1. A three-dimensional body with density distribution. ρ_j is the density of the jth prism. nsx, nsy denote the number of gravity stations in the x, y directions and nb is number of prisms in z direction. padx and pady denote the numbers of cells which may added around the gravity data grid in x and y directions, respectively (after Vatankhah et al., 2015).