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Structural Implication of Pseudogravity Transformation of Aeromagnetic Data over the Riruwai Complex

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Abstract. Pseudogravity transformation of the aeromagnetic data over the Riruwai Complex reveals three geological vent structures: southern, north-western and northern vents in the complex which incredibly compares to the geological information. They consist of mainly agglomerates, breccias, tuffs and rhyolites. These perhaps represent intraplate tectonic and magmatic phenomena linked to deep mantle plumes and asthenospheric upwellings. Bottom depth of about 5.4km is estimated using statistical space domain variogram, the dimensions of the vents are also reported.
Keywords: Pseudogravity, Riruwai, mantle plume, vent structure and variogram.

1. Introduction

Riruwai Complex, north central Nigeria, is an example of an intraplate magmatic region which is anorogenic in nature. Here the intraplate tectonic and magmatic phenomena are linked to deep mantle plumes and asthenospheric upwellings.(Montelli *et al.*, 2004; Pirajno, 2004; Zhao, 2004; Campbell, 2005; Nolet *et al.,* 2006). The pseudogravity transformation enhances the anomalies associated with deep magnetic sources at the expense of the dominating shallow magnetic sources. This transform is an excellent interpretation tool for detection of deep, magnetic igneous pluton and volcanic pile. In this work, the application of pseudogravity transformation of the aeromagnetic data over the complex is used to study the geological structures associated with such transformations with subsequent confirmations from geological field investigation. The transformation is applied to the Riruwai Complex to demonstrate the clear separation of deep sources that are difficult to detect or understand in the context of conventional magnetic image analysis.

2. The Geology of the study area

The Ring Complex is emplaced into the Precambrian to early Paleozoic Basement Complex rocks. It is chemically distinct from the basement suites of cal-alkaline and sub-alkaline granitoid intruded at the close of the Pan –African Orogenic event (Kinnard, 1984). Radioactive dating of the complex using Rb-Sr isotope, Van Breemen *et al* (1977) and Bonin (1988) show a relative 170±5ma age for the complex. During the initial volcanic stages a considerable volume of acid lavas and associated pyroclastics was erupted, giving rise to a thick volcanic succession which also includes occasional flows of basalt. It is believed that the volcanism was accompanied by formation of large surface cauldron or caldera about 13km in diameter in which the bulk of the effusive volcanic material accumulated. The extrusive volcanic rocks are well preserved in north-western half of the complex while in the south-east and extreme north-west, the underlying vent structure can be seen. Towards the end of the volcanic cycle a large plug of quartz-fayalite-porphyry was emplaced in the centre of the Dutsen Shetu vent complex. During the plutonic cycle, the peripheral ring dyke of granite –porphyry, one of the major structural feature of the complex, and the central granite plutons of biotite-and riebeckite-granite were emplaced beneath the volcanic pile The ring structure and cupolas represent roots of volcanoes. The Riruwai Complex provides one of the finest examples in the Nigerian province of the complete cycle of Younger Granite magmatic activity (Jacobson and Macleod 1977).

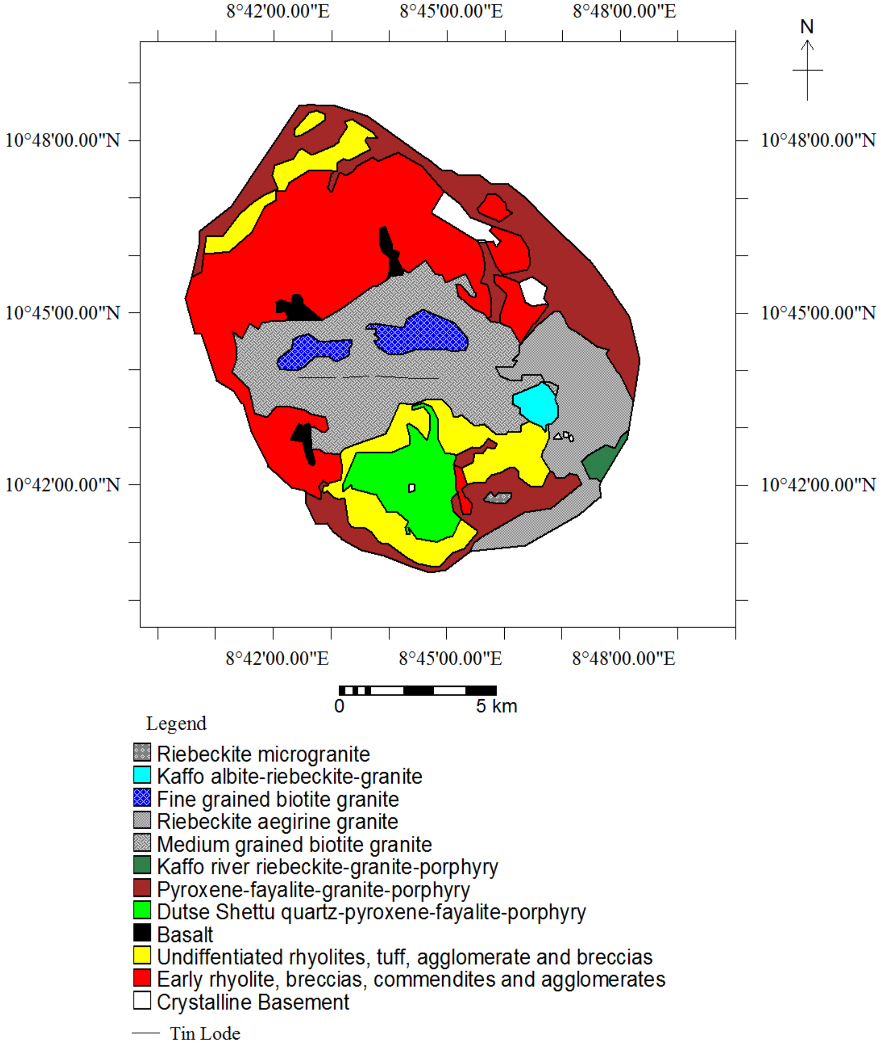

Figure 1. The Geology of the study area (after Jacobson and Macleod 1977).

3. Methodology

The study of the aeromagnetic data over complex magnetic fields can be defined in terms of magnetic potentials in similar manner to gravitational fields.

For a single pole of strength m, the magnetic V at distance r from the pole is given by

$$V = -\frac{Cm}{\gamma}\frac{M}{\rho}\,\boldsymbol{m}.\Delta \mathrm{p} U \ldots\ldots\ldots\ldots\ldots\ldots.\ (1)$$

$$= \frac{Cm}{\gamma}\frac{M}{\rho}\ \mathrm{gm}\ \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.\ (2)$$

where P is the density, M is the intensity of magnetization, m is the direction of magnetization, and grn is the component of the gravity field in the direction of magnetization **m**. In deriving Poisson's relation, we assumed that M and p are constant. However, we can consider a variable distribution of magnetization or density to be composed of arbitrarily small regions of uniform magnetization or density; equation 2 is appropriate for each of these small regions and, invoking the superposition principle, must be appropriate for variable distributions of density and magnetization (Blakely 1995).

Baranov (1957) described an application of Poisson's relation in which the total-field magnetic anomaly is converted into the gravity anomaly that would be observed if the magnetization distribution were to be replaced with an identical density distribution (i.e. M $/\rho$ is a constant throughout the source). He called the resulting quantity a pseudogravity anomaly, and the transformation itself is generally referred to as a pseudogravity transformation.

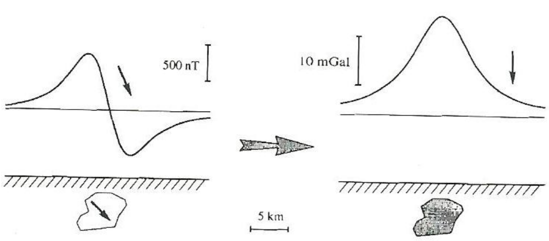

Figure 2. Magnetic anomaly and its pseudogravity transform (after Blakely 1995).

The transformation relates total magnetic field anomaly to the vertical component of the gravity field $g_{z.,}$ Also, the horizontal component of the pseudogravity field gx and gy can be derived from the magnetic via the Equation (3) below (Pedersen, 1989):

$$\Gamma=\begin{pmatrix} g_{xx} & g_{xy} & g_{xz} \\ g_{xy} & g_{yy} & g_{yz} \\ g_{xz} & g_{yz} & g_{zz} \end{pmatrix} \quad \text{.......(4)}$$

Outside the source, Laplace's equation is satisfied. Hence the trace tensor is equal to zero. Γ, being a symmetric matrix which can be diagonized as:

$$VT\ \Gamma V= \Lambda \quad \text{.......(5)}$$

$$V=[v_1\ v_2\ v_3] \text{ and } \Lambda = \begin{pmatrix} \lambda_1 & 0 & 0 \\ 0 & \lambda_2 & 0 \\ 0 & 0 & \lambda_3 \end{pmatrix} \quad \text{.......(6)}$$

Physically, equation 6 means that at any observation point, one can find a new coordinate system with axes along the eigenvectors in which the gradient tensor is in diagonal form (Pedersen and Rasmussen, 1990 and Mikhailov et al., 2007).

The effect of depth to source z follows the variogram equation put forward by Maus (1999), where:

$$V(\tau) = \pi c_s(\frac{\mu_0}{2N})^2 B[1/2,(\beta+1)/2 \ x\int_0^\infty [T\text{-}2T_0J_0(\tau s)\text{-}2\,\frac{T2}{\tau s}J_1(\tau s) - \frac{6T4}{t^2s^2}J_{2(\tau s)}]\, e^{-2zs}\, s^{2-\beta} ds \quad \text{.......(7)}$$

$$T= \frac{3}{4}(n_y^2+n_x^2)^2 + 2n_z^2(n_y^2+n_x^2+n_z^2) \quad \text{.......(8)}$$

$$=\frac{3}{4}H^4 + 2n_z^2N^2 \quad \text{.......(9)}$$

$$T_0 = n_z^4+n_x^4+2n_z^2n_x^2 \quad \text{.......(10)}$$

$$T_2 = 6n_y^2n_x^2+2n_y^2n_z^2-2n_x^4-2n_x^2n_z^2 \quad \text{.......(11)}$$

$$T_4 = n_y^4-6n_y^2n_x^2+n_x^4 \quad \text{.......(12)}$$

Where, $N=(n_x, n_y, n_z)$ is expressed in coordinates relative to the flight line. Since only even powers of n_x, n_y, n_z appear we need to take care of the orientation of the coordinate system as long as $n_y = 0$ for H parallel to the profiles and $n_x = 0$ for H perpendicular to the direction of the profiles.

C_s is the intensity of variation considered as practical interest since it reflects the intensity of source variations. For magnetic data, the square root possibly related to the magnetization of the source rocks.

z is the depth to source, with increasing depth to source, the variogram of the potential field experiences a drastic decrease in overall amplitude.

4. Aeromagnetic Data

This transformation is applied to the aeromagnetic data set from the Riruwai Complex (Figure 3) and the objective is to locate major geological features. Magnetic measurements are usually made from aircraft flown along closely spaced, parallel flight lines. Additional flight lines are flown in the perpendicular direction to assist in data processing. These measurements then are processed into a digital aeromagnetic map. Assisted by computer programs, a geologic interpretation and model is developed from these data. The airborne Geophysical Survey used was flown and compiled by hunting geology and geophysics Limited, produced by the geological survey of Nigeria at a scale of 1:100,000 with flight line of $150^0/330^0$, norminal flight line spacing of 2Km and tie line direction of 60/240

5. Result and Discussion

The Pseudogravity components are calculated to locate the geological features and indicate the dimensions. These features correlate with the low pseudogravity values possibly reflecting the buoyancy of the heated lithosphere (Figure 4). From which uplift is followed by subsidence due to loss of buoyancy of the plume head or removal of the magma from the top of the plume, thermal decay or combination of the three (Condie 2001). The geological feature corresponds to three vent structures of the Riruwai Complex:(a) North-Western vent (b) Northern vent and (c) Southern or DutseShetu vent. These major vents represent the deep level intrusive volcanic structures, intraplate tectonic and magmatic phenomena which are linked to deep mantle plumes and asthenospheric upwelling (Pirajino, 2004).

The largest is the Southern or Dutse Shetu vent which has a crude annular structure as revealed by concentric vent agglomerate and other components around the central fayalite-porphyry plug. The Dutse Shetu vent is separated

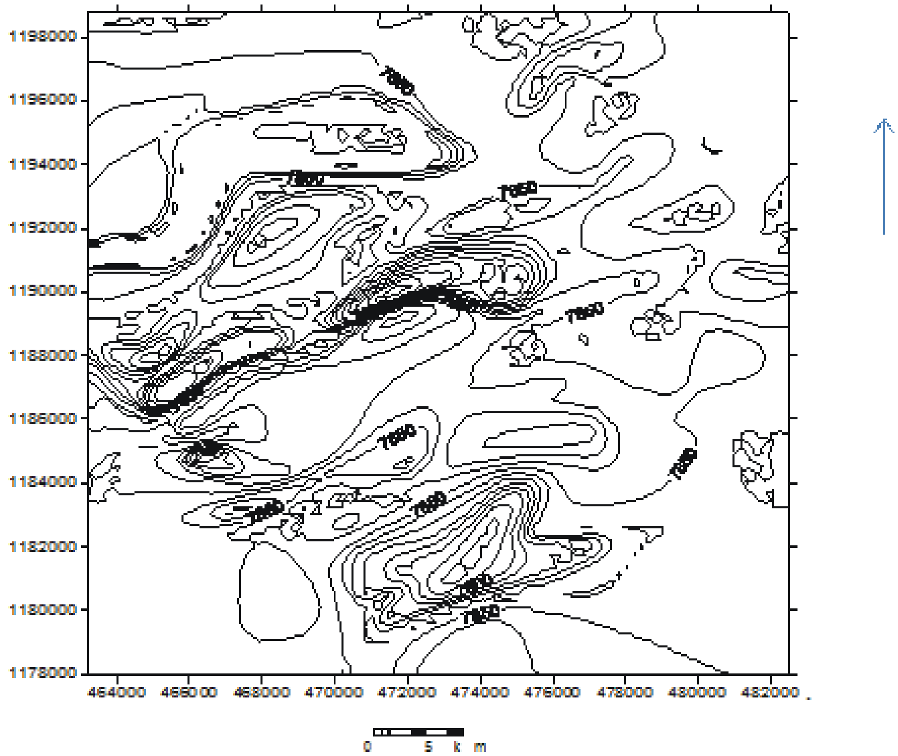

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Figure 3. Total magnetic intensity in gammas

from the other two by later granite intrusion. The North-Western vent is a linear vent structure parallel to the peripheral ring fault in NE direction. The fact that the lavas dip towards the vent suggest that they have been down-faulted (Jacobson *et a*l 1977 and Olasehinde *et al*, 2012). The volcanic succession in the North-western block consists of series of extrusive rhyolites and pyroclastic with occasional interbedded flows of basalt. The Northern vent is bounded by the granite- porphyry ring dyke; the vent is probably separated from the extrusive lavas on the north-west. It consists of agglomerate rhyolite subordinate breccia and tuff. The dimensions of the vents were taken along the general tectonic lineament in NE-SW direction (Olasehinde *et al,* 2012) and across (Table 1).

Profile AB (Figure 5) and two- dimensional model (Figure 6) were constructed from the filtered pseudogravity anomalies along profile AB and estimated bottom depth of 5.4km using statistical analysis of magnetic field anomalies implemented in space domain variogram (Figure 7) as counterparts of a fractal power spectral model after Maus (1999) and Maus *et al.* (1999). Isometric projection of the three-dimensional pseudogravity model was also presented (Figure 8).

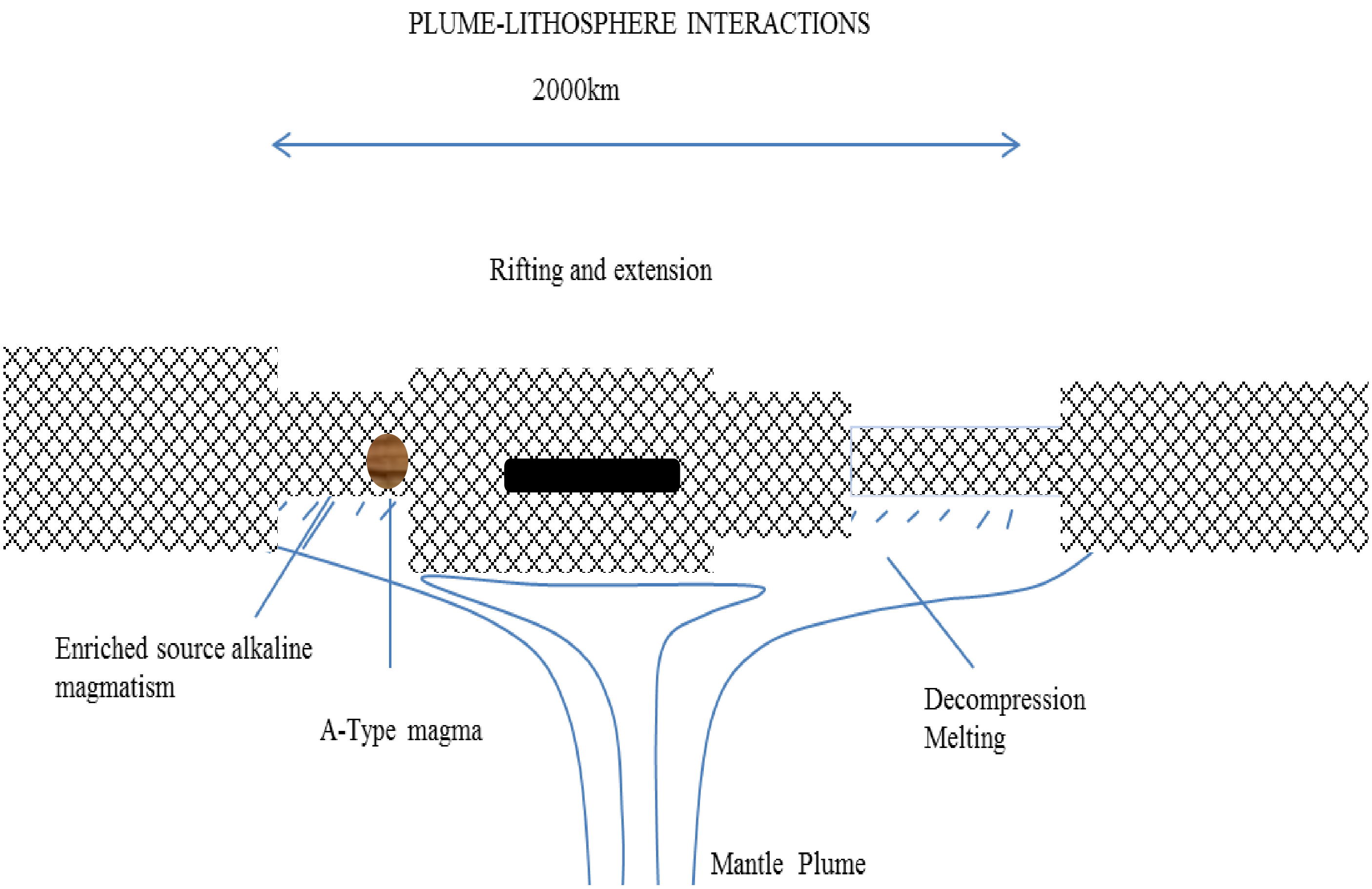

Figure 4. Uplift and extension result in rifting and decompression melting of plume head (After Saunders *et al.,* 1992)

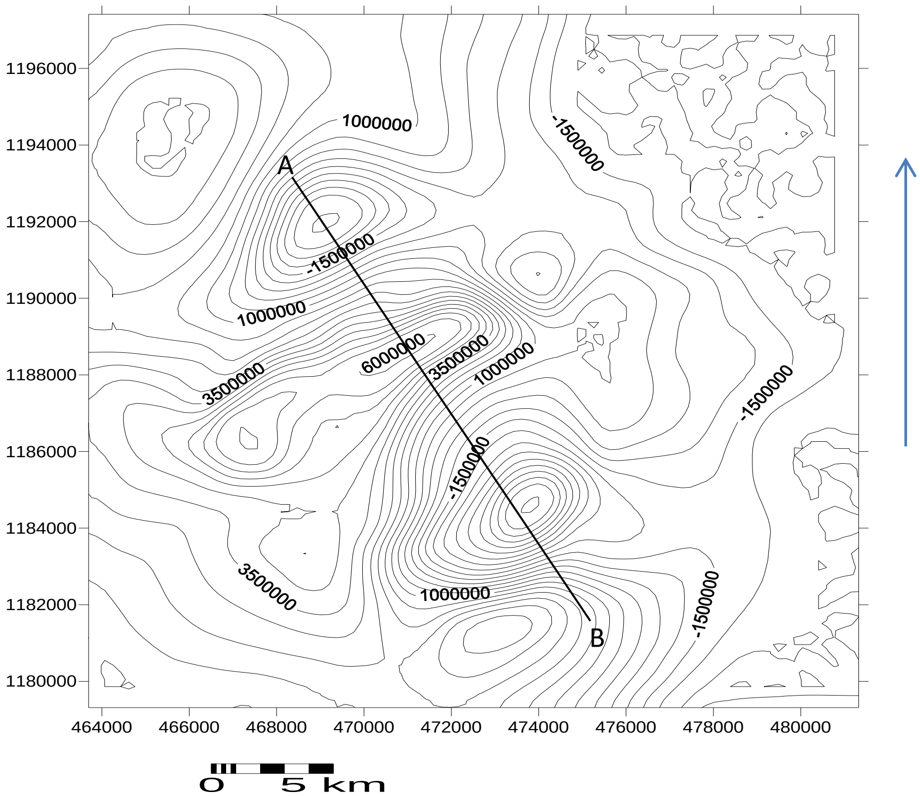

Figure 5. Profile AB of Pseudogravity transformation of the magnetic data

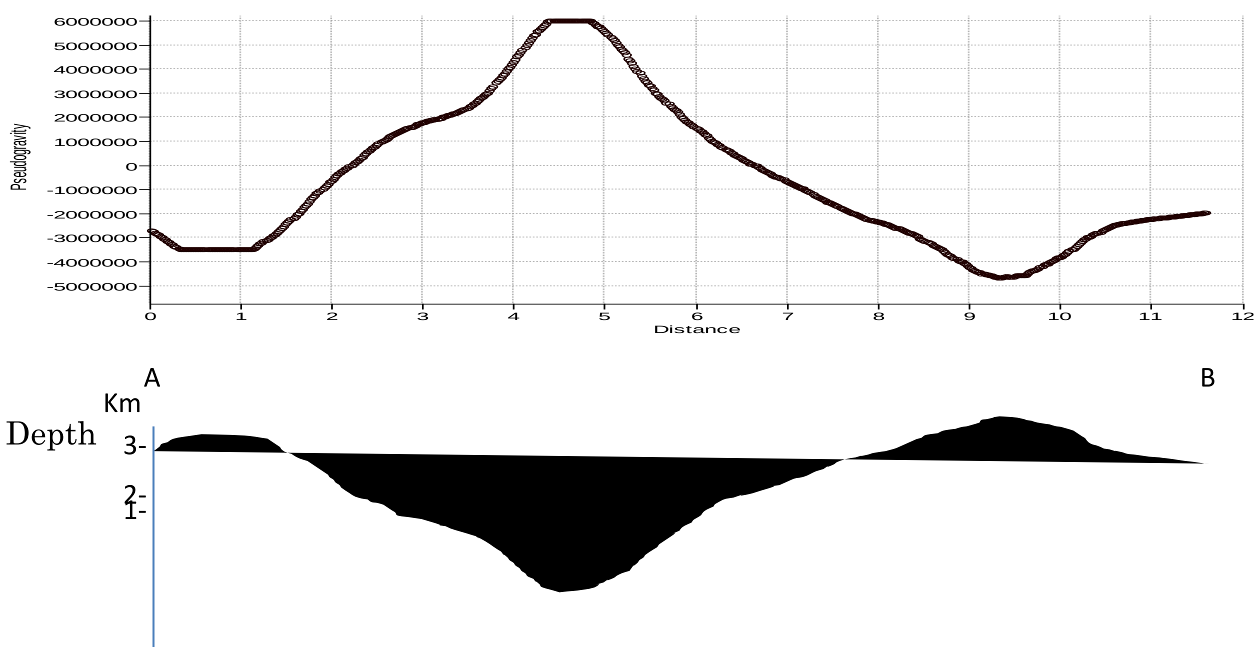

Figure 6. Pseudogravity profile along AB

Table 1. Riruwai vents and dimensions

Vents	Direction of measurement	Diameter (Km)
North-Western	NE-SW	3.9
	NW-SE	2.8
Northern	NE-SW	1.7
	NW-SE	2.0
Southern Dutse Shetu	NE-SW	5.8
	NW-SE	4.9

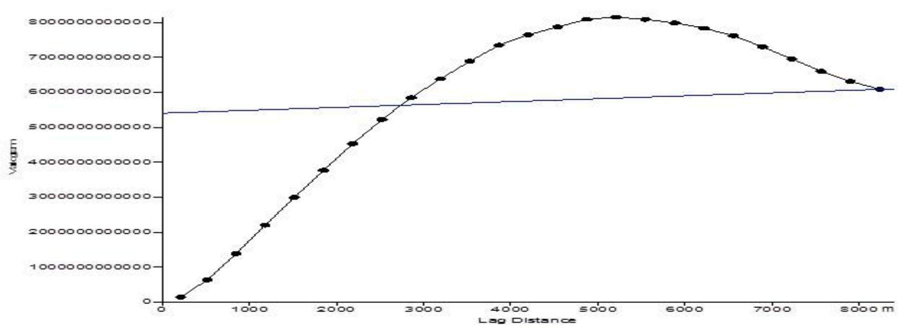

Figure 7. Variogram estimating depth of about 5.4km

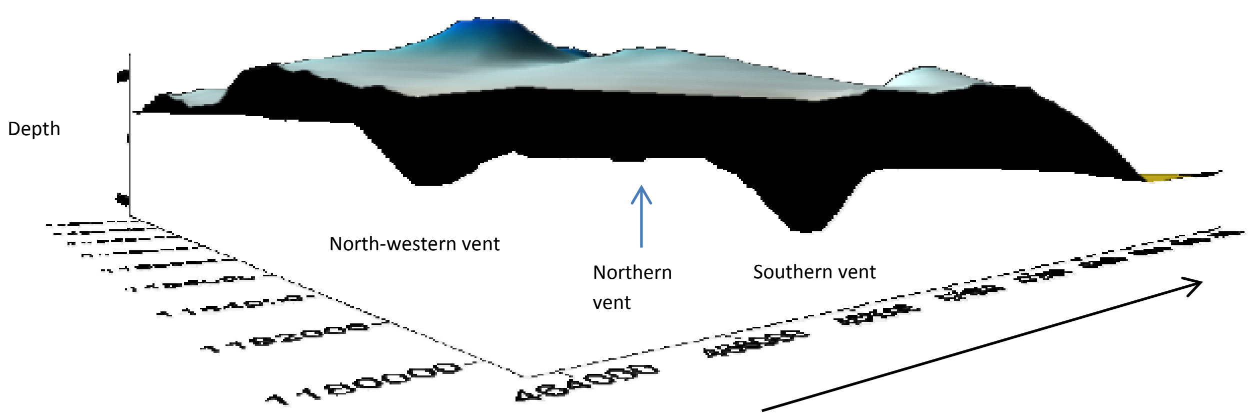

Figure 8. Isometric projection of the three-dimensional pseudogravity model of the Riruwai Complex.

6. Conclusion

We have described Riruwai vent structure using pseudogravity transformation in estimating the location, dimension and source of the causative bodies which relate to mantle plume. Space domain variogram model has been used to estimate the depth. The detected geological features in the Riruwai Complex are inconceivably compared to the geological information.

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