Estimation of source parameters using extreme points of the scaled potential field

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Summary

The characterization of the sources of gravity anomaly in the Vindhyan basin is important to constrain the basement structure for hydrocarbon exploration. In this method, scaling function which is a function of altitude is used to characterize the scaling behavior of homogeneous field. It determines the depth to sources of bodies like sphere, cylinder, dike, sill etc. using extreme points of the scaled potential field. The method is tested on synthetic cases of gravity anomaly of isolated and extended sources such as sphere, elongated prism and applied on the gravity data of Jabera-Damoh region of Vindhyan basin, central India. The results show that the shallow features represent high density material which is underlain by the combination of high and low density material of crystalline basement along both sides in Vindhyan basin.

Introduction

Several methods give estimation of the source position and structural index (SI) (e.g., Reid et al., 1990; Martelet et al., 2001) which help in characterization of the sources associated with gravity and magnetic data. The parameters are important for understanding the geometry of the subsurface sources of the anomaly and can help to build a starting model for forward modeling approaches (Chamoli et al., 2011). The Depth from Extreme Points is one of such approach and usually applied to the potential field. It gives information about the depth to sources of potential field anomalies, the excess of the mass (gravity case) or the dipole moment intensity (magnetic case) and the kind of source (Fedi, 2007). In this paper, DEXP method is first tested for the gravity anomalies due to synthetic sources of different geometries such as uniform sphere and elongated prism. The stability of the method is also checked by adding random Gaussian noises to the synthetic magnetic anomaly data. Then, the interpretation of the Bouguer anomaly across Jabera dome in central India is carried out using the DEXP method.

Methodology

Fedi (2007) has formulated the theory of the DEXP. The DEXP methodology can be summarized in following steps:

I) First, we create the 3D data volume of the potential field (f) and apply upward continuation to this field to get the transformed scaled field (W)

II) The extreme points of the transformed scaled field are used in estimation of depth of the sources.

The Newtonian potential field for n[th] order (f_n) can be written in terms of altitude (z) and depth to source (z_0):

$$f_n = \frac{1}{(z - z_0)^{n+1}} \tag{1}$$

The scaling function (τ_n) depends on the n[th] vertical derivative of potential field (f) and altitude (z) is given by Fedi, 2007:

$$\tau_n = \frac{\partial \log[f_n(z)]}{\partial \log(z)} \tag{2}$$

By substituting (1) in (2):

$$\tau_n = \frac{\partial \log[f_n(z)]}{\partial \log(z)} = -\frac{(n+1)z}{z - z_0} \tag{3}$$

At extreme points $(z = -z_0)$, the scaling function τ_n is:

$$\tau_n(z=-z_0)=\frac{\partial \log[f_n(z)]}{\partial \log(z)}=-\frac{(n+1)}{2} \qquad (4)$$

For $n=1,\ \tau_1(z)=-1$ (5)

The scaling coefficient (α_n) is given as:

$$\alpha_n=-\tau_n=0.5(n+1) \qquad (6)$$

The DEXP transformed scale field is defined as (Fedi 2007):

$$W_n=z^{\alpha_n} f_n \qquad (7)$$

The scaling behavior of W_n gives information about the source geometry.
The scaling coefficient (α_n) is calculated from the intercept of plot of τ_n versus q from the following equation, which is derived after substituting $z=1/q$ in (3):

$$\tau_n(q)=-\frac{(n+1)z}{1-z_0 q} \qquad (8)$$

The behavior of the scaling function for (5) is shown in figure 1.

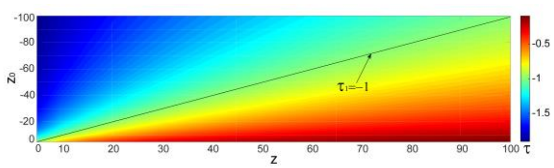

Figure 1. The scaling function τ_1 for n=1potential field.

Similarly the behavior of scaling function for n[th] order vertical derivative can be estimated. This scaling function is related with type of sources. The scaling function is used in estimation of DEXP transformed field at extreme points.

Synthetic Examples

In the present study, the DEXP method is applied to two synthetic gravity data. Although different source parameters are assumed but one case of both type is presented here for clarity.

1. **Sphere**- In first case, the figure 2 shows the gravity anomaly due to an uniform sphere with density contrast 200 kg/m^3, 5 km radius and centre at position (125, 125, 15) km. The data interval is1km in both directions. The DEXP transformation is applied on the upward continued data of the generated gravity anomaly. The figure 3 shows the scaled field Wg1with extreme point at z= -z_0. It has an extreme point (white mark) at depth 14.2 km. which gives average depth of the source.
The figure 4 shows the structural index 1.92 which is closed to assumed parameter (the depth 15 km and structural index of sphere 2).

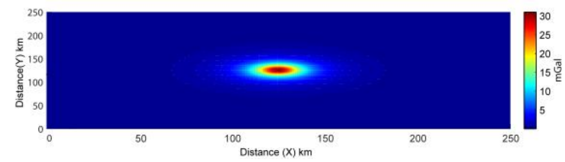

Figure 2. Synthetic gravity anomaly due to a uniform sphere having source position at (125,125, 15) km and having density contrast 200 kg/m^3.

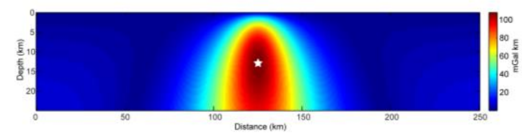

Figure 3. The DEXP transformed field calculated up to 25 km altitude at the interval of 1 km has extreme point (white mark) at depth of 14.2 km, which is close to the assumed depth of the source.

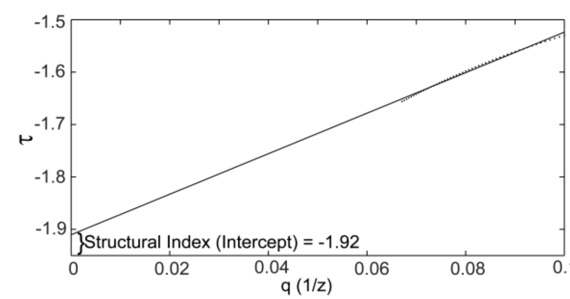

Figure 4. Plot of the scaling function versus q with intercept 1.92, which gives the structural Index of the source (Sphere in the present case).

The shape of the source is represented by structural index, which corresponds to sphere in the present case. The methodology has also been tested on different synthetic cases.

2. **Elongated prism**- In second case, the assumed dimensions of the prism is (10×20×11 km^3) with a 10 km depth to the top and density contrast 100 kg/m^3.The prism horizontal dimensions is (10×20 km^2) and the profile is perpendicular to the longest side. The generated gravity anomaly is shown in figure 5a. The DEXP transformation is applied on the upward continued data of the generated synthetic gravity

anomaly. Finally the extreme point ($z= -z_0$) of the scaled field is used in estimation of depth to source. The scaled field Wg1 with extreme point at $z= -z_0$ is shown in figure 5b. It has an extreme point (white mark) at depth 9.8 km. which gives average depth of the source.

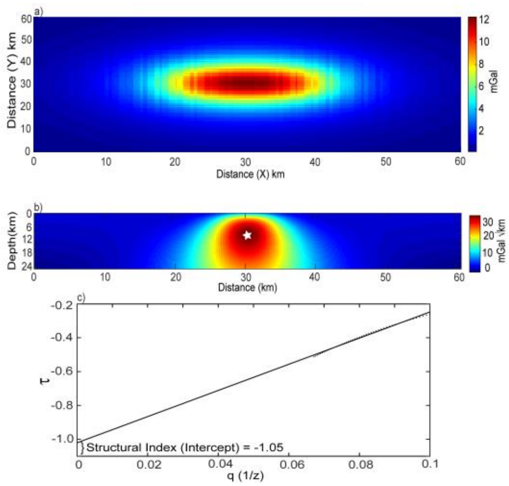

Figure 5. a) Synthetic gravity anomaly due to an elongated prism with dimension (10×20×11) km^3 and depth of the top 10 km. b) The DEXP transformed field calculated up to 24 km altitude at the interval of 1 km has extreme point (white mark) at depth of 9.8 km, which is close to the assumed depth of the source. c) Plot of the scaling function τ versus q with intercept 1.05, which gives the structural Index of the source (horizontal prism in the present case).

The figure 5c shows the structural index 1.05 which is closed to assumed parameter (the depth 10 km and structural index of elongated prism 1).

DEXP as a stable tool

DEXP method perform better in case of noisy data. If data contains noises the position of source does not changes. Here we have taken a magnetic anomaly of a homogeneous sphere (figure 6a) and applied the DEXP transformation on this magnetic anomaly. It gives the depth of the source at 4.8 km (figure 6b) represented by white mark.

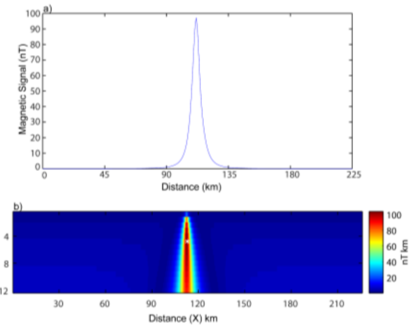

Figure 6. a) Magnetic signal of a homogeneous sphere. b) The DEXP transformed field calculated upto 12 km altitude at the interval of 1 km has extreme point (white mark) at depth of 4.8 km.

Adding random Gaussian noises to the data (figure 7a, 7c, 7e) the correct position of the source is still obtained at 4.8 km depth, represented by white marks (figure 7b, 7d, 7f).

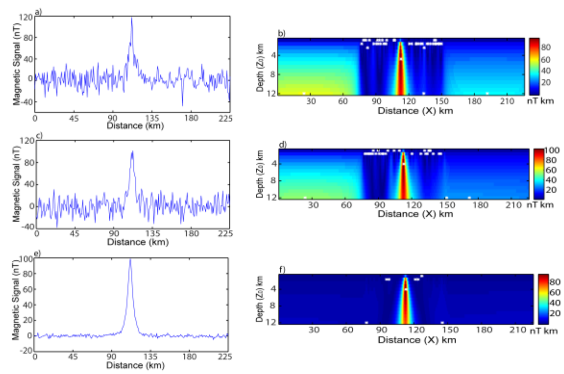

Figure 7: a) Adding SNs ratio of 0.1 to the magnetic data in form of Gaussian random noise. b) The calculated DEXP transformed field has still extreme point (white mark) at depth of 4.8 km. c) Adding SNs of 1 to the magnetic data as Gaussian random noise. d) The DEXP transformed field with extreme point at depth of 4.8 km. e) Adding SNs ratio of 10 to the magnetic data. f) The DEXP transformed field has extreme point at depth of 4.8 km shown by white mark.

It shows the method works well in case of low SNs ratio. Hence the correct depth of the source does not changes, while the presence of noises in the data.

Case study-

Gravity profile across Jabera dome

The Proterozoic Vindhyan basin covers an area of approximately 1, 62,000 sq.km. Our study area Jabera-Damoh region is located in southern part of Vindhyan basin. According to Directorate General of Hydrocarbons (DGH), lower Vindhyan shales, are considered as potential source rocks for hydrocarbons. Jabera- Damoh region is associated with faults, folds and domal structures. Oval shaped Jabera dome is located about 40 km NW of Jabalpur. It extends in ENE-WSW direction and developed during early stages of upper Vindhyans consequent to structuring of the great Vindhyan syncline (Jokhan Ram et al., 1996). It covers an area of about 320 km^2. Such domes have special significance due to associated basement uplifts and possible potential for hydrocarbon accumulation (Srivastava et al., 1983). Srivastava et al. (2007) has given detailed information of this region. Different exploration surveys are conducted by various organization such as CSIR-NGRI, Oil and Natural Gas Corporation of India (ONGC), Alphageo and DGH. Thus the area has been of interest for hydrocarbon and lithospheric studies.

In the present work, the depth of crystalline basement over central part, across Jabera dome is estimated using DEXP method. Jabera- Damoh region is covered by dense rivers and forests. Profile BB' across Jabera dome is selected for depth estimation (Srivastava et al., 2007).

The selected Bouguer gravity profile BB' (figure 8b) across Jabera dome is extracted from the Bouguer anomaly map of Srivastava et al., 2007 as shown in figure 8a.

The Bouguer anomaly spreads over an area of 75 km across Jabera dome. A 2D source is assumed of shape horizontal cylinder (scaling coefficient 0.5), due to large spread of an area. The depth is estimated using DEXP transformation on upward continued data as shown in figure 8c. It has three extrema points (maxima and minima) at a depth of 2km and 9.8 km as shown by white marks.

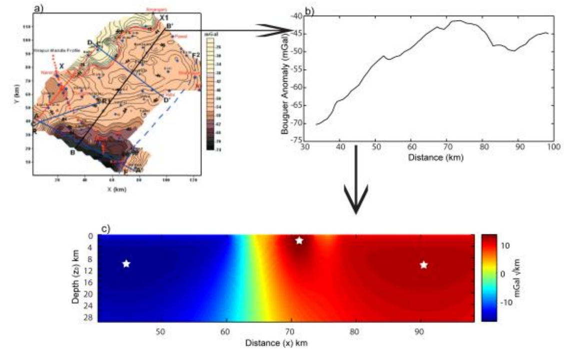

Figure 8. a) The Bouguer gravity anomaly plot of the Vindhyan basin area (after Srivastava et al., 2007). b) The Bouguer anomaly profile BB', across Jabera dome. c) The DEXP section obtained using scaling coefficient 0.5 of an infinite horizontal cylinder. The extreme points (white marks) indicate the sources positions at depth 2 km and 9.8 km.

The shallow features represent high density material which is underlain by the combination of high and low density material of crystalline basement along both sides. The result of the method is similar to the result obtained by forward modeling by Srivastava et al. (2007).

Conclusions

The application of the DEXP method on synthetic data as well as gravity data of Vindhyan basin has shown its applicability for identifying the source information. The estimated depth is inferred as the average depth of crystalline basement, which can give important constrain for future exploration studies. The method can also be efficiently applied to the problems of mineral exploration, delineating sedimentary structure and in petroleum exploration.

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