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# A rapid approach to depth determination from magnetic anomalies due to simple geometrical bodies

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## ABSTRACT

The present paper deals with a rapid approach to depth determination of a buried structure from magnetic anomalies. The problem of depth determination is transformed into the problem of finding the zero-anomaly distances from the observed magnetic anomalies. Formulas have been derived for different components of the magnetic anomalies (vertical, horizontal, and total) due to long horizontal cylinders, thin dikes, and geologic contacts; and for vertical and horizontal components only of the magnetic anomalies due to spheres. Procedures are also formulated to estimate the amplitude coefficient (magnetic moment) and the index parameter (the effective angle of magnetization). The method was applied to synthetic data with and without random error and tested on a field example from India.

## INTRODUCTION

In large number of exploration problems, it is valid to assume a geologic structure which is related to either a horizontal cylinder or a sphere. Both models are frequently used in magnetic interpretation to find the depth of a class of geologic structures (Smellie 1956; Paul 1964; Gay 1965; Radhakrishna Murthy 1967 & 1974; Rao *et al.* 1973 & 1977; Bhaskara Rao & Radhakrishna Murthy 1979; Atchuta Rao & Ram Babu 1980; Mohan *et al.* 1982; Ram Babu *et al.* 1983; Sampath Kumar & Prakasa Rao 1984; Prakasa Rao *et al.* 1986; Abdelrahman 1990).

In the present paper, the depth estimation problem is transformed into the problem of finding the zero-anomaly distances from the observed magnetic data. Formulas have been derived for the different components of magnetic anomalies (vertical, horizontal, and total) due to horizontal cylinders and for vertical and horizontal components of the magnetic anomalies due to spheres. Since the magnetic anomaly due to a horizontal cylinder, the first horizontal derivative of the magnetic anomaly due to a thin dike, and the second horizontal derivative of the magnetic anomaly due to the geological contact are identical in shape (Atchuta Rao *et al.* 1980), accordingly, the present method can also be applied to the magnetic anomalies due to thin dikes and geologic contacts. Procedures were also formulated to estimate the index parameter (the effective angle of magnetization) and the amplitude coefficient (magnetic moment).

Finally, the method was applied to synthetic data with and without random error and was tested on a field example from India.

## THEORY

Following Prakasa Rao *et al.* (1986) and Prakasa Rao & Subrahmanyam (1988), the general expression for the magnetic anomaly (vertical, horizontal, and total) due to a horizontal cylinder and for the magnetic anomaly (vertical and horizontal) due to a sphere is given in the form of

$$H(x,z,\theta) = K\frac{(az^2+bx^2)(\sin\theta)^m(\cos\theta)^n + cxz(\sin\theta)^n(\cos\theta)^m}{(x^2+z^2)^q}. \qquad (1)$$

where

$K$: is the amplitude coefficient (magnetic moment)
$z$: is the depth
$\theta$: is the index parameter (effective angle of magnetization)
$a$, $b$, $c$, $m$, $n$ and $q$: are defined in Table 1.

**Table 1.** Definition of $a$, $b$, $c$, $m$, $n$, and $q$ values shown in Eqn (1).

| Model | Magnetization | $a$ | $b$ | $c$ | $m$ | $n$ | $q$ |
|---|---|---|---|---|---|---|---|
| Horizontal cylinder | Total Vertical horizontal | 1 | −1 | 2 | 0 | 1 | 2 |
| Sphere | Vertical | 2 | −1 | −3 | 1 | 0 | 5/2 |
| | horizontal | −1 | 2 | −3 | 0 | 1 | 5/2 |

Geometrical configuration of these models is shown in Fig. 1.

Setting Eqn (1) to zero, we obtain the following equation

$$(\tan\theta)^{n-m} = -\frac{az^2+bx_0^2}{cx_0z}, \qquad (2)$$

where $x_0$ is the horizontal distance from the origin ($x=0$) to point at which the anomaly attains its zero value. However, because there are two horizontal distances

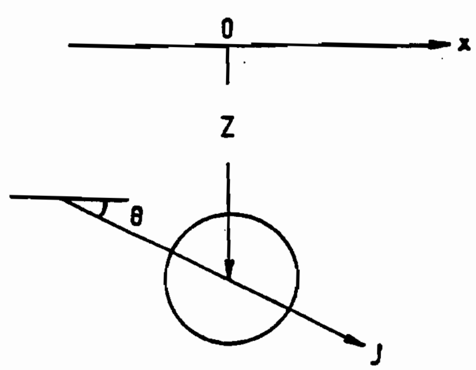


**Fig. 1.** Geometry of a magnetized cylinder or a sphere.

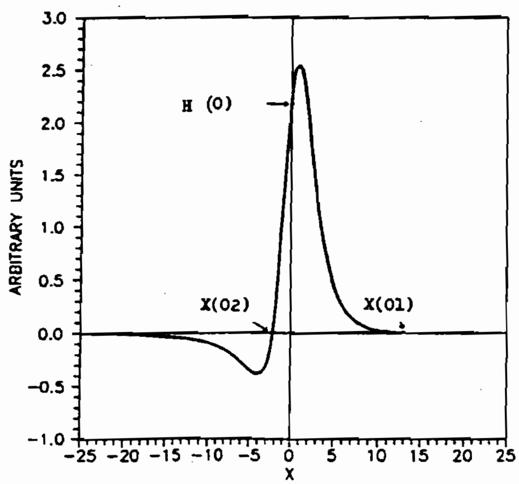


**Fig. 2.** A typical vertical magnetic anomaly over a sphere showing the definition of $x_{01}$, $x_{02}$, and $H(0)$.

along the anomaly profile where the magnetic anomaly attains its zero value, namely, $x_{01}$ and $x_{02}$ (Fig. 2), we conclude from Eqn (2) that

$$\frac{az^2 + bx_{01}^2}{cx_{01}z} = \frac{az^2 + bx_{02}^2}{cx_{02}z}, \tag{3}$$

and finally if the equation is solved for $z$, we obtain after simplifications:

$$z = \sqrt{\frac{bx_{01}x_{02}}{a}}. \tag{4}$$

Thus knowing the positive horizontal distance $x_{01}$ and the negative horizontal distance $x_{02}$ from a given anomaly profile, the depth parameter $z$ can be obtained uniquely from Eqn (4).

Because $z$ is known, the $\theta$ value can be determined from Eqn (2). Knowing $z$ and $\theta$, the $K$ value can be determined from the following relationship

$$K = H(0)z^2/a(\sin\theta)^m(\cos\theta)n \tag{5}$$

where $H(0)$ is the anomaly value at $x = 0$.

**Table 2.** Criteria for determining the actual value of *e*.

| Position and sign of dominant anomaly | Actual value of $\theta$ |
|---|---|
| *The horizontal cylinder* | |
| *(Different components of magnetization)* | |
| Dominant positive and on left of profile | $\theta$ |
| Dominant positive and on right of profile | $\theta - 360$ |
| Dominant negative and on left or right of profile | $\theta - 180$ |
| *The sphere* | |
| *(Vertical magnetization)* | |
| Dominant positive to the south | $\theta$ |
| Dominant positive to the north | $180 + \theta$ |
| Dominant negative to the south | $180 + \theta$ |
| Dominant negative to the north | $360 + \theta$ |

**Table 3.** Theoretical examples (in arbitrary units).

| | The sphere (vertical magnetization) | | The horizontal cylinder (All types of magnetization) | |
|---|---|---|---|---|
| | Model 1 | Model 2 | Model 3 | Model 4 |
| Parameters assumed | | | | |
| $z$ | 3.00 | 4.00 | 5.00 | 6.00 |
| $\theta$ | 45° | 135° | −240° | −310° |
| $K$ | 100 | 100 | 100 | 100 |
| Parameters evaluated using synthetic data | | | | |
| $z$ | 3.11 | 4.10 | 5.08 | 6.05 |
| $\theta$ | 46° | 134° | −240° | −310° |
| $K$ | 108.89 | 106.06 | 101.89 | 101.16 |
| Parameters evaluated using synthetic data with 10% random error | | | | |
| $z$ | 3.11 | 4.10 | 5.09 | 6.05 |
| $\theta$ | 46° | 134° | −240° | −310° |
| $K$ | 111.60 | 108.35 | 104.59 | 103.57 |

The value of $\theta$, as obtained from the present method, lies in the range of −90° to 90°, although, in reality, they can take any value between 0° to 360°. The actual value can be determined by a careful examination of the field anomaly profile and making use of the rules given in Table 2.

To this stage, we have assumed knowledge of the origin. In practice, a field traverse will have an arbitrary origin, in which case the position of the structure ($x = 0$) in Eqn (1) must first be determined. In most cases, the position of the turning points, i.e. the main maximum value of the profile and the main minimum value of the profile can be used to obtain the correct location $x = 0$, particularly, when the anomaly profiles has a phase-shift of 90°. A straight line joining the maximum to the minimum of the profile will intersect the anomaly curve at the point $x = 0$.

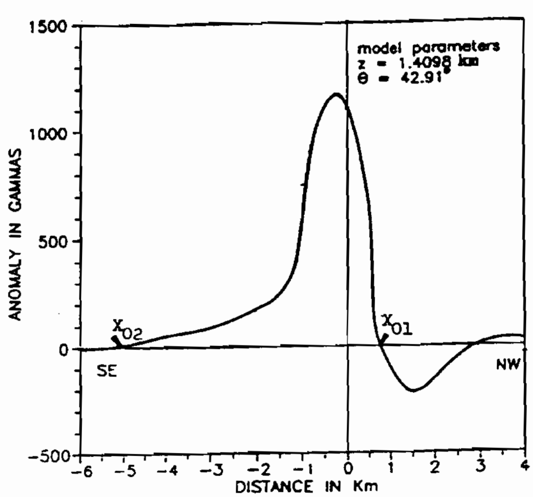


**Fig. 3.** Vertical magnetic anomaly profile over a spherical feature in the Bankura area, west Bengal, India (Verma and Bandopadhyay 1975).

**Table 4.** Comparative results.

| Parameters | Using Verma and Bandopadhyay method (1975) | Using Rao *et al.* method (1975) | Using Prakasa Rao and Subrahmanyan method (1988) | Using present method |
|---|---|---|---|---|
| $z$ | 1.32 km | 1.32 km | 1.52 km | 1.41 km |
| $\theta$ | Induction | 40° | 39° | 43° |

## THEORETICAL EXAMPLES

The parameters of four theoretical models are given in Table 3. The magnetic anomalies are generated from Eqn (1) with a station separation of 1 depth unit. In each case, a search algorithm is used to determine $x_{01}$ and $x_{02}$ values using a simple linear interpolation technique between the observed values (Davis 1973). From $x_{01}$ and $x_{02}$, the depth is obtained using Eqn (4), and $\theta$ and $K$ values then obtained using Eqn (2) and (5), respectively. In this way the parameters are evaluated and given also in Table 3, for comparison. It is clear from Table 3 that the amplitude factor ($K$) for the synthetic data with and without random error for models 1 and 2 show great deviation from the assumed parameters than the two other models. This may indicate that this method applies with better accuracy for sources at relatively greater depths.

## FIELD EXAMPLE

Figure 3 shows a vertical magnetic anomaly profile from Bankura area, west Bengal, India (Verma & Bandopadhyay 1975). It represents a vertical anomaly due to a spherical mass of gabbroic composition. The principal profile shown in Fig. 3 has the dominant positive to the south. The positive zero anomaly value distance ($x_{01}$) is 0.75 km to the northwest and the negative zero anomaly value distance ($x_{02}$) is −5.3 km to the southeast. Using these values, Eqn (4) yields $z = 1.41$ km, and from Eqn (2) and (5), we obtain $\theta = 43°$, and $K = 2264\,\gamma/\text{km}^3$, respectively. The estimated depth value is found to be generally in good agreement with the results obtained by different authors (Table 4).

## CONCLUSION

The present method is very simple to execute. The problem of depth determination of a buried structure from magnetic data is transformed into the problem of finding the zero-anomaly distances from the observed data. When using theoretical data with and without random errors and field data, the model parameters are found to be in good agreement with the actual parameters.

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# طريقة سريعة لتعيين العمق لأجسام هندسية بسيطة من الشذات المغناطيسية

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## الخلاصة

نقدم في هذا البحث طريقة سريعة لإيجاد العمق للتراكيب الجيولوجية المدفونة تحت سطح الارض من الشذات المغناطيسية وقد تم تحويل مشكلة تعيين العمق الى ايجاد المسافات الموجبة السالبة من بيانات الشذات المغناطيسية التي تصل فيه قيمة الشاذة الى صفر وقد أمكن اعطاء معادلة لجميع المركبات (الرأسية والأفقية والكلية) لجسم اسطواني أفقي والمركبات الرأسية والأفقية للكرة، ثم أعطيت طرق أيضا لتعيين الميل المغناطيسي والعزم المغناطيسي لجميع التراكيب الجيولوجية.

تم تطبيق الطريقة على نماذج نظرية ذات أعماق وميل مغناطيسي مختلف وعزم مغناطيسي ثابت بها خطأ عشوائي بنسبة ١٠٪ وبدون خطأ عشوائي ووجد في جميع الحالات المدروسة أن نسبة الخطأ في تقدير الأعماق والميل المغناطيسي والعزم المغناطيسي في حدود ١٠٪.

كما تم تطبيق الطريقة على مثال حقلي من منطقة بنكورا غرب البنغال بالهند ووجد أن العمق والميل المغناطيسي لخام جيولوجي والمقدر بالطريقة الجديدة يتفقان مع النتائج التي توصل اليها العديد من العلماء السابقين.