Predictive Profiling. The 5-Point Method of Interpretation (Magnetic Gradients)

Ronald Green

Department of Geophysics,
University of New England,
Armidale, NSW 2351 Australia

The combination of a high precision, direct reading, digital, magnetic gradiometer with a hand-held, programmable calculator enables continuous processing of the magnetic data to be carried out in the field. Furthermore, using a development of a method originally introduced by Werner (1953) it is possible now to predict a contact that is being approached as progress is made along the survey-profile. The prediction of the position of a geological contact allows for detailed examination to be made when the contact is reached. The method is referred to as 'predictive profiling'.

Introduction

Improved methods of interpretation of magnetic data can be carried out with the increased availability and convenience of access to computational facilities. As an example, Ianas, Hannich and Sava (1977) in an excellent paper have presented a method involving the Hilbert Transform of the horizontal derivative of the total magnetic field which locates the position and depth of geological contacts. Nevertheless, the method, as described by Ianas *et al* (1977) assumes that the data is collected in the field, and subsequently the data is processed by computer in the office, and an interpretation is then made (Green and Stanley, 1975).

The ready availability of small but computationally powerful hand-held programmable calculators, now makes feasible data reduction procedures in the field, which were not possible prior to the introduction of the calculator.

In 1953, Werner developed the four-point method of interpreting the horizontal gradient of the magnetic field. At that time, the horizontal gradient had to be obtained by taking the difference between the total field measured at two closely spaced points. However, recent instrumental developments such as the VIW-2302 C2 portable Cesium gradiometer enable the gradient to be measured directly and accurately (0.1 gamma/m). The hand-held calculator enables the computations to be carried out in the field and interpretation to be made on the spot in the field. When the field geophysicist uses this technique it can be described as 'predictive profiling'.

For the operators to be able to make a geophysical interpretation while operating in the field it is a great advantage compared with the system whereby the interpretation is made only after completing the day's field-work and returning to the base-camp. Predictive profiling enables additional careful investigations to be made of all contacts crossed by the traverse.

In this paper, Werner's (1953) method of profile inversion has been improved to remove the difficulty that arose from the interference caused to one anomaly by a second anomaly located closely by.

The field-data is interpreted by the method, in terms of the position, depth and angle of dip of each contact between rocks of differing susceptibility, in the survey area. In addition, a numerical value for the susceptibility contrast, and also the off-set of the base-value of the magnetic gradient is obtained. The off-set value is a reliable indication of any interference to the anomaly by a neighboring contact.

It is obvious that if the method accurately locates the position, depth, dip, and susceptibility of every contact, then a precise and reliable reconstruction of the geology can be made.

Theoretical foundation of the method

It is assumed that the horizontal gradient, $\Delta T_x(x)$ be measured directly by means of an instrument such as the Varian VIW 2302 C2 portable Cesium gradiometer. For a contact, striking at an angle λ where the depth to the contact is h, the angle of dip, d and the susceptibility contrast, k, it has been shown by Ianas *et al* (1977) (their eq. 3) that the horizontal gradient, $\Delta T_x(x)$) is given by:

$$F = 2kTc \sin.d \; [h \sin \phi + x\cos \phi] \; (h^2 + x^2) \ldots\ldots (1)$$

where

$c = (1 - \cos^2 I . \cos^2 \lambda)$

I = inclination of the geomagnetic field (positive downwards)

T = total geomagnetic field

x_0 = distance along the profile

$\phi = (d - 2b)$

b = arctan (tan I/sin λ)

f = arbitrary origin for F

k = 2kTc

Consequently, equation (1) becomes (Bosum, 1968):

$$F - f = K\,[(h \sin \phi + (x - x_0) \cos \phi] \,/\, (h^2 + (x - x_0)^2 \ldots \quad (2)$$

which may be written as:

$$\begin{aligned} Fx^2 = {} & F\,x\,.\,(+2x_0) \\ & + F\,.\,(-x_0 2 - h^2) \\ & + x^2\,.\,(+f) \\ & + x\,.\,(-2x_0 f + K \cos \phi) \\ & + 1\,.\,(+f\,(x_0^2 + h^2) + Kh \sin \phi - Kx_0 \cos \phi \quad \ldots\ldots\ldots (3) \end{aligned}$$

It is assumed that F is measured at five points, $x_1, \ldots, x_5$. Thus (x_i, F_i); i = 1, . . ., 5, are known.

Equation (3) can be written in the predictive matrix form:

$$\begin{bmatrix} F_1x_1^2 \\ F_2x_2^2 \\ F_3x_3^2 \\ F_4x_4^2 \\ F_5x_5^2 \end{bmatrix} = \begin{bmatrix} F_1x_1 & F_1 & x_1^2 & x_1 & 1 \\ F_2x_2 & F_2 & x_2^2 & x_2 & 1 \\ F_3x_3 & F_3 & x_3^2 & x_3 & 1 \\ F_4x_4 & F_4 & x_4^2 & x_4 & 1 \\ F_5x_5 & F_5 & x_5^2 & x_5 & 1 \end{bmatrix} * \begin{bmatrix} +2\,x_0 \\ -(x_0^2 + h^2) \\ +f \\ -(2x_0 f + K \cos \phi) \\ +f\,(x_0 + h^2) + Kh \sin - K\,x_0 \cos \phi \end{bmatrix} \ldots\ldots\ldots (4)$$

If the measurements are made at equally spaced distances along the profile, considerable simplification results in the subsequent computations. If the spacing is taken as unit distance and the arbitrary origin of the profile distance be taken from the centre point of the 5 measurements (see Fig. 1) then equation 4, can be written as:

$$\begin{bmatrix} 4F_1 \\ F_2 \\ O \\ F_4 \\ 4F_5 \end{bmatrix} = \begin{bmatrix} 2F_1 & F_1 & 4 & 2 & 1 \\ F_2 & F_2 & 1 & 1 & 1 \\ O & F_3 & O & O & 1 \\ -F_4 & F_4 & 1 & -1 & 1 \\ -2F_5 & F_5 & 4 & -2 & 1 \end{bmatrix} * \begin{bmatrix} +2x_0 \\ -(x_0^2 + h^2) \\ +f \\ -(2x_0 + k \cos \phi) \\ +f(x_0^2 + h^2) + Kh \sin - Kx_0 \cos \phi \end{bmatrix} \ldots (5)$$

All the elements in the 5 x 5 matrix are known and in its simplified form of equation (5) its inverse is readily found on a hand-held calculator. The column vector, $F_i x_i^2$ is also known and hence the five elements of the column vector on the right-hand side of matrix equation 5 are obtained.

- x_0 is the distance to the contact from the centre of the 5 evenly spaced measurements;
- h the depth to the contact;
- f the off-set of the zero field of the anomaly in $\Delta T_x(x) = F$.

Remembering that

$K = 2kTc \sin d$,

and $\phi = d - 2b$,

the geological dip of the contact, d, and the susceptibility contrast, k, are found. Care should be taken to remember that we have adopted the convention that unit distance is the spacing between the measurements along the profile. As a result, the depths and the susceptibility will be modified. Because K is the susceptibility contrast, its value will be positive at one contact and negative at the other contact when a dyke is crossed.

It should also be noted that the value of the determinant in equation (5) is an indicator of the reliability of the solution of the matrix equation (5).

It should be noted also that a gradiometer such as the Varian VIW 2302 C2 gradiometer can be used to measure directly both the horizontal and vertical gradients. Having both types of anomalies, facilitates the interpretation of the data (Jung, 1953).

Advantages of the 5-point method

Many methods of interpreting magnetic data assume knowledge of the position of the zero-line (Jung, 1953; Bruckshaw *et al*, 1963; Stanley, 1977). If an error is made in assigning a value to the position of the base line then an error in the interpretation results. One attractive feature of the 5-point method is that the value of the position of the base-line is found independently.

The method of 'simplified characteristics' (Moo, 1965) requires the accurate positioning along the profile of the maximum and the minimum of the anomaly. Accurate positioning requires a closer density of stations to be measured in the vicinity of the maximum and the minimum. With the 5-point method the location of the turning points is not required.

The very popular method of Koulomzine *et al* (1970) requires detailed and closely spaced observations in the vicinity of each anomaly. The 5-point method will *predict* the position of a contact before the maximum and minimum associated with the contact have been crossed.

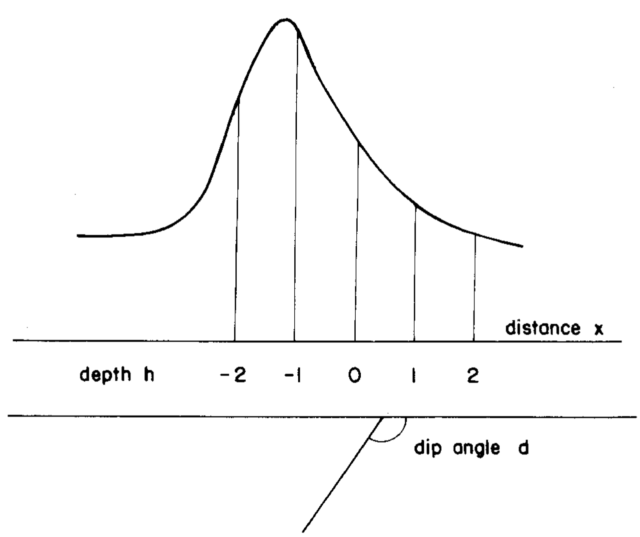


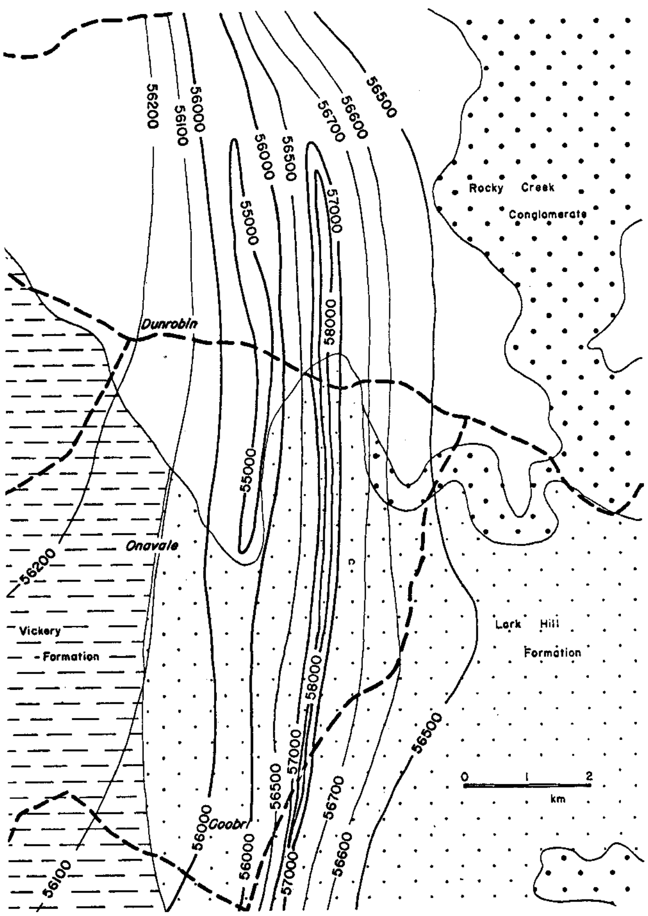
FIGURE 1

Five points of measurements along the profile x. The value of x_0 obtained from the solution of the matrix equation (5) gives the distance to the geological contact measured from the centrally placed station of the five station values used in the method of interpretation.

TABLE 1

Distance to contacts		Depths		Dip	
22	957	17	11	28	26
45	955	13	13	4	7
49	959	16	16	14	16
50	960	14	14	23	26
52	962	16	16	39	40
55	963	12	12	43	46
54	963	11	11	28	29

Predictive profiling giving the position of contacts. It can be seen that the dyke is 910 m in thickness.



Furthermore, for every additional measurement after the initial five measurements have been made an additional prediction about the position of the contact will be made.

It is worth reiterating that the greatest advantage of the method for a field-survey party is, perhaps, the ability of the measurement of 5-points to predict the presence of a concealed contact between two rock-types before the survey has crossed the contact. This opens up the opportunity for a detailed geological inspection to be made when the contact is actually arrived at.

The result is not only efficient geophysical field-work but an improvement in the accompanying geological work. The method of 'predictive profiling' has been applied to a simple anomaly on the Dunrobin road. The thickness of the dyke-like body is shown to be 910 m.

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