methods available to farmers and agricultural scientists will assist in the future control of salinity problems.

Acknowledgements

The authors wish to thank Tesla–10 for assistance with data processing and the technical staff of the Department of Agriculture and Geological Survey for their invaluable work in the field.

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A NEW FORMULATION OF THE MAGNETIC RELIEF PROBLEM

C. Z. Tarlowski and I. Koch

Introduction

An accurate estimate of the depth to the crystalline basement in sedimentary basins is of great importance for mining and oil exploration.

Many methods are available for estimating the depth to basement rocks from airborne magnetic observations. The three main approaches commonly used are spectral analysis, error minimisation between the measured field and the field calculated from simple geometric reliefs and finally the more heuristic methods of characteristics. All these methods implicitly assume that the basement rocks have a flat surface.

Direct two-dimensional structure calculations were carried out a few decades ago; Peters (1949) derived an integral equation for the vertical component of the magnetic field in terms of the topography of the basement. However, there was an error in his analysis, which does not seem to have been corrected in the literature.

More recent research has been devoted to this problem again, but most of these efforts are concerned with specific geometries and are often stated in terms of magnetic potential as the latter simplifies the mathematical analysis. Unfortunately, the potential is not measured directly, which poses the question of how to apply such an analysis to real magnetic data.

In contrast to these efforts, we are interested in the general three-dimensional inverse problem of recovering the relief of basement from measurements of the magnetic field. As a first step towards this goal, we present a formulation of the general 3-D problem that has to be solved in realistic situations. We also discuss possible approximations to the 3-D problem in order to obtain numerically more tractable solutions to the relief equation.

The Relief Equation

We are interested in variations in magnetic field which result from the topography of crystalline basement. For most basement rocks the magnetization I can be regarded to be uniform and parallel to the inducing field. Under these assumptions, a relationship between the magnetic field and the relief function describing the topography of crystalline rocks, can be represented by the following equation (see Fig. 1 for notation and a description of co-ordinate system):

$$\overline{H}(x,y,0) = -\int_\sigma (I_\alpha f_\alpha + I_\beta f_\beta - I_\gamma) \times \frac{(x-\alpha, y-\beta, -(h+f(\alpha,\beta)))\,d\alpha d\beta}{[(x-\alpha)^2 + (y-\beta)^2 + (h+f(\alpha,\beta))^2]^{3/2}} \qquad (1)$$

where:

$\overline{H}(x,y,0)$	- magnetic field at point $(x,y,0)$,
$(I_\alpha, I_\beta, I_\gamma)$	- components of the magnetisation vector at point (α,β,γ),
h	- the average depth from the plane $Z=0$ to the basement,
$f(\alpha,\beta)$	- the deviation of the relief function from h,
$f_\alpha = \frac{\partial f}{\partial \alpha}, f_\beta = \frac{\partial f}{\partial \beta}$	- partial derivatives of f,
σ	- the surface described by the equation $\gamma(\alpha,\beta) = h + f(\alpha,\beta)$.

In this form, one can see that the magnetic field depends nonlinearly on the relief function f.

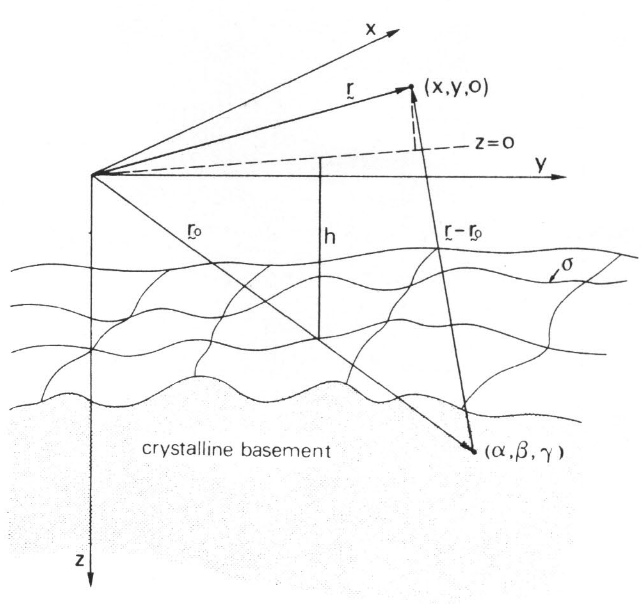

FIGURE 1
Description of basement rocks in 3-D.

The Two-dimensional Field Equation

Under the assumption that the magnetization in the y-direction is constant, the 2-D restriction of the relief equation becomes:

$$\overline{H}(x,0) = -2\int (I_\alpha f'(\alpha) - I_\gamma)\frac{(x-\alpha, h+f(\alpha))d\alpha}{(x-\alpha)^2+(h+f(\alpha))^2} \qquad (2)$$

However, for the 2-D case there is also an alternative derivation of the above equation which can be obtained by looking at the geometry of the problem (see Fig. 2).

If $d\overline{H}$ denotes the contribution of a line element *dl* of the curve *f*(α) to the magnetic field, then $d\overline{H}$ is given by:

$$d\overline{H}(x,0) = -2\int (I_\alpha \sin\theta - I_\gamma\cos\theta)\frac{(\cos\beta, \sin\beta)}{r-r_0}d\ell \qquad (3)$$

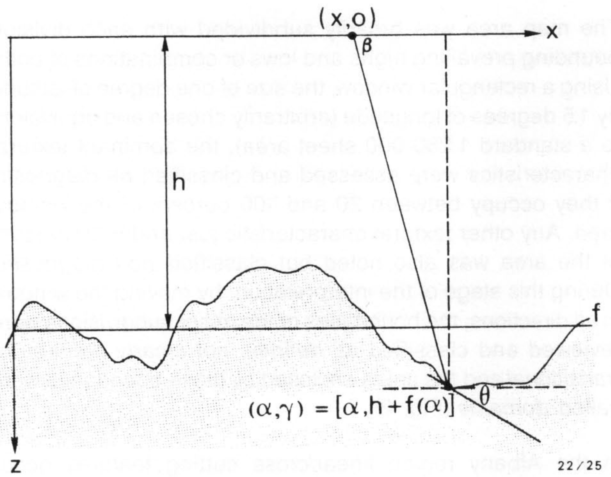

FIGURE 2
Geometrical representation of 2-D structure.

This is the approach which was adopted by Peters (1949). However, an inspection of Peters' formulation (see his equation (3) shows that his derivation is invalid. The mistake in Peters' analysis does not seem to have been corrected in the literature.

The Linear Relief Equation

Since the relief equation (1) is nonlinear, a solution will have to be found iteratively. This process is often difficult and expensive. For this reason, it is advantageous to derive a linear relief equation which approximates the original nonlinear equation and which is easier to solve.

A good approximation can be obtained if we assume that $|f(\alpha,\beta)| \ll h$. In this case we obtain the linear relief equation:

$$\overline{H}(x,y,0) \cong \int_\sigma (I_\alpha f_\alpha + I_\beta f_\beta - I_\gamma) \times \frac{(x-\alpha, y-\beta, -h)d\alpha d\beta}{[(x-\alpha)^2+(y-\beta)^2+h^2]^{3/2}} \qquad (4)$$

In many applications it is assumed the top surface of the magnetic rocks is flat and the underlying assumption is that changes in the magnetization cause the variations in the field.

In this case the general 3-D relief equation reduces to the equation:

$$\overline{H}(x,y,0) = \int_\sigma I_\gamma \frac{(x-\alpha, y-\beta, -h)d\alpha d\beta}{[(x-\alpha)^2+(y-\beta)^2+h^2]^{3/2}} \qquad (5)$$

If we recall that the magnetization I can be related to the inducing field by $\overline{I}(\alpha,\beta,\gamma) = k\overline{H}(\alpha,\beta,\gamma)$, where *k* denotes the magnetic susceptibility and is assumed to be constant in the area of interest, we obtain well known equation of the downward continuation of the magnetic field.

Discussion

We have noticed the relief equation is nonlinear in *f*. The inverse problem of calculating the relief function from the discrete measurements of the magnetic field *H* is therefore not straightward. Even the linearised field equation is unstable and ill-posed.

Finding a solution to the downward continuation problem has become an area of active research and many different techniques are being applied. These include Wiener fittering (see Chittineni (1984), matrix perturbation methods (see Silva and Hohmann (1984)), Gilbert — Backus techniques (see Huestis and Parker (1979)) and direct surface smoothing techniques (see Koch and Anderssen (1984)).

Because of the mathematical similarity between the downward continuation problem and the linear relief equation it is hoped that any method which achieves good results for downward continuation of the magnetic field will also produce good approximations to the gradients f_α and f_ζ of the relief function. For some applications this information about the relief function suffices. In other cases, the relief function can be found from a knowledge of the average depth *h* and the gradients f_α and f_ζ.

Summing up, the explicit formulation of the magnetic relief problem presented here represents a new approach to depth estimation from magnetic observations. Future work which provides numerical solutions should prove of great value to mineral and oil exploration.

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A SYSTEMATIC VISUAL APPROACH TO INTERPRETATION OF AEROMAGNETIC TOTAL INTENSITY ANOMALY PIXEL MAPS AT 1:1 000 000 SCALE

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Introduction

Although aeromagnetic surveys continue to play a prominent role in mineral exploration, the interpretation of aeromagnetic data (Paterson & Reeves, 1985) has been influenced by the geology and the ore occurrences of a given region. Magnetic interpretation maps should not be constrained to resemble maps of the existing geology (Grant 1984/85a, Chandler, 1985).

A considerable amount of regional aeromagnetic data has been accumulated in Australia by government agencies and exploration companies. The survey data have not been adequately and systematically processed and analysed and subdued magnetic variations have mostly been neglected.

Following the lead of the Geological Survey of Canada (Teskey *et al.* 1982), the Bureau of Mineral Resources (BMR) has engaged in the time consuming and costly process of assembling very large area high quality pixel maps, the most advanced elaboration of aeromagnetic data to date, on a regional scale (Tucker *et al.* 1985a). While laboratory study of magnetic properties of rocks is proceeding to unravel magnetic processes as summarised by McIntyre (1980) and Grant (1984/85b), a non selective systematic analysis of all magnetic data was undertaken with specific careful reference to the subdued magnetic features independently and uncontaminated by premature speculative geological constraints.

Magnetic anomalies in between the obvious features correlated with known geology were carefully studied to gather new information taking maximum advantage of the TMI pixel map presentation and at the same time devising a suitable way to display it.

A region can be subdivided and regional features of interest can be identified and presented in a map form with a very flexible standard legend, which incorporates relevant characteristics in set combinations and permutations.

Magnetic Domains Model Procedure

The aeromagnetic total intensity anomaly grey-scaled pixel maps display the dynamic range of magnetic data and use the ability of the eye to recognise subtle patterns.

A representative model has been devised with a flexible legend suitable for analysis of these pixel maps. A minor modification will be needed to accommodate gradient and colour pixel maps. The example used in this paper is the Albany 1:1 000 000 sheet (Tucker and D'Addario 1986; D'Addario and Tucker 1986).

The Albany grey-scaled pixel map (Tucker *et al.* 1985) was analysed at 1:1 000 000 scale on its own merit, without any input from the available literature, and without geological control, trying to avoid any possible bias (Fig. 1).

The approach is visual and the map was observed and studied to focus and detect peculiar specific patterns. These patterns were identified as *textural characteristics.* They have a certain range of anomaly width and are unevenly distributed throughout the map.

The map area was broadly subdivided with each division bounding prevailing highs and lows or combinations of both. Using a rectangular window, the size of one degree of latitude by 1.5 degrees of longitude (arbitrarily chosen and equivalent to a standard 1:250 000 sheet area), the dominant textural characteristics were assessed and classified as *diagnostic* if they occupy between 20 and 100 percent of the window area. Any other textural characteristic just under 20 percent of the area was also noted but classified *non diagnostic.* During this stage of the interpretation, by moving the window in all directions, the boundaries of the major subdivisions were reviewed and classified as *definite, not clearly defined,* or *transitional* and the areas enclosed by those boundaries were called *domains* (Fig. 2).

In the Albany region linear/cross cutting features occur throughout the region and their visual impact tends to overshadow the other features, although they do not occupy 20 percent of any particular area. Circular/elliptical closed areas are noted in five of the eight domains but they do not define any domain and therefore, like linear/cross cutting, are considered non diagnostic by definition.

The legend was constructed in the form of a table where domains are defined by their main textural characteristics (Fig. 3).

Some non-diagnostic textures, including those widespread but less than 20 percent of each area, could be quite relevant to the determination of specific targets, e.g. for regional exploration, detailed exploration or drilling. It is significant that, by excluding two features so important to exploration, namely the *circular/elliptical closed areas* and *linear/cross cutting* the emphasis is mainly shifted towards other features and these are the features which define each domain in the model.

Textural characteristics have tentatively and individually been associated with specific geological and structural features according to conventional geophysical interpretation only after the legend was completed.