PART I

A CRITICAL REVIEW OF THE INTERPRETATION METHODS OF MAGNETOSTATIC AND GRAVITATIONAL FIELDS

1. Introduction

In the theory of interpretation, the magnetostatic and the gravity methods may be conveniently classed together, because both utilise natural Newtonian potential fields. As a matter of fact, it is possible, under certain conditions, to compute one field when the other is given (vide section I-6). In detail, however, the magnetic map usually exhibits more complexities due to its bipolar nature. Magnetic anomalies are not only shifted* in position by unpredictable amounts relative to the source structure, but their shapes and sizes also vary between wide limits depending on the location, orientation and other factors. Figure 1 illustrates the variation in the nature of magnetic anomalies due to an infinitely long symmetrical ridge with a vertical angle 90 degrees and striking east-west under various inclinations of the inducing field**. Conditions are further aggravated

*However, see section I-6.

**An approximate formula for the vertical magnetic anomaly is

$$Z = \frac{\sigma_1}{\sqrt{2}} \log \frac{(x-a)^2+1}{x^2+(1-a)^2} + \sqrt{2}\,\sigma_1 \arctan \frac{a(x-a+1)}{x^2+1-a(x+1)} + \frac{\sigma_2}{\sqrt{2}} \log \frac{(x+a)^2+1}{x^2+(1-a)^2}$$
$$- \sqrt{2}\,\sigma_2 \arctan \frac{a(x+a-1)}{x^2+1+a(x-1)} - 2\sigma_3 \arctan \frac{2a}{x^2-a^2+1} ,$$

where distances are in units of the depth to the flat surface, 'a' is the depth to the top of ridge, 'x' is the horizontal distance from the top of ridge and σ_1, σ_2 & σ_3 are the induced surface polarities.

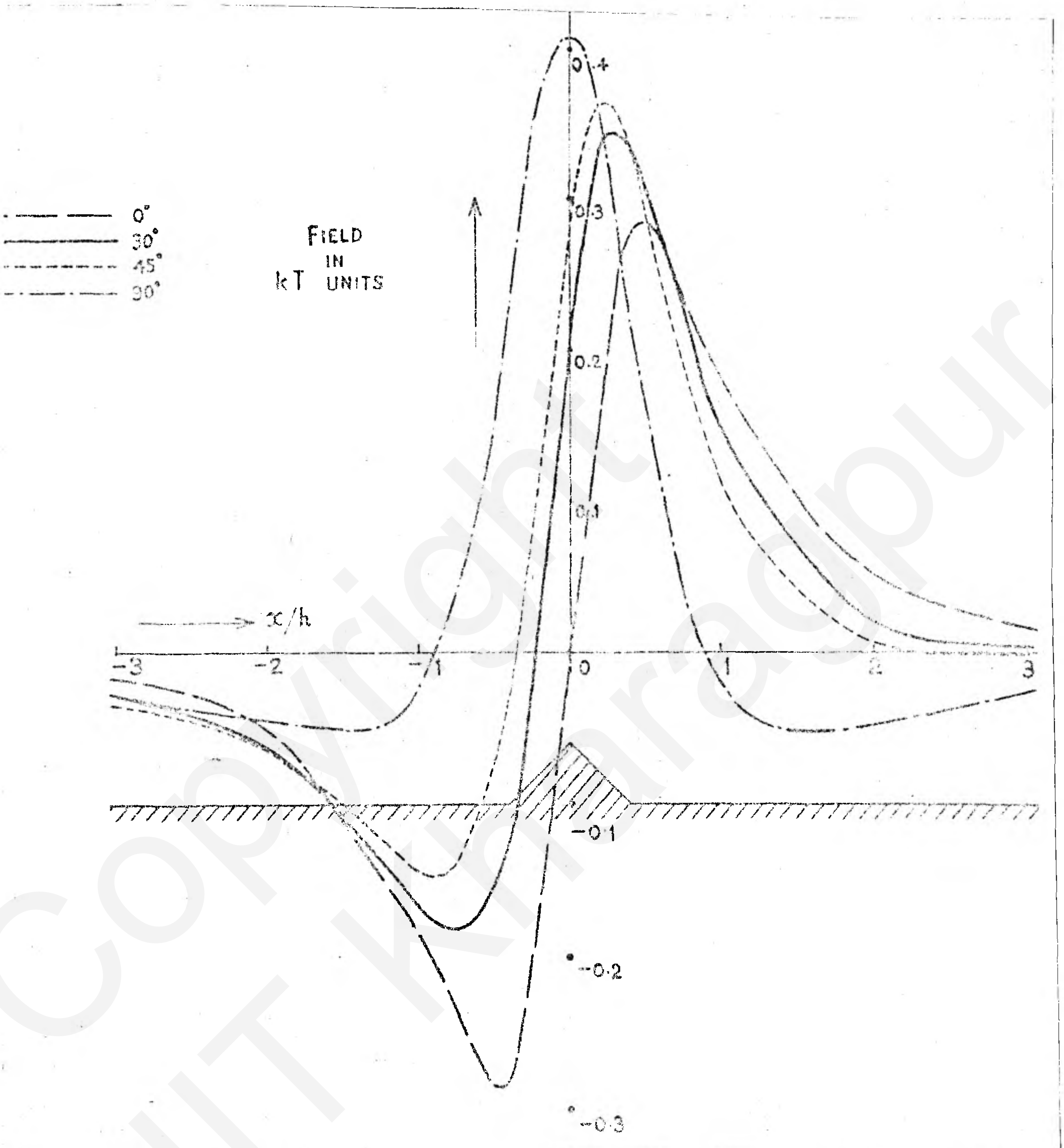

Fig. 1. A two-dimensional triangular basement ridge striking east-west has a 90 degree included angle at the apex and a height equal to 0.4 times the depth of the base. Figure illustrates variation in shape, size and position of vertical magnetic anomaly for the ridge at northern latitudes corresponding to magnetic inclinations 0°, 30°, 45°, and 90°, 'T' is the magnitude of the inducing terrestrial magnetic field and 'k' the susceptibility contrast.

in practice by assymmetry, presence of remanent magnetisation, non-eastwest alignment, etc. It is even possible to think of a situation when such a ridge will not produce any magnetic anomaly at all. Except in very high latitudes, the interpretation of a magnetic picture in oil exploration may need a great deal of caution and tact in order not to be misleading. On the other hand, the highs and the lows of a properly resolved gravity map are directly above the density excesses and deficiencies, and their characters are dependent only on the size and shape of the source bodies, not on their location, orientation, etc. Considering along with these the fact that the gravity maps will reveal all the anomalies detectable by magnetic surveys, and more, it appears that ground magnetic surveys are generally unnecessary in Oil Geophysics. There may be special cases, however, where a combined magnetic and gravity analysis may be desirable (vide section I-6).

The above remark may seem to be in apparent contradiction to the (currently accepted) wide use of Aeromagnetic surveys as a tool of rapid reconnaissance. This is because of the fact that gravity surveys from air are not possible (Muffly 1946). It does not seem difficult to predict (Roy 1958b) that, should anything like an aero-gravity survey develop, aero-magnetic surveys for oil exploration are going to go out of date. Such days may not be very far, because the design of air-gravity instrumentation based on gradient measurements (not gravity itself) is already receiving a good deal of attention, (Lundberg 1956). It may be of interest to note in passing that areas barren of aeromagnetic anomalies are not necessarily barren of oil interest. Aeromagnetic anomalies are usually due to undulations on the basement surface, which might have induced the formation of desirable structures in the overlying sediments. But it is possible to imagine sedimentary structures unrelated to basement relief, and also stratigraphic traps, which will produce little or no magnetic anomaly. There is no reason to believe that the structural traps originating from basement topography are more abundant than the other two types mentioned. On the contrary, no less a person than A.I.Levorsen writes (1956): "If 75 per cent of the oil is stratigraphic, we have been wasting a lot of effort. At least 75 per cent or more of our (i.e. U.S.A.) efforts has been in search for structural traps". Generally speaking, therefore, magnetic surveys from air will locate not more than one-third of the total number of oil traps (Roy op.cit.)

Conditions are reverse in Mining Geophysics. Here the gravity method is less readily applicable, because the order of anomalies created even by large-size ore-bodies are quite small. For example, a vertical vein, exposed at the surface, 30 feet wide, extending infinitely in the strike and depth directions and having a density contrast of unity, would give rise to a maximum anomaly of only about 0.4 milligals (equivalent to 4×10^{-4} cms/sec/sec. anomalous acceleration). In general, the anomalies are even less and often comparable in magnitude with the noise background. Besides, the various corrections become important and difficult to evaluate. In contrast, the magnetic effects of ore-bodies, when present, may be quite high and diagnostic. The quantitative interpretation of magnetic anomalies in mining problems are easier because, very often, ore-bodies can be approximated reasonably well (from known geology) by simple geometrical shapes (unlike oil geophysics). It remains valid, however, that, had there been a reliable gravity picture for mining problems (and there are some, vide Goetz 1958, Nettleton and Hastings 1945, Davis et el 1957, etc.), interpretation would have been still easier.