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# "How Deep Can My Magnetometer See?"

A common question when using magnetometers or gradiometers is, "How deep is my instrumentation seeing?" This *Magnetic Moment* provides some answers to this question while emphasizing quick analysis methods for depth estimation. The premise is that if the reader has a basic knowledge of depth estimation, they can then view their data to determine the answer to the key question posed above.

As noted in Sheriff, R. E., "the shape of a magnetic anomaly varies somewhat with magnetic latitude and also with the shape of the magnetic body, its attitude, its dimensions, its orientation with respect to magnetic north and especially, the shape of the magnetic body." This physical relationship (i.e. the depth relationship) has led to the development of a number of methods for estimating depth:

1. Maximum slope method for magnetic data
2. Peter's (Half-slope) method for magnetic data
3. Nomograms (estimation curves)
4. Total field method for gradiometer data
5. Euler deconvolution
6. Werner deconvolution
7. Modeling

The first four methods represent "quick analysis" or empirical methods; the last three are numerical.

## *Slope Method for Magnetic Data*

The basic concept of the slope method is to approximate the anomaly curve using a straight line whose slope is the maximum slope of the anomaly (see figure 1).

Therefore, if we divide the horizontal distance by an "index value" of 0.7 to 1.0, we arrive at an estimate for the depth that is accurate to within 25 per cent. Note that this index value increases with the width

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to depth ratios for the causitive body. Depth to the body is the depth to the upper surface.

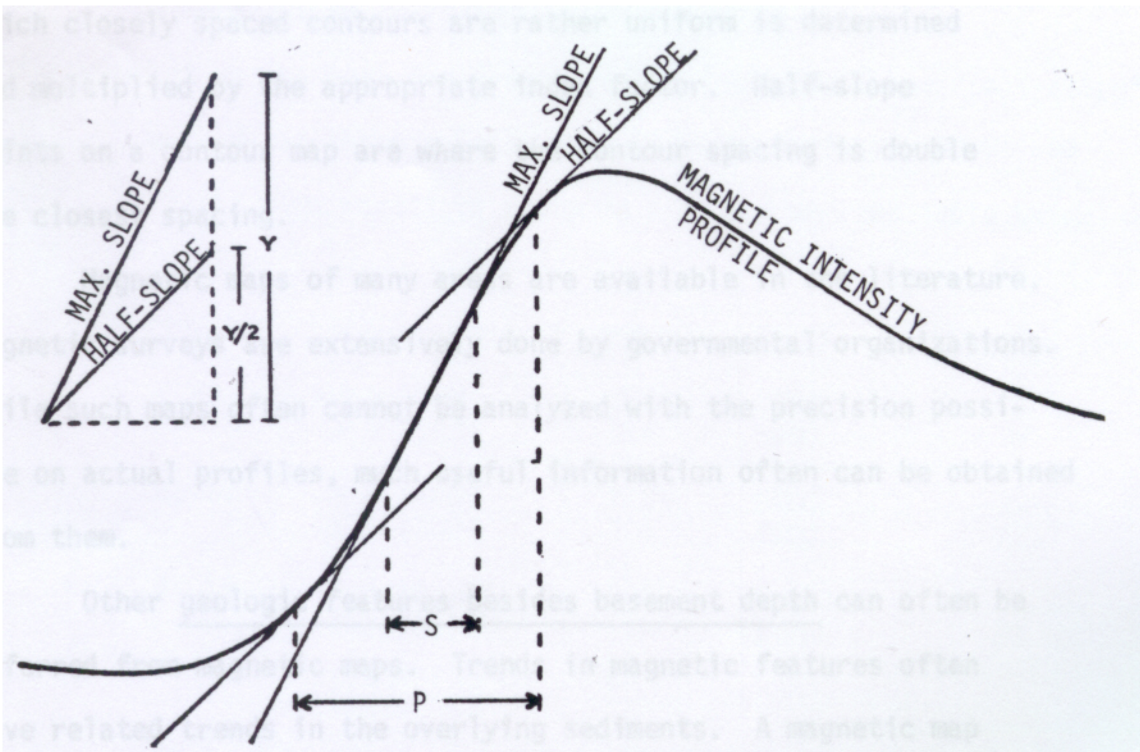


Figure 1: Derivation of values for Half-Slope and Peter's Methods. From Sheriff, R.

## *Peter's Method for Magnetic Data*

According to Sheriff, Peter's method is less subjective than the maximum slope method. Again, referring to figure 1, the approach is to determine two points; points at which lines with half the maximum slope are tangent to the magnetic profile.

Then, if we divide the horizontal distance by an "index value" of 1.2 to 2.0, we obtain an estimate for the depth to the body. Note that this index value increases with the width to depth ratios for the causitive body. Depth to the body is the depth to the upper surface.

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## *Nomograms*

Historically, magnetic interpretation has relied on a variety of interpretation curves (particularly prior to the last twenty years). These curves are still valid although they are likely currently being replaced by numerical methods in many instances. Still, they provide a reasonable first-pass depth estimate and are considered here for compeleteness.

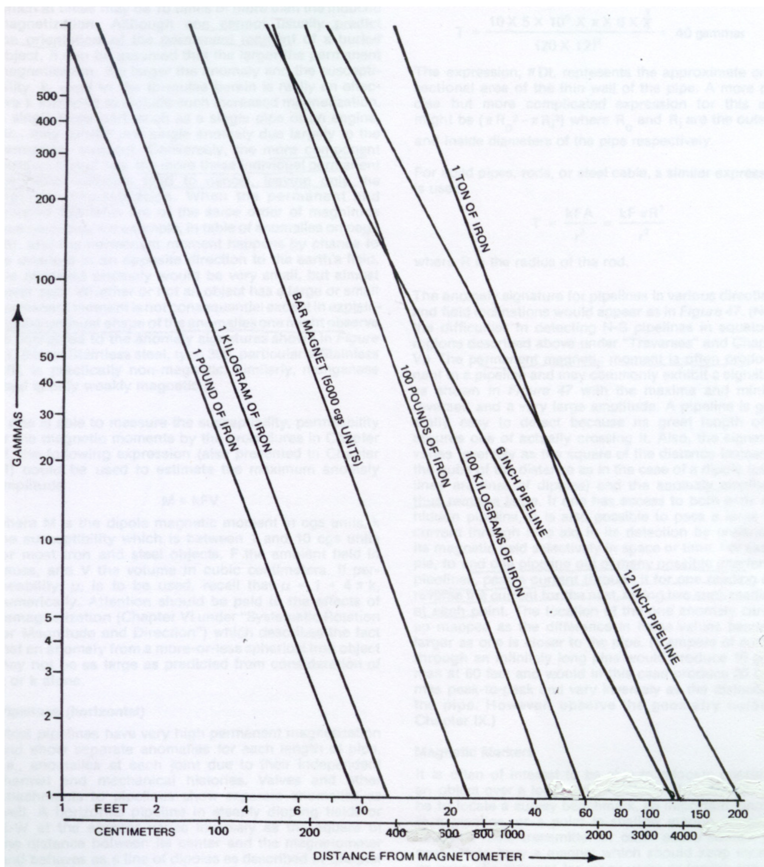


Figure 2: Depth Estimation Using Nomograms. From Breiner, S.

To estimate depth using the curve, first select a model for the target that you believe to be represented in the data. Then, find the value of the anomaly (maxiumum) corresponding to the target. Draw a horizontal line to intersect the model line and then extend this line vertically downward to intersect with the abscissa (bottom line). You can then read the depth directly.

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### *Total Field Method for Gradiometer Data*

Assuming a dipolar source, the expression for depth is:

r = - 3T / (DT/dr)

where r is the depth, T is the magnetic field and DT/dr is the vertical gradient.

Thus, to estimate depth, you require only to find the value of T, its corresponding gradient and then you can calculate depth.

Similarly, for a monopole, the expression is:

r = -2T / (DT/dr)

The general form is:

r = -nT / (DT/dr)

where n is a shape factor that determines the fall off of an anomaly with distance. For example, a line of monopoles (i.e. the top of a a linear body extending to depth) and a horizontal semi-infinite sheet have shape factors of 1 and 0, respectively. In practice, shape factors are typically non-integers.

### *Semi-Automated Methods*

So-called semi-automated interpretation methods (here focused on Werner deconvolution and the Euler method) use the approach of pre-definition of simple geometric form with constant physical parameters or estimate position of singularities of anomalous field, which are connected with typical geometrical points of anomalous bodies.

They are called semi-automated since the interpreter has control over various parameters, including size of moving "calculation" windows, etc. Various computer programs are available to provide this level of functionality.

### Werner Deconvolution

As noted by Northwest Geophysical Associates, Inc., "Werner Deconvolution is used to determine the depth to source bodies along a magnetic profile and is based on the popular Werner Deconvolution technique (Werner, 1953; Ku & Sharp, 1983)."

Werner Deconvolution assumes the source bodies are either dikes or contacts with infinite depth extent and uses a least-squares approach to solve for the source body parameters in a series of moving windows along the profile. The user specifies both the range of window sizes and the increments between window placements, thereby maximizing solution accuracy.

### Euler Deconvolution

As noted by Reid, "Euler deconvolution has come into wide use as an aid to interpreting profile or gridded magnetic survey data. It provides automatic estimates of source location and depth. In doing this, it uses a structural index (SI) to characterize families of source types.

The structural index can be interpreted as the exponent in a power law expressing the fall-off of field strength versus distance from the source. For magnetic data, SI range from 0 to 3."

## *Modeling*

There are, in fact, two forms of modeling available for magnetic data … forward modeling and inverse modeling, and a corresponding variety of commercial software programs for generating these.

In general, forward models are used with a variety of pre-defined parameters and generate an anomaly of a specific shape and amplitude (i.e. the expected survey response). Forward models can be devised that vary the depth parameter; the resulting affect on the anomaly can be used to verify that depth estimates are reasonable.

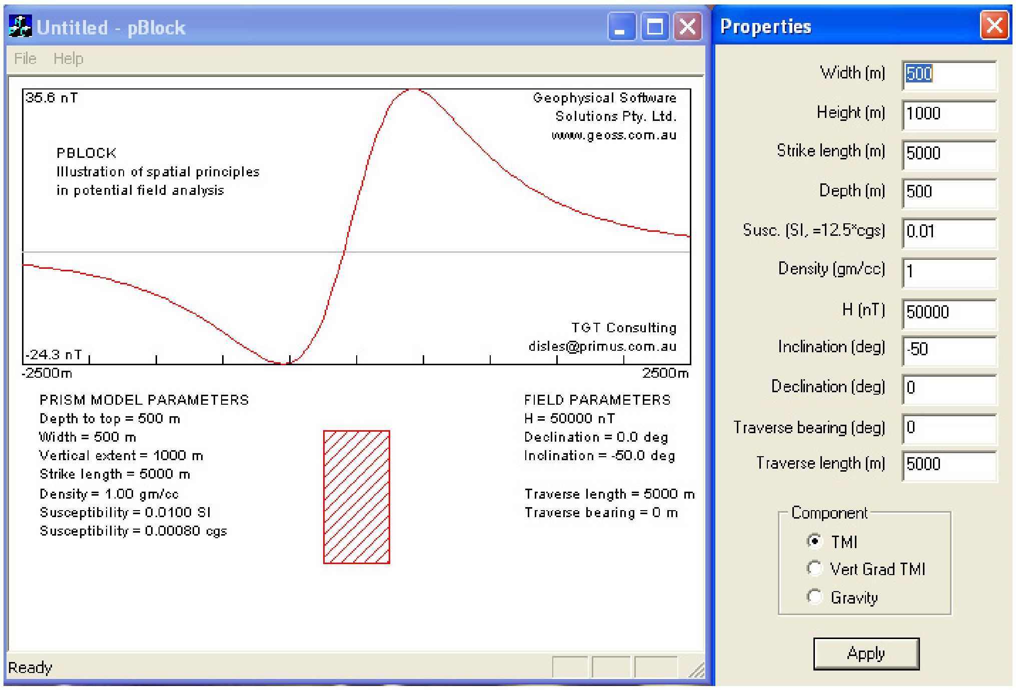


Figure 3: Forward model generated using a block model. Generated using pBlock from Geophysical Software Solutions.

Inverse models are generally focused on obtaining a specific parameter, such as depth, directly. Survey data is required and is entered into the modeling program. After a number of iterations (i.e. determined by the routine logic), a value is returned for further plotting and interpretation.

## *Summary*

The question, "How Deep Can My Magnetometer See?" is a classic question in magnetics. Determining the answer to this question can be done using any of the seven methods described here (including both empirical and numerical approaches).

In general, it can be said that the depth of investigation is a function of the target size and shape; for near surface investigations, depth of investigation (as can be seen from the nomogram in Figure 2) varies from 0 to 55m depending on the quantity (i.e. size) of the buried source. A gradiometer will read much closer to surface, say, up to 5 to 10 m for a large source (ex. ton of iron). Generally, near surface gradiometer anomalies will have depths from 0 to 3m (i.e. assuming relatively small magnetic bodies).

Moreover, it is important to note that there is also typically information from deeper sources in the data as evidenced by longer wavelength anomalies. The corresonding sources can be from several hundred metres to 1000 metres or more, depending, as indicated before, on the "size" of the buried object or geologic horizon.

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