Magnetic Modelling – basic concepts

GeoVista AB, Håkan Mattsson (PhD in applied geophysics with speciality in magnetic properties of rocks)

Introduction

The earth is surrounded by a magnetic field, which is believed to be generated by electrical currents in the liquid part of the earth's core (Fowler, 1994). The shape of the earth magnetic field is very close to that of a bar magnet and the magnetic field lines are vertical close to the magnetic poles and horizontal close to the equator (Fowler, 1994). If no magnetic materials were present, as in vacuum, the magnetic flux density **B** is related to the magnetic field strength **H** according to: $\mathbf{B} = \mu_0\mathbf{H}$, where μ_0 is the magnetic permeability in vacuum (Parasnis, 1993). However, if there are magnetic materials present (such as for example iron bearing rocks), the magnetic contribution from these has to be added to the relation between **B** and **H**; hence the relation is: $\mathbf{B} = \mu_0 (\mathbf{H} + \mathbf{M})$, where the contribution from magnetic materials is $\mathbf{M} = \kappa\mathbf{H}$ (Nordling and Österman, 1987). The parameter "κ" is called magnetic susceptibility and describes the so called induced magnetization response from a material when subjected to an applied magnetic field (in this case the applied field equals the earth magnetic field). Some rocks may, apart from the induced magnetization, also carry a "permanent" magnetization, termed remanence. The remanent magnetization is similar to a standard magnet and can be described by a vector (Collinson, 1983). Hence, when a magnetic exploration survey is carried out, one measures the total magnetic field, which basically is a summation of the earth magnetic field and the contribution (induced and remanent magnetization) from magnetic rocks.

Basics of magnetic forwards modelling

Forward modelling has been a standard technique in several disciplines of geophysics for more than 30 years. There are several commercial software for magnetic forward modelling, e.g. IX2D (Interpex), ModelVision (Encom), MAG3D (UBC), Potent (GEOSS) and others. Magnetic rocks give rise to anomalies in the magnetic field, and the basic aim of forward magnetic modelling is to create models of the bedrock with specific geometries and magnetic properties (susceptibility and remanence) that give rise to a magnetic field similar to the measured field. The actual modelling procedure starts by visualizing a desired profile of measured magnetic data. In order to isolate the anomaly to be modelled the regional (background) magnetic field is estimated, generally by regression analysis. Thereafter a model body is constructed graphically and it is given magnetic properties. The program calculates the response from the model, and the response is compared with the measured data. The shape of the body and/or its magnetic properties is changed until the model response reasonably fits the measured data (expert judgement), see example in Figure 1. This is actually some kind of a guessing technique, but if there are supportive data in the form of geologically mapped boreholes and/or measurements of the magnetic properties on rock samples from the site, the model geometry and its susceptibility and remanence can be constrained. The latter is very important, and significantly improves the reliability of the geological model.

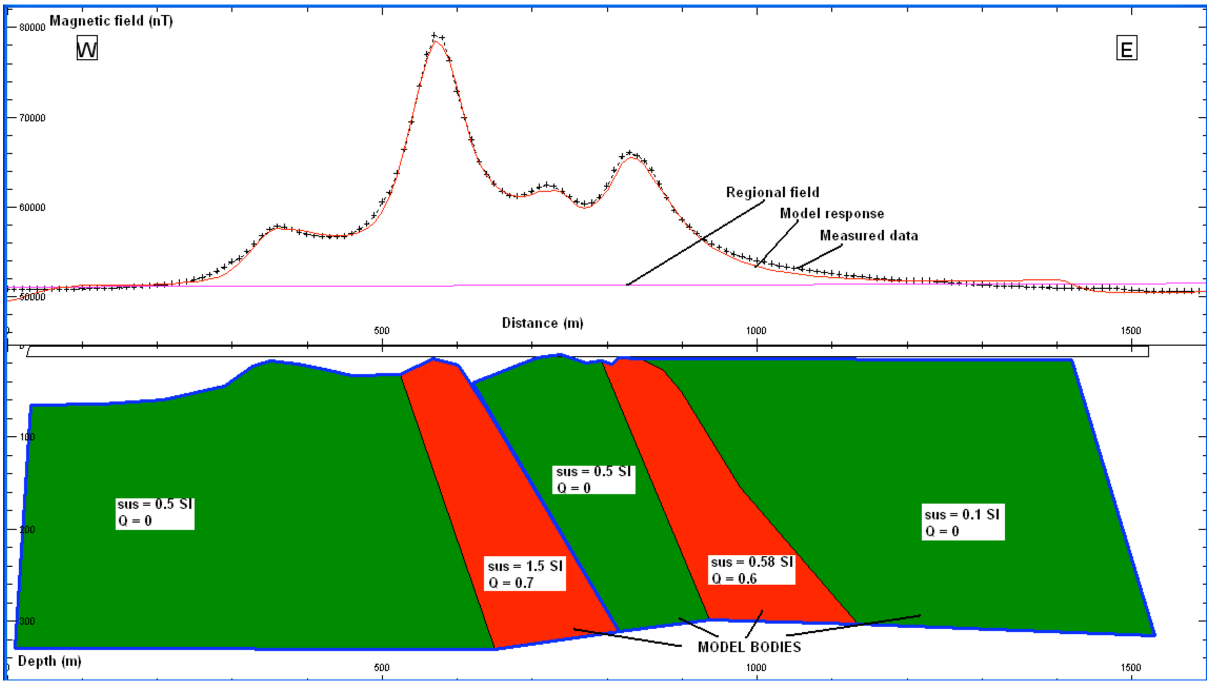

Figure 1. *Example of a magnetic forward model, vertical section. Red bodies show inferred magnetite mineralized rocks, with sus = magnetic susceptibility (SI unit) and Q = Königsberger ratio, it is the remanent magnetization intensity divided by the induced magnetization intensity.*

Estimation of Fe-content based on the magnetic susceptibility

The magnetic susceptibility of rocks is mainly governed by the amount of ferrimagnetic minerals, and magnetite is by far the most "powerful" mineral with a susceptibility of as much as 15 SI; most rocks have a magnetic susceptibility < 0.05 SI (Parasnis, 1993). Hence, in rocks with more than 1 vol% magnetite the susceptibility is directly related to the magnetite content, and vice versa. It is possible to show that there is a clear statistical correlation between the magnetic susceptibility and the magnetite content (for example Parasnis, 1993, Figure 2). If we "know" the magnetic susceptibility it is therefore possible, and simple, to get a rough, but fair, estimate of the vol% magnetite and hence also the weight% Fe of a model body (Fe content of magnetite is 72,4 weight%). Further, from the modelling work we get an estimate of the volume of the mineralized rock body, hence based on the above assumptions, and if we estimate the density of the rock matrix, it is also possible to estimate the total mass of Fe of the model body.

Uncertainties

The modelling of geophysical data is always impaired by uncertainties. In magnetic forward modelling it is basically assumed that we know the magnetic susceptibility distribution of the rock types. By applying more or less fixed values of the magnetic susceptibility, this parameter is held fixed, and the modelling is mainly carried out by varying the geometry of the model bodies. This procedure will never result in a unique or true geological solution. It is important to note that a small body with high susceptibility can cause the same type of anomaly as a larger body with lower susceptibility. Hence, the model may exaggerate the volumes of the bodies and underestimate the magnetite content, or vice versa.

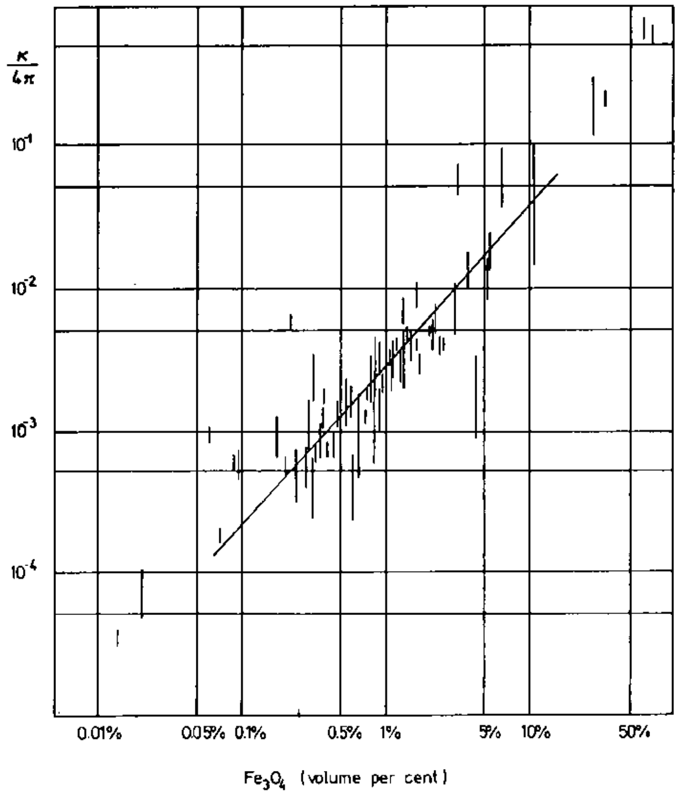

Figure 2. *Relation between the magnetic susceptibility and the magnetite content (the figure is copied from Parasnis, 1993)*

The strength of the magnetic field decreases significantly with distance from the source, the spatial resolution therefore decreases with depth and the majority of the information supporting the models inherits from the uppermost 10-50 m of the bedrock. It is therefore important to test how deep down below the ground surface, variations in the model geometry will give rise to significant effects on the magnetic anomalies being modelled.

In order to constrain a magnetic model and increase its geological reliability it is important to have knowledge of the magnetic properties of the rocks in the survey area, target rocks as well as surrounding rocks. Most important is the magnetic susceptibility and the natural remanent magnetization. It is also important to add as much independent information as possible regarding rock contacts and geological structures, for example from mapped cores from boreholes or geological surface mapping data.

The estimation of vol% magnetite based on magnetic susceptibility data depends on grain size, mode of distribution, susceptibility range, and it may also vary between different mineralizations. Hence, this estimation is a bit rough and should be taken with some caution.

References

Collinson, D.W., 1983. Methods in rock magnetism and paleomagnetism, Chapman and Hall, London, United Kingdom. 503 pp.

Fowler , C.M.R, 1994. The solid earth – an introduction to global geophysics. Cambridge University Press. 472 pp.

Nordling C. and Österman J., 1987. Physics handbook. Studentlitteratur. 431 pp

Parasnis, D.S., 1993. Principles of applied geophysics. Chapman and Hall. 429 pp.