Magnetic mentor

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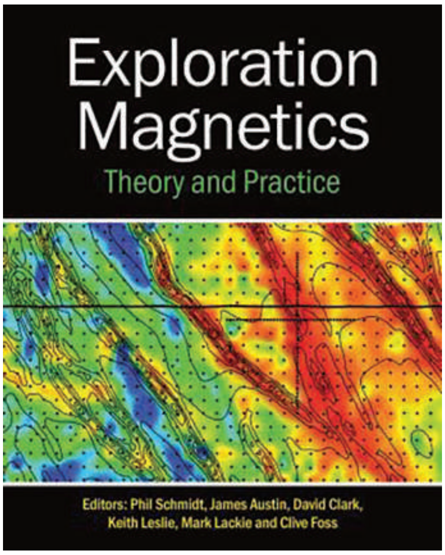
Review of *Exploration Magnetics Theory and Practice*



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The editors of this book, Phil Schmidt, James Austin, David Clark, Keith Leslie, Mark Lackie and Clive Foss are highly accomplished and well published authors. Collectively, they specialise in advanced magnetic theory, algorithm and instrumentation development, industry-funded research projects, magnetic petrophysics, applied projects, workshops, teaching and training. All are highly regarded at a global level for their contributions to our science. Clive is the lead author for all chapters and hence has taken the junior position on the list of editors. Use this link to get the free digital version or buy the book.

Much of the work presented in the book is new and expands upon research covered in past publications. It is illustrated with diverse datasets across Australia using data downloaded from the Australian state geological surveys or Geoscience Australia's GADDS country-wide archive facility. Clive Foss has worked on many datasets from this world leading geophysical data resource.

The book focuses on a particular class of magnetic problems that relate to isolated magnetic anomalies. They are called sweet-spots and provide the basis for robust estimation of depth, magnetisation and remanence detection. Geological models using fast parametric or faceted shapes are used to investigate the value and pitfalls of magnetic interpretation along with aggregated groups of geo-bodies to model complex geology.

A book for all

This is a book for all applied geophysicists from third year geoscience students to experienced practitioners. By way of example, I have been working on the practical uses of the magnetic tensor for many years and in Chapters 5 and 9, I found that Clive had presented an important piece of new research. I now have a practical global solution for automatically detecting the existence of remanence in a profile at any IGRF inclination using the vertical gradient of the vertical magnetic component (B_{zz}).

Chapters 1 and 2 are especially useful for undergraduates and recent graduates. Chapter 1 is an easy introduction with sage advice and examples of the application of the magnetic method to exploration geophysics. You will find a summary of some major pitfalls as well as the advantages of the magnetic method. The strategy for the book is about producing *defensible geological interpretations* rather than unconstrained, algorithm-generated inversions that should never be called interpretations.

Chapter 2 provides an overview of data preparation, visualisation and inversion strategies for recovering quantitative geological information from magnetic data. Many important geological principles are set out in this chapter which focuses on isolating anomalous components of the magnetic field for geological interpretation, modelling and lithology constrained inversions. In general, but not always, the models are based on a magnetic unconformity surface which truncates a steeply dipping basement geology. This technique provides an efficient foundation for rapid geological modelling and interpretation of specific anomaly subsets. By working with the original high-resolution line data, precision depths, edge mapping and rock properties can be assessed for the modelled lithologies. Clive explores the nuances of these techniques in his well-illustrated examples. I note that Clive is a story-teller par extraordinaire and there are many excellent stories here that have never been told. For the younger reader, there are many pearls of wisdom that are worth absorbing. For the experienced practitioner, you will see that he has a penchant for long paragraphs, and you may find yourself skipping quickly to the next.

Sweet-spot anomalies

Clive coined the term sweet-spot to define anomalies that are reasonably isolated from their neighbours and whose curvature characteristics define a source with a single magnetisation. Based on geological principles, it is assumed that they have sharp edges and are truncated by a non-magnetic unconformity surface. This concept is fundamental to quality depth inversion. When the truncation surface is missing, the rules change and limit the spatial deductions that can be determined from the sweet-spot anomaly. However, you can still recover the centre of magnetisation and magnetisation vector.

Compact sources

The compact magnetic source concept is fundamental to the robust recovery of a magnetisation vector and identification of magnetic remanence. It has an implicit definition that was originally assigned by David Clark to dipole-like magnetic anomalies in his work on the magnetic gradient tensor. My working definition is as follows: *A compact magnetic body refers to a physically confined, isolated subsurface source whose maximum spatial extent is less than twice the distance to the nearest magnetic field measurement point. It exhibits a homogeneous or bulk magnetisation, and its magnetic field expression approximates that of a simple dipole or sphere.* In practice, the geological shape can be an ellipsoidal or pipe-like (sub-vertical) and a semi-elliptic horizontal section. The long axis is preferably less than four times the short axis. Your data requires coverage of the complete sweet-spot anomaly and removal of the local regional.

Depth

Depth to magnetic basement is an important concept in quantitative interpretation where sweet-spot anomalies identify *defensible targets* for depth estimation.

Chapter 3 explores factors that limit the depth accuracy such as data sampling, parameter insensitivity, sensor elevation, terrain elevation precision, regional field and geological shape. Although implied by the title, this chapter is mainly about the pitfalls of depth interpretation rather than the art of depth estimation. To fully understand the implications, you must read it from the very start to the end. The chapter abstract indicates that the first part is a sensitivity analysis and not about running depth inversions as I thought when I read it for the first time. Figure 3.7 shows the sensitivity of inversion for susceptibility, thickness, strike length and depth extent. Each data point is associated with a fixed depth that is offset from the true depth of 400 m and inverted for three of the parameters.

Since depth inversion is an important skill for an applied geophysicist, I provide a link to a short demonstration video (1). I have reproduced Clive's pipe model to show you how the depth inversion would work in practice. It demonstrates an important limitation defined by a width/depth ratio of pipe-like anomalies. The equivalence limitation shows up as a susceptibility sensitivity in Clive's study.

The pitfalls are important to understand so that you can achieve the best possible results and Clive then moves onto depth inversions of full survey models followed by practical examples. At the end of Chapter 3, he introduces the use of gradients for inversion which in general provide a higher quality depth estimate. They have better separation from interfering anomalies, and the gradients are very sensitive to depth differences.

Distal and proximal fields

Clive explores the concept of proximal and distal magnetic fields as a prelude to understanding the use of the dipole magnetic field to extract the magnetisation vector. Essentially, a 3D source is distal if the field measurements are far enough away that the anomaly is equivalent to a magnetic dipole. I have prepared a short demonstration video (2) of the meaning of distal and proximal using the same Chapter 3 pipe model.

Magnetisation and remanence

The word magnetisation occurs 2759 times in the book compared with just 69 for susceptibility. This may seem strange for a book all about magnetic theory and practice, but it is an important reason why this book is different to any that have come before. It is defined as *a vector field of the density of magnetic dipole moments* and it is responsible for the anomalous component of the measured magnetic field. It contains the vector sum of the remanent and induced magnetisation components. Importantly, when the magnetisation vector direction departs from the inducing field direction (IGRF), it means that you can detect the presence of magnetic remanence or possibly demagnetisation.

You do not directly measure the magnetisation in a magnetic field survey. The magnetisation vector must be extracted from magnetic field data using analytic methods (generally geophysical inversion). This can only be reliably achieved over sweet-spot anomalies, otherwise the magnetisation vector is unlikely to be valid. Even though it is mathematically possible, recovery of the magnetisation vector is not physically realisable in complex areas with interfering anomalies, unresolved background fields and absent geological constraints. I note that published validations of some of the voxel methods are based on inversions of model data over isolated compact sources which are then assumed to work in more complex situations that do not comply with the compact source rule.

Section 2 (Chapters 5 to 15) is devoted to the investigation of magnetisation and the detection of magnetic remanence. These chapters present new methods, ideas, theory and case histories. In greenfields exploration, where your geologist has an understanding of the basement geology context, the remote recognition of remanence can provide diagnostic information to prioritise ground follow up and drilling, increasing the probability of success and reducing exploration expenditure. Important commercial minerals that may have detectable remanence include diamonds, iron ore, pyrrhotite related skarns, some VHMS deposits and stratiform Ni-Co-PGE deposits. Some chapters won't be important until you have a relevant field problem and thus may not be of immediate interest. In these cases, I recommend that you read the abstract and conclusions and file the benefits in your memory. These chapters cover:

5. Introduction to remanent and resultant magnetisation and estimation of the vector rotational displacement (ARRA).
6. Sensitivity study of estimation methods for plunge (dip), position and shape.
7. Direct estimation using magnetic field components and the magnetic tensor.
8. A new innovative magnetic field component method using grid statistics rather than peak-trough analysis.
9. A new direct estimation method using the vertical magnetic gradient Bzz tensor component.
10. Inversion study of UAV and fixed wing airborne magnetic surveys.
11. Tenterfield inversion study of remanently magnetised terrain and its utility for studying Martian terrain.

12., 13. Remanence-like anomalies due to holes in normally magnetised rocks.

14. Tripole and quadrupole anomaly shape at low magnetisation inclinations.

The Australian Remanent Anomalies Database (ARAD)

ARADS is a CSIRO initiative to develop a national accessible database of magnetisation estimates for anomalies associated with magnetic remanence using public domain datasets. The survey data is available from the Geoscience Australia GADDS site and the anomaly subset can be downloaded from the AuScope Discovery web portal. Clive's Geomagnetophilia *Preview* series uses examples from ARADS.

Summary

This is an important contribution to the advancement of magnetic interpretation methods, especially the understanding of magnetisation and the detection of magnetic remanence. I encourage you to submit your feedback to the book's authors and any recommendations you have that can be incorporated into updates to the freely available digital version. Supporting material for this review can be found on the Magnetic Mentor series link.