Practical Magnetotellurics

by Fiona Simpson and Karsten Bahr

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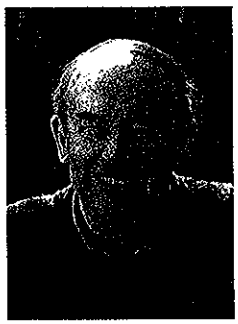
Reviewed by:



Ted Lilley
ted.lilley@anu.edu.au

This book is friendly, just what is needed to welcome newcomers to magnetotellurics, and start them off in the right direction. Having done that, the book will then accompany them for quite a long way. In its pleasant manner it gets to the heart of the subject, and to many of the more advanced points.

Much of Australia is ideal for MT, being flat and remote. The flatness makes for easier observation (such as the laying out of cables), and the remoteness makes for quiet low-noise electromagnetic conditions. The saltiness of the surface layer in many places however can cause distortions which are hard to handle.

In this review, written especially for Australian audiences, it is of interest to note that Simpson and Bahr, in collaboration, have extensive Australian experience, having held field programs here in recent years. Their purpose has been to exploit the expected high resistivity of the Australian Proterozoic crust to see through it into the mantle, and to test there for anisotropic electrical properties, reflecting tectonic history. The cover figure of the book shows Australian results.

At the start of the book, a sensible list of symbols used and their units follows a welcoming Preface. Especially in electricity and magnetism it is essential to keep units correct, and the widespread adoption of SI has been of great benefit. The reader still needs to take care however with what may be the practical units of geophysics. For example whereas in the symbols skin depth is listed as km, a later equation for its calculation will result in a quantity in metres.

Chapter 1 describes the basic natural physical phenomena being exploited in MT studies, and immediately goes to the geological significance of Earth electrical conductivity values. In fact of the two possibilities, conductivity and (its reciprocal) resistivity, the authors more often use resistivity. In some diagrams, an axis for the other could be included as well, to advantage. The historical perspective concluding Chapter 1 is particularly good value, given the direct lineage of MT back to a scientific giant like Gauss.

Chapter 2 is a very efficient production of the theoretical results upon which modern MT practice is based. At the start a list of assumptions of the MT method are stated. With these accepted, critical situations are dealt with in more detail, such as induction as a diffusion phenomenon and its frequency dependence; the case of horizontal layering; and the particular case of two-dimensional structure. Induction arrows (many Australian readers will know them as Parkinson arrows) are introduced in a discussion of transfer functions, and the MT impedance tensor is also introduced. In many respects, the extent to which the elements of this chapter are grasped will ultimately govern the success of many MT field projects.

While the reader is digesting the important information in Chapter 2, Chapter 3 moves to planning a field campaign. Here the approach is that of a field manual, with proven techniques described. It explains what the newcomer needs to know straight away. It is now relatively easy to make MT measurements (the signals are there naturally all the time) and the best way to get started in the subject may well be to get started on some measurements. This chapter tells you how.

No sooner has one gone to the field and set some MT gear going, than one will have data, and be waiting with excitement to see what is there. Initially the actual forms of the time series recorded will be of great interest, and perhaps this fascination will never be lost.

An appeal of geophysics is to see basic physics happening on a grand scale, in this case electromagnetic induction taking place "in real time".

While you watch, the magnetic field changes, and corresponding voltages are induced at the surface of Earth. However very soon the large number of data recorded have to be reduced to fewer (and more easily managed) transfer functions. Transformation to the frequency domain arises, and complex quantities. In Chapter 4 the book provides a clear path to follow.

Then, with values for magnetotelluric impedance tensors in hand, interpretation starts in Chapter 5 with the matter of determining basically how complicated the inversion of the data will need to be. Rotation of axes may arise here too. A major advance occurred in MT with the recognition that much of the strongest distortion of observed data occurs locally (some boulder in the ground near where one of the electrodes has been buried, perhaps) and that such distortions can be removed reasonably easily. The procedure may be viewed as MT tensor decomposition, and often a 2D situation is then left, greatly aiding subsequent modelling and inversion of the data. The discussion in the book on this point is realistic, and the policy is advised of facing up to data more complicated than galvanically scattered 2D, if that is what you clearly have.

Chapter 6 on numerical forward modelling is brief, and demonstrates how MT is dependent on the ability of

[1] *Copies can be ordered directly from Cambridge University Press: Tel (03) 9676 9955 or from www.cambridge.edu.aus*

computers to handle differential equations applied simultaneously to a mesh of points dividing up a block model. For anyone, especially the newcomer, some forward modelling will be very instructive, and help them to understand their data much better. Ultimately they may use an inversion scheme which will be more automated and they will not have so much the feel of their data. Forward modelling will have prepared them well.

Chapter 7 is on Inversion of MT data, and we have now travelled a long way from when instruments were first installed in the field. The most important points of basic inversion science are addressed, so that much of this chapter forms a good introduction to inversion in geophysics generally. The closing sections of this chapter coach the reader in inversion techniques, and pass on the benefits of a lot of experience.

The procedure has now been followed to the point of having models of Earth electrical conductivity, and in Chapter 8 the book goes into its final stage, of returning to the geological significance of the results. There is further discussion on rock electrical conductivity, at a more advanced level than earlier. The discussion covers the crustal conductivities familiar in the exploration geophysics world, and also includes the conductivities of the lower crust and upper mantle as, most importantly, these are within reach of the lower frequencies and strong natural source fields exploited by MT. Dependence on temperature is fundamental, and attention is also given to the strong anisotropy often observed in field data. Resistor networks are introduced as models of rock resistivity.

Chapter 9 brings in a wider look, first of the relation of MT with seismic results. Various applications to geodynamics are then addressed, and lead naturally to seafloor MT and the probing of ocean plates, rises and trenches. Mentioning the ocean introduces motional induction due to the movement of seawater in Earth's steady magnetic field. The phenomenon, which occurs with tides, currents and waves, is demonstrated with tidal observations. The chapter concludes with attention to industrial and environmental applications.

Chapter 10 continues to look widely, revisiting various things possible with magnetometer measurements only, whether in arrays or as gradiometers. It is pleasing, at the end, to return to where some of the subject started, and a resolution of the journey. Active induction techniques are mentioned where they overlap with MT and may be used in a complementary manner, such as to determine the surface resistivity. Such surface values may be used to reset MT data which have been left floating after distortion removal.

The book concludes with succinct and valuable appendices on the mathematical tools needed, and a glossary of terms occurring frequently in MT discussion. The glossary is a summary of the subject in itself, and suggests all sorts of pithy examination questions for a lecture course on MT. The

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der Weinstrasse. He is rightly remembered with a number of memorials, a prestigious scientific medal awarded in his name, a German high school, and many placenames including a homestead, valley[3] and parish in Queensland, a New Guinea river, a group of New Guinea islands, a mountain in Greenland, a number of significant Antarctic features, the current German Antarctic base and a crater on the moon.

Acknowledgements

I must thank the Directors of the State Library of Victoria, the State Library of New South Wales, the National Library of Australia and the National Gallery of Australia for their kind permissions to reproduce some unique and historic images for this series and I particularly wish to thank the following for their continued interest and input – Shaun Hardy of the CIW/DTM-Geophysical Laboratory Library, Washington DC; Walter Struve of the State Library of Victoria; Hobartian and ASEG member Bob Richardson; ASEG member Peter Wolfgram for his helpful responses to my detailed questions on Neumayer's German language writings (particularly the 1856 Pfalz survey); and our editor David Denham who volunteered and obtained permissions for some essential images.

Postscript – Lamont's *Reisetheodolit* :

In June 2006, Heinrich Soffel, Emeritus Professor of geophysics, University of Munich, published an article in EOS, the newsletter of the American Geophysical Union commemorating the 200th anniversary of the birth of Georg Neumayer's mentor, Johann Lamont[4] and in July co-authored with Reinhold Häfner a substantial book on the life work of Lamont[5]. These writings confirm that Lamont performed regional magnetic surveys of France, Spain and Portugal in 1856-57 using a magnetically clean instrument of his design and construction, his "Reisetheodolit" (Figures 4 and 5).

It is significant that Neumayer wrote that the start of his Victorian fieldwork was delayed as his magnetometer was being used by Lamont in Spain and Professor Soffel's stories confirm this was the case. Eugene von Guérard sketched Neumayer observing with this particular instrument at Benalla in 1862 (see *Preview 123, page 18*). Neumayer had two of these Lamont magnetometers in Victoria and it was the backup instrument which was used briefly on the Burke and Wills expedition. It is possible the instruments have survived.

[3] Neumayer Valley, in the gulf country of Queensland was named on the 15th February 1862 by William Landsborough on his expedition in search of Burke and Wills.

[4] Soffel, H., "Johann von Lamont: A Pioneer in Geomagnetism", EOS, Vol.87, Number 25, p.247, 20 June 2006.

[5] Häfner, Reinhold and Heinrich Soffel, "Johann von Lamont, 1805-1879, Leben und Werk", Astronomical and Geophysical Observatory, University of Munich, July 2006.

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list of references covers the topic well, and there is a good index.

Were space unrestricted, what would I add to the subject matter above? Further to the important caution about care in the calibration of instruments, I would add that it is easy to give recorded electric fields the wrong sign, due to making a mistake in the convention for a positive electric field. Electric fields are often squared in MT, and wrong signs may be lost sight of. However their effects may become evident elsewhere, such as in phase values in the wrong quadrant.

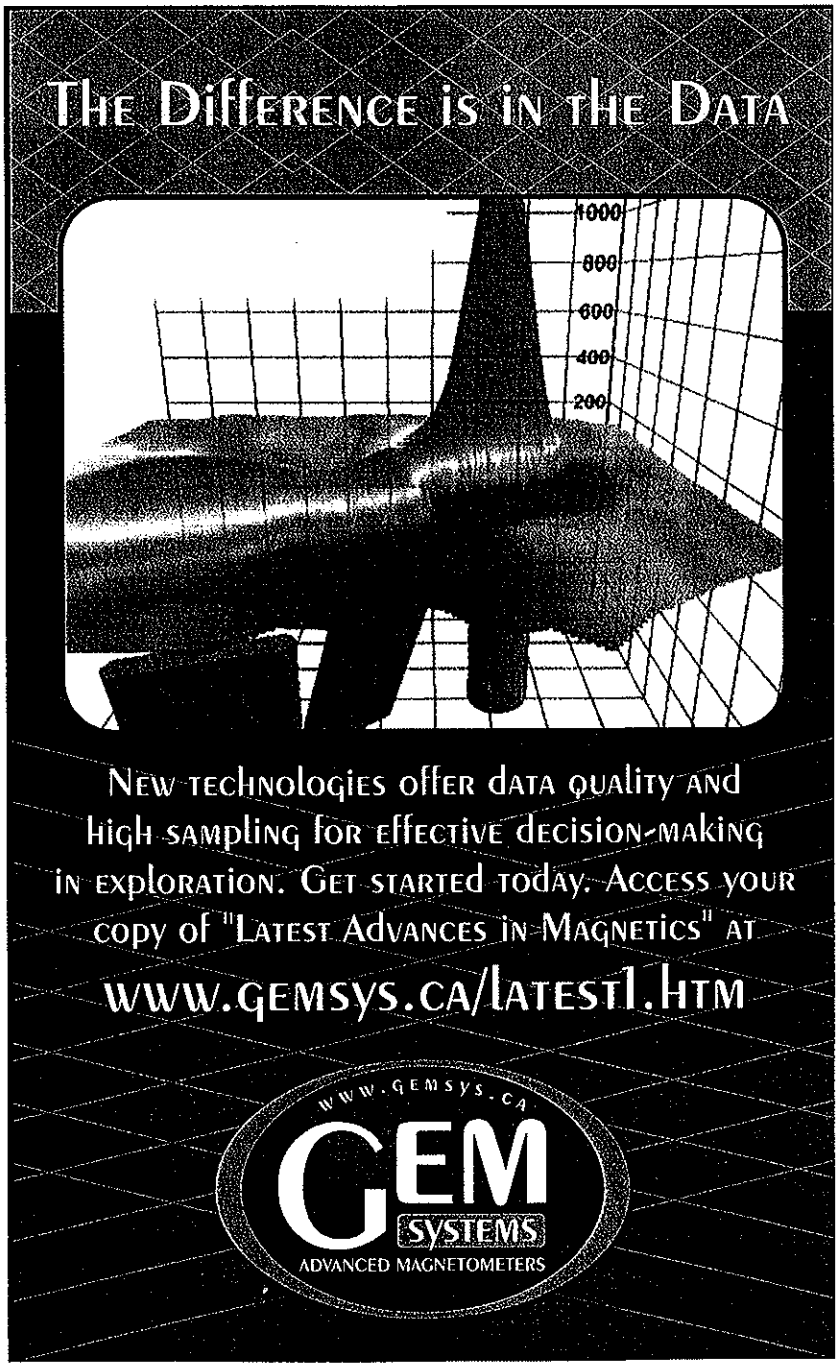
Regarding phase values, I would mention that there is a consequence for the signs of phases when making the choice of exp (+iωt) or exp(-iωt) in the Fourier transform process (on this point one of equations A5.6 has a negative sign missing). Also (a personal favourite) I would draw Mohr circles to illustrate dimensionality and distortion of the MT tensor. Such diagrams can be helpful in understanding what is going on.

The authors have produced a valuable book which I expect will be used widely. I am not aware of any other book like this dealing with magnetotellurics. For a variety of reasons magnetotellurics has in recent years reached a stage of maturity. Newcomers can proceed down a beaten path in the comfort of applying a developed technique, rather that having the feeling, as was the (albeit exciting) case just a generation or so ago, that they were in frontier research from the first observation. That is not to say that their particular geological situation and MT data will not provide frontier research, and its excitement, soon enough!

It is entirely appropriate that the book should come from the University of Gottingen, Germany, which has a great tradition in geomagnetism, dating back to Gauss.

Also, Australian readers will enjoy joining the authors and others around the world for whom it is a pleasure to imagine, as examples of diffusion, roast beef being cooked in an oven, while red wine is brought up from a cellar.

The book is well produced by CUP, with hard cover. Each chapter starts with a summary. Every group making MT observations should have a copy (perhaps several).



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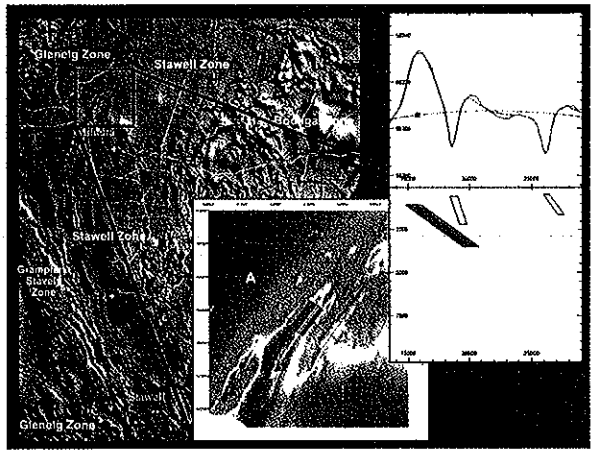

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