METHODS IN GEOCHEMISTRY AND GEOPHYSICS

EXPLORATION WITH DEEP TRANSIENT ELECTROMAGNETICS

K.-M. STRACK

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I am dedicating this book to those
who have given me their infinite love
while I was working on this manuscript:

Heather, Ian and Gurumayi

Only your support has allowed to
accomplish this huge task.

PREFACE

This book has a story. The author's first version was used for lectures at the University of Cologne and as a training program for foreign scientists. The second version was written as part of a project report and the third version as lecture notes for the lecture series "New Methods in Electromagnetic Exploration" held in 1989/90.

This book is history. It is a milestone in the history of electromagnetic geophysics, or to be precise, of quantitative electromagnetic exploration methods.

It all started 50 years ago with the telluric method. After that came Magnetotellurics in 1953, introduced by Cagniard, Tikhonov and Rikitake. Thanks to subsequent advances in technology, this method proved its effectiveness for crustal studies, as well as a number of specific situations encountered in hydrocarbon exploration.

Because reliance on natural signals does have some drawbacks, a great deal of effort was made later to develop controlled source electromagnetics. We are all indebted to the work carried out in the former USSR in this field in the last thirty years. A whole new appendix devoted to a Russian bibliography would have to be added to the book to give these pioneers the place they deserve in history.

In the beginning, there were two competing families of methods: frequency and time domain measurements. Time Domain Electromagnetics (TDEM) or Transient Electromagnetics (TEM) have won broad acceptance for a wide range of applications from shallow exploration to deep crustal studies. LOTEM, the method taken in this book as a reference, is now gaining recognition among geophysicists. This is the result of a natural selection process. Since LOTEM combines the advantages of TEM methods, the measurement of a broadband secondary field in the absence of a source signal and the advantage of DC soundings, it resolves resistive markers.

Kurt Strack's involvement in TEM started in the USA, continued in Australia, until he finally settled in Germany. His contributions have been decisive, ranging from the introduction of modern signal processing algorithms to the development of multichannel equipment, and resulted in Cologne becoming a focal point for a number of international experts, particularly for modeling. Last but not least, he managed, after overcoming formidable difficulties, to organize demonstrative surveys on four continents.

This book is going to influence history.

With its nine chapters, seven appendices, exercises and floppy disk, we consider it to be the most comprehensive textbook currently available. So, you want to become an expert in deep transient electromagnetics? Well, just study and understand this book. it will doubtless influence present and future specialists in TEM, whether they wish to concentrate on instrument design, data processing and interpretation or hydrocarbon discovery.

Exploration managers and Chief Geophysicists should read at least chapter 6 to 9 in which feasibility studies and case histories are covered. A particularly important topic is the integration of seismic and LOTEM for studies of lithology, porosity and fluid content.

Chapter 1 to 5 are for TEM specialists in universities and oil companies and, of course, for students who will be delighted to read a book which offers a rare combination of depth, thoroughness, and clarity.

Both of us have worked for many years for a contracting company which, since the days of C. Schlumberger, S. Stefanesco, L. Cagniard, V. Baranov, and G. Kunetz, has taken pride in offering a comprehensive range of geophysical services including electromagnetics.

We are particularly pleased today to have this opportunity to tell all potential readers, who not only want to understand deep transient electromagnetic soundings but also to discover how they fit into a well designed exploration program: "This is THE BOOK for you!"

Gildas Omnes and Pierre Andrieux — Massy, France, February 10th, 1992

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SUMMARY

Over the past few decades electromagnetic (EM) techniques have taken an increasing importance for the exploration of hydrocarbons and geothermal resources as well as deep crustal studies. The reason lies in the response to different physical rock properties, namely electrical resistivity, in comparison to the elastic properties for seismic methods. Among the electromagnetic techniques the deep transient electromagnetic technique has seen an increasing interest because of the possibility of overcoming typical electromagnetic noise problems as well as obtaining higher resolution with better transmitter control. Although many excellent theoretical books exist on electromagnetics and some applied books on individual electromagnetic methods, there is no coherent description of deep transient electromagnetics which allows the geophysicist to learn about the technique from the beginning of instrument design to the final interpretation.

This book is trying to fill that gap by summarizing many man years of research. It is directed towards a broad audience: the *research geophysicist* who is going to design his own transient electromagnetic field system; the *student* who is trying to learn about the theoretical background and its direct relation to real practical application; the *exploration geophysicist* who will have to make the survey design, cost evaluation and interpretation. This review will help him to refresh some of the background material. All chapters have a very strong relation to real case histories. Problems are included to help deepen the understanding beyond the content of this book and test programs to demonstrate the application. A combination of all should allow the newcomer to deep transient electromagnetics to reach very quickly state-of-the-art level.

Chapter one contains a general introductory section which explains where deep transient electromagnetics is placed in geophysical exploration. It also explains the background of rock resistivity often used as a priori information in the interpretation of electromagnetic data. The second chapter gives a short review of the basic physical principles in order to allow the practicing geophysicist to relate to possible problems in interpretation. The material is restricted to the basic needs for data interpretation; more detailed derivations are given in the appendix 1.

The difficult problem in acquiring and processing electromagnetic data is the improvement of the signal-to-noise ratio, which is treated in chapter three. Using the information in this chapter, the reader should be able to handle even extremely strong cultural noise successfully. The effects of the different processing techniques are demonstrated using synthetic and real data.

The data interpretation part includes several different ways of applying inversion to real field situations as well as initial attempts to integrate three-dimensional model-

ing with real data interpretation. Three–dimensional interpretation is to date still being hindered by excessive computational requirements and will be the area with the fastest growth rate.

The chapter on the field system gives the basic design criteria. The design description has been kept general enough to accommodate future technology easily, while being explicit enough to allow the reader to design his own field system using todays technology. New field procedures which can be used to improve the signal–to–noise ratio are discussed to allow a direct correlation with standard techniques.

Before going to the field it is very important that the exploration geophysicist evaluates the prospect of a successful survey. In particular, the detailed survey setup parameters and the probability of success of the technique need to be evaluated. In many instances it is important to define the necessity of additional geophysical techniques before the measurements are carried out. This can be done using the information given in the chapter on presurvey feasibility studies.

To cover the broad range of application, extensive case histories ranging from coal exploration, geothermal exploration and hydrocarbon exploration to the application of deep transient electromagnetics for deep crustal investigations are given. In particular, the chapters on joint inversion of magnetotellurics and transient electromagnetic data and the resolution of resistive layers offer new applications of the technique in hydrocarbon exploration. The first 3–D interpretation of real field data is included to illustrate that 3–D TEM is now within our reach.

Problems are included at the end of each chapter. They can be used as material for students as well as to deepen the understanding of the given information. Some of them are formulated to connect different ideas and to highlight important points.

Most of the cumbersome mathematical derivations which are of interest, but not essential, are not included in the main body but are given in the appendix. The appendix also includes a glossary, standard data formats and PC demonstration software for forward modeling.