PHYSICAL PRINCIPLES OF EXPLORATION METHODS

GEOMAC

PHYSICAL PRINCIPLES OF EXPLORATION METHODS

An Introductory Text for
Geology and Geophysics Students

A. E. Beck

Dept. of Geophysics, University of Western Ontario

M

© A. E. Beck 1981

All rights reserved. No part of this publication
may be reproduced or transmitted, in any form
or by any means, without permission

First published 1981 by
THE MACMILLAN PRESS LTD
London and Basingstoke
Companies and representatives throughout the world

ISBN 978-0-333-26394-5 ISBN 978-1-349-16605-3 (eBook)
DOI 10.1007/978-1-349-16605-3

The paperback edition of this book is sold subject to the condition that it shall not, by way of trade or otherwise, be lent, resold, hired out, or otherwise circulated without the publisher's prior consent in any form of binding or cover other than that in which it is published and without a similar condition including this condition being imposed on the subsequent purchaser

To my wife Julia and the late J. C. Jaeger who between them have made me what I am and therefore, for better or worse, bear some responsibility for this book.

Contents

<i>Foreword</i>	x
1. INTRODUCTION	
Purpose Of Geophysical Exploration	2
Basis of Geophysical Exploration	2
Required Physical Property Contrast For Various Methods	3
Signal, Message and Noise	5
2. ELECTRICAL METHODS	
Electrical Properties Of Rocks	7
Basic Equations	8
Important Types Of Arrays	12
Field Use Of Arrays	13
Comparison Of Wenner And Schlumberger Arrays	20
Basics Of Curve Fitting	22
Equipotential Method	26
Whole Body Excitation	28
3. SELF POTENTIAL OR SPONTANEOUS POLARIZATION	
Introduction	31
Field Observations	32
Analogies With Well Known Phenomena	33
General Field Mechanism	36
Some Geologic Implications	37
Self Potentials In Geothermal Areas	39
Field Mapping Of Potentials	39
4. INDUCED POLARIZATION	
Origin	43
Common Cause Of Electrode And Membrane Potentials	47
Concept Of Chargeability	47
Definition Of Frequency Effect	53
Relation Between Chargeability And Frequency Effect	54
Metal Factor	55
Complex Resistivity Measurements (CR)	56
Magnetic Induced Polarization	58
5. GRAVITY METHODS	
General Ideas	61
The Exploration Problem	64
Anomaly Due To A General Mass Distribution	64

Total Anomalous Mass	66
Corrections To The Field Data	67
Anomalies Due To Simple Bodies	72
The Eötvös Correction For A Moving Platform	79
Second Vertical Derivative	81
Absolute Values Of Gravity	85
6. MAGNETIC METHODS	
Intensity Due To A Bar Magnet	89
The Earth As A Dipole	91
Physics Of Magnetism	92
Elements Of The Earth's Field	94
Important Geochemical Groups	95
Remanent Magnetisations	96
Magnetisation Induced By The Earth's Main Field	98
Calculation Of Anomaly Fields	98
Types Of Magnetometers	101
7. ELECTROMAGNETIC METHODS	
Basics Of Wave Propagation	109
Electromagnetic Waves	110
Basis Of Electromagnetic Method	112
Polarised Waves	117
Dipole Approximation	122
Mutual Inductance	122
General Classification Of Methods	127
Secondary Field Relationships	128
Induction Number	130
Typical Exploration Problem	130
Typical Transmitter – Receiver Geometries	132
Depth Of Penetration And Matching System To Geological Structure	142
Comparison Of Moving Source And Fixed Source Systems	144
Very Low Frequency (VLF) Systems	146
Airborne Measuring Systems	147
Ground Follow Up	151
8. SEISMIC METHODS	
Definitions Of Elastic Constants	155
Types Of Seismic Waves	157
Seismic Detectors	159
Reflection And Refraction	161
Wave Fronts And Rays	163
Refraction Methods	165
Reflection Methods	174
Presentation Of Records	180
Filters, Convolution And Deconvolution	182
Energy Injection	185

9. RADIOACTIVE METHODS	
Background On Atoms And Isotopes	191
Decay Series Of Interest	194
Secular Equilibrium	196
Gamma Ray Spectrometry	196
Compton Effect	197
Pulse Height Analysers	202
Disequilibrium And eU	204
Radon "Sniffing"	205
Airborne Methods	206
10. WELL LOGGING TECHNIQUES	
Introduction	209
Mechanical Type Logs	210
Electrical Resistivity Methods	210
Continuous Dip Meter	213
Induction Log	216
Self Potential Log	216
Gamma Ray Logs	218
Neutron Logs	219
Nuclear Magnetism Logs	221
Sonic Logs	222
Gravity Logging	225
Thermal Logging Techniques	225
<i>Index</i>	227
<i>Appendix: Useful Aspects of the International System of Units (SI)</i>	233

Foreword

This book is the outcome of a number of years of lecturing in Pure and Applied Geophysics to third and fourth year students drawn from a wide variety of disciplines but principally Geology, Physics and Geophysics. The difficulty in teaching a course to a class of such mixed backgrounds is the usual one of trying to avoid boring all of the people all of the time; I have long since given up trying to avoid boring some of the people some of the time.

The principal purpose of the course is not to produce a good geophysical interpreter but to produce students who understand enough of the basic physical principles involved in any given geophysical method that they will appreciate its limitations as well as its strengths. Once these important aspects are understood it becomes easier to select a particular method, or methods, in any given geological situation.

The book is aimed principally towards the geologically inclined student although experiences show that it is not harmful to the physicist if principles are stressed once again. Thus, where a development can be made simply as well as rigorously, this is done; however, if a rigorous development runs the risk of involving the student in too much boring detail, non-rigorous short cuts are taken without, I hope, losing sight of the basic principles involved. This might offend the purist but I make no apology for that since rigorous development can be left till later for those who are sufficiently determined that that is the direction they wish to go.

For similar reasons, and because of time limitations in the lecture room and space limitations in the book, I have attempted to convey some information by osmosis. For example, in the discussion of electromagnetic methods brief reference is made early on to electric currents being stimulated in conductors by a time varying magnetic field; the physicist would immediately appreciate the principle and think no more about it before moving on. Other brief references to eddy currents are made throughout the chapter, and indeed in other chapters, in slightly different contexts, and the non-physics student will, I hope, arrive at the end of the chapter accepting the principle even if he doesn't

fully understand how it comes about; from there it is but a small step to appreciate some of the problems involved in the electro-magnetic method.

Too often, a student is lead to believe that there is only one way to skin a cat; therefore in some places an alternative development is indicated. For example, in the chapters on Gravity and Magnetic Methods simple equations are developed using either the force field approach or the potential field approach, so that the student may come to realize that in problem solving of any sort there is a choice of technique, the particular selection depending on the problem and, often enough, on personal preference based upon familiarity.

In places the development may be heavy going for students without a first year calculus course under their belt; wherever possible physical principles and mathematical representation are illustrated by simple diagrams.

Although the emphasis of this book is on the physical principles underlying a particular method used in the field, techniques of interpretation are not entirely ignored since they too depend on understanding of the method used. However, there is no detailed examination of interpretation techniques; generally, only an outline of the reasoning is given.

Suggestions for further reading are made at the end of each chapter; they are not all embracing. Some are chosen to lead the reader to a classic paper while others lead to a recent publication with numerous references to earlier work; some lead the reader to a journal or book which may contain a number of interesting and relevant papers and, of course, some are given for the standard reason of allowing the reader to follow up statements made in the text.

One other tricky decision to make relates to questions of units. In the end I have decided to stay with the traditional c.g.s. since this is the system used in the great majority of literature to which students will refer; however, at strategic locations throughout the text, the recommended equivalent SI units are given in brackets.

Finally, I would not be unhappy if by the end of the book the student realizes that there is nothing magical or mysterious about geophysical exploration; that the methods are based upon firm, relatively simple, principles; that success depends on intelligent use of the methods available; and above all that good interpretation requires a careful marrying of the geophysical data collected to the known geology of the area.

Many people have read and commented on the text at various stages; they are too numerous to list all by name but I would

particularly like to thank R.A. Facer, L. Mansinha, H.C. Palmer and D.M. Shaw for their critical comments, D. Graves and F.W. Graves who prepared the diagrams, and Cathy Fodemesi who has patiently prepared the text in copy ready form.