

بسم الله الرحمن الرحيم



# شبكة المعلومات الجامعية التوثيق الالكتروني والميكروفيلم



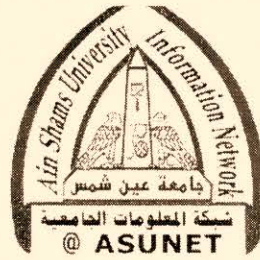
شبكة المعلومات الجامعية

# جامعة عين شمس

التوثيق الالكتروني والميكرو فيلم

## قسم

نقسم بالله العظيم أن المادة التي تم توثيقها وتسجيلها  
على هذه الأفلام قد أعدت دون أية تغيرات



## يجب أن

تحفظ هذه الأفلام بعيدا عن الغبار

في درجة حرارة من ١٥-٢٥ مئوية ورطوبة نسبية من ٢٠-٤٠%

To be Kept away from Dust in Dry Cool place of  
15-25- c and relative humidity 20-40%

# بعض الوثائق الأصلية تالفة



# بالرسالة صفحات لم ترد بالاصل

Ain Shams University Information Network  
جامعة عين شمس  
شبكة المعلومات الجامعية  
@ ASUNET

# **Induced Electrical Polarization in Geophysical Prospecting for Economic Minerals**

**A thesis submitted for the partial fulfillment of the  
Ph.D. degree in Geophysics.**

**From Geophysics Dept., Faculty of Science,  
Cairo University.**

**By**

**Hesham Mohamed Abd El-Rahim El-Kaliouby**  
**Geophysics Lab., Geological and Geophysical Sciences Dept.,  
National Research Center**

**Supervised by**

**Prof. Dr. A.I. Bayoumi**  
**Geophysics Dept.,**  
**Faculty of Science,**  
**Cairo University**  
**Egypt.**

**Prof. Dr. S.A. Hussain**  
**Geological and Geophysical Sciences**  
**Dept.,**  
**National Research Center**  
**Egypt.**

**Dr. E.A. El-Diwany**  
**Associate Prof.**  
**Microwave Dept.,**  
**Electronics Research Institute**  
**Egypt.**

**Dr. E.I. Hashish**  
**Associate Prof.**  
**Electronics and communication**  
**Dept.,**  
**Faculty of Engineering,**  
**Cairo University**  
**Egypt.**

**2001**



بِسْمِ اللَّهِ الرَّحْمَنِ الرَّحِيمِ

﴿رَبِّ أَوْزِعْنِي أَنْ أَشْكُرَ نِعْمَتَكَ الَّتِي

أَنْعَمْتَ عَلَيَّ وَعَلَىٰ وَالِدَيَّ وَأَنْ أَعْمَلَ

صَالِحًا تَرْضَاهُ وَأَصْلِحْ لِي فِي ذُرِّيَّتِي

إِنِّي تُبْتُ إِلَيْكَ وَإِنِّي مِنَ الْمُسْلِمِينَ﴾

[الأحقاف: 15]

# Approval Sheet

Thesis title:

**Induced Electrical Polarization in Geophysical Prospecting for Economic Minerals.**

A thesis submitted for the Ph.D. degree in Geophysics From Geophysics Dept., Faculty of Science, Cairo University.

Student name:


**Hesham Mohamed Abd El-Rahim El-Kaliouby**  
Geophysics Lab., Geological and Geophysical Sciences Dept.,  
National Research Center

## Supervising Committee:

**Prof. Dr. A.I. Bayoumi**, Geophysics Dept., Faculty of Science, Cairo University.



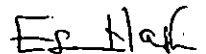
**Prof. Dr. S.A. Hussain**, Geological and Geophysical Sciences Dept., National Research Center.



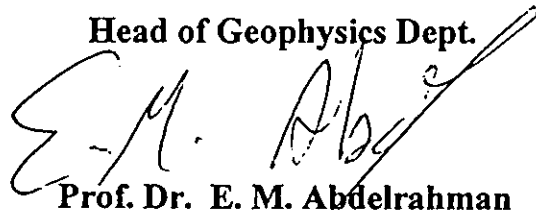
**Dr. E.A. El-Diwany**, Associate Prof., Microwave Dept., Electronics Research Institute.



**Dr. E.I. Hashish**, Associate Prof., Electronics and communication Dept., Faculty of Engineering, Cairo University.



**Head of Geophysics Dept.**



**Prof. Dr. E. M. Abdelrahman**



# Acknowledgment

**All Praises to ALLAH.**

I would like to express my thanks to **Dr. E.M. Abdelrahman**, head of Geophysics Dept., Cairo University for his help and encouragement.

I would like to express my sincere thanks to **Dr. Abd El-Rahim I. Bayoumi**, **Dr. Safwat A. Hussain** and **Dr. Essam I. Hashish** for their good supervision, great help and valuable comments.

I would like to express my deep thanks to **Dr. Essam A. El-Diwany**, Electronics Research Institute for his good supervision, unlimited assistance and consistent advises during the work of this thesis. Thanks to all my colleagues in the Microwave Dept., Electronics Research Institute for facilitating my work during the thesis.

I am very grateful to **Dr. Mary Poulton**, University of Arizona for her continuous guidance and valuable suggestions during the work of this thesis at the Mining and Geological Engineering Dept. I am also very grateful to the faculty and staff at this department who made my time there truly enjoyable.

Special thanks to **Dr. Ben Sternberg** and **Dr. Tsylya Levitskaya**, University of Arizona for their help and cooperation during the measurements of the rock samples at the LASI lab.

Grateful acknowledgment is made to **Dr. Ken Zonge**, and the colleagues in Zonge Engineering and Research Organization, for their cooperation, help and support. I owe them much for the valuable time they gave me during my work in Tucson, Arizona.

Last but not least, I would like to express my sincere thanks and deepest gratitude to my parents; my wife and my kids (Yousuf and Hoda) for their support and continuous encouragement during this work, but no words of thanks and feelings are sufficient...

# Table of Contents

	Page
List of figures	6
List of table	16
Abstract	17
Introduction	19
<b>Chapter 1: Induced Polarization in Electric and Electromagnetic Methods</b>	23
Introduction	23
1.1 Induced Polarization (IP) in rocks	24
1.2 Induced polarization methods	26
1.2.1 Time domain induced polarization (TDIP)	26
1.2.2 Frequency domain induced polarization (FDIP)	27
1.2.3 Phase measurements	27
1.2.4 Complex resistivity measurements	27
1.3 Electromagnetic methods	28
1.3.1 Inductive electromagnetic methods	29
1.3.2 Transient electromagnetic methods	30
1.3.2.1 Diffusion of inductive current in the ground in TEM method.	31
1.3.2.2 The asymptotic transient voltages induced in the coincident loop and the central loop systems.	32
1.4 IP effects in transient EM method	33
1.4.1 Types of negative response in transient electromagnetic systems- coincident, central and two-loop systems	36
1.5 Factors affecting the negative response in coincident and self-loop systems	37
1.5.1 Effects of Cole-Cole parameters on the time of sign reversal and the amplitude of the NR for a half-space model.	38
1.5.2 TEM response of the coincident loop system above a layered ground with a thin conducting layer.	44

	<b>Page</b>
1.5.3 Effects of the ground parameters on the NR of the coincident loop system above a polarizable layered ground	44
1.6 Double sign reversal over layered ground	48
1.7 Transient response due to polarizable finite targets and structures not extending to infinity	52
1.8 Sign reversals above finite polarizable bodies	53
<b>Chapter 2: Geophysical Inversion Methods</b>	<b>54</b>
Introduction	54
2.1 Global and local inversion techniques	54
2.2 Local inversion methods	56
2.2.1 Linearized Least-squares inversion	56
2.2.1.1 The Gauss-Newton least squares solution	58
2.2.2 Marquardt-Levenberg method	59
2.2.2.1 Steepest decent evaluation of the perturbation vector	60
2.2.2.2 Adaptive choice of the damping factor	60
2.2.3 Singular Value Decomposition (SVD)	61
2.2.3.1 Eigenvector analysis	63
2.3 Global optimization methods	65
2.3.1 Simulated Annealing	66
2.3.2 Genetic Algorithms	67
2.4 Neural Networks	70
2.4.1 Construction of the basic NN	72
2.4.2 Neural Network Training	73
2.4.3 Modular neural network algorithm	74
<b>Chapter 3: Inversion Results for TEM Response above Layered Polarizable Ground</b>	<b>76</b>
Introduction	76
3.1 Forward modeling of TEM response	77
3.1.1 Transient response of coincident loop above layered medium	77

	<b>Page</b>
3.1.1.1 Methods of evaluating the inverse Hankel transform integral	78
3.1.1.2 Methods of evaluating the inverse Fourier transform integral	79
3.1.2 Late time series expansion of the voltage induced in a coincident-loop above half-space	80
3.1.2.1 Inverse Hankel transform integral	80
3.1.2.2 Late time series expansion for the transient induced voltage over a polarizable half-space with Cole-Cole model.	81
3.2 Preprocessing of input data for NN inversion	82
3.3 Optimum conditions for NN inversion of TEM data above polarizable half-space	83
3.3.1 Inversion results with a single loop	84
3.3.2 Inversion results with dual loop radii	86
3.3.3 Inversion errors of different parameters for half-space model	88
3.4 Effects of different factors on the inversion of TEM response above layered-earth using NN.	90
3.4.1 Inversion results with a single loop radius	90
3.4.2 Inversion results with dual loop radii	92
3.5 Effect of narrowing the parameter ranges	93
3.5.1 Two-Phases inversion	94
3.6 GA Inversion	95
3.7 Hybrid NN-GA inversion	96
3.8 Inversion results of TEM response above polarizable ground using MNN	98
3.8.1 Half-Space results	99
3.8.2 Layered ground results	100
3.8.2.1 Polarizable first layer	100
3.8.2.2 Polarizable Second layer	105
3.8.2.3 Inversion errors for the different parameters	108
3.8.2.4 MNN inversion for TEM response with double sign reversal.	110
3.9 Uncertainty evaluation	112

	<b>Page</b>
3.10 Sensitivity evaluation	113
3.11 Case study	115
<b>Chapter 4: Electrical Properties of Water-Bearing Sedimentary Rocks</b>	<b>118</b>
Introduction	118
4.1 Electrical characterization of rock materials.	119
4.2 Parameters effecting electrical properties of water-bearing rocks	120
4.2.1 Experimental results for the effect of water content on the electrical properties of water-bearing rocks	120
4.2.2 Effect of porosity and specific surface of the grains	128
4.2.3 Methods of eliminating electrode polarization	132
4.2.4 Effect of clay in clay-bearing sandstone	134
4.2.5 Effect of grain size and shape.	137
4.2.6 Effect of solution conductivity and type of electrolyte.	138
4.3 Ion exchange in clay minerals and grain polarization	141
4.3.1 Ion exchange in clay minerals	141
4.3.2 Grain (electrode) polarization	142
4.4 Proposed models for interpreting the electrical properties of rock-water mixture.	144
4.4.1 Models for surface conduction and diffusion.	144
4.4.2 Models used for clay saturated with water.	148
4.4.3 Results of the models for the conductivity and dielectric constant dispersions	152
4.4.4 Three phase mixture model for shaly sands	154
4.4.5 Membrane polarization model (clay-bearing sandstone)	155
4.4.5.1 Experimental Results	157
<b>Chapter 5: Measurement of Electrical Properties of Rock Samples,     Discussions and Applications</b>	<b>159</b>
Introduction	159
5.1 Measurement Procedures	160
5.1.1 Electrical Models	160



	<b>Page</b>
5.1.2 Measurement setup	162
5.1.2.1 Measuring instruments	162
5.1.2.2 The sample holder	162
5.1.2.3 Nonpolarizable electrodes	164
5.1.3 Stray parameters of measurement setup	165
5.1.3.1 Resistance $R_{ms}$ and inductance $L$	165
5.1.3.2 Stray capacitance	166
5.1.3.3 Calculation Procedures	168
5.1.4 Sample Preparation	170
5.2 Measured Results	171
5.3 Discussion of results	173
5.3.1 Effect of water content	174
5.3.1.1 Effect of water content in different samples	175
5.4 Forward modeling of TEM response using measured samples data	191
5.4.1 Equivalent Cole-Cole model for TEM response	192
5.4.2 Effect of a partially saturated upper layer	194
5.4.3 TEM response for different fully saturated samples	195
5.4.4 Effects of other layering parameters	196
5.5 NN inversion of TEM response using measured sample data	198
<b>Chapter 6: Conclusion and Suggestions for Further Work</b>	<b>202</b>
References	210

## List of Figures

Figure	Page
1.1 Equivalent circuit for IP representation	25
1.2 Time domain induced polarization waveforms.	26
1.3 Schematic diagram for the diffusion of smoke ring current.	32
1.4 Negative Response (NR) Phenomenon.	34
1.5 a) Two-loop system    b) Coincident-loop system	35
1.6 Schematic diagram of ionic movement in a volume of polarizable rock beneath a TEM transmitter loop.	36
1.7 Time of sign reversal against Cole-Cole parameters for a half-space model.	39
1.8 Effect of loop radius on the peak of negative response.	41
1.9 Effect of the IP time constant and the loop radius on the peak of negative-response and its time.	41
1.10 Effect of the dc conductivity and the loop radius on the peak of negative-response and its time.	42
1.11 Effect of the frequency parameter and the loop radius on the peak of negative-response and its time.	42
1.12 Effect of the chargeability and the loop radius on the peak of negative-response and its time.	43
1.13 Effect of the DC conductivity of the second polarizable layer on the peak of NR.	47
1.14 Effect of the thickness of the polarizable layer on the peak of NR.	49
1.15 Double sign reversal phenomenon.	50
1.16 Effect of the layer thickness on the peak of NR for a two-layer earth.	51
1.17 Effect of the thickness of the polarizable layer on the time interval of the NR.	51