

RELATÓRIO SOBRE O "INTERNATIONAL  
SYMPOSIUM ON APPLIED GEOPHYSICS  
IN TROPICAL REGIONS".

PERÍODO: 01 a 08/09/82

LOCAL : BELÉM - PARÁ

AUTOR : CÉSAR EDUARDO T. CARDOSO

DATA : 05/01/83

## INTRODUÇÃO

Durante o período de 01 a 08 de setembro de 1982 foi realizado em Belém - Pará o "International Symposium On Applied Geophysics In Tropical Regions", patrocinado pela Sociedade Brasileira de Geofísica - SBGf.

Os trabalhos apresentados foram de uma maneira geral de alto nível, tanto os estritamente teóricos como os de caráter mais prático.

Ao invés de efetuarmos uma simples tradução dos "abstracts" (foi o único material fornecido até o momento pois os anais, serão distribuídos a posteriori) apresentamos uma cópia dos mesmos e citamos aqueles que mais são do interesse dos geofísicos da CPRM, de um modo geral, o que vem a seguir:

- 1) ON STATE-OF-THE-ART OF GROUNDWATER GEOPHYSICS ZOHDY, A.A.R.
- 2) AN OVERVIEW OF GROUNDWATER PROBLEMS AND GEOPHYSICAL APPROACHES TOWARD THEIR SOLUTIONS IN THE LOWER AMAZON REGION, BRAZIL SAUCK, W.A.
- 3) APPLICATION OF GEOPHYSICAL METHODS TO GROUNDWATER EXPLORATION IN BAHIA, NORTHEASTERN BRAZIL . LIMA, O.A.L. de and DIAS, C.A.
- 4) ELECTRICAL GEOPHYSICS IN THE ARID AND TROPICAL ZONES OF AUSTRALIA. MCCRACKEN, K.G.
- 5) ON THE BRAZILIAN EXPERIENCE IN APPLIED GEOPHYSICS LOURENÇO, J.S.
- 6) HIGH RESOLUTION SEISMICS APPLIED TO COAL EXPLORATION. BEHRENS, J.
- 7) ELECTROMAGNETIC PROSPECTING IN TROPICAL REGIONS. PALACKY, G.J.



- 7) THE APPLICATION OF GEOELECTRICAL SOUNDING IN THE GOMBE AREA, BAUCHI STATE OF NIGERIA. AKO, B.D.
- 8) REGIONAL RESISTIVITY SURVEY FOR GROUNDWATER IN MARAJO ISLAND-BRAZIL. RIJO, L.. PORSANI, M., ABEL, A. and TANCREDI, A.C.
- 9) SALTWATER - FRESHWATER DISTRIBUTION IN COASTAL AQUIFERS OF THE SOUTHERNMOST PART OF THE STATE OF BAHIA. LIMA, O.A.L. de
- 10) DEVELOPMENT OF GEOELECTRICAL TECHNIQUES AND APPLICATIONS IN NIGERIA: A CASE NOTE. AGUNLOYE, O. and OFREY, O.
- 11) THE EFFECTS OF A TROPICAL RAIN FOREST COVERAGE ON THE AIRBORNE GAMMA-RAY SPECTROMETRY. PEREIRA, E.B., NORDEMANN, D.J.R. and MARTIN, I.M.
- 12) ON THE NEAR SURFACE EFFECT OF A TROPICAL FOREST IN AIRBORNE GAMMA-RAY SPECTROMETRY. TRAVASSOS, J.M. and PIRES, A.C.B.
- 13) AIRBORNE MAGNETIC SUSCEPTIBILITY MAPPING SILVA, J.B.C. and HOHMANN, G.W.
- 14) THE EFFECTS OF A CONDUCTIVE OVERBURDEN ON EM RESPONSE OF TILTED CONDUCTIVE HALF-PLANES. SILVA, L.M. da C. e and VERMA, O.P.
- 15) RECOGNITION OF EM OVERBURDEN ANOMALIES WITH THEM SURVEY DATA. VILLEGAS, C. and WEST, G. F.
- 16) The Application of Geoelectrical Sounding in the Gombe area, Bauchi State of Nigeria. Ako, B.D.



## COMENTÁRIOS GERAIS

Apesar de ser bem organizado, o symposium, segundo a opinião de muitos colegas brasileiros, não deveria ter sido apresentado em inglês e sim na língua portuguesa com tradução simultânea para os estrangeiros. Notamos em certas palestras, os apresentadores meios perdidos, pois ao mesmo tempo em que liam em inglês em uma sala escura tinham que assinalar os trechos da explanação nas projeções de slides e transparências, o que se tornou cansativo tanto para os apresentadores como para os ouvintes.

O nível dos trabalhos de geofísica da CPRM está à altura de reuniões técnicas semelhantes, principalmente os efetuados pelos geofísicos do DEPRO e SUREG/PA. Segue aqui sugestão a todos os colegas no intuito de já prepararem trabalhos para o symposium de 1984.

Ao final do Symposium foi discutido muito e não se chegou a algum acordo quanto ao local do 2º Symposium da SEGf, tendo o Professor Luis Rijo sugerido a Nigéria, enquanto o Professor Carlos Alberto Dias lutava para que fosse em Salvador - Bahia, o que provavelmente deverá ocorrer.

Como foi mencionado na introdução, o único material técnico distribuído foi um resumo em inglês, o qual é apresentado em cópia. Tão logo tenhamos recebido os anais do Symposium, nos comprometemos fornecer cópia ao SEDOTE e aos colegas interessados.

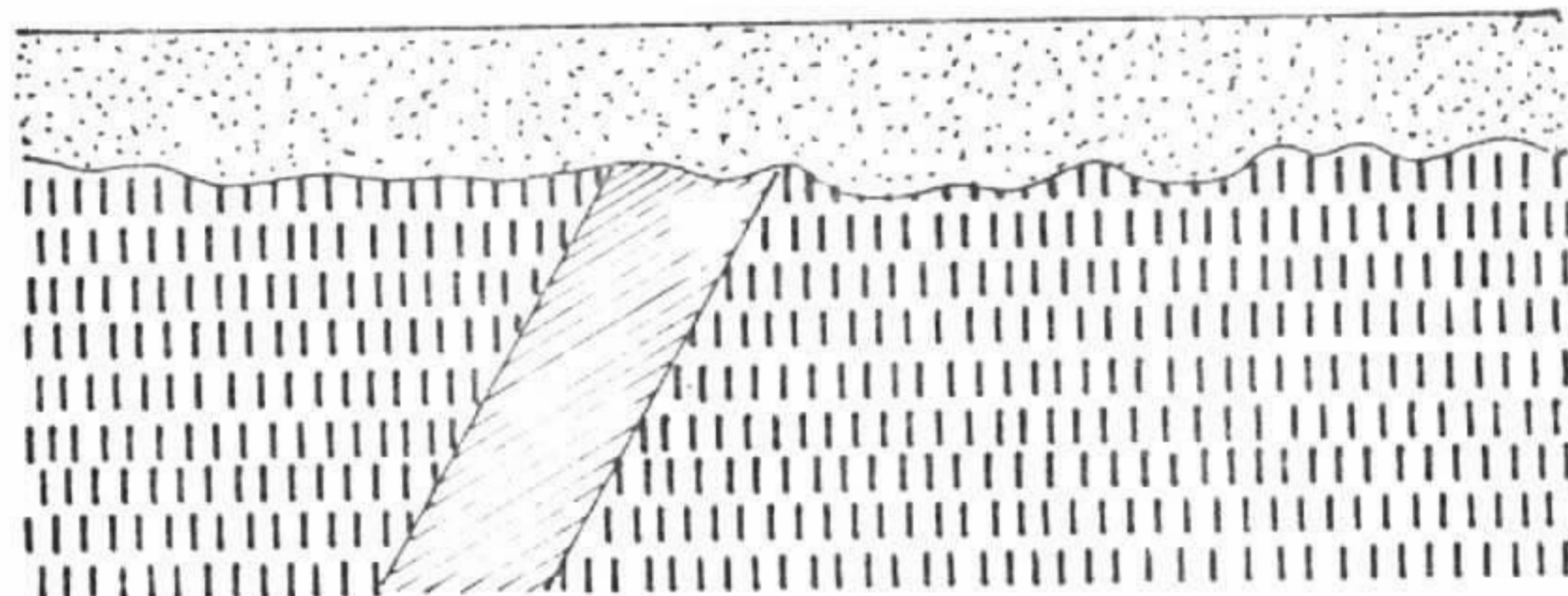
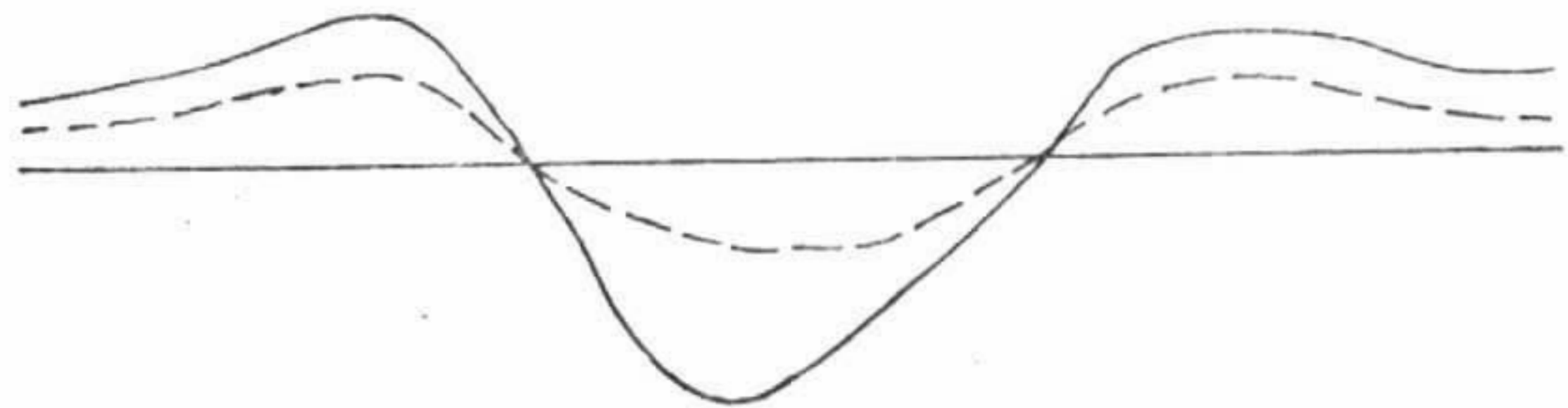
Finalizando, agradeço à CPRM, a oportunidade de me honrar com tal distinção em participar de acontecimento de tão alto nível em termos de geofísica.

*C. Eduardo J. Cardoso*  
CESAR EDUARDO TEIXEIRA CARDOSO  
Geofísico do DEPRO



BRAZILIAN GEOPHYSICAL SOCIETY (SBGf)

INTERNATIONAL SYMPOSIUM  
ON APPLIED GEOPHYSICS  
IN TROPICAL REGIONS



ABSTRACTS

BELEM-BRAZIL  
SEPTEMBER 1-8

1982



## FINAL PROGRAM

Wednesday, September 1

### GEOPHYSICS APPLIED TO GROUNDWATER

#### INVITED SPEAKERS (8:00 – 12:00 Noon)

**A.A.R. Zohdy** (United State Geological Survey, U.S.A.): On state-of-the-art of groundwater geophysics.

**H. Flathe** (Bundesanstalt für Geowissenschaften und Rohstoffe, Germany): On groundwater geophysics.

**W. Sauck** (Western Michigan University, USA): An overview of groundwater problems and geophysical approaches toward their solutions in the lower Amazon region, Brazil.

**O.A.L. da Lima** (Universidade Federal da Bahia, Brazil): On groundwater geophysics in northeastern Brazil.

#### PAPERS (2:00 – 4:30 PM)

**The Application of Geoelectrical Sounding in the Gombe Area, Bauchi, State of Nigeria**

B. D. Ako, Department of Geology, University of Ife, Nigeria.

**A Tentative Method of Correlation between Electrical Resistivity of Sediments and Pollution Levels**

C. José, Instituto de Geociências e Ciências Exatas-UNESP, Rio Claro; A. R. L. Gonçalves, Departamento de Ciências Biológicas UFSCar, São Carlos; J. M. Mendes, Instituto de Geociências-USP, São Paulo; D.A. Giusti, Departamento de Geologia, UFPR, Curitiba, Brazil.

**A Regional Resistivity Survey for Groundwater in the Marajó Island-Brazil**

L. Rijo, M. Porsani and A. Abel, Núcleo de Ciências Geofísicas e Geológicas, UFPA, Brazil and A. C. Tancredi, Instituto Nacional de Pesquisa da Amazônia, Brazil.

**The use of Spontaneous Potential as a Reconnaissance Method for Groundwater Exploration on Marajó Island, Pará-Brazil**

W. Sauck, Western Michigan University, U.S.A.

**Saltwater – Freshwater Distribution in Coastal Aquifers of the Southern-most Part of the State of Bahia, Brazil**

O.A.L. de Lima, Universidade Federal da Bahia, Brazil.

#### WORKSHOP (5:00 – 6:30 PM)

Evaluation of geophysical investigations in mapping of the saltwater-freshwater interface and aquifers in sedimentary and hard rock regions. Discussion of the interpretational problems of electroresistivity.

Thursday, September 2

### MATHEMATICAL MODELLING IN APPLIED GEOPHYSICS

#### INVITED SPEAKERS (8:00 – 11:00 AM)

**G.H. Hohmann** (University of Utah, USA): Numerical modelling for electrical methods.

**N.N. Nabighian** (Newmont Exploration Ltda., U.S.A.): On time-domain electromagnetics.

**L. Rijo** (Universidade Federal do Pará, Brazil): On mathematical modeling in applied geoelectromagnetism.

#### PAPERS (11:00 AM – 12:00 Noon)

**The Strike Effect of 2D-Geological Structure on IP-Resistivity Pseudo-Section**

P. B. M. Guimarães and L. Rijo, Núcleo de Ciências Geofísicas e Geológicas, UFPA, Brazil.

**EM Modelling of 3D Bodies in a Conductive Ground**

S. C. Guerreiro, Programa de Pesquisa e Pós-Graduação em Geofísicas, UFBA, Brazil.

#### PAPERS (2:00 – 4:30 PM)

**A Constitutive Equation for Electrically Polarizable Media; Induced Polarization**

A. F. Gangi and A. Benavidez, Department of Geophysics, Texas A and M University, U.S.A.

**Non-linear Magnetic Inversion Using a Random Search Method**

J.B.C. Silva, Núcleo de Ciências Geofísicas e Geológicas, UFPA, Brazil and G. W. Hohmann, Geology and Geophysics Department, University of Utah, U.S.A.

**Solution of Linear Inverse Problem in Region near the Magnetic Equator**

J.A.M. Moreira, Departamento de Física, UFRN, Natal; A.L. Padilha, N. Ussami, Instituto Astronômico e Geofísico, USP, Brazil.

**Multi-Dimensional Recursive Filters**

E.J.C. Jucá, Programa de Pesquisa e Pós-Graduação em Geofísica, UFBA, Brazil.

**An Approach to Inversion of Three-Dimensional Resistivity Inhomogeneity**

O. Agunloye, Geothermal Research Laboratory, Brink Jones and CO. Ltda., Nigeria

#### WORKSHOP (5:00 – 6:30 PM)

Utilisation of modern numerical methods – integral equation, finite element, boundary element and hybrid methods for modelling complex earth to resolve electromagnetic and electrical prospecting problems.

Analysis of low magnetic latitude-interpretational problems of the magnetic data.

Friday, Saturday and Sunday, September, 3, 4 and 5

### EXCURSION TO CARAJÁS

(Continue on inside of the back cover)



Monday, September 6

**DEVELOPMENT OF GEOPHYSICAL INSTRUMENTS FOR TROPICAL REGIONS**

**INVITED SPEAKERS (6:00 AM – 12:00 Noon)**

**K. Vozoff** (Macquarie University, Australia): On state-of-the-art of magnetotelluric methods.

**W. A. Pelton** (Phoenix Geophysics, Canada): On IP and MT.

**J. Bischoff** (Technische University Berlin, West Germany, and Universidade Federal do Pará, Brazil): On development of geophysical instruments for tropical regions.

**C. A. Dias** (Universidade Federal da Bahia, Brazil): On multifrequency electromagnetic method applied to mineral exploration.

**PAPERS (2:00 – 4:00 PM)**

**Use of Magnetotelluric Method in Estimation of Sedimentary Layers**

S. C. G. Dutra, N. B. Trivedi, D. J. R. Nordemann R. A., Mendes, J. C. Maldonado and J. B. Neto, Instituto de Pesquisa Espaciais-CNPq, Brazil.

**A Magnetotelluric Measuring System for Medium Depth Prospection**

N. R. M. Fonseca, and J. Bischoff, Núcleo de Ciências Geofísicas e Geológicas, UFPA, Brazil.

**Automatic Laboratory System for the Measurement of the Complex Electrical Resistivity**

J. Bischoff, and B. B. Rocha, Núcleo de Ciências Geofísicas e Geológicas, UFPA, Brazil.

**Development of Geoelectrical Techniques and Applications in Nigeria: A Case Note**

O. Agunloye and O. Ofrey, Geotechnical Research Laboratory, Brink Jones and Co. Ltda., Nigeria.

**WORKSHOP (4:30 – 6:30 PM)**

The design and modification of geophysical instruments in view of the geophysical conditions – low latitude, conductive overburden, high natural AFMAG fields; terrain conditions – large water covered areas, tropical forest; and climatic conditions.

Tuesday, September 7

**INVITED MINING GEOPHYSICS II**

**INVITED SPEAKERS (8:00 – 11:00 AM)**

**S.H. Ward** (University of Utah, USA): On state-of-the-art and perspective for mining geophysics.

**K. McCracken** (CSIRO, Australia): Electrical Geophysics in the arid and tropical zones of Australia

**J. S. Lourenço** (Universidade Federal do Pará, Brazil): On the Brazilian experience in applied geophysics.

**PAPERS (11:00 AM – 12:00 Noon)**

**The Effects of a Tropical Rain Forest Coverage on the Airborne Gamma-Ray Spectrometry**

E. B. Pereira, D.J.T. Nordemann and L.M. Martin, Instituto de Pesquisas Espaciais – CNPq, Brazil.

**On The Near Surface Effect of a Tropical Forest in Airborne Gamma-Ray Spectrometry**

J. M. Travassos, Observatório Nacional-CNPq and A.C.B. Pires, CNPq, Brazil.

**PANEL DISCUSSION ON GEOPHYSICAL RESEARCH AND EDUCATION IN DEVELOPING COUNTRIES (2:00 – 6:00 PM)**

Wednesday, September 8

**MINING GEOPHYSICS II**

**INVITED SPEAKERS (8:00 – 11:00 AM)**

**J. Behrens** (Technische Universität Berlin, West Germany): On high resolution seismics applied to coal exploration.

**G. Palacky** (Billiton International Metals, The Netherlands): On EM prospecting in tropical regions.

**O. P. Verma** (Universidade Federal do Pará, Brazil): Analog EM modeling and the modifications of EM anomalies due to a partially conducting environment.

**PAPERS (11:00 AM – 12:00 Noon)**

**Airborne Magnetic Susceptibility Mapping**

J.B.C. Silva, Núcleo de Ciências Geofísicas e Geológicas, UFPA, Brazil and G. W. Hohmann, Geology and Geophysics Department, University of Utah, U.S.A.

**Ridge Regression Applied to Aeromagnetic Data Inversion**  
L. W. B. Leite and J.W.D. Leão, Núcleo de Ciências Geofísicas e Geológicas, UFPA, Brazil.

**PAPERS (2:00 – 4:00 PM)**

**On the Interpretation of Gravimetric Surveys Carried Out in Tropical Regions**

N. L. E. Haralyi, M. da C. A. B. Lima and J. M. Flexor, Observatório Nacional – CNPq, Brazil.

**Electric Field about a Point Source of Alternate current on the Surface of a Homogeneous Half-space**

E.E.S. Sampaio, Universidade Federal da Bahia, Brazil.

**The Effects of a Conductive Overburden on E. M. Response of Tilted Conductive Half-Planes**

L. M. da C. Silva and O. P. Verma, Núcleo de Ciências Geofísicas e Geológicas, UFPA, Brazil.

**Recognition of E. M. Overburden Anomalies with HLEM Survey Data**

C. Villegas, Consejo de Recursos Minerales, Mexico and G. F. West, University of Toronto, Canada.

**Induced Polarization: Simulation and Inversion of Non-Linear Mineral Electrodeics**

O. Agunloye, Geotechnical Research Laboratory, Brink Jones and CO. Ltda., Nigeria.

**WORKSHOP (4:30 – 6:30 PM)**

Analysis of the applicability of various geophysical methods in tropical regions in view of the presence of conducting overburden, rain forest, low magnetic latitude, proximity to the natural sources of EM fields (AFMAG) on the one hand and on the other the vast potentialities of the mineral resources in these regions.

## CONFERENCE PROGRAM COMMITTEE

L. RIJO (Committee Chairman), UFPA; J. S. LOURENÇO (Organizer of the Symposium) UFPA; C. A. DIAS, UFBA; A. C. PIRES, CNPq; O. P. VERMA, UFPA; J. BISCHOFF UFPA; A. G. OLIVEIRA, FAPESP.

The Symposium is supported by grants from CNPq, UFPA, FINEP, FAPESP, GTZ and CAPES.



## INVITED PAPERS

ON STATE-OF-THE-ART OF GROUNDWATER GEOPHYSICS

ZOHDY, A.A.R.\*

*C. Eduardo T. Corobos*

Almost all geophysical methods have been used in groundwater exploration, but the direct current resistivity method always has been and continues to be the most extensively used method. In the past decade, several significant developments have been accomplished in the acquisition, interpretation and presentation of d.c. resistivity data. At present it is not uncommon with Schlumberger soundings to expand the current electrode spacing ( $AB/2$ ) to a distance of 5 km or more to determine the depth to basement, and recently a method has been developed for processing and interpreting Schlumberger sounding data obtained along winding roads. Furthermore, a multichannel instrument for simultaneously measuring the potential differences between 16 pairs of electrodes has been developed by the U.S. Geological Survey. This system should allow the making of soundings and profiling at a substantial savings in time.

Since the early 1970's the interpretation of sounding data in terms of one dimensional horizontally stratified media has rapidly moved from the curve matching methods to the completely automatic interpretation of the data and ultimately to the use of computer generated color cross sections of interpreted true resistivities. For vertical layers (dikes) an extremely rapid procedure using the Gauss-LaGuerr method of numerical integration has been developed for computing the apparent resistivities when an electrode array is oriented at right angles to the strike. The development of this technique has led to the development of an approximation method in which both horizontal and vertical boundaries are combined to compute sounding curves over two and three dimensional structures. Such approximate computations can be made with most programable calculators or much more efficiently with a desk top computer. The method can be used to generate excellent approximation models that can be tested if necessary with other more elaborate two and three dimensional computation techniques.

Applications of the d.c. resistivity method continue to be in: (a) mapping buried stream channels (as in Minnesota); (b)



studies of sea water intrusion into coastal aquifers (as in Florida, Georgia, and in Sri Lanka); (c) mapping the depth and thickness of basaltic aquifers (as in Idaho, Nevada, and on the Islands of Hawaii); (d) basin studies for evaluating the depth to the fresh-salt water interface and the depth to basement (as in Arizona, Texas, and Utah).

Theoretical and practical problems to be solved include the development of fast and accurate methods for the computations of completely generalized two and three dimensional structures, the development of efficient field methods for collecting data suitable for two and three dimensional analysis, the development of efficient high resolution methods, the development of procedures to eliminate and or to correct for cultural effects (fences and pipe lines); and to seek the development of a new geophysical method that can be used for the direct detection of water.

\* U.S. Geological Survey, U.S.A.

#### AN OVERVIEW OF GROUNDWATER PROBLEMS AND GEOPHYSICAL APPROACHES TOWARD THEIR SOLUTIONS IN THE LOWER AMAZON REGION, BRAZIL

SAUCK, W.A.\*

Various locations in the Lower Amazon region have problems with groundwater supply and water quality. These problems are certain to increase as industrialization, agricultural intensification, and population also increase. Understanding the groundwater situation requires also an understanding of surface hydrology, geology, and hydrochemistry. Some problems are worsened by a very pronounced dry season. Geologically, the area has two principal types: thick lateritic soils, rich in clays, developed on stable Precambrian platforms; and young deltaic sediments having predominantly clay, silt, and fine sand. Extensive coarse sand or sandstone aquifer materials are rare. Hydrochemical studies made during the past five years show surface waters and ground water from aquifers having good circulation to be of excellent chemical quality. However, stagnant aquifers in low-lying areas, the majority of Marajo Island for example, have brackish waters. Salt water intrusion



from the Atlantic is only a minor contributor to this problem, as the immense flow of fresh water keeps the shores of Marajo Is. bathed in fresh water for more than ten months per year, even at the most seaward extremity. Acid soils, almost zero hydraulic gradient, and hence long residence times of ground water lead to active leaching and diagenesis of the young sediments. Electrical geophysical methods have been used extensively in the region for nearly ten years. Large-scale investigations using principally Vertical Electrical Soundings have been done on Marajo, with lesser activity from Belem to as far east as Capanema. Field resistivities range from a fraction of an Ohm-m to many tens of thousands of Ohm-m. Access is very difficult to many field areas and conditions for working are often difficult to hostile. Interpretation of VES data routinely uses the Ghosh linear filter technique, coupled with geologic models based on the present understanding of the geologic history. The model for some of the better aquifers which have been found is sand-filled distributary channels, locally termed paleochannels, which are embedded within silts and clays. Other minor aquifers near the shoreline occur in abandoned strand lines dating from a time of slightly higher sea level. The S.P. method shows some promise as an independent, economical reconnaissance method for locating shallow fresh-water aquifers. Due to the drastic changes in agricultural planting patterns and large increases of new farmland required by Brazil's national alcohol program, proposals are made for alternate uses for much of the lowland of Marajo Is., based on the reclamation technology of the polders of the Netherlands. Such a change would require longterm resistivity and hydrologic research and monitoring on Marajo Island.

\* Dept. of Geology, Western Michigan Univ. Kalamazoo, MI 49008

#### APPLICATION OF GEOPHYSICAL METHODS TO GROUNDWATER EXPLORATION IN BAHIA, NORTHEASTERN BRAZIL

LIMA, O.A.L.de\* and DIAS, C.A.\*

Since 1970 the Research and Graduate Program in Geophysics of the Federal University of Bahia has been conducting research on the optimization of the use of geophysical methods in combination with geological studies and drilling, for solution of



groundwater problems in the semi-arid region of northeastern Brazil. The main aims are the establishment of models for surface structures, geometry and patterns of ground-water flow in clastic and karstic sedimentary aquifers. Geophysical methods are being also employed in special hydrologic studies such as artificial storage of water within underground reservoirs, groundwater salinization distribution and localization of regions of high potential flow in the most important aquifers of Bahia State. Resistivity, well logs, seismic refraction, and to a lesser extent gravity and multifrequency EM, are the main geophysical methods employed to solve these problems. As supporting work, physico-chemical and isotopic water analyses with C-14 age-dating have also been employed. The most important results are: (i) the selection and the structural delineation of an experimental area for the storage of water and the prediction of its behaviour under a controlled injection regime, showing the feasibility of the proposed technique; (ii) regional definition of the topographic relief of the Bambui limestone substratum and the limits of karstified zones which constitutes aquifers in this unit, delimitation of the areas of recharge and the regional pattern of underground flow in this system; (iii) the establishment of the tridimensional geometry of the complex aquifer systems in the sediments of the Reconcavo and Tucano basins, and in the coastal Quaternary deposits, in selected areas, surface delimitation of salt-water zones in these systems and establishment of models to explain the origin of this salinization.

\* Programa de Pesquisa e Pós-Graduação em Geofísica, Universidade Federal da Bahia, Brasil.

#### NUMERICAL MODELING FOR ELECTRICAL METHODS

HOHMANN, G.W.\*

With the recent development of accurate, flexible, and reliable digital receivers, electrical methods of geophysics now are limited mainly by a lack of interpretation capacity. Layered earth interpretations are often used when they do not apply, because calculating the response of a 2D or 3D model requires a complicated numerical solution and a large amount of computer time and storage. Progress in developing numerical



solutions has been slow but steady over the last fifteen years.

Differential equation (finite element and finite difference), integral equation, and hybrid methods have been used. Differential equation (DE) solutions are easiest to implement, and they result in large banded matrices. Because the entire earth is modeled on a grid, DE methods are preferable for simulating complex geology. Integral equation (IE) formulations involve more difficult mathematics, but the unknown fields only need to be found in anomalous regions. Thus IE solutions are less expensive for calculating the response of one or a few small bodies and hence are most useful for evaluating field techniques, for designing surveys, and for generating interpretation catalogs. Much recent research on 3D modeling has focused on hybrid methods, which attempt to combine the advantages of DE and IE solutions.

Efficient and reliable frequency-domain numerical solutions are available for 2D models with plane wave or line source excitation. However 2D time-domain solutions are only now being developed; both Fourier transform and time stepping techniques are used, partly to provide cross checks.

Zero-frequency solutions are well developed and widely applied for a 2D model with a 3D source such as a grounded wire; DE techniques are used almost exclusively due to their capability for simulating a complex earth. However only two EM solutions (frequency domain) for this important class of model have been published. This neglect is surprising, since discretization is necessary only over a cross-section and hence complex models can be simulated. The price paid is that numerical solutions must be calculated for several values of the Fourier transform variable.

Good 3D solutions are available for the zero-frequency case, but they are not widely applied-probably due to their complexity and cost. Current research is concentrated on the difficult problem of developing numerical EM solutions for 3D models - both time domain and frequency domain. Integral equation formulations have been the most successful. However, the hybrid technique - basically a DE solution with a limited mesh made possible by calculating boundary values using an integral equation - appears promising. Thus far 3D time domain responses have only been calculated by Fourier transforming frequency



domain IE results. Utilizing a vector-scalar potential approach and incorporating symmetry through group theory permits more accurate and efficient frequency domain calculations. Inverse Fourier transforming via the decay spectrum reduces the number of frequency domain solutions required. We are presently working on new 3D direct time domain solutions, utilizing both IE and DE formulations.

\* Geology and Geophysics Department, University of Utah, Salt Lake City, Utah, U.S.A.

#### TIME DOMAIN ELECTROMAGNETICS

NABIGHIAN, M.N.\*

In the time domain electromagnetic methods the earth is energized by a series of current pulses. The secondary voltages are measured during the current-off times when the primary field is practically negligible.

In this paper the theoretical principles of the time domain methods are reviewed and the practical applications to exploration problems are discussed with special emphasis on advantages and limitations of various approaches.

\* Geophysical Department, Newmont Exploration Limited, U.S.A.

#### ON MATHEMATICAL MODELLING OF APPLIED GEOELECTROMAGNETISM

RIJO, L.\*

Based on the earth complexity, type of transmitter sources, transmitter-receiver position with respect to the model and the mathematical and computational difficulties, one can classify the applied geoelectromagnetic modeling into four categories: 1) one-dimensional modeling; 2) two-dimensional MT, EM-line source, and 2D-3D induced polarization and resistivity modeling; 3) axially symmetric three-dimensional, quasi-three dimensional and three dimensional induced polarization and resistivity modeling, and axially symmetric three dimensional



magnetotelluric and controlled source EM modeling and 4) three-dimensional magnetotelluric, quasi-three and three-dimensional controlled source EM modeling. The first category is now an easy task considering the digital linear filter technique. The second category is also very simple using the finite element and integral equation methods. The finite element method is superior because it can handle more realistic earth models. The third category is more difficult and its discussion is the main objective of this paper. The fast finite element (FFE) algorithm is potentially suitable for this class of modeling problem. The fourth category is the most difficult of all. Some results have already been published but it is still in preliminary stages of development compared with the two first categories. Integral equation, hybrid schemes, and fast finite element are the main modeling techniques presently used to solve this class of modeling problem. Hybrid schemes and the FFE algorithm have equivalent objectives, which is to solve the problem in the vicinity of the heterogeneities and thus eliminate the difficulty of solving large systems of linear algebraic equations. In addition to our ability to develop better software to handle such modeling problems, we have now the benefit of new hardware development such as the "number cruncher" array processors and faster scientific desk top mini-computers. It is likely that the coming years will see accelerating development of geoelectromagnetic modeling spurred by more sophisticated numerical algorithms and computer-aided advanced technology.

\* Núcleo de Ciências Geofísicas e Geológicas da Universidade Federal do Pará, Brasil.

#### ON STATE-OF-THE-ART OF MAGNETOTELLURIC METHODS

VOZOFF, K.

In the technical sense, advances in our ability to obtain better MT data and our advances in modelling capability alternately overtake one another. Improved instrumentation, the advent of in-field microprocessors and particularly the "Remote Reference" technique have enhanced the convenience and effectiveness of field surveys while reducing data scatter



remarkably. At the same time developments in 3D modelling, especially the hybrid schemes, have tended to reduce computer costs while permitting us to use more realistic models. Inversion research has given us the tools to exploit the strengths of the method, and to use it most effectively, alone or in conjunction with other methods. Inversion theoretical studies have also given us a much clearer, if not yet satisfactory grasp of the information content of our data. With these technical improvements there is reluctantly emerging the realization that, in MT as in reflection seismology, good interpretation is still a craft. Skilled interpreters are rare and highly prized.

These advances have been encouraged by needs of several kinds, both academic and industrial. Petroleum exploration continues to move into more difficult areas and MT is now given credit for a discovery. Geothermal targets are often ideally suited to the peculiarities of the MT methods, as attested by a rather thick pile of (US Department of Energy) reports on many of our bookshelves. AMT and CSAMT have demonstrated their effectiveness in mineral exploration for targets at depths greater than 300 m. Groundwater exploration and management is also shifting to basins too deep for DC resistivity alone and AMT has demonstrated its ability to deal with their subtleties. Engineering needs of several kinds have been successfully solved by AMT surveys. These indicate that AMT (and sometimes CSAMT) should be generally useful for large scale mineral exploration in deeply weathered areas. The simplified inversion schemes of Bostick and Goldberg offer almost immediate preliminary interpretation by hand calculator in the field, while making it easier to explain the results to nonspecialists. Improvements are still highly desirable in the costs of MT and AMT, and in the way in which these are reported.

In the more academic area, new interest in some earlier MT results in the US has been aroused by their correlation with deep crustal (COCORP) seismic features. The interpretation by Oldenburg of Filloux's marine results show a relationship between temperature distribution and the age of the sea floor. MT measurements may be possible in oil wells by combining Squid gradiometers, for current density measurements, with Squid magnetometers. The recent demonstration by Cevallos and Martinez that impedance is a (diagonalizable) pseudotensor rather than an



(off-diagonalizable) tensor has clarified a situation that has disturbed many of us for nearly 20 years.

\* Centre for Geophysical Exploration Research, Macquarie University, Australia.

ON IP AND MT

PELTON, B.\*

In the past five years the growth of portable computing power has led to dramatic changes in IP and MT instrumentation and data processing.

IP receivers can now make measurements on one current channel and six voltage channels over nine decades of frequency, from 65 KHz to one cycle in four hours. Deconvolution of the current waveform is done in real time, and so is computation of the mean and standard deviation of the amplitude and phase of the resistivity transfer function.

IP transmitters have recently grown in size to meet the demands of hydrocarbon exploration in conductive sedimentary basins. Phoenix Geophysics and a group of fourteen major oil companies have succeeded in building a 100 Kw, 100 Amp, 2000 Volt IP transmitter. The equipment is presently being used to detect subtle zones of alteration or pyrite chimneys overlying hydrocarbon deposits.

A fast HP9845 computer is used to separate the large electromagnetic coupling effects from the small IP effects. Forward and inverse two dimensional modelling is then carried out on a VAX 11/750 and a FPS 100 array processor.

The same HP9845 computer is used in the field as the processor for a real-time, remote reference MT system. With 16 input channels the equipment can conduct 5 MT soundings simultaneously. Since the antialias filters are programmable and the digitizer is 16 bits, the system can acquire the data from 384 Hz to 1820 sec completely automatically. All plots are available in real time with one keystroke and can all be dumped in final report form within 15 minutes of the completion of the run.

\* Phoenix Geophysics, Canada.



ON DEVELOPMENT OF GEOPHYSICAL INSTRUMENTATION FOR TROPICAL  
REGIONS

BISCHOFF, J.\*

The climate of more than 80% of the Brazilian territory is typical of the humid and subhumid tropics, characterized by annual precipitation of more than 650 mm, heavy seasonal rainfall and small temperature variation throughout the year. These climate conditions, which lead to weathered conductive layer, affect geophysical measurements and thus the methods developed for countries with temperate climate are less effective in the tropical environment. While seismic, gravity and magnetic surveys are not influenced except for instrumental problems caused by high relative humidity, the electrical and electromagnetic surveys are affected by the surface conditions. During the past years attempts were made by the NCGG to adapt and modify instruments for these conditions taking into consideration the often remote prospecting areas with extremely difficult access. Two examples illustrate the successful adaptation of instruments for special applications: An electromagnetic system to locate shallow, fresh water aquifers within brackish areas on Marajó Island in the north of the State of Pará and an electrical system for resistivity surveys in the large water-covered areas of the Amazon regions.

\* Núcleo de Ciências Geofísicas e Geológicas, Universidade Federal do Pará, Brasil.

ON THE MULTIFREQUENCY ELECTROMAGNETIC METHOD APPLIED TO MINERAL  
EXPLORATION

DIAS, C.A.\* and SATO, H.K.\*

This work is a verification and a further development of the idea, first introduced by Dias, on a new method for measuring and interpreting resistivity and induced electrical polarization (IP), using multi-frequency electromagnetic data. For this purpose, a 12-frequency prototype system was specially constructed, consisting of a vertical magnetic dipole transmitter operating at



minimum coupling with a horizontal dipole receiver, measuring absolute magnetic field components in-phase and quadrature, at the values of frequency given by  $21 \times 2^{n-1} \text{ Hz}$ ,  $n=1$  to 12. The field survey was done over a conducting body which possesses a strong effect of induced polarization, in the Jaguarari District, State of Bahia, Brasil, showed that Dias' qualitative scheme proposed for interpretation of inductive IP was able to delineate the anomalous zone. As to resistivity, a further development of the original scheme relates to the possibility of constructing vertical sections of ground resistivity on a laterally heterogeneous medium, as a consequence of two basic steps: (i) the determination of the behavior of the "skin depth" due to a dipole source as a function of the ground electromagnetic response to the excitation. These ideas also provide a framework for an objective discussion on the question of "depth of exploration", when active systems are used. The resistivity profiles so obtained presented an excellent agreement when compared to the geological, geophysical and drilling evidence, known for the studied area. The same scheme for resistivity was also tested for theoretical data, generated using two models: sphere in free space, and three horizontal layers half-space. In both cases, the geometrical patterns obtained for the conductors reproduced the true ones, with some distortions. However, these results were considered good enough to demonstrate that the idea of a geometrical "focus" is physically sound and geophysically invaluable.

\* Programa de Pesquisa e Pós-Graduação em Geofísica, Universidade Federal da Bahia, Brasil.

#### STATE OF THE ART AND PERSPECTIVE FOR MINING GEOPHYSICS

WARD, S.H.\*

The problems encountered in mining applications of the resistivity, induced polarization, and electromagnetic methods are reviewed in detail. Means for minimizing many of these problems are described. This then sets the stage for presentation of some recent developments in these methods. The state of the art for these methods is thus established.



For gamma-ray spectrometry, the problems encountered in its use are reviewed briefly. The use of the full spectrum in gamma-ray spectrometry permits more accurate estimates of uranium, thorium, and potassium concentrations in the ground.

The article concludes by noting two recent developments in magnetics: digital data storage and retrieval for portable ground magnetometers, and commercialization of airborne vertical gradiometers.

\* Department of Geology and Geophysics, and Earth Science Laboratory Division  
Research Institute, University of Utah, U.S.A.

## ELECTRICAL GEOPHYSICS IN THE ARID AND TROPICAL ZONES OF AUSTRALIA

McCRACKEN, K.G.\*

The acceptance and understanding of electrical geophysics has undergone a major revolution in Australia in the past 10 years. Where we were once entirely dependent upon imported ideas and technology, we now make a significant contribution to world research both through our own efforts, and through provision of field histories such as the Elura test case. We now manufacture 30% of the world production of transient EM systems.

Our experience is of relevance to this conference for two reasons, thus:

- (1) some of our developments have been stimulated by the needs of metaliferrous/agricultural geophysics in tropical Australia, and
- (2) the manner in which a very small research community has been able to meet the specific needs of our continent may provide guidance to other countries who, like us, have found over-reliance on imported technology to be demaging to the professional standards of the local geophysical community.

In this paper, I first outline the changes that have occurred in Australian electrical geophysics during the



past decade, and then review the research that is currently in progress.

\* CSIRO, Division of Mineral Physics, Australia

#### ON THE BRAZILIAN EXPERIENCE IN APPLIED GEOPHYSICS

LOURENÇO, J.S.\*

The great progress in basic sciences and technology during the last decades has provided the basis for a significant advance in the methods, techniques and interpretative procedures used in applied geophysics.

In Brazil, the activities in applied geophysics were at the beginning circumscribed to the exploration for oil performed by PETROBRÁS - the Brazilian oil company, but during the decade of the seventies has expanded considerably to other areas, such as engineering, hydrogeology and mineral exploration.

The future for applied geophysics in a country like Brazil seems auspicious, considering the continental dimensions of the Brazilian territory, and its scarcely known mineral resources.

\* Sociedade Brasileira de Geofísica-SBGf

#### HIGH RESOLUTION SEISMICS APPLIED TO COAL EXPLORATION

BEHRENS, J.\*

The paper deals with fine-structure investigations of thin layers with high reflection coefficients such as coal seam sequences.

The wave propagation in a cyclically layered medium in the presence of homogeneous and stratified overburden



structures is characterized by complicated interference signals mainly composed of peg-leg multiples. The presence of significant signal distortions obstruct the interpretation of the real coal seam structures.

It was the aim of the work to study the applicability of different evaluation methods e.g. homomorphic filtering to the problem of coal seam investigations.

\* Institute of Applied Geophysics, Technical University of Berlin, Federal Republic of Germany.

## ELECTROMAGNETIC PROSPECTING IN TROPICAL REGIONS

PALACKY, G.J.

Success in electromagnetic prospecting in tropical regions is dependent upon thorough understanding of electrical properties of the weathered layer. Saprolite layers, which are conductive because of their high clay content, are almost always present in tropical weathering profiles. Depending upon climatic, topographic and lithologic variations, the conductivity of the weathered layer may range between 5 and 500 mS/m. Generally, the weathered layer is thin and rather poorly conductive over granite and gneiss, but it can reach a considerable thickness and high conductivity over mafic and ultramafic rocks. The electrical properties can be conveniently studied in situ by resistivity soundings. Also EM measurements can be used to detect changes in conductance of the weathered layer. Several examples from Upper Volta illustrate suitable interpretation techniques.

Important applications of EM methods include prospecting for kimberlites and massive sulphide orebodies, groundwater search and geological mapping. The old, preconceived bias that EM techniques cannot be effectively used in tropical environments has been proven unfounded by recent experience. If EM measurements are properly conducted and interpreted, they can yield as much, if not more, information than in regions of temperate climate. The selective tropical weathering facilitates new applications of EM



methods. Of the four above mentioned uses three depend directly upon enhancement of lithological and structural features by the weathering process (kimberlite prospecting, groundwater search and geological mapping). The four applications will be illustrated on airborne and ground EM data from Brazil and Africa. In interpretation of airborne EM data, statistical techniques should be used to distinguish lithological anomalies from those caused by discrete sources (e.g. massive sulphides). In conducting ground measurements, care must be taken in selecting the most suitable instrument and operations parameters (e.g. frequency, coil separation).

\* Billiton International Metals, The Hague, Netherlands

#### ANALOG EM MODELING AND THE MODIFICATIONS OF EM ANOMALIES DUE TO A PARTIALLY CONDUCTING ENVIRONMENT

VERMA, O.P.\*

Electromagnetic analog models in applied geophysics are most often used to resolve interpretation problems and to understand the large scale phenomena in the laboratory under controlled conditions. Although numerical solutions of realistic situations of EM prospecting advanced highly vis-a-vis the computation technology in the seventies, the scale models are still essential as well as complementary to study the response of the complex geoelectromagnetic situations for which the numerical approach is cumbersome. The reduction in the linear dimensions of the model is compensated for either by increasing the conductivity or the frequency or both according to the law of EM similitude. Experimental set-up consists of (a) the transmitting system (b) receiving-signal analysing-recording system and (c) the physical model simulating the prospecting conditions at a reduced scale.

Some important results are reviewed for the effects of the partially conducting (a) overburden (b) host-rock and (c) halo on the EM anomalies. These, in general, greatly modify the anomalies - both the phase and amplitude - thus, complicating the interpretation. Multifrequency and multi-coil systems of EM prospecting have been advocated by various authors as a solution.

\* Núcleo de Ciências Geofísicas e Geológicas da Universidade Federal do Pará, Brasil.



## CONTRIBUTED PAPERS

### THE APPLICATION OF GEOELECTRICAL SOUNDING IN THE GOMBE AREA, BAUCHI STATE OF NIGERIA

AKO, B.D.\*

The Gombe area though immediately underlain by a sequence of sedimentary rocks lies in that northern part of Nigeria (between lat  $11^{\circ}00'$  to  $11^{\circ}15'$  E and long  $10^{\circ}15'$  to  $10^{\circ}25'$  N) generally referred to as the "water-less country". The need for adequate water supply from groundwater source has prompted pre-drilling investigation to locate and map high yield aquifers in the Kerri, Gome, Pindiga, Yolde formations and the Bima sandstone which directly overlies the basement complex rocks of Nigeria. The obtained data from 31 VES stations located on the outcrops of the formations listed above do not show any appreciable differences in the electrical properties of the various formations.

Furthermore, although the electrode separation (AB/2) was often greater than 1000 m the depth of investigation rarely exceeded 400 m.

A re-interpretation of the data based on grouping according to formations penetrated however yielded a far more superior information on the complex subsurface geology.

Evidently the principles of suppression and equivalence did affect some of the curves, but the effect of conductive overburden which is usually prevalent in the tropical environment was minimal.

\* Department of Geology, University of Ife, Nigeria.

### A TENTATIVE METHOD OF CORRELATION BETWEEN ELECTRICAL RESISTIVITY OF SEDIMENTS AND POLLUTION LEVELS

CLOVIS, J.\*, GONÇALVES, A.R.L.\*\*\*, MENDES, J.M.B.\*\*\*, GIUSTI, D. A.\*\*\*\*

The Electrical resistivity method was applied to determine the contamination effects of the polluted river water



on the aquifer in Quaternary deposits. This geophysical method was considered suitable to study this problem because the electrical resistivity of the aquifer is highly susceptible to chemical variations in the groundwater.

Electrical soundings, on parallel and perpendicular lines to the banks of the Pinheiros river in the city of São Paulo, were carried out in order to determine the pollution level of the aquifer.

This study demonstrates the viability of the electrical method, which is fast and simple, in determining the pollution levels compared to more cumbersome techniques.

\* Instituto de Geociências e Ciências Exatas, UNESP, Rio Claro-SP, Brasil

\*\* Departamento de Ciências Biológicas, Universidade Federal de São Carlos, Brasil.

\*\*\* Instituto de Geociências (DGG), Universidade de São Paulo, Brasil.

\*\*\*\* Departamento de Geologia, Universidade Federal do Paraná, Curitiba, Brasil.

#### REGIONAL RESISTIVITY SURVEY FOR GROUNDWATER IN MARAJÓ ISLAND- BRAZIL

RIJO, L.\*, PORSANI, M.\*, ABEL, A.\* and TANCREDI, A.C.\*\*

Marajó Island is located in the north of Brazil in the state of Pará. Its area is 49,606 km<sup>2</sup> with approximately 300,000 inhabitants. The principal economic activity is cattle raising with a total of about 500,000 head. Each year, during the dry season, five to ten percent of the cattle die due to the shortage of water, although in the rainy season there is abundant surface water. In the last ten years, a large effort has been made by Government agencies and the University to evaluate the groundwater potential in the eastern half of the Island which is most populated. In this paper we present the results of the automatic interpretation of about 800 VES collected by IDESP and NCGG. Three types of aquifers were identified in the area: a) the bay aquifers in the southeast region, b) the deep aquifers located about 100 meters below the surface and extend throughout the region and c) the shallow paleochannel aquifers scattered on the area. The last type of aquifer is recommended to supply the



cattle farms whereas the bay aquifers are indicated to the population of the southeast region. If these two alternatives are not possible, the deep aquifers could be used.

\* Núcleo de Ciências Geofísicas e Geológicas da Universidade Federal do Pará, Brasil.

\*\* Instituto Nacional de Pesquisas da Amazônia, Brasil, formerly at Instituto de Desenvolvimento Econômico e Social do Pará-IDESP, Brasil.

THE USE OF SPONTANEOUS POTENTIAL AS A RECONNAISSANCE METHOD FOR  
GROUNDWATER EXPLORATION ON MARAJÓ ISLAND, PARÁ, BRAZIL

SAUCK, W.A.\*

The unforested eastern half of Marajo Island, located on the equator at the mouth of the Amazon, is an economically important center of cattleraising activity in northern Brazil. Paradoxically, in spite of being bounded by major fluvial systems and receiving about 3 meters of rainfall per year, the majority of the groundwater on the island is brackish. This lack of reliable potable water causes heavy losses to the ranchers during some of the more severe annual dry seasons. Resistivity methods have been used successfully during the past decade to discover and map some shallow, fresh-water aquifers. Parallel measurements with the S.P. method in several of the field research areas show a striking inverse correlation between the S.P. and resistivity plots of the horizontal profiles. These areas are characterized by shallow water table, almost no topography, uniform Holocene deltaic sediments, natural grassland vegetative cover, and apparent resistivities (Wenner "a"=25m) ranging from 1 Ohm-m background to 100 Ohm-m over fresh-water zones. S.P. over the fresh-water aquifers ranges 50 to 100 mv below the potentials of the background or brackish areas. These considerations, as well as lithologic information from exploratory wells, can be used to eliminate most of the many possible S.P. mechanisms, except the mechanism of chemical concentration potential. Hydrochemical data showing large lateral contrasts in water salinity support the conclusion that the source of the observed potentials is the lateral chemical concentration differences. As another check, the expression for electrochemical potential developed across a cell with activities  $a_1$  and  $a_2$  provides potentials of the correct



magnitude and sign when the specific conductance ratio of the ground water (from test wells) is used in place of the activity ratio. This relationship between S.P. and resistivity on the horizontal profiles is very similar to the S.P. and resistivity relationships in some vertical profiles or logs from oil wells, and has the same principal mechanism as the cause of the S.P. differences, the chemical concentration potential.

In this remote region with no roads or electric power grid, extensive surveying with resistivity requires a heavy load of batteries or a spare motor generator, a large crew, and much more wire and electrodes than the S.P. method. In this geologic and hydrologic environment, the S.P. method is the most rapid and efficient reconnaissance method to locate shallow, fresh-water aquifers, although conventional resistivity methods may be used later to map the horizontal and vertical extent of the aquifers.

\* Dept. of Geology, Western Michigan Univ., Kalamazoo, 49008, formerly at Núcleo de Ciências Geofísicas e Geológicas, Universidade Federal do Pará, Brasil.

#### SALTWATER - FRESHWATER DISTRIBUTION IN COASTAL AQUIFERS OF THE SOUTHERNMOST PART OF THE STATE OF BAHIA

LIMA, O.A.L. de\*

The existing and the future possibilities of saltwater contamination of the Quaternary and Tertiary aquifers of the coastal areas of Caravelas and Alcobaça counties - Bahia, were studied through the analysis of 29 VES, two geological logs and one electrical log of wells drilled in the region. The upper main aquifer is a complex aquifer composed of marine sands interbedded with clays and marls, containing an extensive saltwater body invaded by sea water. The lower and most important aquifer of the region, the Caravelas limestone, dips gently toward the east and is found in the area from the depth range of 20 to 40m up to about 600m. It is confined by shale layers and, as indicated by the electrical log of a well drilled near the shore, it contains fresh water up to the depth of 375m. As the Caravelas aquifer does not outcrop in the area, a lateral



hydraulic connection with the Barreiras formation is suggested as the recharging mechanism to the groundwater system. The spatial configuration of the systems with a saltwater body above the Caravelas limestone as shown from the electrical soundings calls for considerable caution in groundwater exploration in this area. Controlled well pumping tests of the Caravelas aquifer to quantify its hydraulic parameters and also to measure the effective leakage between the two systems are necessary for optimum utilization of this groundwater reserve.

\* Instituto de Geociências, Universidade Federal da Bahia, Brasil.

#### STRIKE EFFECT OF 2D-GEOLOGICAL STRUCTURE ON IP-RESISTIVITY PSEUDO-SECTION

GUIMARÃES, P.B.M.\*\* e RIJO, L.\*

The IP-Resistivity surveys carried out in the Carajás mineral district were not orthogonal to the strike of the structure because they were executed on the lines already opened by the geochemistry crews. This fact motivated us to study theoretically the influence of the direction on the IP-Resistivity survey lines with respect to the strike of the structure. We used Rijo's finite element program developed for surveys perpendicular to the structures, with the necessary adaptations. The main modification was in the inverse Fourier transform routine. For the simple case of the perpendicular surveys, the inverse transform is an easy discrete integral with seven points. However for oblique surveys the integrand is oscillatory and therefore the integral to be evaluated is more complex. We adapted a method presented by Ting and Luck using thirteen points in each integration.

It was found that the effect of the direction of the line with respect to the strike is negligible for angles greater than  $60^\circ$ . For smaller angles the effect is to "open" the anomaly with minor changes in its center. There is no obvious way to compensate this effect with changes in the model parameters.

\* Núcleo de Ciências Geofísicas e Geológicas da Universidade Federal do Pará, Brasil.

\*\* Conselho Nacional de Desenvolvimento Científico e Tecnológico /Observatório Nacional, Brasil.



## EM MODELLING OF 3D BODIES IN A CONDUCTING GROUND

GUERREIRO, S.C.\*

The EM response of 3D bodies immersed in a conducting half-space is formulated through equations. Solutions of the equations is obtained by Neumann series instead of the usual systems of linear equations. The singularity of Green's tensor is treated by a method due to Fikioris. A new way of computing the magnetic field is presented to avoid the calculation of the curl of Green's tensor. The limits of the integral equation approach to EM Modelling are clearly established.

\* Programa de Pesquisa e Pós-Graduação em Geofísica da Universidade Federal da Bahia, Brasil.

## A CONSTITUTIVE EQUATION FOR ELECTRICALLY POLARIZABLE MEDIA; INDUCED POLARIZATION

GANGI, A.F.\* and BENAVIDEZ, A.

A number of constitutive equations have been derived for electrically polarizable media. These have been based on phenomenological and microscopic views of the induced polarizability property. Some are based on the accumulation of charges near clay particles in pores which leads to membrane polarization, others are expressed in terms of mixed ionic and electronic conduction paths for the charges (which is expressed in terms of a Warburg impedance) while still others are based on the assumption that the volume current of induced "current couples" is proportional to the primary current density. In addition, others are based on electrochemical interactions in disseminated ores and are modelled by conducting spheres and/or conducting ellipsoids in an electrolyte. While these models are useful in understanding the induced polarization phenomenon, they are unwieldy in solving the boundary-value problems of exploration geophysics using IP. We have developed a constitutive equation by taking a macroscopic or continuum mechanics approach. We find that many of the measured properties of IP media can be described



by simplified cases of the constitutive equation. These simplifications lead to linear differential equations in the electromagnetic field strengths and, as such, allow us to use all the techniques developed for such equations. The results for plane waves in an infinite homogeneous medium are consistent with measured laboratory results. The introduction of frequency-dependent, complex (apparent) dielectric constant and complex (apparent) conductivity is a direct result of the theory which presumes only real dielectric constants and conductivities which are not frequency dependent.

\* Department of Geophysics, Texas A & M University, U.S.A., Presently Visiting Professor of Geophysics, Programa de Pesquisa e Pós-Graduação em Geofísica, Universidade Federal da Bahia, Salvador-Bahia, Brasil.

#### NON-LINEAR MAGNETIC INVERSION USING A RANDOM SEARCH METHOD

SILVA, J.B.C.\* and HOHMANN, G.W.\*\*

A robust magnetic interpretation technique is described. It is based on the minimization of an objective function by a random search algorithm. Instead of just one estimate, this algorithm yields several points in parameter space, all producing objective function values below an assumed noise level. The centroid of the search points is in general a better estimate than each individual search point, specially when data are corrupted by noise. Since no derivatives are employed, even non-differentiable objective functions, such as the  $\ell_1$  norm of residuals can be used. The computation of parameter covariance matrices and confidence ellipses is possible using simple formulas.

The usefulness of R- and Q-mode factor analysis applied to the correlation matrix is demonstrated. The R-mode factor analysis can be used in parameter variance control, and the Q-mode factor analysis provides means to find models which are extreme in some sense.

The technique was applied to theoretical data and to field data from three different geological settings. The results show that the algorithm produces accurate estimates of source parameters under different types of geological constraints.



The proposed technique has three main advantages. First, it attacks the multiple minima problem, which is always present in non-linear inversion. A possible range of acceptable models consistent with a priori geological information is computed. Second, when the multiple minima are not caused by the inherent ambiguity in potential field data, for example when presence of noise in data is significant, or the wrong interpretation model is used, the technique provides parameter estimates which can be more significant than the estimates obtained by most optimization algorithms. Third, it can easily incorporate a priori geological information, which is always available and should be used in order to reduce ambiguity.

The technique can be applied at any stage of magnetic interpretation. However, its efficiency will depend on the amount of a priori geological and geophysical information available.

\* Núcleo de Ciências Geofísicas e Geológicas, Universidade Federal do Pará, Brasil.

\*\* Geology and Geophysics Department, University of Utah, Salt Lake City, U.S.A.

#### SOLUTION OF THE LINEAR INVERSE PROBLEM IN REGIONS NEAR THE MAGNETIC EQUATOR<sup>†</sup>

MOREIRA, J.A.M.\*, PADILHA, A.L.\*\* and USSAMI, N.\*\*

The magnetization distribution in an equivalent layer of finite thickness (linear inverse problem) can be easily done by using the Fast Fourier Transform (FFT) facilities as it can be found in the literature. In the solution of this problem the reduction to the pole is implicit. The practical application of this kind of transformation presents numerical instability as we approach the magnetic equator. Therefore, for magnetization calculated from anomalies caused by bodies found in low magnetic latitude regions the same instability appears.

A technique to eliminate this instability is presented and it has been applied on aeromagnetic data belonging to a low magnetic latitude region of NE Brazil (Seridó Region).



+ This study is supported by FAPESP under grant number 78/1449.

\* Departamento de Física da Universidade Federal do Rio Grande do Norte, Brasil.

\*\* FAPESP. Instituto Astronômico e Geofísico da Universidade de São Paulo, Brasil.

#### MULTI-DIMENSIONAL RECURSIVE FILTERS

JUCÁ, E.J.C. de A.\*

A method for the construction of multi-dimensional recursive filters was obtained. This method permits the construction of recursive filters with required frequency response, amplitude and phase, and is specially important in the construction of recursive filters of two or more dimensions because it avoids the "Huang curse", that is, the factorization impossibility of the general polynomial of two or more variables.

This methods was applied in the design of one and two-dimensional recursive filters for processing potential field data. To check the stability and precision of the filters so designed, they were used to transform the field of two magnetic models. The stable ones presented excellent frequency response and the results of filtering were very good. Although all the filters, synthesised from precision Fourier coefficients, turned out to be stable, no general demonstration of this fact has been obtained.

\* Programa de Pesquisa e Pós-Graduação em Geofísica da Universidade Federal da Bahia, Brasil.

#### AN APPROACH TO INVERSION OF THREE-DIMENSIONAL RESISTIVITY INHOMOGENEITY

AGUNLOVE, O.\*

The three dimensional resistivity problem is formulated as an integral equation and solved by the generalized image approximation technique which takes care of the effect of local



interactions of induced charges at regions with non-vanishing conductivity gradients. The properties of the technique are discussed. Forward modelling consists of pole-pole, dipole-dipole fields and resistivity pseudo-sections generated by an arbitrarily shaped three dimensional inhomogeneity embedded in an isotropic half-space. The inversion of the theoretical data is accomplished after 2 iterations to a high degree of accuracy.

As a further test of the technique it has successfully been applied to simulate the dipole-dipole pseudo-sections generated by Dey and Morrison using the explicit finite difference approximation. The more encouraging results have come from the possibility of inverting Morrison's dipole-dipole pseudo-sections after 4 iterations with 3.2% relative root-mean-square error and being able to predict the three-dimensional anomaly reasonably.

\* Geotechnical Research Laboratory, Brink Jones & Co. Ltd., Nigeria.

#### USE OF THE MAGNETOTELLURIC METHOD IN THE ESTIMATION OF SEDIMENTARY LAYER THICKNESSES

DUTRA, S.L.G.\*, TRIVEDI, N.B.\*, NORDEMANN, D.J.R.\*, MENDES, R. A.\*, MALDONADO, J.C.\* and BIANCHI NETO, J.\*

The usefulness of magnetotelluric measurements in estimation of thickness of sedimentary layers is well known. We describe here the M.T. equipment constructed at INPE and present an illustrative magnetotelluric sounding in the region of Paraná river basin. The M.T. sounding is done in three bands of frequencies 0.001 to 0.05 Hz, 0.01 to 0.5 Hz and 0.1 to 5 Hz.

\* Instituto de Pesquisas Espaciais-INPE, Conselho Nacional de Desenvolvimento Científico e Tecnológico-CNPq, Brasil.



## A MAGNETOTELLURIC MEASURING SYSTEM FOR MEDIUM DEPTH PROSPECTION

FONSECA, N.R.M.\* and BISCHOFF, J.H.\*

For magnetotelluric prospecting a system was developed using three coils for the components of the magnetic field and two channels for electric field. Based on the specific resistivities of the subsurface in tropical regions, the system was designed for a frequency band of 0.1 Hz to 1 KHz. The coils consist of 400,000 turns on a core of mumetal. The frequency response is almost linear within the above mentioned band, insured by compensation windings. The signals of the magnetic and electric fields are amplified, filtered and finally recorded simultaneously on a multichannel tape recorder. For interpretation the analog signals are digitized and directly inputted to the computer system of NCGG. Tests measurements were made on the island of Tatuoca situated in Marajó Bay.

\* Núcleo de Ciências Geofísicas e Geológicas da Universidade Federal do Pará, Brasil.

## AUTOMATIC LABORATORY SYSTEM FOR THE MEASUREMENT OF THE COMPLEX ELECTRICAL RESISTIVITY

BISCHOFF, J.\* and ROCHA, B.R.P. da\*

For the measurement of the complex electrical resistivities of different rock types within the laboratory of Electrical Properties of Rocks of the NCGG-UFPA., an automatic digital system was designed.

The system is capable of determining the amplitude and phase as well as the real and imaginary components of the electrical parameters.

In the time domain minimal sample intervals of 100ns can be achieved. The maximum frequency in the frequency domain is 1 MHz.

The system is controlled by a desk computer which automatically changes the frequency and generates the desired output signal.



The results of different measurements are stacked, corrected, and finally outputted on a printer/plotter.

\* Núcleo de Ciências Geofísicas e Geológicas da Universidade Federal do Pará, Brasil.

#### DEVELOPMENT OF GEOELECTRICAL TECHNIQUES AND APPLICATIONS IN NIGERIA: A CASE NOTE

AGUNLOYE, O.\* and OFREY, O.\*\*

Non-focussed but highly penetrating two-electrode system and the Schlumberger configuration have been used extensively for geoelectrical profiling and sounding respectively in various geological settings in Nigeria. The portable, rugged, and versatile solid state instrument locally designed for this purpose is briefly described. The interpretation technique developed by us is either by the direct method in the wave number space or by an unconditionally stable stochastic inversion scheme employing the transmission line analogy and the linear filter theory. Both methods are accomplished by interactive computer programs.

Examples of the applications discussed are taken from the basement complex areas, sedimentary regions, and the contact zones with respect to structural and stratigraphic prospecting for underground water. The inverted geoelectrical models are compared with actual borehole results where possible and the aquifer characteristics are presented.

\* Geotechnical Research Laboratory, Brink Jones & Co. Ltd., Nigeria

\*\* Department of Geology, University of Ibadan, Nigeria.

#### THE EFFECTS OF A TROPICAL RAIN FOREST COVERAGE ON THE AIRBORNE GAMMA-RAY SPECTROMETRY

PEREIRA, E.B.\*, NORDEMANN, D.J.R.\* and MARTIN, I.M.\*

Theoretical calculations were performed to estimate the effects of a tropical rain forest on the gamma-ray spectrum of



soils at typical gamma-spectrometry altitudes (100 m). The model employed for these calculations assumes four homogeneous layers; the soil, the root system, the vegetation cover, and the atmosphere; and includes both primary and scattered radiations. Absorption for a 35 m height canopy is shown to vary between 40% and 60% of the original gamma-ray photopeaks at 2.62 MeV ( $^{208}\text{Tl}$ ), 1.76 MeV ( $^{214}\text{Bi}$ ), 1.46 MeV ( $^{40}\text{K}$ ), and 0.61 MeV ( $^{214}\text{Bi}$ ), respectively. The average dry biomass (dead and live biomass, including roots) was 60 kg/m<sup>2</sup>, and the water content was 50%, compiled from an extensive list of references. These absorption values are 30% more to nearly twice the absorption calculated for temperate conifer and mixed deciduous forests. Of major interest is the knowledge of the relative contribution of the vegetation cover in the gamma-ray flux measured at low altitudes. The most remarkable characteristic found for the tropical rain forest is the complete masking of the soil gamma photopeak of 1.46 MeV. This is due to the relatively high concentration of potassium in the biomass with respect to the generally potassium depleted soil. The relative contribution of the vegetation over the 2.62 MeV, 1.76 MeV, and 0.61 MeV photopeaks are negligible (less than 17% of the total photopeak area). An experimental assembly is being tested for field measurements and application of the model in some selected areas of the Amazon forest. The authors also suggest the use of gamma-ray spectrometry in the monitoring of the biomass growth and water stress of large standing crops by employing the model and experimental techniques reported here.

\* Instituto de Pesquisas Espaciais-INPE, Conselho Nacional de Desenvolvimento Científico e Tecnológico-CNPq, Brasil.

#### ON THE NEAR SURFACE EFFECT OF A TROPICAL FOREST IN AIRBORNE GAMMA-RAY SPECTROMETRY

TRAVASSOS, J.M.\* and PIRES, A.C.B.\*\*

A forest cover exerts a screening effect on the gamma-ray field due to extended sources in the ground. On evaluating this effect, a tropical rain forest of "terra firme"



type, near Manaus (Brazil), with a biomass of  $10 \text{ g/cm}^2$  is used. The screening is estimated assuming a layered structure of the aerial phytomass. This effect is found to be independent of survey altitude in the range of 100-200 m, with errors being less than 10%. The Monte Carlo method is used to estimate the anisotropy introduced by the trunks. This anisotropy can lead to errors in the estimated screening effect reaching 20%. Radioactive properties of the stands were taken into account. This has been shown to reach 10% of the radiation from gamma-ray sources in the ground.

\* Observatório Nacional/CNPq, Brasil

\*\* Conselho Nacional de Desenvolvimento Científico e Tecnológico-CNPq

#### AIRBORNE MAGNETIC SUSCEPTIBILITY MAPPING

SILVA, J.B.C.\* and HOHMANN, G.W.\*\*

An automated three-dimensional multibody aeromagnetic interpretation technique is presented. It operates on the total intensity map by means of straight forward operations. The magnetic field is reduced to the pole and the magnetization of an equivalent layer of poles is computed at discrete points by a linear inversion procedure. Assuming induced magnetization only, the computed magnetization map can be transformed into a susceptibility map by dividing it by the total intensity of the geomagnetic field.

The computed susceptibility map will approximate the true variations in susceptibility if the magnetic sources have vertical sides, flat horizontal tops lying at the same depth, and bottom at infinity. In this case the horizontal outline of the sources is obtained. In order to apply this technique to large areas, a stabilization procedure is introduced. Using theoretical data, we analyze the effects of violating some of the above assumptions: uneven top, assuming wrong depth to the top, and finite thickness. We have found that in general the technique produces reasonable estimates of the magnetic susceptibility and a rough outline of the sources.

The relationship between this approach and downward



continuation is shown. Using this relationship we conclude that, under certain conditions, the magnetic field continued downward to a level below the top of the sources still contains useful information about the sources at that level.

We applied the technique to field data from three different geological settings. The results show that, when the magnetic sources outcrop, rough topography can be a serious obstacle. In any case, the ambiguity involving depth and susceptibility cannot be resolved without independent geophysical or geological information. However, the susceptibility map will produce a qualitative picture of the susceptibility distribution and an outline of the sources or the depths to the basement, which can be used to select favorable sites for detailed anomaly modeling.

\* Núcleo de Ciências Geofísicas e Geológicas da UFPa, Brasil.

\*\* Geology and Geophysics Department, University of Utah, U.S.A.

#### RIDGE REGRESSION APPLIED TO AEROMAGNETIC DATA INVERSION

LEITE, L.W.B.\* and LEÃO, J.W.D.\*

This work deals with the application of the methodology of Ridge Regression to the automatic inversion of aeromagnetic data on profiles. The problem is approached as the minimization of the object function defined by the Sum-of-Squares of the observation residuals, using the Newton-Raphson estimator in a damped form for the iterative search. The algorithm utilizes the Marquardt's scaling of the problem matrix, and his basic idea for modifying the diagonal additive in order to stay as close as possible to the Gauss-Newton vector. Two synthetic models have been constructed based on the geologic structural outline of the area from which some real data will be interpreted. The experiments on these synthetic profiles have been performed to study the sensitivity coefficients of the isolated semi-infinite vertical bidimensional prisms forming the model; the effect of the damping factor on the convergence in the presence of noise; and the resolution of the method considering only segments of the entire profile.

\* Núcleo de Ciências Geofísicas e Geológicas da Universidade Federal do Pará, Brasil.



ON THE INTERPRETATION OF GRAVIMETRIC SURVEYS CARRIED OUT IN  
TROPICAL REGIONS

HARALYI, N.L.E.\* , LIMA, M. da C.A.B.\* and FLEXOR, J.M.\*

An average standard deviation of 2-2.5 mgals were computed by Haralyi in the elaboration of the Bouguer gravity trend chart of the Central-East part of Brazil (23 square degrees area). Analysis of that data suggests that part of that value, estimated of 1.0-1.5 mgals is related to uncorrected, variable thickness of soils.

Overburden thickness in tropical regions can reach up to 50 meters or more. Under these conditions the direct application of the Nettleton method may result in inconsistent calculated density and consequently incorrect calculations of Bouguer anomalies.

Tests carried out in the Precambrian basement area in the state of Rio de Janeiro show differences of up to 10% between the real density of the rocks and the one calculated by minimum correlation between Bouguer anomalies and topography.

The evaluation of the thickness of the soil and its gravimetric anomaly allowed the reduction of that difference to less than 1%. The Bouguer anomaly map calculated using appropriate density matched the known petrological variations in the test area. Thus, the removal of the "noise" caused by variable thickness of soils and correct density evaluation improved the resolution of the gravimetric interpretation of geological structures.

Some recommendations are presented for the adequate location of the gravity station and, in conclusion, a methodology is proposed tentatively for the interpretation of gravity surveys carried out in regions where the soil thickness is great and variable.

\* Department of Geophysics, CNPq/Observatório Nacional, Brasil.



ELECTRIC FIELD ABOUT A POINT SOURCE OF ALTERNATING CURRENT ON  
THE SURFACE OF A HOMOGENEOUS HALF-SPACE

SAMPAIO, E.E.S.\*

Galvanic alternating current is a source of noise seldom taken into account in Turam and CSAMT data interpretation. On the other hand, IP/CR data interpreters disregard the alternating characteristic of the conducted current, and tacitly assume that the frequency is "very low". In this paper we analyse the behavior of the radial electric field due to a point source of alternating current on the surface of a homogeneous and isotropic half-space. We investigate both a polarizable and a non-polarizable medium, and establish the results by solving Helmholtz's homogeneous wave equation in cylindrical coordinates. We verify that for induction numbers larger than 0.5 the apparent resistivity defined in IP/CR and electrical sounding data deviates considerably from the true resistivity.

\* Instituto de Geociências, Universidade Federal da Bahia, Brasil.

THE EFFECTS OF A CONDUCTIVE OVERBURDEN ON EM RESPONSE OF TILTED  
CONDUCTIVE HALF-PLANES

SILVA, L.M. da C. e\* and VERMA, O.P.\*

The presence of a well-developed conductive overburden in tropical and sub-tropical regions has been found to modify the EM anomalies. As a consequence, the parameters of the target determined on the basis of simple models are found to be in considerable error when the conductive environment is neglected.

The overburden effects were studied with scale models in the frequency domain using the horizontal dipole-dipole system for varying response parameters of the overburden and the ore body as well as for varying depth and dip of the tabular target. The overburden and the ore body were simulated by metallic sheets of varying thickness and conductivity in accordance with the law of electromagnetic similitude.



The results of the present investigation show that the overburden affects the anomaly by causing:

- a) phase rotation;
- b) amplitude reduction;
- c) base level displacement;
- d) reversion of the quadrature and
- e) appearance of an extra peak in the quadrature in the case of low dipping models.

The base level displacement could be avoided by calibrating the equipment in the presence of the overburden. In this case greater amplitude reduction is found.

The development of the extra peak in the case of low dipping models is a consequence of the greater interaction between the overburden and the ore body due to the proximity between them. This peak combined with the reversal in the quadrature component complicates the qualification of the anomalies, yet it provides a qualitative indication of the response parameters of the overburden and the ore body and its dip.

\* Núcleo de Ciências Geofísicas e Geológicas da Universidade Federal do Pará, Brasil.

#### RECOGNITION OF EM OVERBURDEN ANOMALIES WITH HLEM SURVEY DATA

VILLEGAS, C.\* and WEST, G.F.\*\*

Electromagnetic methods have been a traditional and successful tool in the search for sulphide ore deposits for more than than 50 years. The early EM systems were designed to search for those deposits under favorable conditions, in areas where sulphide bodies occur in a relatively high resistivity rock. As a consequence standard interpretation techniques usually treat a detected anomaly as if it had been caused by a uniformly conductive body isolated in a halfspace.

The increasing demand for base metals has forced explorers to search for mineral deposits in unfavorable geological environments. Areas with conductive overburden are now subject to intense EM exploration. Examples of these environments



are the areas covered by glacial clay sediments in the Precambrian Shields and those covered with deep surface weathering in tropical countries. The first problem the interpreter must solve in such areas is the differentiation of anomalies caused by target conductors in the bedrock from those caused by undesirable features. One of the main sources of such "geological noise" are inhomogeneities in the overburden.

In this paper we report results of an extensive analog modelling program conducted to investigate how the Horizontal Loop EM. Method responds to ramp-like, ridge-like and valley-like inhomogeneities in a conductive overburden. In particular we report those responses which can be mistaken as being caused by bedrock conductors. Criteria by which overburden responses and anomalies due to bedrock mineralization can be recognized and differentiated will be provided. In order to apply such criteria, survey data at several frequencies and/or coil separations are required.

\* Consejo de Recursos Minerales, Mexico

\*\* University of Toronto, Canada.

#### INDUCED POLARIZATION: SIMULATION AND INVERSION OF NON-LINEAR MINERAL ELECTRODICS

AGUNLOYE, O.\*

Graph theoretic representations are used to model non-linear electrodicts while forward and inverse simulations are based on reaction rate theory. The electrodict responses are presented as distorted elliptical Lissajous shapes obtained from dynamic impedance over a full cycle. Simulations show that asymmetry in reaction energy barrier causes slight asymmetry in the shape of the response ellipse and hardly affects the phase angle of the complex electrode impedance. The charge transfer resistance and the diffusion constraints tend to have opposite effects. The former causes reduction in the phase angle tending to make the impedance purely resistive. Both of these mechanisms show saturation effects. Charge transfer resistance, in its



limit, forces a thin "S"-type symmetry on the Lissajous patterns while for the diffusion control, the size of the Lissajous patterns begins to reduce after saturation. The fixed layer causes substantial increase in the phase angle and tends to "enlarge" the Lissajous patterns. It is responsible for the hysteresis-like shapes of the Lissajous patterns when superimposed on strong charge transfer resistance. It has been possible to deduce the mechanisms which control the electrodic processes by inverting electrodic parameters from "observed" distorted, non-elliptical Lissajous patterns characteristic of non-linear electrodictics. The results and qualities of the inversion technique are discussed.

\* Geotechnical Research Laboratory, Brink Jones & Co. Ltd., Nigeria.