

GeoPlanet: Earth and Planetary Sciences

Jerzy Sobotka

# Reservoir Rock Diagnostics for Water or Hydrocarbon Exploration

Acoustic and Electric Fields Interaction  
Phenomena in Geophysical Research  
(Seismoelectric & Electro seismic Effect)

 Springer

# **GeoPlanet: Earth and Planetary Sciences**

## **Editor-in-Chief**

Paweł Rowiński, Polish Academy of Sciences, Institute of Geophysics,  
Warsaw, Poland

## **Series Editors**

Marek Banaszekiewicz, Warsaw, Poland

Janusz Pempkowiak, Sopot, Poland

Marek Lewandowski, Warsaw, Poland

Marek Sarna, Warsaw, Poland

The GeoPlanet series is a forum for presenting the latest achievements in the Earth and space sciences. It is published by the GeoPlanet consortium (Earth and Planetary Research Centre) formed by five institutes affiliated with the Polish Academy of Sciences: Institute of Geophysics, Space Research Centre, Institute of Geological Sciences, and Institute of Oceanology, and Nicolaus Copernicus Astronomical Centre. Its main objective is a multidisciplinary approach to link scientific activities in various Earth-related fields (geophysics, geology, oceanology) with Solar System research. Our publications encompass topical monographs and selected conference proceedings, authored or edited by leading experts of international repute as well as by promising young scientists. The GeoPlanet series aims to provide the stimulus for new ideas and discoveries by reporting on the state of the art and laying the foundations for the future development of the Geosciences.

More information about this series at <http://www.springer.com/series/8821>

Jerzy Sobotka

# Reservoir Rock Diagnostics for Water or Hydrocarbon Exploration

Acoustic and Electric Fields Interaction  
Phenomena in Geophysical Research  
(Seismoelectric & Electro seismic Effect)

Jerzy Sobotka  
Institute of Geological Sciences,  
Laboratory of Geophysics  
University of Wrocław  
Wrocław, Poland

The GeoPlanet: Earth and Planetary Sciences Book Series is in part a continuation of Monographic Volumes of Publications of the Institute of Geophysics, Polish Academy of Sciences, the journal published since 1962 (<http://pub.igf.edu.pl/index.php>).

ISSN 2190-5193                      ISSN 2190-5207 (electronic)  
GeoPlanet: Earth and Planetary Sciences  
ISBN 978-3-030-31048-6              ISBN 978-3-030-31049-3 (eBook)  
<https://doi.org/10.1007/978-3-030-31049-3>

© Springer Nature Switzerland AG 2019

This work is subject to copyright. All rights are reserved by the Publisher, whether the whole or part of the material is concerned, specifically the rights of translation, reprinting, reuse of illustrations, recitation, broadcasting, reproduction on microfilms or in any other physical way, and transmission or information storage and retrieval, electronic adaptation, computer software, or by similar or dissimilar methodology now known or hereafter developed.

The use of general descriptive names, registered names, trademarks, service marks, etc. in this publication does not imply, even in the absence of a specific statement, that such names are exempt from the relevant protective laws and regulations and therefore free for general use.

The publisher, the authors and the editors are safe to assume that the advice and information in this book are believed to be true and accurate at the date of publication. Neither the publisher nor the authors or the editors give a warranty, expressed or implied, with respect to the material contained herein or for any errors or omissions that may have been made. The publisher remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

This Springer imprint is published by the registered company Springer Nature Switzerland AG  
The registered company address is: Gewerbestrasse 11, 6330 Cham, Switzerland

## Series Editors

- Geophysics      Paweł Rowiński  
*Editor-in-Chief*  
Institute of Geophysics  
Polish Academy of Sciences  
ul. Ks. Janusza 64  
01-452 Warszawa, Poland  
[p.rowinski@igf.edu.pl](mailto:p.rowinski@igf.edu.pl)
- Space Sciences    Marek Banaszekiewicz  
Space Research Centre  
Polish Academy of Sciences  
ul. Bartycka 18A  
00-716 Warszawa, Poland
- Oceanology      Janusz Pempkowiak  
Institute of Oceanology  
Polish Academy of Sciences  
Powstańców Warszawy 55  
81-712 Sopot, Poland
- Geology          Marek Lewandowski  
Institute of Geological Sciences  
Polish Academy of Sciences  
ul. Twarda 51/55  
00-818 Warszawa, Poland
- Astronomy        Marek Sarna  
Nicolaus Copernicus Astronomical Centre  
Polish Academy of Sciences  
ul. Bartycka 18  
00-716 Warszawa, Poland  
[sarna@camk.edu.pl](mailto:sarna@camk.edu.pl)

# **Managing Editor**

**Anna Dziembowska**

Institute of Geophysics, Polish Academy of Sciences

# Advisory Board

## **Robert Anczkiewicz**

Research Centre in Kraków  
Institute of Geological Sciences  
Kraków, Poland

## **Aleksander Brzeziński**

Space Research Centre  
Polish Academy of Sciences  
Warszawa, Poland

## **Javier Cuadros**

Department of Mineralogy  
Natural History Museum  
London, UK

## **Jerzy Dera**

Institute of Oceanology  
Polish Academy of Sciences  
Sopot, Poland

## **Evgeni Fedorovich**

School of Meteorology  
University of Oklahoma  
Norman, USA

## **Wolfgang Franke**

Geologisch-Paläntologisches Institut  
Johann Wolfgang Goethe-Universität  
Frankfurt/Main, Germany

## **Bertrand Fritz**

Ecole et Observatoire des  
Sciences de la Terre  
Laboratoire d'Hydrologie  
et de Géochimie de Strasbourg  
Université de Strasbourg et CNRS  
Strasbourg, France

## **Truls Johannessen**

Geophysical Institute  
University of Bergen  
Bergen, Norway

## **Michael A. Kaminski**

Department of Earth Sciences  
University College London  
London, UK

## **Andrzej Kijko**

Aon Benfield  
Natural Hazards Research Centre  
University of Pretoria  
Pretoria, South Africa

## **Francois Leblanc**

Laboratoire Atmospheres, Milieux  
Observations Spatiales, CNRS/IPSL  
Paris, France



**Kon-Kee Liu**

Institute of Hydrological  
and Oceanic Sciences  
National Central University Jhongli  
Jhongli, Taiwan

**Teresa Madeyska**

Research Centre in Warsaw  
Institute of Geological Sciences  
Warszawa, Poland

**Stanisław Massel**

Institute of Oceanology  
Polish Academy of Sciences  
Sopot, Poland

**Antonio Meloni**

Instituto Nazionale di Geofisica  
Rome, Italy

**Evangelos Papathanassiou**

Hellenic Centre for Marine Research  
Anavissos, Greece

**Kaja Pietsch**

AGH University of Science and  
Technology  
Kraków, Poland

**Dušan Plašienka**

Prírodovedecká fakulta, UK  
Univerzita Komenského  
Bratislava, Slovakia

**Barbara Popielawska**

Space Research Centre  
Polish Academy of Sciences  
Warszawa, Poland

**Tilman Spohn**

Deutsches Zentrum für Luftund  
Raumfahrt in der Helmholtz  
Gemeinschaft  
Institut für Planetenforschung  
Berlin, Germany

**Krzysztof Stasiewicz**

Swedish Institute of Space Physics  
Uppsala, Sweden

**Ewa Szuszkiewicz**

Department of Astronomy  
and Astrophysics  
University of Szczecin  
Szczecin, Poland

**Roman Teisseyre**

Department of Theoretical Geophysics  
Institute of Geophysics  
Polish Academy of Sciences  
Warszawa, Poland

**Jacek Tronczynski**

Laboratory of Biogeochemistry  
of Organic Contaminants  
IFREMER DCN\_BE  
Nantes, France

**Steve Wallis**

School of the Built Environment  
Heriot-Watt University  
Riccarton, Edinburgh  
Scotland, UK

**Wacław M. Zuberek**

Department of Applied Geology  
University of Silesia  
Sosnowiec, Poland

**Piotr Życki**

Nicolaus Copernicus Astronomical  
Centre  
Polish Academy of Sciences  
Warszawa, Poland

# Foreword

The monograph *Reservoir Rock Diagnostics for Water or Hydrocarbon Exploration: Acoustic and Electric Fields Interaction Phenomena in Geophysical Research (Seismoelectric & Electro seismic effect)* by Jerzy Sobotka is a compact compendium of theoretical and practical knowledge of electric and acoustic mutual interactions and suggestions how the discussed phenomena can be used in geophysical prospecting. The author showed the physical basis of phenomena recognized theoretically in the past which were now classified as useful in applied geophysics for the construction of modern measurement equipment.

The author presents the theory and practical solutions for laboratory and field measurements dedicated to hydrocarbons and water exploration. Common approach to methods determining petrophysical parameters for hydrocarbons (industry object) and water (life object) prospecting is highly sensible because porosity and permeability are crucial properties in recognition storage and fluid flowability in reservoir rocks. Their determination from simple acquisition ways is the basis for hydrocarbons and water prospecting and exploitation. Applicability of the presented solutions known from the theory of physical phenomena recognized during years in design and construction of modern, sophisticated equipment is a second important aspect underlined in the monograph.

Chapters contain the theoretical basis for mutual acoustic and electric fields interactions in rock formation, named seismoelectric and electro seismic effects. Modern technology of weak signals measurements and advanced processing software are able to increase the signal/noise ratio, so the identification of the above-mentioned effects and their measurements are useful tools in applied geophysics. Now, they form the base of advanced solutions in the field data acquisition which were not possible in the previous practice in natural resources prospecting. Great progress observed in applied geophysics acquisition technology encourages constructors to use the known but not yet used physical phenomena. In applied sciences (applied geophysics), the progress is always based on the construction of new, advanced measurement tools or improvement of data processing technology. New solutions based on IT technology can be applied to process the old data to increase the practical ability of better understanding the rock formation and its

properties. In the monograph, the physical bases for the new measurement technology are presented. They are a good illustration of technological trends observed in modern applied sciences. Nowadays, prospection for natural resources (hydrocarbons, water) is a great challenge, because many deposits of high parameters have been earlier exploited. So, scientists and engineers need to focus their attention on difficult, challenging objects applying new technologies which can bring expected results. Physical phenomena described in details in the monograph and suggestions of using them in modern prospection approaches are the great value of the presented work.

Porous, geological formations with their complicated mineral composition, structure and texture, saturated with media of differentiated parameters are complicated objects for investigations of various physical interactions in heterogeneous media. Analysis of electric resistivity of electrolytes and hydrocarbons in ultrasonic field included in the monograph is an introduction for laboratory and field experiments and modeling of a borehole and artificial rock samples in ultrasonic field. Conceptual and physical experiments with ultrasounds acting on the electrical double layers in heterophase media proved changes in zeta potential, the most important part of the electrokinetic coupling in the filtration component of spontaneous potential measured in SP log related to mechanical stress. Diffusion and sorption processes were also influenced by elastic vibrations. So, finally measurable components of SP signals carrying new information useful from geophysical and geological viewpoint were selected. Such results are a success for the field measurements' simplicity and effectivity.

Transition induced polarization processes observed in sedimentary rocks are the sum of the fast interactions at the interphase boundary and the relatively slow processes associated with diffusion–adsorption in the pore liquid. Individual polarization signal components can be distinguished by acting with acoustic field whose nature is different from that of the original field. The induced polarization signal relaxation components of different duration are linked to the properties of the selected parts of a heterophase medium (liquid, solid phase, electrical double layer), so they carry specific information about the properties of the investigated formation. The seismoelectrical effect and the electroseismic effect (the reverse one) are observed in rocks influenced by seismic (elastic wave) field or electric field. Processes of electromagnetic radiation generation in sedimentary rocks are connected with the activation of diffusion–absorption processes and influence the SP potentials measured in boreholes.

Exemplary results of the applications of physical field interactions in geological formations in field investigations as vibrostimulated electromagnetic radiation and vibrostimulated SP potentials observed above deposits of hydrocarbons are tangible evidence of the practical use of the discussed physical phenomena. The examples are from the 1990–2000s. Now, the field equipment building technology is more advanced, so it is assumed that modern apparatus measuring the discussed effects will be more effective and provide interpreters with the better material.

This monograph, due to the author's scientific basis from his physical study and experience in field and laboratory geophysical measurements, provides the practical solutions based on sophisticated theory which can be the basis for new effective measurement methods providing geophysicists and petrophysicists with good acquisition results.

Kraków, Poland  
May 2019

Jadwiga Jarzyna

# Introduction

During the last decades, the exploration geophysics has relied mainly on traditional prospecting methods. Such methods can be refined through improving measuring devices and of data processing technology as well as through combining different methods into integrated complexes.

Development of essentially new methods in exploration geophysics requires a non-traditional, innovative approach, chiefly at the stage of studying the physical properties of rocks. Particularly promising in this respect seems to be investigation of secondary effects brought about by stimulation of geological formation with one or more physical fields, interacting with one another. New diagnostic and exploration methods can be based on phenomena of such an interaction. Thus, we can induce one physical field, e.g., acoustic one, but then we monitor and measure the system reaction as reflected in the behavior of another physical field, e.g., electrical, or vice versa.

The study here reported was aimed at establishing a set of diagnostic parameters appropriate for characterization of the behavior of a geological medium stimulated by external fields and their interactions, in order to set up a physical basis for inventing new methods in exploration geophysics. The present volume contains a synthesis of laboratory and field investigations carried out by its author during the last several years. Described are theoretical principles (a physical/mathematical model) of applicability of interactions of various types of physical fields in geological media for the needs of exploration geophysics. A detailed description of the invented and then elaborated and developed investigation methods as well as of measuring gauges is given (including laboratory, field, and borehole devices). Experimentally, field and modeling work has been done on the interaction of mechanic/electromagnetic fields in reservoir rocks. An effectiveness of the methodology proposed has been evaluated and shown using case studies that solved certain geophysical diagnostic/exploration problems. The research results have allowed the present author for inventing a number of new geophysical prospecting methods and obtaining letters patents to protect them.