

# Analysis of elastic wave propagation in stratified fluid-filled porous media for interwell seismic applications

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The analytical solution for seismic wave propagation associated with a point force in a fluid-filled porous medium is developed. The point force solution is applied to solve the boundary value problem of seismic wave propagation in a stratified poroelastic medium. The coupled Biot vector wave equations are expressed in cylindrical coordinates and expanded in Fourier series with respect to azimuth. The resulting equations are transformed to the wave-number domain using the Hankel transform method. Following this analysis, one set of three coupled partial differential equations associated with fast compressional, slow compressional, and vertically polarized shear waves is derived. The unknowns are the radial and vertical displacements associated with the solid frame motion as well as the fluid pore pressure. A separate partial differential equation associated with waves whose particle motion is polarized in horizontal planes (*SH* waves) is derived as well. The general solution of the three coupled differential equations is obtained by the Kupradze method. This solution of the Biot's motion equations in the wave-number domain leads directly to closed form expressions for the vector wave displacement and the pressure produced by a point force in a poroelastic unbounded medium. In order to develop the solution of a point force in the presence of a stratified porous medium, the displacement-stress matrix, the pressure, and the vertical component of the displacement of the fluid in its relative motion versus the solid for different regions are expressed in terms of upgoing and downgoing waves and unknown wave coefficients. The wave coefficients are determined by applying boundary conditions of continuity of displacements, pressure and stresses across each layer interface, and the radiation conditions at infinity. To determine the unknown wave coefficients, a method that consists in expressing the kernels of the Hankel transform integrals in terms of factorization of upgoing and downgoing wave amplitudes in each layer is used. These factorizations are based on the generalized reflection and transmission coefficient matrices, which are formed recursively, from one layer boundary to the next, including all of the reflection/conversion/transmission properties of the layered medium. Their factorization method allows the field within each layer above or below the source to be determined once the field in the medium containing the source is known. The final equations provide a complete description of the field throughout the layered medium. The particular form of the equations makes possible the simultaneous evaluation of the response at a number of detector locations for a number of different source positions in a borehole for interwell seismic applications. Numerical model results demonstrate the validity of this theoretical development for predicting spectral responses associated with porosity and permeability effects. The seismic pressure response of a thin gas-saturated porous layer was analyzed. The results inferred that the gas-saturated porous layer strongly attenuates the waveforms observed by detectors within the layer. Alternatively, large multiple reflections and converted waves from the layer are observed by detectors in the water-saturated porous formation.

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## INTRODUCTION

Many sedimentary rocks consist of a porous skeleton saturated with water. This skeleton is made up of granular particles held together by some degree of cementation; the skeleton may be a continuous matrix containing connected solution channels and vugs, or the skeleton may be a mass of fractured rock where the porosity is confined to the cracks among slightly displaced blocks. Those less predominant cases where the pore space is filled with oil or gas are of

special interest, placing important emphasis on the effects of the pore fluids on seismic velocities and other properties of porous rocks.

To approach this problem with a minimum of simplifying assumptions, Gassmann<sup>1</sup> supposed that the properties of the skeleton could be measured in an independent way, and he derived expressions for the corresponding properties of the rock when saturated with any fluid of known properties. In this derivation, he assumed that any relative motion between the fluid and solid was negligibly small in compari-

# Seismic Wave Propagation In Stratified Media

**Brian Leslie Norman Kennett**



## **Seismic Wave Propagation In Stratified Media:**

*Seismic Wave Propagation in Stratified Media* Brian Kennett, 2009-05-01 *Seismic Wave Propagation in Stratified Media* presents a systematic treatment of the interaction of seismic waves with Earth structure. The theoretical development is physically based and is closely tied to the nature of the seismograms observed across a wide range of distance scales from a few kilometres as in shallow reflection work for geophysical prospecting to many thousands of kilometres for major earthquakes. A unified framework is presented for all classes of seismic phenomena for both body waves and surface waves. Since its first publication in 1983, this book has been an important resource for understanding the way in which seismic waves can be understood in terms of reflection and transmission properties of Earth models and how complete theoretical seismograms can be calculated. The methods allow the development of specific approximations that allow concentration on different seismic arrivals and hence provide a direct tie to seismic observations. *Seismic Wave Propagation in Stratified Media* Brian Leslie Norman Kennett, 1983. The success of this book stems from its clear and concise yet detailed summary of the advances in seismic source studies during the past two decades. Dr Kennett presents a mainly theoretical account of the passage of seismic waves from source to receiver, linking the theoretical development to the nature of seismograms observed across a wide range of distance scales from a few kilometres as in shallow reflection work for geophysical prospecting to many thousands of kilometres for earthquakes. A unified framework is presented for all classes of seismic phenomena for both body waves and surface waves. Each topic is taken up systematically, including many topics not normally covered in discussion of propagator theory such as source representation theory, generalised ray theory, and the calculation of complete theoretical seismograms including all wave effects arising from the presence of the Earth's surface. **Seismic Waves** Masaki Kanao, 2012-01-25. The importance of seismic wave research lies not only in our ability to understand and predict earthquakes and tsunamis; it also reveals information on the Earth's composition and features in much the same way as it led to the discovery of Mohorovicic's discontinuity. As our theoretical understanding of the physics behind seismic waves has grown, physical and numerical modeling have greatly advanced and now augment applied seismology for better prediction and engineering practices. This has led to some novel applications such as using artificially induced shocks for exploration of the Earth's subsurface and seismic stimulation for increasing the productivity of oil wells. This book demonstrates the latest techniques and advances in seismic wave analysis from theoretical approach, data acquisition and interpretation to analyses and numerical simulations as well as research applications. A review process was conducted in cooperation with sincere support by Drs Hiroshi Takenaka, Yoshio Murai, Jun Matsushima, and Genti Toyokuni. *Waves in Fluids and Solids* Ruben Picó Vila, 2011-09-22. Acoustics is a discipline that deals with many types of fields, wave phenomena. Originally, the field of Acoustics was consecrated to the sound that is the study of small pressure waves in air detected by the human ear. The scope of this field of physics has been extended to higher and lower frequencies and to higher intensity levels. Moreover, structural

vibrations are also included in acoustics as a wave phenomena produced by elastic waves This book is focused on acoustic waves in fluid media and elastic perturbations in heterogeneous media Many different systems are analyzed in this book like layered media solitons piezoelectric substrates crystalline systems granular materials interface waves phononic crystals acoustic levitation and soft media Numerical methods are also presented as a fourth order Runge Kutta method and an inverse scattering method

**Seismology and Structure of the Earth** Barbara Romanowicz, Adam Dziewonski, 2010-04-20

Treatise on Geophysics Seismology and Structure of the Earth Volume 1 provides a comprehensive review of the state of knowledge on the Earth's structure and earthquakes It addresses various aspects of structural seismology and its applications to other fields of Earth sciences The book is organized into four parts The first part principally covers theoretical developments and seismic data analysis techniques from the end of the nineteenth century until the present with the main emphasis on the development of instrumentation and its deployment The second part reviews the status of knowledge on the structure of the Earth's shallow layers starting with a global review of the Earth's crustal structure The third part focuses on the Earth's deep structure divided into its main units the upper mantle the transition zone and upper mantle discontinuities the D region at the base of the mantle and the Earth's core The fourth part comprises two chapters which discuss constraints on Earth structure from fields other than seismology mineral physics and geodynamics Self contained volume starts with an overview of the subject then explores each topic with in depth detail Extensive reference lists and cross references with other volumes to facilitate further research Full color figures and tables support the text and aid in understanding Content suited for both the expert and non expert

**Introduction to Petroleum Seismology, second edition** Luc T. Ikelle, Lasse Amundsen, 2018-03-26

Introduction to Petroleum Seismology second edition SEG Investigations in Geophysics Series No 12 provides the theoretical and practical foundation for tackling present and future challenges of petroleum seismology especially those related to seismic survey designs seismic data acquisition seismic and EM modeling seismic imaging microseismicity and reservoir characterization and monitoring All of the chapters from the first edition have been improved and or expanded In addition twelve new chapters have been added These new chapters expand topics which were only alluded to in the first edition sparsity representation sparsity and nonlinear optimization near simultaneous multiple shooting acquisition and processing nonuniform wavefield sampling automated modeling elastic electromagnetic mathematical equivalences and microseismicity in the context of hydraulic fracturing Another major modification in this edition is that each chapter contains analytical problems as well as computational problems These problems include MatLab codes which may help readers improve their understanding of and intuition about these materials The comprehensiveness of this book makes it a suitable text for undergraduate and graduate courses that target geophysicists and engineers as well as a guide and reference work for researchers and professionals in academia and in the petroleum industry

*Introduction to Applied Geophysics* S. Mares, 1984-08-31 TO APPLIED GEOPHYSICS STANIS LAY MARE et al Faculty of Science Charles University

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CONTENTS XI INTRODUCTION LIST OF PRINCIPAL SYMBOLS AND UNITS USED XIII CHAPTER I GRAVIMETRIC METHODS S Hrach I I Physical principles of gravimetric methods Volume gravitational potential I 1 2 Gravity field of the Earth 3 1 3 Anomalies of gravitational acceleration Gravity anomalies 9 1 3 1 Faye anomaly Free air anomaly 9 1 3 2 Bouguer anomalies 10 1 3 3 Isostatic anomaly 14 1 3 4 Geological significance of anomalies 17 1 4 Rock densities 19 1 4 1 Natural rock densities 20 1 4 2 Rock density determination 22 1 4 3 Determination of density characteristics 25 25 1 5 Gravity observations 26 1 5 1 Instruments for absolute gravity observations 1 5 2

*Q of the Earth: Global, Regional, and Laboratory Studies* Barbara Romanowicz, Brian J. Mitchell, 2012-12-06 Variations in seismic Q are sensitive to a much greater extent than are seismic velocity variations on factors such as temperature fluid content and the movement of solid state defects in the earth For that reason an understanding of Q and its variation with position in the earth and with time should provide information in earth's tectonic evolution as well as on aspects of its internal structure Progress in understanding Q has suffered from difficulty in obtaining reliable amplitude data at global and temporary stations Moreover laboratory determinations of Q until recently were most often made at frequencies much higher than those measured by seismologists for waves propagating through the earth Recent advances in seismic station distribution and quality as well as in methodology at both high and low frequencies have greatly improved the quality of observational data available to seismologists from global stations Concurrent advances have been made in measuring Q using laboratory samples at frequencies that pertain to the earth and in theoretical understanding of seismic wave attenuation Papers of this volume present new information on Q in the earth from several perspectives methodology results from global and regional observations of both body and surface waves laboratory measurements and theoretical understanding The editors believe that we have reached a new threshold in Q studies and that advances in data quality and methodology will spur increased interest in this difficult but interesting field

*Physical Ultrasonics of Composites* Stanislav Rokhlin, Dale Chimenti, Peter Nagy, 2011-03-03 The objective of this book is to treat the behavior of ultrasonic waves as they interact with layered anisotropic materials incorporating those structural aspects unique to composite laminates addressing both experimental and modeling methodologies Anisotropic material interfaces guided waves waves in layered media and laminated plates are

treated The influence of finite aperture transducers on electronic signals and the field of air coupled ultrasonics end the work

**Understanding Downhole Microseismic Data Analysis** Jubran Akram,2020-01-01 This book is designed as an excellent resource text for students and professionals providing an in depth overview of the theory and applications of downhole microseismic monitoring of hydraulic fracturing The readers will benefit greatly from the detailed explanation on the processes and workflows involved in the acquisition design modeling processing and interpretation of microseismic data

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## **Table of Contents Seismic Wave Propagation In Stratified Media**

1. Understanding the eBook Seismic Wave Propagation In Stratified Media
  - The Rise of Digital Reading Seismic Wave Propagation In Stratified Media
  - Advantages of eBooks Over Traditional Books
2. Identifying Seismic Wave Propagation In Stratified Media
  - Exploring Different Genres
  - Considering Fiction vs. Non-Fiction
  - Determining Your Reading Goals
3. Choosing the Right eBook Platform
  - Popular eBook Platforms
  - Features to Look for in an Seismic Wave Propagation In Stratified Media
  - User-Friendly Interface
4. Exploring eBook Recommendations from Seismic Wave Propagation In Stratified Media
  - Personalized Recommendations
  - Seismic Wave Propagation In Stratified Media User Reviews and Ratings
  - Seismic Wave Propagation In Stratified Media and Bestseller Lists
5. Accessing Seismic Wave Propagation In Stratified Media Free and Paid eBooks
  - Seismic Wave Propagation In Stratified Media Public Domain eBooks
  - Seismic Wave Propagation In Stratified Media eBook Subscription Services
  - Seismic Wave Propagation In Stratified Media Budget-Friendly Options
6. Navigating Seismic Wave Propagation In Stratified Media eBook Formats

- ePub, PDF, MOBI, and More
- Seismic Wave Propagation In Stratified Media Compatibility with Devices
- Seismic Wave Propagation In Stratified Media Enhanced eBook Features
- 7. Enhancing Your Reading Experience
  - Adjustable Fonts and Text Sizes of Seismic Wave Propagation In Stratified Media
  - Highlighting and Note-Taking Seismic Wave Propagation In Stratified Media
  - Interactive Elements Seismic Wave Propagation In Stratified Media
- 8. Staying Engaged with Seismic Wave Propagation In Stratified Media
  - Joining Online Reading Communities
  - Participating in Virtual Book Clubs
  - Following Authors and Publishers Seismic Wave Propagation In Stratified Media
- 9. Balancing eBooks and Physical Books Seismic Wave Propagation In Stratified Media
  - Benefits of a Digital Library
  - Creating a Diverse Reading Collection Seismic Wave Propagation In Stratified Media
- 10. Overcoming Reading Challenges
  - Dealing with Digital Eye Strain
  - Minimizing Distractions
  - Managing Screen Time
- 11. Cultivating a Reading Routine Seismic Wave Propagation In Stratified Media
  - Setting Reading Goals Seismic Wave Propagation In Stratified Media
  - Carving Out Dedicated Reading Time
- 12. Sourcing Reliable Information of Seismic Wave Propagation In Stratified Media
  - Fact-Checking eBook Content of Seismic Wave Propagation In Stratified Media
  - Distinguishing Credible Sources
- 13. Promoting Lifelong Learning
  - Utilizing eBooks for Skill Development
  - Exploring Educational eBooks
- 14. Embracing eBook Trends
  - Integration of Multimedia Elements
  - Interactive and Gamified eBooks

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