SUBSURFACE FLUID FLOW AND IMAGING

The practice of imaging has grown tremendously over the past few decades. At the same time, understanding fluid flow at depth has become increasingly important to activities such as hydrocarbon production, groundwater exploitation, environmental remediation, and sequestration of greenhouse gases.

This book introduces methodologies for subsurface imaging based upon asymptotic and trajectory-based methods for modeling fluid flow, transport, and deformation. It describes trajectory-based imaging and inversion from its mathematical formulation, through the construction and solution of the imaging equations, to the assessment of the accuracy and resolution associated with the image. Unique in its approach, it provides a unified framework for the complete spectrum of physical phenomena from wave-like hyperbolic problems to diffusive parabolic problems and non-linear problems of mixed character. The practical aspects of imaging, particularly efficient and robust methods for updating high resolution geologic models using fluid flow, transport, and geophysical data, are emphasized throughout the book.

Complete with online software applications and examples that enable readers to gain hands-on experience, this volume is an invaluable resource for graduate-level courses, as well as for academic researchers and industry practitioners in the fields of geoscience, hydrology, and petroleum and environmental engineering.

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SUBSURFACE FLUID FLOW AND IMAGING

With Applications for Hydrology, Reservoir Engineering, and Geophysics

DONALD WYMAN VASCO AND AKHIL DATTA-GUPTA



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Contents

	Pref Acki	ace nowledgments	<i>page</i> vii ix
1	The propagation of a disturbance in relation to imaging		1
	1.1	Background and motivation	1
	1.2	A propogating disturbance	3
	1.3	An example involving dissipation	5
	1.4	A non-linear example	10
	1.5	Heterogeneity and imaging	12
	1.6	Summary	26
2	Principles and equations governing fluid flow and deformation		27
	2.1	Introduction	27
	2.2	Underlying principles	27
	2.3	Deformation	40
	2.4	Elastic deformation	53
	2.5	Fluid flow	57
	2.6	Coupled deformation and fluid flow	76
	2.7	Summary	100
3	Trajectory-based modeling		101
	3.1	Introduction	101
	3.2	Series representation of a moving front	104
	3.3	The frequency domain and high-frequency approximations	106
	3.4	Asymptotic series and solutions	108
	3.5	Characteristics and trajectories	114
	3.6	Trajectory-based modeling: the wave equation	117
	3.7	Multiple scale asymptotics	123

vi	Contents	
4	 Equations in diffusion form 4.1 Introduction 4.2 A high-frequency asymptotic solution 4.3 Applications 4.4 Summary 	131 131 131 147 171
5	 Equations governing advection and transport 5.1 Introduction 5.2 The governing equation 5.3 An asymptotic solution 5.4 The streamline approach for transport modeling 5.5 Applications 5.6 Summary and conclusions 	172 172 172 174 188 201 219
6	 Immiscible fluid flow 6.1 Introduction 6.2 Governing equations for two-phase flow 6.3 An asymptotic approach 6.4 Streamline modeling of immiscible fluid flow 6.5 Applications 6.6 Summary 	220 220 220 226 233 264 284
7	 Coupled deformation and fluid flow 7.1 Introduction 7.2 Deformation in a porous body containing a single fluid 7.3 A porous body containing three fluids 7.4 Application 7.5 Summary 	285 285 286 311 317 326
8	 Appendix: a guide to the accompanying software 8.1 Fronts3D: computing pressure propagation by Fast Marching 8.2 Trace3D: software for trajectory-based modeling and inversion 	327 328 329
	References Index	336 349

Colour plate section between pages 150 and 151

Preface

The practice of imaging has grown tremendously in the past few decades, both in sophistication and importance. There is a strong thread of commonality in the diverse quilt of applications of imaging in medicine, engineering, and the physical sciences. In particular, the same mathematical techniques, such as the use of trajectory-based and asymptotic methods, the central topic of this book, often serve as the underpinnings of each application. However, to the uninitiated, it might seem that each discipline has adopted a distinct formulation of the imaging problem. Thus, a sense of unity is lost in traversing the various applications. In addition, the development of imaging methods may be more extensive in one particular field compared to others. For example, in applied mathematics, trajectory-based imaging methods have been extended to a wide range of situations, such as diffusive and non-linear wave propagation. These advancements may not be appreciated or even known in other areas.

The goal of this book is to bring unity to the range of trajectory-based techniques for modeling fluid flow that may serve as the basis for efficient imaging algorithms. A secondary objective is to highlight the wide array of physical phenomena to which trajectory-based imaging methods lend themselves. It is widely known that a trajectory-based method, such as ray theory, is applicable to hyperbolic equations, typified by the wave equation. Less well known is the fact that trajectory-based methods may be used to study diffusive systems, governed by a parabolic equation. Similarly, ray methods for non-linear waves have been developed in applications such as gas dynamics and plasma physics, but are relatively unknown in such fields as hydrology. The fundamental techniques are then applied to important problems in the Earth sciences. Hopefully, after finishing this book the reader will glimpse the full range of trajectory-based imaging methods.

This book describes trajectory-based imaging from its mathematical formulation, through the formation and solution of the imaging equations, to the determination of the accuracy and resolution associated with the image. Our presentation CAMBRIDGE

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viii

Preface

is unique in that we cover a rather complete spectrum of physical phenomena. At the same time we have tried to focus on the practical side of imaging, emphasizing methods that are efficient and robust. Obtaining an image is not the end of the story, we need some measure of the reliability of our solution. We describe methods for assessing the solution, computing the resolution and uncertainty associated with an image. Finally, as illustrations, we include a wide range of applications and emphasize their similarity.

This book is intended for those involved in imaging research. It is hoped that the cross-fertilization between disciplines will spur innovation. The book is also appropriate for students involved in the physical sciences, engineering, medical imaging, and applied mathematics. Online resources including computer softwares and example data files have been provided for the reader to acquire hands on experience in the techniques and applications discussed throughout the book.

Acknowledgments

This book is a reality because of the direct and indirect contributions of many people. We are thankful to all of them, but a few warrant special mention. The Basic Energy Sciences geophysics group at Lawrence Berkeley National Laboratory and their groundbreaking work on poroelasticity was an inspiration and an education for us. Their impact on the book is clear. Particular thanks go to Dr. James Berryman, Professor Lane Johnson, and Dr. Steve Pride, who read through and commented on various chapters over the years that it took to complete this project. Many Petroleum Engineering graduate students at Texas A & M University have contributed to this effort through their thesis and dissertations. Many of the results presented here are due to their hard work and dedication. Special thanks to Dr. Lihua Zhao for reviewing the content and helping with word to LaTex conversion. We would like thank the Petroleum Engineering Department at Texas A & M, especially Dr. Dan Hill for allowing us to use the departmental resources. Thanks to the colleagues at Texas A & M, especially Dr. Michael J. King for countless discussions and for sharing his knowledge and insight on many topics in the book.

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