MATHEMATICS IN INDUSTRY **7**

Armin Iske
Trygve Randen
Editors

Mathematical Methods and Modelling in Hydrocarbon Exploration and Production

Springer Schlumberger

Editors

Dr. Armin Iske

University of Leicester
Department of Mathematics
University Road
Leicester, LE1 7RH, United Kingdom
Email: iske@mcs.le.ac.uk

Dr. Trygve Randen

Schlumberger Stavanger Research
Risabergveien 3
4068 Stavanger, Norway
Email: trygve.randen@slb.com

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Preface

Fossil fuels, including oil and gas, store a part of the energy which the earth has received from the sun during the last several hundred million years. These days, oil and gas account for around 64 % of the total world energy consumption. Despite the efforts in developing new renewable energy sources, oil and gas will continue to play a major role in meeting the world's ever increasing energy demand for the next few decades. Moreover, oil and gas are expected to remain the most cost effective and the most convenient sources of energy that we have at our disposal.

The required exploration and production of hydrocarbons, however, incorporate great technological challenges for the oil and gas industry. Indeed, about 70 % of today's oil and gas production rate comes from hydrocarbon fields that are more than 30 years old. But several of these fields are exhibiting a significant production decline. In order to meet the world's future demand for oil and gas, further technological advances are essentially needed, where new developments should aim at efficiency and accuracy in sub-surface mapping, monitoring of reservoir depletion, and numerical simulation of production scenarios. This requires research across multiple disciplines, including mathematics, geophysics, geology, petroleum engineering, signal processing, and computer science.

This work explains important aspects and fundamental concepts in hydrocarbon exploration and production. Moreover, new developments and recent advances in the relevant research areas are discussed, where special emphasis is placed on mathematical methods and modelling. The book reflects the multi-disciplinary character of the hydrocarbon production workflow, ranging from seismic data acquisition through imaging, seismic analysis & interpretation, and geological model building to numerical reservoir simulation. Various challenges concerning the production workflow are discussed in detail.

The thirteen chapters of this joint work, authored by international experts from academic and industrial institutions, include survey papers of expository character as well as original research articles. The material of this book is arranged in three parts.

Part I. *Seismic Interpretation*;
Part II. *Geological Model Building*;
Part III. *Reservoir Modelling and Simulation.*

The first part of the book, comprising Chapters 1-5, treats the analysis and interpretation of the input seismic data. The first chapter provides a very brief and basic introduction to geology and seismic. The next two chapters present a set of seismic attributes (measures computed from the seismic data) which are useful for the subsequent classification of geological responses. Chapters 4 and 5 propose novel pattern recognition strategies for the automated interpretation of seismic data.

The second part of the book, Chapters 6-9, addresses the construction of models of the sub-surface. Chapter 6 provides a very comprehensive treatment of geological modelling and reservoir simulation. The following Chapters 7 and 8 propose new concepts for 3D geo-body model building. The approach taken in Chapter 7 is based on hierarchical segmentation, whereas the method of Chapter 8 works with level set and marching methods. Velocity estimation is an important task in sub-surface model construction, and techniques from tomography are effective tools in this respect. The complexity of tomographic inversion from seismic data is, however, significant. Chapter 9 uses modern techniques from seismic tomography in order to design efficient tomographic inversion methods.

The last part of the book, Chapters 10-13, is concerning the simulation of oil and gas production from geological models. Chapter 10 presents an integrated workflow and a case study, where advanced concepts from previous chapters of the book are applied. The resulting workflow, ranging from seismic data acquisition to reservoir simulation, is orders of magnitude faster than the conventional workflow. In order to effectively model physical phenomena in reservoir flow, multiscale methods are essentially required for reservoir simulation. To this end, a novel finite volume method over adaptive triangular meshes is explored in Chapter 11, where multivariate scattered data interpolation is an important ingredient. Selected details and principles of optimal multivariate interpolation are discussed in Chapter 12. Finally, Chapter 13 provides a practical approach to history matching the model with time-lapse measurements. This includes an illustrative real-world case study concerning monitoring the injection of CO_2 into the sub-surface.

Large parts of the material presented in this book were developed between November 2000 and April 2004 through the European research and training network NetAGES, "Network for Automated Geometry Extraction from Seismic". The NetAGES project hosted a distributed multi-disciplinary team of young researchers, PhD and postdoctoral students, and senior researchers at one industrial partner (Schlumberger Stavanger Research, Norway) and three academic partners (Munich University of Technology, University of Vienna, and Stavanger University College). Recent research results of the NetAGES young researchers and their supervisors are presented in Chapters 7-12.

In addition, collaborators from other institutions contributed to this book, either through interconnected projects (University of Surrey, University of Oxford and Schlumberger Abingdon Technology Centre, UK) or by extensions of the NetAGES training network (SINTEF Petroleum Research, Trondheim, Norway). Chapters 1-6 and Chapter 13 were written on the basis of such joint work.

All thirteen contributions to this book are invited chapters. In order to ensure their scientific and instructive quality, the chapters went through two stages of reviews. The first stage was organized by the editors in October 2003, where each chapter was carefully reviewed by independent experts external to NetAGES, as well as by experts from the NetAGES consortium and by young researchers from NetAGES. After submission of its prefinal version to Springer-Verlag in March 2003, the entire manuscript was then reviewed by a panel of ten anonymous reviewers. This second review stage was organized by Springer-Verlag.

Finally, we wish to thank those who supported the making of this book. It is in particular our great pleasure to acknowledge Dr. Martin Peters from Springer-Verlag, Heidelberg, for his everlasting support and great enthusiasm towards the book project. Moreover, the friendly and effective collaboration with Ute McCrory (Springer-Verlag) is kindly appreciated. Special thanks go to the authors for their fine contributions, and to the reviewers for their constructive comments and suggestions. Last but not least, partial financial support was granted by the European Commission through the NetAGES network (contract no. IST-1999-29034).

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Armin Iske
Trygve Randen

Table of Contents

Part III Reservoir Modelling and Simulation

List of Contributors

Per Bergmo
SINTEF Petroleum Research
N-7465 Trondheim, Norway
Per.Bergmo@iku.sintef.no

Hilde G. Borgos
Schlumberger Stavanger Research
P.O. Box 8013
N-4068 Stavanger, Norway
Hilde.Borgos@slb.com

Alexander A. Boukhgueim
University of Vienna
Department of Mathematics
A-1090 Wien, Austria
boukhga5@univie.ac.at

Alexis Carrillat
Schlumberger Stavanger Research
P.O. Box 8013
N-4068 Stavanger, Norway
ACarrillat@slb.com

Geir Vaaland Dahl
Schlumberger Stavanger Research
P.O. Box 8013
N-4068 Stavanger, Norway
gvdahl@slb.com

Maria Faraklioti
University of Surrey
CVSSP, SEPS
Guildford GU2 7XH, UK

Chris L. Farmer
University of Oxford
Centre for Industrial and
Applied Mathematics
Oxford OX1 3LB, UK
farmer5@slb.com

Hans Georg Feichtinger
University of Vienna
Department of Mathematics
A-1090 Wien, Austria
hans.feichtinger@univie.ac.at

Kristine Årland Halvorsen
Schlumberger Stavanger Research
P.O. Box 8013
N-4068 Stavanger, Norway
KHalvorsen@slb.com

Armin Iske
University of Leicester
Department of Mathematics
Leicester LE1 7RH, UK
iske@mcs.le.ac.uk

Martin Käser
University of Trento
Civil & Environmental Engineering
I-38050 Trento, Italy
martin.kaeser@ing.unitn.it

Erik Lindeberg
SINTEF Petroleum Research
N-7465 Trondheim, Norway
Erik.Lindeberg@iku.sintef.no

Magne Lygren
Statoil ASA
Forusbeen 50
N-4035 Stavanger, Norway
mly@statoil.com

Erik Monsen
Schlumberger Stavanger Research
P.O. Box 8013
N-4068 Stavanger, Norway
Erik.Monsen@slb.com

Jan E. Odegard
Rice University
CITI
Houston, TX, U.S.A.
odegard@rice.edu

Stein Inge Pedersen
Schlumberger Stavanger Research
P.O. Box 8013
N-4068 Stavanger, Norway
Stein.Inge.Pedersen@slb.com

Maria Petrou
University of Surrey
CVSSP, SEPS
Guildford GU2 7XH, UK
m.petrou@surrey.ac.uk

Trygve Randen
Schlumberger Stavanger Research
P.O. Box 8013
N-4068 Stavanger, Norway
Trygve.Randen@slb.com

Stine Kjersti Richardsen
Norwegian Defence
Research Establishment
FFI Horten, P.O. Box 115
N-3191 Horten, Norway
Stine-Kjersti.Richardsen@ffi.no

Jürgen Schlaf
ConocoPhillips Norway
P.O. Box 220
N-4098 Tananger, Norway
juergen.schlaf@conocophillips.com

Thorleif Skov
Schlumberger Stavanger Research
P.O. Box 8013
N-4068 Stavanger, Norway
Thorleif.Skov@slb.com

Lars Sønneland
Schlumberger Stavanger Research
P.O. Box 8013
N-4068 Stavanger, Norway
Lars.Sonneland@slb.com

Brice Vallès
RF - Rogaland Research
Thormøhlensgt. 55
N-5008 Bergen, Norway
Brice.Valles@rf.no

Tobias Werther
University of Vienna
Department of Mathematics
A-1090 Wien, Austria
tobias.werther@univie.ac.at

Part I

Seismic Interpretation