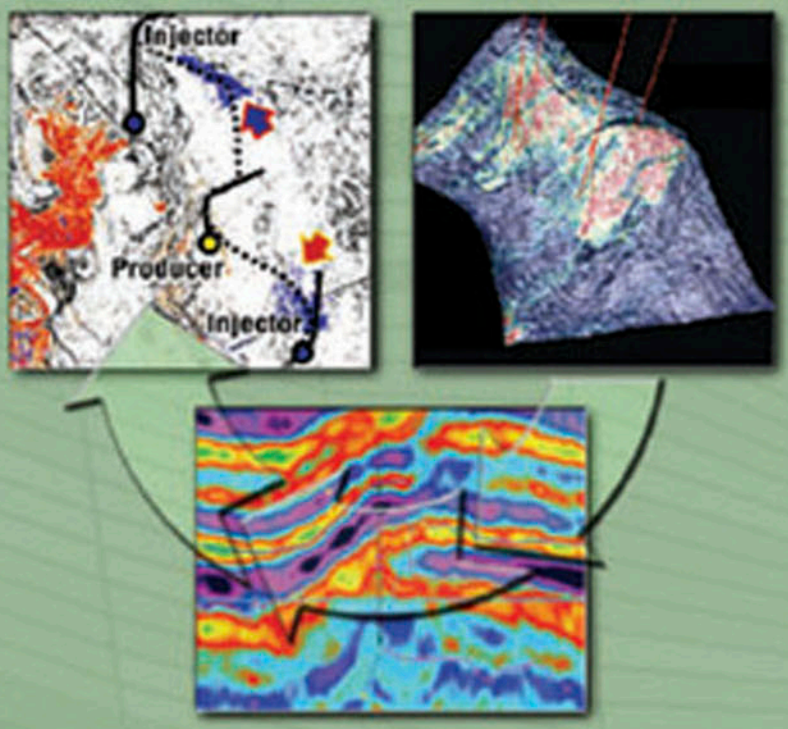
INVESTIGATIONS IN GEOPHYSICS NO. 15

METHODS AND APPLICATIONS IN RESERVOIR GEOPHYSICS

edited by
DAVID H. JOHNSTON



SOCIETY OF EXPLORATION GEOPHYSICISTS

Methods and Applications in Reservoir Geophysics

Investigations in Geophysics Series No. 15

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About the Editor

David H. Johnston is global geophysics coordinator for ExxonMobil Production Company in Houston, Texas. He joined Exxon Production Research Co. in 1979. The focus of his career has been reservoir geophysics, with assignments in rock-physics research, seismic reservoir characterization, and seismic reservoir monitoring.

Johnston received a B.S. degree in earth sciences in 1973 and a Ph.D. in geophysics in 1978, both from Massachusetts Institute of Technology. He is active in SEG, SPE, and AAPG. He was secretary/treasurer of SEG in 1990 and has chaired the Development and Production Committee and the Interpretation Committee. Johnston received the award for best presentation from SEG in 1993 and for best paper in THE LEADING EDGE in 2005. He was a 1992–1993 SPE Distinguished Lecturer, the SEG Distinguished Lecturer in 1999, and an AAPG Distinguished Lecturer in 2008.

In 2003, Johnston received honorary membership in the Geophysical Society of Houston in recognition of distinguished contributions to the geophysical profession. In 2004, he was awarded life membership in SEG. He was the first recipient of ExxonMobil's Peter Vail Award for distinguished technical achievement, in 2007. Johnston has had 25 journal articles published and has given more than 40 presentations at professional society meetings. He was coeditor of *Seismic Wave Attenuation* (SEG Geophysics Reprints Series No. 2), published in 1981, and *Reservoir Geophysics* (SEG Investigations in Geophysics No. 7), published in 1992.

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Preface

The Society of Exploration Geophysicists published *Reservoir Geophysics,* the predecessor of this book, in 1992. This was a time of transition in the geophysical profession and in the petroleum industry, which had suffered a significant downturn in the mid-1980s. With the exception of the months just before and after the first Gulf War, oil prices were low compared with the boom of the late 1970s. Exploration was moving toward more challenging and costly areas — deeper water, deeper targets, more remote locations. Improved recovery in existing fields became an industry imperative.

In geophysics, maturing 3D seismic technology helped the industry to reduce the finding cost of oil from about $15 per barrel in 1979 to about $6 per barrel in 1992. Although many talented people left geophysics for other careers in the mid-1980s, computer workstations increased the productivity of the remaining seismic interpreters and provided powerful new tools to understand the subsurface. The focus of many geophysicists shifted, subtly at first, from simply imaging structure to characterizing the reservoir.

The challenges facing the industry in the early 1990s required that fields be brought on stream more quickly and that recovery be maximized. The concepts of reservoir management focused on reducing development and operating costs in addition to maximizing reserves and optimizing recovery. *Reservoir Geophysics* arrived on the scene when geophysical technology, which historically had been limited to exploration, was becoming part of that reservoir-management equation — finding reserves that otherwise might not have been developed and lowering costs by minimizing dry holes and poor producers. In addition, the book was published at a time when the industry and the petroleum upstream technical disciplines were beginning to appreciate the value of integration.

Reservoir Geophysics was a product of the SEG Development and Production Committee, charged with improving communication among geophysicists, petroleum geologists, and reservoir engineers. The book was part of a strategy to demonstrate through case studies that each discipline had much to contribute to the others. Other elements of that strategy included special sessions of invited papers on reservoir geophysics at annual meetings of SEG, the American Association of Petroleum Geologists (AAPG), and the Society of Petroleum Engineers (SPE) and at joint SEG/SPE workshops and forums.

The primary objective of *Reservoir Geophysics* was to raise awareness of geophysical contributions to reservoir studies. Its audience was intended to be reservoir engineers (although I suspect most copies were purchased by geophysicists). Thus, the case studies chosen for the book were designed to show off the results of reservoir-geophysics applications and not necessarily to detail geophysical methods. The organization of *Reservoir Geophysics* was task oriented, with chapters on

- reservoir delineation — characterizing the trap
- reservoir description — defining reservoir properties
- reservoir surveillance — monitoring production

Eighteen years later, with the publication of this book, *Methods and Applications in Reservoir Geophysics*, the petroleum industry and the technical professional disciplines face challenges no less daunting than those faced in 1992. Oil prices have been extremely volatile, and costs have risen steadily. Exploration, which had moved to deep water in the late 1990s, is moving to even more hostile environments such as the Arctic and ultradeep water. The remaining exploration targets are increasingly more difficult to image (below salt or basalt) or the targets have reservoirs that are more difficult to characterize — tight sands, shales, and carbonates. In addition, geophysicists, geologists, and engineers who were at the prime of their careers in 1992 are at or near retirement. Because of restricted industry hiring in the late 1990s, there is a gap in experience that results in technical professionals having more responsibility thrust on them earlier in their careers.

Reservoir geophysics, an emerging application in 1992, is now mainstream. The SEG Development and Production Committee once had to solicit papers on res-

ervoir geophysics for the SEG annual meeting, but at the 2007 annual meeting in San Antonio, more than 30% of the technical sessions focused on reservoir applications. As a result, the objective of *Methods and Applications in Reservoir Geophysics* is not simply to demonstrate the value of geophysics in reservoir management but also to provide guidance on how to apply geophysical technologies in reservoir studies more effectively. Although we hope reservoir engineers will find this book useful, the audience is meant to be geophysicists. Thus, the case studies chosen for this volume focus on the processes, methods, and techniques used in reservoir geophysics, not just the results.

In addition, the organization of this book explicitly recognizes that geophysics is not simply an exploration tool but that the tasks of reservoir delineation and characterization are applied throughout the life cycle of a field:

- discovery and appraisal
- development planning
- production optimization

Chapter 1, "Reservoir Management and Field Life Cycle," sets the stage for this book. It defines the fundamental concepts of the reservoir-management process, field life cycle, integrated reservoir studies, and reservoir geophysics. It examines the business case for investing in geophysical data and the skills required by geophysicists to apply their technologies more effectively in an integrated team environment.

Chapter 2, "The Supporting Technologies," introduces key concepts and terminology in reservoir engineering and reservoir geophysics. Geophysicists will find the reservoir-engineering paper to be a rich source of information on issues and data critically important to the engineer. The second paper discusses seismic rock physics, which is the critical link between the engineering and geophysical descriptions of the reservoir. Chapter 2 concludes with a tutorial on reservoir geophysics in which both the engineer and the geophysicist will find explanations of the tools and data discussed in the papers throughout this book.

Chapter 3, "Exploration Appraisal," focuses on the methods used in seismic and nonseismic geophysics to help evaluate the critical elements of reservoir delineation and appraisal during field exploration — lithology, pore fluid type, pore pressure, and reserves.

Chapter 4, "Development Geophysics," addresses geophysical reservoir characterization at the different scales required to justify commercial development of a field. The chapter also deals with the application of geophysics to plan for reservoir monitoring.

Chapter 5, "Production Geophysics," describes how the application of geophysical methods can help to maximize recovery by identifying reservoir heterogeneities that control flow or by monitoring the changes in fluid saturation and pressure that occur during field production.

Chapter 6, "The Road Ahead," examines emerging technologies that define the future of reservoir geophysics — novel acquisition methods, more quantitative analyses, and new areas of application.

At the end of the book, the glossary provides definitions for many of the terms used in the papers included in the text.

As with *Reservoir Geophysics* in 1992, this volume is the product of a committee effort spanning many years. Many of the papers chosen for this book have been published previously, but 20% are new contributions solicited by the book editors to cover key applications or technologies. The editors thank the authors who contributed this material.

In addition, I express my sincere appreciation to the members of the *Methods and Applications in Reservoir Geophysics* editorial committee, Bill Abriel, Farrukh Ahmad, Alistair Brown (who also served with me on the *Reservoir Geophysics* editorial committee in 1992), Ian Jack, Kyle Lewallen, Colin MacBeth, Sankar Muhuri, Mike Payne, Jim Schuelke, Bob Sheriff (editor of *Reservoir Geophysics*), Ken Tubman, John Waggoner, and Mike Wilt. I also thank the SEG Publications Committee and managing editor Mike Cooper in particular, the SEG Development and Production Committee, and the SEG Interpretation Committee for their support.

— David H. Johnston
Committee chairman and editor
Houston, Texas, September 2010