Numerical Methods of Exploration Seismology With Algorithms in MATLAB

Exploration seismology uses seismic imaging to form detailed images of the Earth's interior, enabling the location of likely petroleum targets. Owing to the size of seismic datasets, sophisticated numerical algorithms are required. This book provides a technical guide to the essential algorithms and computational aspects of data processing, covering the theory and methods of seismic imaging. The first part introduces an extensive online library of MATLAB seismic data-processing codes maintained by the CREWES project at the University of Calgary. Later chapters then focus on digital signal theory and relevant aspects of wave propagation and seismic modeling, followed by deconvolution and seismic migration methods. Presenting a rigorous explanation of how to construct seismic images, it provides readers with practical tools and codes to pursue research projects and analyses. It is ideal for advanced students and researchers in applied geophysics, and for practicing exploration geoscientists in the oil and gas industry.

Gary F. Margrave has extensive experience with seismic data in both the corporate and academic worlds. His career began with 15 years at Chevron, before 20 years as a professor of geophysics at the University of Calgary, where he taught courses on which this book is based. He then spent two years as Senior Geophysical Advisor at Devon Energy. He is now retired but still pursuing a vigorous research program.

Michael P. Lamoureux is a professor of mathematics at the University of Calgary, with a research focus on functional analysis and its application to physics, signal processing, and imaging. He has a keen interest in developing advanced mathematical methods for use in real industrial settings.

'This book is a masterpiece in scope and content. It explains the essential algorithms and computational aspects of data processing, covering the theory and methods of seismic imaging. A particularly outstanding feature is that it gives useful methods and tools to pursue research projects and analyses – representing the way that things should be taught in the computer age. For this reason, it should be adopted in the undergraduate curriculum and will be a wonderful resource for graduate students and researchers in applied geophysics. Practicing geoscientists will also welcome this book as it will make their daily tasks easier and more productive.'

Enders Robinson, Professor Emeritus, Columbia University, New York City

'The authors are to be commended for putting together this valuable resource which will instantly be highly useful to many geophysicists in the academic and industrial communities. The book is a pleasing and unusual mixture of rigorous geophysical signal processing theory and practical concepts, algorithms and code snippets. The MATLAB library functions and scripts that are provided or available for download will prove indispensable to all readers.'

Peter Cary, Chief Geophysicist, TGS Canada

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With Algorithms in MATLAB

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GFM: To Joan. Thank you so much for supporting me spiritually through the years. Your friendship, counsel, and encouragement have been my guiding lights.

MPL: To Olga and our children Gaby, Alex, Jakub, and Veronika. Thank you for your patience, support, and inspiration while writing this book, and more.

Contents

Preface

Exploration seismology is a complex technology that blends advanced physics, mathematics, and computation. Seismic imaging, an essential part of exploration seismology, has evolved over roughly 100 years of effort into a sophisticated imaging system capable of forming detailed 3D images of the interior of the Earth's crust. We have been involved in research, teaching, and practice in this field for many decades and this book is an outgrowth of our experience. With it we hope to bring a more detailed understanding of the methods of seismic imaging to a broad audience of scientists and engineers.

Often, the computational aspect is neglected in teaching because, traditionally, seismic processing software is part of an expensive and complex system. Also, understanding the numerical methods behind the software requires a considerable knowledge of digital signal theory, which is often omitted in a typical graduate curriculum. However, it is our opinion that true understanding only comes through mastering the computational aspects as well as the concepts and mathematics. We have often been surprised at the additional mental struggle required to transition from a formula in a book to an actual digital computation of the same formula. Even so, we have never regretted spending the extra time needed for that purpose.

This book is intended for those scientists who wish for an introduction to the computational aspects as well as the theory of seismic data processing. Such people may be graduate students at universities, professional data processors in seismic processing companies, researchers in energy companies, or literally anyone who wishes to gain a greater understanding of seismic data-processing algorithms. The appropriate background for this material is roughly that achieved at the B.Sc. level in physics, mathematics, or geoscience. Knowledge of vector calculus, undergraduate physics, some understanding of geophysics, and experience with a computer programming language (not necessarily MATLAB) are all assumed as background.

This book and the MATLAB library it describes are the product of many years of teaching and research at the University of Calgary and in industry. The first author began the development of the library while employed at Chevron and, with Chevron's permission, continued this development after joining the University of Calgary and the Consortium for Research in Elastic-Wave Exploration Seismology (CREWES) in 1995. He is now retired from the university, and still evolving the codes. The second author became involved because the mathematical complexity of the seismic imaging problem appealed to his expertise in functional analysis and signal processing, as a member of the university's Department of Mathematics and Statistics. Both authors are involved in an ongoing collaboration with one another and with other members of the CREWES project, and these codes are the fruit of that collaboration.

We have chosen to limit the scope of this volume primarily to those methods that can be regarded as "single-channel algorithms." This term means that these methods act one at a time on each of the millions or even billions of 1D time series that comprise a seismic dataset. Mostly in our final chapter, we do discuss some multichannel methods but these only scratch the surface of what can be found in our MATLAB library. Even to describe the single-channel methods in algorithmic detail requires a lengthy introduction to digital signal theory, our Chapters 2 and 3, and also a solid introduction to the relevant mathematical physics, Chapter 4, which then culminates in a detailed discussion of deconvolution methods in Chapter 5. Chapters 6 and 7 comprise an introduction to seismic migration methods.

We hope this book proves useful to our readers, and welcome any feedback. We realize that it will seem overly complex to some, while others will find it lacking in detail essential to their interests. We only ask for understanding that it is difficult to satisfy all readers, but we hope that all who make the required effort will find value here.

Online Resources

How to Obtain the MATLAB Codes

There are three types of MATLAB codes needed to fully utilize this book:

1. The standard MATLAB functions that come with a MATLAB installation. We recommend that you have standard MATLAB and the *signal* toolbox.
2. The library of MATLAB functions maintained and distributed by the CREWES project at the University of Calgary. To obtain this library, go to www.crewes.org/ResearchLinks/FreeSoftware/ and download *crewes.zip*. This is completely free for any purpose except resale. Also available there is a very early version of this text (from 2005).
3. The specific scripts that are presented in this text and used to make most of the figures. If you have already downloaded the CREWES library from the previous item, then you will already have these codes and they will appear in the subfolder *NMES_book*. Most of these codes are scripts that illustrate the use of many of the CREWES library tools. Nearly all of the figures in Chapters 1–5 have corresponding scripts in this subfolder that generate them. Chapters 6 and 7 also have support codes but not as extensively as the others. We have attempted to give the scripts suggestive names, but it usually takes some exploring to find exactly what you want. A useful MATLAB tool for this purpose is the multiple-file-search tool that is activated by typing ctrl-shift-f in the MATLAB command window. In the search for the code for a particular figure, you can sometimes succeed by using this search tool to find a particular text string that appears in the figure. Note also that each *code snippet* gives the file name where it is found, beneath the snippet. The corresponding plotting commands are usually found in a similarly named file.

The CREWES codes and the NMES book codes change regularly. It is a good idea to download a fresh copy of the archive at least monthly. Neither CREWES, the University of Calgary, nor the authors of this book make any guarantees of the correctness of these codes. We have tried our very best to produce mathematically correct and easy-to-understand codes but errors are almost certainly present. Use these codes at your own risk.