Simultaneous Source Seismic Acquisition

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Lianjie Huang, managing editor
David Monk, volume editor
To my family and to my teachers: in particular, Arthur Friedrich, Milton Dobrin, Frank Levin, and Jon Claerbout.

—Ray

To my parents, Keith and Mary, and my family, Heleen and Allan.

—Mark
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About the authors

Ray Abma graduated from Stanford University in 1995 with a Ph.D. in geophysics after working in the Stanford Exploration Project with Jon Claerbout as his advisor. He graduated from Iowa State University in 1974 with a B.S. in Physics and minors in Mathematics and Computer Science. He worked for BP and ARCO as a senior research geophysicist from 1997 to 2018, Shell from 1995 to 1997, and Western Geophysical from 1974 to 1991. He is presently a visiting scientist at the Texas Consortium for Computational Seismology (TCCS) at the University of Texas in Austin. Ray’s research interests are noise attenuation, interpolation and regularization, simultaneous sourcing, and coded sources.

Mark Foster retired from BP in 2016 as Director of Technology Integration, Upstream, based in London. During his 26-year career in BP, he held various positions in seismic processing, acquisition, and operations based in numerous locations around the world from Australia and Indonesia to Colombia and Trinidad and Tobago. These roles varied from running geophysical operations and survey teams to hands on seismic processing and processing QC roles. He created and ran the Land Seismic R&D program in 2006 that resulted in the acceptance of land simultaneous source technology at BP. Prior to BP, he worked for Shell International in The Netherlands as a seismic geophysicist. Mark has a Ph.D. in Solid State Physics from the Cavendish Laboratories of Cambridge University, UK where he also obtained a B.A./M.A. in Natural Sciences (Physics).
Foreword

Not just faster and cheaper seismic data, but also safer and higher quality—what’s not to like?

This book tells the story of how this remarkable change occurred in the land environment and how it is finding its way into marine exploration, so it is very timely. It gives careful definitions of the new blending and deblending terminology, and it describes the technology and methodology without making any assumptions about readers and their backgrounds. For this and for other reasons which will be enumerated, it is highly recommended for scientists, data processors, field staff, aspiring innovators, and managers alike. I also sincerely hope that the data management and standards communities will read it—they need to. Usefully, the authors point specific disciplines toward specific chapters. The authors are unusual in that they have not only pursued the research personally and moved it forward into successful practice but have also taken it out into the field and understood and overcome the many practical issues which always attend major changes in systems and techniques. And they understand costs, because the economics of the various geometries are well explained. There are theoretical models, plus lots of actual data results, including convincing comparisons of the new methodology with conventional methods. The book brings together both land and marine technologies in this fascinating world of deblending. It is very well illustrated and has extensive references.

The development of seismic data acquisition and processing technology over the years has been an amazing story. Several times from the 1970s onward, I have heard explorers for oil and gas say that the conventional seismic method was asymptotically “mature” and had little further progress to make. On land in the 1990s, for example, the expectation of production on desert Vibroseis crews had gradually risen to (and settled at) about 1000 vibrator points (VPs) per day. Then, thanks to the introduction in 1996 of so-called “slip sweeps” by Jan Wams and Justus Rozemond and their colleagues at PDO, that expectation was raised by about 50% by making better use of the time/frequency space. But a much larger step was introduced by BP in 2007 with a full-scale trial of “Independent Simultaneous Sourcing,” utilizing 14 vibrators, all operating independently, in the deserts of North Africa. This very quickly raised the expectation level to over 15,000 VPs/day, and surveys with production rates significantly greater than this now have been recorded. The economic driving forces for this achievement were that land seismic costs were increasing relentlessly and conventional exploration work in large new areas was technically unsatisfactory and took too long—normally it would consist of a large 2D survey followed by processing and interpretation, and then subsequent 3D surveys focused on limited areas. This was also a time when explorers were becoming accustomed to the very large “exploration” 3D surveys which were being recorded by marine crews.

This book explains how the conventional approach was turned on its head, such that large-scale 3D surveys now could be acquired much faster and more cheaply—and safely—than before, in an “exploration” mode. The technology is explained in detail with many good examples of the actual results, and fascinating details of the problems and pitfalls (not only with equipment but also with people) which were encountered during the projects and how these were solved. You will find discussions about source and detector sampling and their possible limits, and how the much faster source productivity subsequently drove changes in detector and recording systems. You also will read about the successful deployment of this new technology in widely different terrains including former war zones containing unexploded military ordnance. How would you like to reduce your crew headcount from 500 down to 75, safely, in terrains such as these? You may find the book difficult to put down.

The marine seismic industry has experienced its own plateaus as the number of towed cables (and the power of the vessels required to pull them) increased over the years, as far as engineering limits gradually allowed. However, the acceptance of overlapping or simultaneous shooting has been slower. Craig Beasley at Western Geophysical reported some early 2D trials in 1998, but the typical multi-streamer geometries and the traditionally regular shot timing of marine surveys, coupled with the uncertainty of the suitability of the technique for time-lapse work, delayed the acceptance of the methodology. Meanwhile, a data quality ceiling was breached thanks to the demanding requirements of imaging for reservoir development, especially in challenging geological environments. Marine seismic techniques (so-called “broadband”) had begun to emulate some of those used on land, for example, by populating
the azimuthal shot-receiver domain using additional source vessels, and sometimes by replacing streamers with ocean-bottom nodes. This made these “broad-band” marine surveys much more expensive than single-vessel work, but the improved data quality became a compelling factor. They were recorded, however, using sequential and mostly non-overlapping shots, so the potential of the simultaneous or overlapping source technology—initially just to reduce costs—was very high.

As is clear, the time was ripe for a change—it was logical to try to extend these earlier simultaneous-source land successes into the marine environment. Again, the explanations and the advantages and disadvantages of the various methods of noise attenuation are explained and many clear examples are given. Critical aspects of shot-fire and positioning randomness are explained, and you will learn some interesting and important facts about the problems of generating genuine randomness in the marine environment. The groundbreaking recent development of inversion techniques for deblending is described with a fascinating blow-by-blow account written by the actual developers and practitioners. Because the deblending technology is new and still developing, the authors suggest several areas for future research and advancement, such as using the arrival angle of data where multi-component detectors are available, and the use of low energy sources for marine mammal protection. And, how marine seismic interference could be a thing of the past! More good news—deblending by inversion is given the all-clear for time-lapse work, and (of course) for VSPs. The authors also discuss Apparition shooting, and they give useful instruction and examples on the number of inversion iterations required to deblend a data set successfully. If you wish to experiment yourself, a Python code example is included.

The relationships between data acquisition and data processing are discussed, because never before have they been so intertwined. In addition to describing the underlying technologies, this book is also a user-guide which takes you through survey design and describes the sensitivities of the processing algorithms which can allow simultaneous source technology to succeed. It would be most unwise to embark on a project (land or marine) without reading the sections containing pitfalls, warnings, QC suggestions, the requirements and limitations of the technology, and the data management issues (and not only because the data volumes are eye-watering).

Most interestingly, this book gives a rare and remarkably frank insight into how technology can be developed and moved into production in a big company such as BP. More than a technical book, it is in a sense the personal story—a journey—of the two authors and contains some very useful lessons about project management. How does one persuade skeptical management—and indeed convince and motivate skeptical technical staff—to become comfortable spending tens or even hundreds of millions of dollars on seismic surveys using new technology, many aspects of which appear counter-intuitive to traditionalists? This book may hold the answers.

Ian Jack
Cambridge, U.K.
Acknowledgments

Seismic simultaneous sourcing has been a multi-year, multi-team, multi-continent, multi-company effort. We would like to thank and acknowledge our many colleagues for their contributions, their commitment, and their efforts over the years. It is not possible to mention all of the people who have contributed to this effort. There are too many, and many of the contributions were likely made without our being aware of it. We would like to thank, in particular, our seismic acquisition contractors who made these efforts possible.

Within BP, there was a unique and valuable collaboration between the research, processing, acquisition, as well as the interpretation and analysis groups that made the delivery of this technology achievable. We are also grateful for the culture of innovation that allowed several disruptive, but eventually valuable, changes in seismic data acquisition to be developed.

The land simultaneous source technology in BP was initiated, developed, and delivered initially by numerous people from the London seismic central teams. This rapidly grew to include key people from WesternGeco and seismic experts and exploration personnel in key North Africa and Middle Eastern business units before extending across the wider BP company and its contractors. There are too many people to name individually, though many are recognized in the references in this book. We would like to acknowledge the specific contribution of Dave Howe, originally of the BP London central acquisition team. He not only developed the initial idea for the land independent simultaneous source approach, but also worked, in the offices and in the field, with others across the company and WesternGeco. Dave ensured its testing and operational delivery in North Africa and its development and advancement to use with land node acquisition before supporting the use of the technology in other parts of the company, even after his retirement. Dave also gave us invaluable input for this book. On the land processing side, we would specifically like to thank Tony Allan for his input to this book and his work with developing the constantly changing processing flow in the UK and in the field in North Africa.

There was a large and varied input from across BP and various contractors, in particular, WesternGeco, Seabird, and Fairfield. WesternGeco overcame some significant challenges in doing the first land simultaneous source surveys, both in the engineering and organizational aspects. Seabird did BP’s first marine simultaneous source test survey with a fairly short notice using the available survey fleet. WesternGeco acquired a test survey in the North Sea in which there were several unusual operational modifications to conventional practices but completed both the tests and the production acquisition over the next two years successfully.

There were numerous contributions from interns. In particular, in the early development, Jia Yan produced the software infrastructure required for efficient deblending, and Tim Lin did some of the early investigations into shot scheduling that guided our seismic acquisition efforts, and other interns generated somewhat less direct support. Contributions from within BP included those from the organization around the world. In an effort of this size, it is impossible for the authors to list or even know all of the people involved, but we are grateful for the work of everyone involved.

Any project of this size will have a substantial number of contributors, and this project has had a significant number of champions that have made these successes possible. This was reflected by the ‘One Team’ Helios Award, an internal BP award, presented to the teams in 2012. The Atlantis simultaneous source survey was made possible by BP’s Houston Advanced Seismic Imaging (ASI) team, the Houston acquisition group, and the Gulf of Mexico team. The Trinidad and North Sea simultaneous source surveys were a combined effort of the Houston and Sunbury ASI teams and the North Sea and Trinidad business units. Since this time, simultaneous source surveys were obtained in Alaska, Azerbaijan, Indonesia, and more in the Gulf of Mexico. These people have made BP the leader in seismic simultaneous source acquisition and have provided a significant economic advantage to the company. There are too many contributors to mention individually here. As an example, there were about 300 people involved in acquiring just the first Machar and Trinidad ISS surveys. We would like to thank everyone who supported this effort.

We have had the good fortune of having several university consortia that have contributed to the original ideas behind these developments. An incomplete list would be the Stanford Exploration Project at Stanford University, the Signal Analysis and Imaging Group at the University of Alberta, the Center for Wave Phenomena at the Colorado School of Mines, the Texas Consortium for Computational Seismology at the Bureau of Economic Geology at the University of Texas in Austin,
the Seismic Laboratory for Imaging and Modelling at the University of British Columbia, and the Delphi Consortium for Geo-Imaging at the Technical University of Delft. It was interesting to note that some of the ideas were not originally aimed at simultaneous sourcing but were in the more general area of seismic data processing ideas. We are keenly aware of these contributions, perhaps more than our consortia partners realize.

We must also acknowledge our competitors in oil companies, seismic contractors, and in academia. No technology progresses in a vacuum, and the seismic community inspired and encouraged these efforts. Oil companies often work together as partners, and we work together to utilize these technologies. We appreciate the internal support from within our partners. Seismic contractors actually acquire the seismic data as well as providing inspiration, ideas, and suggestions for acquisition. They also provided some of the original concepts. While our academic partners are not often considered competitors, a friendly rivalry drove ideas forward. Our collaborations with them have been exceptionally valuable.

The SEG deserves our gratitude for their interest, encouragement, and their help in making this book. It has been a pleasure working with them. In particular, the authors thank Susan Stamm, SEG books manager, for her many improvements in the manuscript. The book has become significantly more readable because of her efforts. Dave Monk also deserves special thanks for his careful work in reviewing this book.

We are grateful for BP’s support and permission to present some of the material in this book and for all of the talks and papers that led up to it. All of the figures showing real seismic data in Chapters 2 and 3 are courtesy of BP and used with permission of SEG.

Several of the figures have been generated using the Madagascar seismic processing system; we appreciate the assistance of Harpreet Kaur of TCCS at the University of Texas at Austin in the production of these images.

A number of the figures are photos of the exhibits at the Geophysical Society of Houston’s museum. We thank the volunteers there for their help and enthusiasm. We encourage you to visit the museum when you are in Houston.

Ray would like to thank his wife, Debbie, for editing the documents that became this book and for all of her editing help over the years. Christen Abma created several of the figures in this book. Finally, both of us would like to thank our families for their support and for their tolerance of some aspects of the life of a geophysicist. While we love our occupations, they occasionally require some sacrifices, from both us and our families. It is our hope that our enthusiasm for the science of geophysics has rubbed off on our families and on others.