GEOPHYSICS Today:
A Survey of the Field as the Journal Celebrates its 75th Anniversary

Edited by
The Editors of GEOPHYSICS

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Introduction

Geophysics is 75 years old this year. To celebrate this milestone, the editors decided to publish a special section in our journal containing a series of specially invited review papers to summarize the current state of the art in exploration geophysics, but with particular emphasis on developments during the past five years. The papers you will find in what follows describe a number of areas in which significant progress has been made. Of course it has not been possible to do justice to all areas of our field, yet the wide range of subjects covered surely indicates the current sound health of our profession. It also behooves us to keep in mind that what appears promising today may turn out to have lost luster a few years from now; time alone will tell. Most invited authors were able to contribute submitted manuscripts; in the end, only a few were unable to do so.

By the time most of the invited papers were already in hand, the editors, along with Ted Bakamjian of the SEG publications staff, decided that the original collection of 17 invited papers should be augmented by an additional number of papers drawn from the pages of Geophysics, and mostly from issues published during the past five years. These articles were selected by the editors to fill gaps that inevitably arose in the subject matter covered by the invited contributions. Because the collection of 28 papers was now too large for the special section, it was decided to publish this extended set in book form. This means that the 17 invited papers actually appear twice: once in the special 75th anniversary section of Geophysics, and again in the present volume, appropriately titled "Geophysics Today." While this second collection of 12 papers represents material already published in Geophysics, all additional contributions were chosen on the basis of their timeliness and their tutorial qualities.

The purely technical portions of this volume are nicely complemented by several short pieces with recollections recorded by past editors, an article on impact factor along with listings of past best papers, classic papers published in previous special issues, and listings of papers most often cited in the literature.

Perhaps an appropriate measure of progress in our journal is to look backward, so let us briefly return to Geophysics, Vol. 1, No. 1, page 1, January 1936. The very first article is authored by L.W. Blau and titled "Black Magic in Geophysical Prospecting." The fact that it was then considered appropriate to print an entire piece devoted to the exposure of black magic in exploration geophysics is in itself quite revealing. Anybody seeking a bit of comic relief from the study of a particularly difficult paper in Geophysics, Vol. 75 might take the time to look at this article, from which we shall quote the following passages:

"It is characteristic of these inventors that they stress emphatically the fact that they have never studied any exact science. The assumption seems to be that all the really great inventions are made by people who know nothing about the subject and that training in the exact sciences tends to build up complexes as well as beliefs that certain things cannot be done…Another great talking point is that they have worked on the invention for many years, rarely fewer than ten and often seventeen to twenty, the number depending somewhat on the age of the inventor…Substances do not attract according to Newton's law…, the force of attraction is alleged to vary with the chemical constitution of the substances…organic substances exhibit sexual characteristics; sex, being one of the strongest emotions, can therefore be very profitably exploited in oil prospecting if the proper technique is employed"

Clearly we have come a very long way since those early days: our field has undergone spectacular changes during the past three-quarters century. At the very least, people who know something about the subject and have had training in the exact sciences are now recognized as the mainstays of exploration geophysics! On the other hand, one must hope that the editors preparing the introduction to the 150th anniversary issue of Geophysics will not find reason to deride what we are doing today.

In what follows, we give brief summaries of the papers included in this anthology. We believe that our selection is a good, while admittedly incomplete snapshot of the present state-of-the-art of exploration geophysics. The ordering of papers follows the alphabetical section ordering of Geophysics in 2010.

Amplitude Variation with Offset (AVO)
Amplitude variation with offset (AVO) analysis of seismic reflections has become an important tool for hydrocarbon prospecting. Foster, Keys, and Lane review the development of AVO technology and give guidelines for the interpretation of AVO responses in terms of reservoir properties. They give examples of the use of AVO technology to detect hydrocarbons and distinguish high porosity reservoir sands from low porosity sands and shales.

Anisotropy
The role of anisotropy in seismic prospecting has dramatically increased over the past two decades due to advances in parameter estimation, the transition from poststack imaging to prestack depth migration, the wider offset and azimuthal coverage of 3D surveys, and acquisition of high-quality multicomponent data. Tsvankin, Gaiser, Grechka, van der Baan, and Thomsen present a comprehensive review of seismic modeling, processing, and inversion for anisotropic media. They discuss the foundations of methods operating with both P-waves and multicomponent data, demonstrate the improvements achieved by anisotropic imaging algorithms, and outline the possibilities of applying anisotropy parameters in reservoir characterization.

Borehole Geophysics and Rock Properties
Rock physics provides a link between geologic reservoir parameters (e.g., porosity, clay content, sorting, lithology, saturation) and seismic properties (e.g., acoustic impedance, the V_P/V_S ratio, bulk density, and the elastic moduli). Avseth, Mukerji, Mavko, and Dvorkin review some existing rock physics models and practical workflows, and they demonstrate the importance and benefit of linking rock physics to geologic processes. They highlight a hybrid modeling approach applicable to high porosity siliciclastic sediments and rocks.

Electrical and Electromagnetic Methods
Two papers are dedicated to electrical and electromagnetic methods. Zhdanov provides a historical overview of electromagnetic (EM) geophysics with a focus on the major discoveries and some critical turning points of this development. He outlines a framework for the further developments, which should focus on the multitransmitter and multireceiver surveys, analogous to seismic data acquisition systems, and on the multidimensional modeling and inversion methods. In a second paper, Constable provides a review of marine CSEM for hydrocarbon exploration, accessible to the nonspecialist. The paper also contains new material on the sensitivity of the CSEM method to 3D structure and anisotropy, as well as a comparison of time domain and frequency domain methods.

Engineering and Environmental Geophysics
Surface wave analysis is nowadays widely adopted for building near-surface S-wave velocity models. Socco, Foti, and Boiero provide a comprehensive review of the literature, with particular attention to the historical perspective, methodological issues, applications, and the most promising approaches developed in recent years. They discuss the inclusion of higher modes and the retrieval of lateral variations, and they review the current scientific debate on these topics. The paper concludes with a best practice guideline.

Gravity Exploration Methods
A 2005 paper by Nabighian, Ander, Grauch, Hansen, LaFehr, Li, Pearson, Peirce, Phillips, and Ruder describes the historical development of the gravity method in exploration geophysics. Even while eclipsed by seismology, gravity techniques often serve as crucial constraints to an interpretation based on seismic considerations alone. The gravity method is particularly applicable in salt provinces and in overthrust and foothill belts; it has a long history of successes in mining geophysics, particularly for the calculation of ore reserves for massive sulfide bodies.

Ground-Penetrating Radar
Ground-penetrating radar (GPR) is a geophysical method for obtaining information about the subsurface with extremely high resolution. GPR waves are sensitive to changes in the subsurface. Contrasts in electrical and magnetic properties can be detected, imaged, and characterized from GPR data. Slob, Sato, and Olhoeft review how GPR has developed into a versatile tool used at the ground surface and in boreholes, for subsurface characterization and monitoring changes, in a variety of applications.

Interpretation Methods

Two papers are devoted to interpretation methods. Helbig gives an interesting account of seismic interpretation in the predigital era. Traditionally, the "input" acquired in the field consisted of the original paper records, and the "output" submitted to the client consisted in structural sections and depth-contour maps of selected interfaces. Before the introduction of magnetic recording, it was common practice to do the conversion in the field office. Helbig's message is that the techniques of data acquisition and data interpretation have changed considerably, but the underlying principles are still the same. Therefore, many of the new methods are based on ideas formulated in the early times of the industry. A contribution by Gao reprinted from Volume 74 deals with 3D seismic volume visualization and interpretation. A series of case studies from worldwide exploration projects suggests that an integrated 3D seismic volume visualization and interpretation workflow can reduce an interpretation's inherent uncertainties. It does so by exposing critical geologic information from within the seismic data volumes.

Magnetic Exploration Methods

A second 2005 paper by Nabighian, Grauch, Hansen, LaFehr, Li, Peirce, Phillips, and Ruder offers a historical description of the evolution of the magnetic method over time. It is probably the oldest geophysical exploration method, and it enjoyed its prime with the advent of airborne magnetic surveys during and after World War II. With improvements made since then with instrumentation, navigation, and platform compensation, it is now possible to map the entire crustal section at a variety of scales. This can be done from a strongly magnetic basement at a regional scale to weakly magnetic sedimentary contacts at a local scale.

Passive Seismic Methods

Two papers deal with passive seismic methods. Maxwell, Rutledge, Jones, and Fehler review key projects associated with the development of downhole microseismic imaging for hydraulic fracturing and reservoir monitoring over the last 40 years. They describe the evolution of reservoir monitoring projects in North America, the North Sea, and the Middle East; and the growth of hydraulic fracture imaging projects from the first known example in 1974, through commercial offerings spawn from the Cotton Valley Sand Project and the first fracture image in the Barnett Shale. In a second paper, Duncan and Eisner review the practice of microseismic reservoir monitoring using surface and near-surface arrays. The history, theory, field techniques, processing approaches, and data interpretation methodologies are described and opportunities for future developments are suggested.

Poroelasticity

Understanding and quantification of attenuation and dispersion of seismic waves due to wave-induced flow has attracted considerable research interest over the last decades. Numerous models have been developed with varying degrees of rigor and complexity. Though all models predict attenuation and velocity dispersion typical for a relaxation process, there exist differences that can be related to the type of disorder (periodic, random, space dimension) and to the way the local flow is incorporated. Müller, Gurevich, and Lebedev review recent experimental and theoretical developments in a comparative manner.

Reservoir Geophysics

Reservoir geophysics is treated in a paper by Duffaut and Landrø. By a comparison between rock models and time-lapse AVO data, they show how the V_P/V_S ratio depends on differential stress and rock consolidation. A second reservoir geophysics contribution by Bosch, Mukerji, and Gonzalez reviews various approaches in seismic inversion and its combination with rock physics and geostatistics for quantitative reservoir characterization. Rock physics plays the important role of linking elastic parameters, such as impedances and velocities, to reservoir properties of interest such as lithologies, porosity, and pore fluids, while geostatistical methods help to add constraints of spatial correlation, conditioning to different kinds of data and to incorporate subseismic scales of heterogeneities.

Seismic Attributes and Pattern Recognition

Seismic attributes and pattern recognition are discussed in a paper by Guo, Lewis, and Marfurt. Their tutorial shows how to map multiple attributes to three- and four-component color models. They point out that careful visualization and display of multiple attributes continues to remain one of the most powerful tools available to the seismic interpreter.

Seismic Data Acquisition
Maurer, Curtis, and Boerner discuss seismic data acquisition. They review the history of geophysical experimental design, and describe possible extensions to current state-of-the-art methods. Their theoretical models are supported by four experimental design examples which are based on four different geophysical techniques.

Seismic Interferometry
Seismic interferometry is covered in a two-part contribution by Wapenaar, Draganov, Snieder, Campman, Verdel, Slob, and Curtis. Part 1 reviews the basic principles step by step, starting with 1D interferometry for direct waves and ending with 3D interferometry for reflected waves. The authors emphasize that the common aspect of direct and reflected wave interferometry is that virtual sources are created at positions where there are only receivers, without requiring knowledge of the subsurface medium parameters nor of the positions of the actual sources. In part 2, the authors discuss the underlying theory, starting with a review of the relation between time-reversed acoustics and the virtual source method, and ending with exact Green's function representations for seismic interferometry. Next they discuss many variants and extensions, including unified representations for general diffusion and wave phenomena, variants for virtual receivers and virtual reflectors, modifications for time-lapse interferometry and, last but not least, interferometry by deconvolution.

Seismic and Electromagnetic Inversion
This section has been expanded from the GEOPHYSICS' Seismic Inversion section to include electromagnetic inversion. Three papers are dedicated to seismic and electromagnetic inversion. The first is the 1987 classic by Constable, Parker, and Constable that introduced their Occam's inversion method. Their basic idea was (and still is) that the data should be fitted by a model which is as simple and as smooth as possible in order to reduce the temptation to over-interpret the data. Two additional papers are taken from the supplement to the November-December 2009 issue of GEOPHYSICS. The first, by Weglein, Zhang, Ramirez, Liu, and Lira, presents a thorough study of the fundamental meaning of the approximate linear inversion of seismic data. They remark that attempting to solve a direct forward problem in an inverse sense is not the same as solving an inverse problem directly. A second paper by Virieux and Operto gives a comprehensive overview of full-waveform inversion (FWI) in exploration geophysics. Recent advances in high-performance computing and multifold/multicomponent wide-aperture and wide-azimuth acquisition make 3D acoustic FWI possible. Following ideas proposed during the 1980s by Tarantola and his students, the authors describe multiscale strategies designed to mitigate the nonlinearity and ill-posedness of FWI by incorporating progressively shorter wavelengths in the model parameter space.

Seismic Migration
Another paper taken from the supplement to the November-December 2009 issue of GEOPHYSICS, authored by Etgen, Gray, and Zhang, deals with seismic migration. The past few decades have seen migration move from its heuristic roots to mathematically sound techniques that, using relatively few assumptions, render accurate pictures of the interior of the earth. The authors describe the progress made in depth migration to the present and the most significant barriers to attaining its inversion goals in the future. They also conjecture on progress likely to be made in the years ahead and on challenges that migration might not be able to meet.

Seismic Modeling and Wave Propagation
Carcione, Morency, and Santos deal with seismic modeling and wave propagation by introducing the partial differential equations for wave propagation in fluid-saturated rocks. In particular, they discuss finite-difference, pseudospectral, and finite-element methods. The modeling is based on Biot-type theories of dynamic poroelasticity, which constitute a general framework to describe the physics of wave propagation.

Seismic Velocity/Statics
Woodward, Nichols, Zdraveva, Whitfield, and Johns review the recent evolution of depth-imaging tomography as computer power and exploration requirements have grown. They give examples of the steady increase in model resolution, the shift from narrow- to wide-azimuth data sets, and a progression from isotropic to anisotropic models.

Signal Processing

Three papers are devoted to geophysical signal processing. The first, by Zwartjes and Sacchi, deals with the Fourier reconstruction of nonuniformly sampled as well as aliased seismic data. While techniques exist that handle the uniformly sampled and aliased case, few can handle the more difficult nonuniformly sampled and aliased situation. A second paper by Fomel addresses the problem of adaptive multiple subtraction by the use of regularized nonstationary regression. The author has developed a general method of match filtering that holds for the nonstationary case. This formulation is of value when the stationary model is no longer justifiable. A third contribution by Dragoset, Verschuur, Moore, and Bisley gives a fine description of the surface related multiple elimination (SRME) method. SRME is the most successful approach yet found for predicting and attenuating surface multiples. The authors present a brief history of the basic concept, a simple explanation of the method, a discussion of the challenges it faces in practice, and examples of how these challenges can be overcome.

GEOPHYSICS *Today: A Survey of the Field as the Journal Celebrates its 75th Anniversary* is truly a collaborative effort as the "Editors of Geophysics" credit suggests. Yet certain of the many editors involved played prominent roles in organizing and presenting this full-spectrum compendium of overview and tutorial papers. Sven Treitel, Kees Wapenaar, Enders Robinson, and SEG Editor Vladimir Grechka served as special editors of the September-October 75th anniversary special section of GEOPHYSICS from which 17 of the papers are drawn, working under the guidance of Special Sections/Supplements Assistant Editor Tamas Nemeth. Treitel, Wapenaar, Mauricio Sacchi, and Grechka advanced that project by organizing the material into this book, adding other recently published overview and tutorial papers to provide material under all GEOPHYSICS subject headings. Managing Editor Sergey Fomel provided constructive guidance while shepherding the book through the Publications Committee approval process. Numerous associate editors and reviewers contributed their expertise to this collection of work by many of the Society's leading authors. Ted Bakamjian, Dean Clark, Jennifer Cobb, Elise Cunningham, and Sheral Danker from the SEG staff provided invaluable help and advice throughout. The hope of everyone who contributed to this project is that this diamond-anniversary publication serves for years as a valuable reference for students, researchers, and practitioners of applied geophysics.

The Editors