Peter C. Wille

Sound Images of the Ocean

in Research and Monitoring

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With contributions of more than 120 sound image authors and marine experts of 22 countries

With 452 Images

Springer

Author

Professor Dr. Peter C. Wille

Kitzeberger Straße 31
24226 Heikendorf
Germany

Cover image: Seafloor relief of the *South Pacific Rise* near the *Wilkes Transform Fault*, a very fast spreading Mid Ocean Ridge (Sect. 5.2.4.1).
Image ©: J. R. Cochran, Lamont-Doherty Geological Observatory of Columbia University, Palisades, USA.
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Foreword

A technical invention and its evolution during the last decades of the twentieth century, comparable to the invention of photography and X-ray imaging at the end of the nineteenth century, happened nearly unnoticed by the public. This evolution has created a special art of imaging considered impossible before: the ability to generate images of large areas of the ocean floor nearly as detailed as aerial photographs. These images are three-dimensional and generated by sound. Echosounding, invented already in the second decade of the last century, produced depth data along the ship's course but no images of the kind we are familiar with. Imaging requires covering a surface. The breakthrough of imaging the sea floor by three-dimensional sampling of its surface along broad stripes instead of lines became possible only with the concurrence of three fundamental technologies: precise and worldwide *satellite navigation*, high speed *computers* with storage of huge amounts of data and the hard- and software of *multibeam echosounders* of up to a hundred sound beams and more in parallel.

It is a peerless maritime imaging technology in kind, accuracy and resolution, and it deals with a unique documentation. It is the history of the ocean floor, imprinted in its relief, visualized by sound imaging. The deep sea floor has preserved its geodynamic history over many millions of years; on the continents most of such traces have been lost due to erosion. Imaging the ocean floor is exemplary for the role of scientific imaging: *it is the visualisation of the reality that has guided research, brought forth discoveries, and confirmed or refuted theoretical presumptions.* This applies in particular to fields of high complexity like marine geo-science, exploring the specific and significantly different interacting processes of the vast variety of ocean areas. High resolution sound imaging provides also a guide for follow up research applying non acoustic methods such as magnetometry, gravimetry, close-up photography and bottom sampling and -coring. But advanced sound imagery has become itself an indispensable diagnostic tool to identify fundamental processes reshaping the floor of the ocean.

The sound images presented in this book comprehend examples of quite different areas and formations of the world's oceans provided by more than a hundred image authors from institutions of over 20 countries. The amazing progress is evident from the age of the images shown: the majority are a few years old at most. The progress encloses the development of further methods of sound imaging the sea, below, at, and above the sea floor. It has resulted in a broad and ever growing field of scientific, technical, economic, and governmental applications. These applications, their achievements and possibilities are definitely deserving of a sur-

vey. The fascination of the images, revealing widely unknown scenarios of the hidden side of our planet will inspire and raise interest of scientific neighbors and of non-experts. It will be a contribution to an interdisciplinary understanding of the subject of sound imaging the ocean which is in fact a common tool, connecting ocean research, utilization, and protection.

The understanding of the interaction between the hot interior of the Earth and its surface, the lithospheric plates causing volcanism and earthquakes, the rise of new sea floor at the mid ocean ridges and the processes of sea floor subduction at the opposite margins of the tectonic plates, is essentially based on acoustic imagery. This includes the outer relief as well as the internal structure. Comparable time spans of many million years of climate history are documented in the sediment stratification. It is part of the prehistoric diary of the Earth, resolved by advanced high resolution sub-bottom profilers, which also disclose sub-sediment morphologies and discover large deposits of hydrocarbons. Acoustic Doppler current profilers, together with other acoustic facilities and methods give us the features of ocean current systems, the Conveyor Belt of by far the largest amount of mobile heat energy on Earth, determining the climate of continents. It has been disclosed by acoustic means that current systems are guided by the sea floor relief far beyond the ridge crests. Marine acoustics quantifies also other processes of climate relevance like air intrusion into the sea. It has imaged coastal sediment motion like the migration of large dunes and various types of erosion and re-sedimentation up to past coastal slides of thousands of cubic kilometers with disastrous impact.

It is true: imaging the sea by sound has developed to an admirable degree of perfection but it cannot remove the fact that imaging of entire oceans is time consuming to say the least. It is realized with research- and hydrographic survey vessels proceeding not much faster than a bicycle as they cover the sea floor with a carpet of soundings, a few times the width of the water depth at most. Thus, only a minor part of the deep sea floor, in other words, of two thirds of the Earth's surface, is as yet known in as much detail as the surface of the moon.

The book compares the *slow but high resolution* acoustic imaging with another, *indirect* kind of ocean floor imaging: a *rapid but low resolution* method where satellite technology is the key requirement. Scanning the sea surface by satellite radar provides a coarse copy of the floor relief below by utilizing its varying local gravity. Undersea mass concentrations like large mountains attract the water above slightly more than the girdling abyssal plain, and deep valleys with their mass deficit correspondingly less, which causes bulges and dents respectively at the surface. This *gravity anomaly* method has revealed large scale structures of the ocean floor for the first time in their totality and in remote ocean areas. It has become an important guide to select sites of interest for detailed tectonic and geologic research relying on advanced ship-borne sound imagery. The overviews based on gravity anomaly, improved in resolution by blending with soundings are presented as global depictions and in comparison with high resolution acoustic imagery.

Limitation was necessary. Beyond scope are methods of acoustic underwater communication and remote control, in particular for offshore construction activities. Ocean surveillance and reconnaissance by Sonar in the framework of military defense is excluded as well – with the exception of acoustic sea mine hunting – although the navies also deal with acoustic imaging and naval underwater acous-

tic technology has often been the forerunner of ocean research applications. Nevertheless Naval officers, in particular Sonar-operators, need to familiarize themselves with the acoustic features of their environment, its various peculiarities and varying potential of natural camouflage, hiding or simulating targets of interest by acoustic similarities.

Some of the sea floor images of large areas with many details would require a much larger type area than a book can provide. These images are copied in addition for zooming on the CD attached to the book. The CD moreover contains several *Fledermaus*-versions of sea floor reliefs where choosing the preferred direction of view is essential. This is particularly necessary with the *Globe* containing the complete land and sea relief of our planet with a resolution of 5 arc minutes. The Fledermaus-Globe can be easily turned around the two axes with the PC-mouse and arbitrarily zoomed. Several virtual flight-animations through undersea landscapes of recent high resolution relief imagery and a quick-motion movie of dune migration from a panorama-echosounder are included as well. Some examples of different sea floor material acquired by the respective acoustic backscatter can be visualized as genuine 3D-depictions with red-green binoculars.

The book, covering a wide variety of special subjects of international sound imaging application in the sea is necessarily a composite product. The main part consists of course of the sound images, many of them unpublished, and scientific information provided by the image authors and their institutions. Most of the section texts and image captions including the introduction to the basic facts are written by the author of the book. The image-related texts are based on the correspondence with the various experts and image authors and have been reviewed by them. The correspondence included thorough discussions as to how to explain complex relationships to non experts and to condense the results to the essence of the investigation, the "message". Two key sections are complete articles specially written for the book by the respective experts. They are indicated by the authors' names, as well as a few others which have been essentially written or rewritten by the respective experts.

The book respects the reader who is interested in key technologies and achievements of ocean research but does not want to be confused with highly specialized terminology or wearied by complicated theory. The book therefore relies heavily on the direct, nearly self-explanatory evidence of the product of ocean acoustics: the authentic, quantitative sound image. There is strong emphasis on practical results in order to outline what we can expect in reality in accordance with the limits set by physics and environment. Mathematics are replaced by verbal explanations. An appendix includes some formal relations and the literature indexes of the subject sections refer to the related textbooks and recent original papers.

Altogether this way of generating an interdisciplinary special book provides much of the authenticity and actuality of congress proceedings and also much of the homogeneity of a normal textbook. The contributors provided their voluntary and generous collegial support because they consider such a book useful, even necessary.

Hans Werner Schenke
Alfred-Wegener-Institut
für Polar- und Meeresforschung

Foreword by the Sponsor

In this book, Peter C. Wille opens the hidden world of seafloor landscapes, which until now were nearly accessible exclusively to specialists. The impressive images presented here were generated during recent years by means of advanced echosounder systems of various techniques. The beauty of these sound images and their almost self-explanatory message will also fascinate other scientists and a wider public. The images have been contributed by 120 experts from 22 countries engaged in geosciences, offshore industry, offshore economy, surveillance and even archaeology.

The comparison of sound images of the sea floor with its coarse copy by the sea surface relief deformed by mass attraction of the seamounts below and recorded by satellite radar is of particular interest. It underlines the peerless role of high resolution acoustics but also the necessity to complete our insufficient knowledge of the deep sea floor world which is disclosed in detail by only a few percent as yet. But the sound images also reveal the necessity for protection because the future of mankind will depend to a great extent on the resources to be taken from the ocean volume and the seafloor.

For many decades now, our company has been one of the major players on the scene of ocean acoustic system development and production. In particular multibeam systems and non-linear high resolution sediment echosounders facilitated the hydroacoustic examination of the seafloor. These activities encompass the whole range of hydroacoustic surveying equipment: from portable units for the survey of riverbeds and inland waterways to permanently installed systems for oceangoing research vessels. The acoustic data collected by research vessels have been processed in the images which are part of this book.

In the future, however, autonomous underwater vehicles (AUV) will increasingly be used for the research and inspection of the water volume, the seafloor and the structures built upon the seabed. These vessels will take over many of the tasks which until now could only be performed by complex and expensive research vessels. For these tasks, the AUV will have its own intelligence, very precise navigation systems, optical and acoustical sensors, communication and fuel cell energy and propulsion systems. The growing market of AUV will be expanded by products which can be summarized as *robotics*. In the years to come, not only the unmanned and autonomous exploration but also the automatic execution of manual functions will become possible in the “blue waters”. Comparable developments can be

seen in the military naval sector, where this trend is aptly described as *the sonars are leaving the ships*. Both markets are served by ATLAS ELEKTRONIK GmbH with products that are setting new trends as our multibeam echosounders did years ago. The further deployment of AUV will be analogous to the missions of space probes with the distinction that operations in the hydrosphere offer the benefit of repeated use.

Our commitment in the compilation of this book is characterized by our participation in the worldwide gathering of *Sound Images of the Ocean* through the provision of our multibeam- and sediment echosounders. Additionally, we realize that this largely unknown part of our blue planet, presented with this book, is worthy of appreciation by a wider audience.

ATLAS ELEKTRONIK GmbH
Bremen, December 2004

Manfred Meyersieck Manfred Siegel

Preface

The particular fascination evoked by many of the sound images of the sea floor presented in this book has changed its character since the 26th December 2004. Formations of scientific and general interest, where large parts of the sea floor, the tectonic plates, are being subducted under adjacent tectonic plates have now become a frightening subject of another dimension. The mechanisms of destruction of human settlements by tectonic processes were known before: the majority of earthquakes and volcanism happen at or near plate margins. History reports of giant waves, propagating at enormous speed, which devastated coastal areas. The Japanese, overrun by the largest number of this kind of deluge, generated by a sudden uplift of the overriding tectonic plate, named them *Tsunami*. Through the last four centuries nearly two dozen giant Tsunamis have been recorded, each of which killed from more than 2 000 up to 40 000 people. The Sumatra Tsunami of December 2004, when presumably more than 300 000 died and millions became homeless, is unparalleled in history however: an apocalyptic catastrophe. The earthquake magnitude 9.0 is one of the highest ever recorded and corresponds to the energy of 32 000 Megatons TNT. The disaster, unimaginable before, has created an overwhelming response in charity worldwide, but has made us aware again that we are living on the cool but fragile skin of a glowing globe of which we still know only little. The need for a global Tsunami warning system has become strikingly evident. Though earthquakes cannot be predicted, they can be detected, localized and measured in magnitude, and the arrival of resulting Tsunamis, propagating oceanwide, can be made known in advance to save human lives.

The compilation and preparation of this book was completed before the date that shocked the world. However, the publisher has agreed to insert an image of the sea floor relief with the epicenter area in the Indian Ocean. This image, on short notice personally prepared and provided by the Director of the Center for Coastal and Ocean Mapping, L. Mayer, USA, is based on the Sandwell and Smith predicted topography data from NGDC, available prior to the Sumatra Tsunami. Scientific evaluation of actual seismic records in detail and subsequent mapping of the area in near future by high resolution sound imaging will throw light on the origin of this tragedy.

This book is the first attempt to publish a comprehensive overview of the wide variety of acoustic applications in the fields of research, of utilization, surveillance and protection of the ocean. This sound image collection covering a large number of subjects and sites of the world's oceans and coastal waters is both interdisciplinary and international. It has been enabled by the generous support of more than 120 ex-

perts and sound image authors from 22 countries. The images have been selected as representative of the work of the image authors and their subjects. These subjects range from the evidence of plate tectonics and continental shift and from methane-hydrate deposits, containing more than twice the amount of all other carbon hydrates on Earth, to indications of ocean warming imaged by acoustic tomography; from submerged cities to historic ship wrecks; from large submarine canyons to huge landslides; from sea lane surveillance and biomass monitoring to images and sound tracks of whale echosounding and communication; from sub-polar ice imaging to steering of the Gulf stream by undersea topography; and from the Arctic Ocean to Antarctica. Unlike the continents and islands inhabited and shaped by man, the deep sea, much more than the continental shelf, is the exclusive territory of nature with marginal human impact hitherto, apart from relics of ship disasters and wars through the centuries and communication cables in the last few decades.

The book is not a high-resolution sound imaged atlas of the world's sea floor. Two-thirds of the globe is ocean, and only a low percentage of ocean floor has been sound imaged by advanced technology so far. Nevertheless, the book *does* provide a global atlas of the hidden side of the Earth, albeit in less detail. All available echosounder data – the sparse sounding lines in remote areas of the world as well as the denser measurements near coasts and sea lanes – has been merged with satellite radar data of the sea surface relief, providing a coarse copy of the sea floor beneath. The weak bulges and dents are generated by gravity anomalies which attract the sea volume above a submarine mountain slightly more than above a valley. The merger of these two independent data sets, combined to form a complete globe – a pioneering work by leading experts – is the best possible overview at present of the nearly infinite variety of sea floor formations. This overview has become indispensable as a guide for site selection of follow-on high resolution acoustic close-ups of the outer relief and the structure below, to reveal the details of processes for further on-site research. The CD included with the book allows zooming and turning of the relief globe, as well as of very large sound images.

The book demonstrates the capability of the various technologies of sound imaging as *diagnostic tools* – similar to ultrasonics in medicine – but the aesthetic appearance of many of these images evokes appreciation beyond mere information. The book is intentionally written for the non-expert who may be a scientist from a neighboring faculty. All comments and textual documentation accompanying the image collection, as well as the introduction to the basic facts of ocean acoustic imaging, have been reviewed and supplemented by the respective experts. The intention is to raise and maintain interest in those formations and processes of the ocean which are beyond the access of photography – by far the majority.

Peter C. Wille April 2005

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The generous support of the book project by the subsequent sound image authors and marine experts is cordially and respectfully appreciated. These experts contributed sound images typical of their respective fields of work as original, unabbreviated files, often prior to their own publications and provided the related scientific and technical information together with text reviews, supplements, and literature. The willingness and patience to discuss the formulation of the scientific message for non-expert readers deserves particular respect. The names of researchers who provided supplementary reviews and revisions of image comments in the field of their special expertise for images provided by colleagues are indicated by an asterisk. Book sections and box insets written by image authors and other experts carry the respective names.

Juan Acosta Yepes	Geology and Geophysics Dept., Instituto Español de Oceanografía, Madrid, Spain *(Sect. 5.3.5, 5.6.1, 5.6.2)*
Dr. Matina Alexandri	Dept. of Marine Geology & Geophysics, Institute of Oceanography, Hellenic Centre for Marine Research, HCMR, Athens, Greece *(Sect. 5.6.4)*
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Andrea Bellettini	Nato Undersea Research Centre, La Spezia, Italy *(Sect. 7.1.5)*
George Bernardel	Law of the Sea Group, Geoscience Australia, Canberra, Commonwealth of Australia *(Sect. 5.2.2)*
Manfred Bersch	Institut für Meereskunde, Universität Hamburg, Germany *(Sect. 6.1.2)*
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Andreas Beyer	Alfred-Wegener-Institut für Polar- und Meeresforschung AWI, Bremerhaven, Germany *(Sect. 5.3.4, 5.3.6)*
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Constanze Hohmann Nicola Engineering GmbH, Hamburg, Germany *(Sect. 5.5.3)*

Egil Ingebretsen Marine Surveys, Pipelines and Marine Operations, Norsk Hydro ASA, Norway *(Sect. 5.3.7)*

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Heiner Josenhans Geological Survey of Canada (Atlantic), Bedford Institute of Oceanography, Canada *(Sect. 5.3.9)*

Ingo Junge Institut für Strömungsmechanik und Elektronisches Rechnen im Bauwesen, ISERB, University of Hannover, Germany *(Sect. 7.1.2)*

Edward L. King Geological Survey of Canada (Atlantic), Bedford Institute of Oceanography, Canada *(Sect. 5.3.9)*
Dr. Dirk Kläschen Leibniz-Institut für Meereswissenschaften an der Universität Kiel, Germany *(Sect. 6.2.1)*
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Dr. Hermann-Rudolf Kudrass Bundesanstalt für Geowissenschaften und Rohstoffe BGR, Hannover, Germany *(Sect. 5.3.2)*
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*Dr. Walter Lenz** Institut für Meereskunde, Universität Hamburg, Germany *(Sect. 2.11)*
Dr. Michael Z. Li Geological Survey of Canada (Atlantic), Bedford Institute of Oceanography, Canada *(Sect. 5.3.9)*
Prof. Dr. Char-Shine Liu National Center for Ocean Research, Institute of Oceanography, National Taiwan University, Taipei, Taiwan, Republic of China *(Sect. 5.2.9)*
Dr. Benoît Loubrieu DRO Institut français de recherche pour l'exploitation de la mer, Ifremer, Bres, France *(Sect. 5.6.6)*
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Prof. Dr. Douglas G. Masson Southampton Oceanography Centre, United Kingdom *(Sect. 5.3.1)*
Prof. Dr. Dr. h.c. Larry Mayer Center for Coastal and Ocean Mapping CCOM/NOAA-UNH Joint Hydrographic Center, University of New Hampshire, Durham, United States of America *(Sect. 5.2.1, 5.2.2, 7.3.5)*
Dr. Lev Merklin P. P. Shirshov Institute of Oceanology, Academy of Sciences of Russia, Moscow, Russian Federation *(Sect. 5.4.3, 5.7.7)*

Prof. Dr. Jürgen Mienert Department of Geology, University of Tromsø, Norway *(Sect. 5.3.5)*

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Dr. Atle Nygård Department of Earth Science, University of Bergen, Norway *(Sect. 5.3.2)*

Walter Offenborn Marineamt Abt GeoInfoW – Geo 1, Rostock, Germany *(Sect. 7.1.1)*

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Prof. Dr. Dimitrios Papanikolaou Department of Marine Geology, University of Athens, Greece *(Sect. 5.6.4)*

Russell Parrott Geological Survey of Canada, Natural Resources Canada, Dartmouth, Nova Scotia, Canada *(Sect. 5.3.9)*

Gianni Pavan Centro Interdisciplinare di Bioacustica e Ricerche Ambientali Universita' degli Studi di Pavia, Pavia, Italy *(Sect. 6.3.3)*

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Marc Pinto Nato Undersea Research Centre, La Spezia, Italy *(Sect. 7.1.5)*

Dr. Katrin Premke Alfred-Wegener-Institut für Polar- und Meeresforschung AWI, Bremerhaven, Germany *(Sect. 6.3.2)*

Dr. Cesar Ranero Leibniz-Institut für Meereswissenschaften an der Universität Kiel, Germany *(Sect. 5.1.2, 5.2.1, 5.2.3, 5.2.6)*

Dr. Michael D. Richardson Seafloor Sciences Branch, Marine Geosciences Division, Naval Research Laboratory, Stennis Space Center, United States of America *(Sect. 5.7.2, 6.2.2)*

Claudia Roedle Wasser- und Schifffahrtsamt WSA, Hamburg-Wedel, Germany *(Sect. 7.1.2)*

Cris A. Sabo RESON Inc., Goleta, United States of America *(Sect. 7.1.4, 7.2.2)*

Dr. Eberhard Sauter Alfred-Wegener-Institut für Polar- und Meeresforschung AWI, Bremerhaven, Germany *(Sect. 6.2.2)*

Dr. Hans Werner Schenke Alfred-Wegener-Institut für Polar- und Meeresforschung AWI, Bremerhaven, Germany *(Sect. 5.2.6, 5.3.4, 5.3.6, 5.4.1, 5.4.2, 5.5.1, 5.5.2, 5.5.3)*

Dr. Thomas Scholz Forschungsanstalt der Bundeswehr für Wasserschall und Geophysik FWG, Kiel, Germany *(Sect. 2.1)*

Dieter Seefeldt Strom- und Hafenbau, Hamburg, Germany *(Sect. 7.1.3)*

Dr. Torsten Seifert Institut für Ostseeforschung IOW, an der Universität Rostock, Germany *(Sect. 5.7.1, 5.7.2)*

Prof. Dr. Uwe Send Leibniz-Institut für Meereswissenschaften an der Universität Kiel, Germany *(Sect. 6.1.3)*

*Prof. Manfred Siegel** Atlas Elektronik and Hochschule Bremen, Germany *(Sect. 2.11)*

Jonathan S. Smith Geomatics, EP Technology, Shell International Exploration and Production Inc., Ashford, Houston, United States of America *(Sect. 7.4.1.2)*

Dr. Deborah K. Smith Woods Hole Oceanographic Institution, Woods Hole, United States of America *(Sect. 5.2.3)*

Dr. Per Söderberg FOI, Stockholm, Sweden *(Sect. 5.7.5)*

Prof. Dr. Volkhard Spiess Marine Technology/Environmental Research, Department of Earth Science, University of Bremen, Germany *(Sect. 5.3.2)*

Prof. Dr. Rüdiger Stein Alfred-Wegener-Institute for Polar- and Marine Research, Bremerhaven, Germany *(Sect. 5.4.3)*

Prof. Dr. Peter Stoffers Institut für Geowissenschaften GPI, Universität Kiel, Germany *(Sect. 5.2.4)*

Dr. Siegfried Stolte Lüneburg, Germany *(Sect. 2.9)*

*Federico De Strobel** Nato Undersea Research Centre, La Spezia, Italy *(Sect. 2.11)*

*Prof. Dr. Erwin Suess** Leibniz-Institut für Meereswissenschaften an der Universität Kiel, Germany *(Sect. 6.2.1)*

Dr. Franz Tauber Institut für Ostseeforschung Warnemünde IOW an der Universität Rostock, Germany *(Sect. 5.7.1, 5.7.2)*

Dr. Jaroslaw Tegowski Institute of Oceanology, Polish Academy of Science, Sopot, Poland *(Sect. 5.7.2)*

Alex Trangeled Nato Undersea Research Centre, La Spezia, Italy *(Sect. 6.3.4)*

*Juliusz Tuszyñski** Hydrographic Office Polish Navy HOPN, Poland *(Sect. 7.1.4.4)*

Michael Unger Forschungsanstalt der Bundeswehr für Wasserschall und Geophysik FWG, Kiel, Germany *(Sect. 3.2.2)*

*Heinz G. Urban** Atlas Elektronik Bremen, Germany *(Sect. 4.4.1–4.4.8)*

Nat Usher EPT GeoDrilling; technical guidance to GeoHazards, GeoPressure, Geodetics, BP America Inc, Houston, United States of America *(Sect. 7.4.1)*

Prof. Dr. Tore O. Vorren Dpt. of Geology, University of Tromsø, Norway *(Sect. 5.3.7)*

Prof. Dr. Peter Wadhams Department of Applied Mathematics and Theoretical Physics, University of Cambridge, United Kingdom *(Sect. 5.4.4)*

Donald J. Walter Naval Research Laboratory, Stennis Space Center, United States of America *(Sect. 6.2.2)*
Daniel J Warren Marine Archaeology Section, C & C Technologies, Inc., Lafayette, United States of America *(Sect. 7.4.1)*
Dr. Tjeerd C. E. van Weering Netherlands Institute for Sea Research (NIOZ), Texel, The Netherlands *(Sect. 5.3.4)*
Dr. Wilhelm Weinrebe Leibniz-Institut für Meereswissenschaften an der Universität Kiel, Germany *(Sect. 5.1.2, 5.2.1, 5.2.3, 5.2.6)*
Stein Wendel Norsk Hydro ASA, Ormen Lange Project, Aker Kværner, Lysaker, Oslo, Norway *(Sect. 5.3.1, 7.4.2)*
Prof. Dr. Gert Wendt Institut für E-Technik der Universität Rostock, Germany *(Chap. 1–4, Sect. 6.2.2, 7.2.2)*
Dr. Friedrich Werner Kiel, Germany *(Sect. 5.3.3)*
Dr. Thomas Wever Forschungsanstalt der Bundeswehr für Wasserschall und Geophysik FWG, Kiel, Germany *(Sect. 6.2.2)*
Roger Wiik Fugro Survey AS, Oslo, Norway *(Sect. 5.3.7)*
Nico van Woerkom NeSA B.V./ Thales GeoSolutions, The Netherlands *(Sect. 7.1.3)*
*Dr. Tim J. Worthington** Institut für Geowissenschaften GPI, Universität Kiel, Germany *(Sect. 5.2.2, 5.2.4)*
Dr. Sébastien Zaragosi Département de Géologie et Océanographie, Université de Bordeaux I, France. *(Sect. 5.3.2)*
Dr. Manfred Zeiler Bundesanstalt für Seeschifffahrt und Hydrographie BSH, Hamburg, Germany *(Sect. 5.3.3, 7.1.1, 7.2.2)*
Dr. Walter Zenk Leibniz-Institut für Meereswissenschaften an der Universität Kiel, Germany *(Sect. 6.1.1)*
*Prof. Dr. Günter Ziehm** Passau, Germany *(Sect. 2.11)*

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Contents

List of Images