Wave Inversion Technology

Wave Inversion Technology
established 1997 in Karlsruhe

Annual Report

1998

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with contributions
from the WIT Groups:

Geophysical Institute
Karlsruhe University
Hertzstr. 16
76187 Karlsruhe
Germany

Tel.: (+49) 721/608-4443
Fax: (+49) 721/71173
e-mail: peter.hubral@physik.uni-karlsruhe.de

Dept. of Applied Math.
IMECC - UNICAMP
C.P. 6065
13081-970 Campinas (SP)
Brazil

Tel.: (+55) 19/788-5984 or -5973
Fax: (+55) 19/289-5808
e-mail: tygel@ime.unicamp.br

Institute of Geophysics
Hamburg University
Bundesstr. 55
20146 Hamburg
Germany

Tel.: (+49) 40/4123-2975
Fax: (+49) 40/4123-5441
e-mail: gajewski@dkrz.de

Nancy School of Geology
Rue Doyen-Marc Roubault - BP40
54501 Vandoeuvre-les-Nancy
France

Tel.: (+33) 383 596442
Fax: (+33) 383 596460
e-mail: shapiro@ensg.u-nancy.fr

WIT Web Page:
http://www-gpi.physik.uni-karlsruhe.de/pub/wit/wit.html

Preface

The second WIT report gives a compilation of the 1998 activities. The global WIT-constellation with one group in Campinas, one in Hamburg, two in Karlsruhe and one in Nancy functioned effectively and harmoniously in 1998 with approximately 30 researchers being involved. The WIT research is now strengthened by the fact that Serge Shapiro (formerly Nancy) has received a full professorship in Berlin, where he will continue his WIT activities with an improved infrastructure. The WIT research in 1998 was also reinforced by the two visiting professors (Dr. Boris Gelchinsky and Dr. Mikhail Popov) in Karlsruhe.

As further WIT contributions (in addition to this second report) which appeared in 1998, I would like to mention the book on ”Amplitude-Preserving Seismic Reflection Imaging” which appeared at Geophysical Press. It is a summary of the EAGE/SEG-sponsored Karlsruhe workshop, organized by the WIT Consortium in Seeheim, Germany. I also would like to mention the new book available at Springer Verlag ”Seismic Waves in Random Media” authored by S. Shapiro and myself.

Finally, the WIT consortium also organized the EAGE/SEG sponsored ”Karlsruhe Workshop on Macro-model-independent Seismic Reflection Imaging” from February 14-15, 1999. All WIT partners are pleased that some of its previous contributions to the WIT research have been recognized internationally by the J.C. Karcher Award given by the SEG to our founding member Dr. Jörg Schleicher.

Peter Hubral

Karlsruhe, February 16, 1999

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Modeling

Other Topics

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Reviews: WIT Report 1998

Responsible for compilation and layout: M. Riede & R. Essenreiter[1]

Imaging

G. Höcht et al.: The common reflection surface stack is a macro velocity model independent method to simulate zero-offset sections. It is based on attributes of wavefronts associated with hypothetical experiments that are used to describe the kinematic reflection response of inhomogeneous media. In this context we derive the stacking operator and with respect to application its more convenient Taylor series expansions.

In the second part of The Common Reflection Surface Stack **R. Jäger et al.** apply the common reflection surface stack method to synthetic data. In addition to the simulated zero-offset section we obtain a set of data-derived wavefront attributes. We compare them to the model-derived attributes exposing a wide agreement. We discuss different strategies to determine the attributes with respect to accuracy and computional costs.

Jürgen Mann shows that seismic image wave methods allow to transform a seismic image with respect to a change in an imaging parameter which depends on the imaging method under consideration. This strategy is dicussed for different imaging problems: post-stack time migration, post-stack depth migration, dip moveout correction, and migration to zero-offset. For migration the imaging parameter is the constant migration velocity, whereas for the latter two imaging problems it is the source/receiver offset.

Vieth et al.: Instead of picking data in in- and cross-line sections the entire wavefield of the common-shot sections is used for computing dip and strike of a reflector.

Pasasa et al. demonstrate the superior performance of their novel technique of wave front extrapolation on a computational grid. The approach is used in Prestack Kirchhoff Migration of the SEG/EAGE Salt data set and results in unprecedented high-resolution images.

Tygel et al. introduce a new inverse integral formula to the classical Kirchhoff-Helmholtz forward modeling integral. The new formula is more natural than the conventional Kirchhoff migration integral. This new inverse formula consists of an integration along the reflection traveltime surface, reconstructing the Huygens sources along the reflector.

[1]**email:** mriede@gpiwap3.physik.uni-karlsruhe.de & Robert.Essenreiter@physik.uni-karlsruhe.de

Birgin et al. describe a new algorithm to extract from multicoverage data, the traveltime parameters required for CRS stacking. The algorithm uses a newly developed spectral projected gradient method combined with a global optimization technique. First experiments indicate that the method is able to produce accurate results in an efficient way.

Cruz and Urban derive the weight function and the diffraction stack integral operator for the two and one half dimensional (2.5-D) seimic models and apply it to a set of synthetic seismic data in a noisy enviroment. The result shows the accuracy and stability of the 2.5-D migration as a tool for obtaining the reflectivity properties of the earth subsurface, which is of great interest for a AVO or AVA analysis.

Rock Physics and Waves in Random Media

In 1998 we continued to develop the method of the SBRC (Seismicity Based Reservoir Characterization). The corresponding contribution of **S. A. Shapiro** with his coauthors describes in details an approach to the seismicity-data inversion for the permeability tensor for the case of poroelastic media with anisotropic fluid transport.

Vieth shows his first results on crack imaging in randomly heterogeneous media. He suggests to apply a simple post-migration approach to detect fractures embedded in randomly heterogeneous structures.

For waves in 2-D and 3-D randomly heterogeneous media **Tobias Müller** is going to develop an approximation of the Green Function which takes into account effects of small-scale heterogeneities. His formalism is similar to the generalized O'Doherty-Anstey formula valid in multilayered structures. However, one should emphasis the increased complexity of the problem now. In his contribution Tobias shortly describes his approach.

In order to understand the wave propagation in fractured structures we have to perform a modeling in media with high-contrast inclusions. **Erik Saenger** will present the modified Finite Difference grid, which permits to model waves in such situations.

Stephan Bojinski reports about his Thesis on seismic characterization of randomly fractured media.

Serge Shapiro gives a short summary of his and Peter Hubral's book on seismic strategraphic filtering.

Modeling

Ettrich has developed a 3D Finite Difference eikonal solver for elliptical anisotropic media. It allows for arbitrary orientation of the tensor ellipsoid and for strong anisotropy. It serves as the background medium to compute traveltimes for arbitrary anisotropic media using a perturbation approach. A second-order approximations of the eikonal equation results in a high accuracy with relative errors in the order of a few permille.

Falk et al. present a modelling technique for wave propagation simulation based on the Finite Difference techniques which allows efficient computations of wave fields even if small scale heterogeneities are present in the model. It is demonstrated on an cross-well experiment where the influence of the source and receiver well is included. The scattering of borehole guided waves results in very complex seismogramms.

Gajewski uses the hyperbolic variant of the paraxial approximation to determine the complete ray propagator from traveltimes. The ray propagator enables the evaluation of many important properties of seismic waves, like migration weights, divergence corrections etc. Moreover, the propagator provides a very efficient technique to interpolate traveltimes, which is demonstrated on some examples.

A 3-D Finite-Difference eikonal solver for non-cubical grids was developed by **Leidenfrost et al.** A carefully chosen set of grid spacings for a non-cubical grid can reduce the model size and thus save computational time. Moreover, it may even allow stronger velocity contrasts in the model without the appearance of acausalities. Numerical examples demonstrate the functionality of the method.

Ekkehart Tessmer optimizes computational effort in finite-difference seismic modeling by using domain dependent time step sizes. Applications demonstrate the high accuracy of the method and its efficiency.

Schleicher et al. discuss the Kirchhoff integral for general anisotropic elastic media. They show hot standard Kirchhoff-Helmholtz approximation can be generalized for this case. If one elementary seismic wave is considered, a scalar reflection coefficient describes the amplitude change under specular reflection.

Tygel and Ursin introduce a new representation integral to model scattering from a weak-contrast interface within a general elastic, anisotropic medium. Asymptotic evaluation of the integral leads to an appealing description of the total sctattered field as a sum of individual contributions such as specular reflections, as well as i edge and edge diffractions.

Santos et al. investigate the seismic imaging process called demigration in greater detail. They argue that demigration is *not* the same as forward modeling and point out the main differences.

M. Karrenbach shows applications of parallel computing to seismic processing and full wave form modeling. Seismic processing and modeling show a large degree of parallelism on various levels that can be exploited in order to speed up computation and turn around time. A complete parallel processing sequence is applied to the Mobil AVO data set and a parallel 2D modeling run is carried out to produce a complete prestack data set from the SEG/EAEG Salt model. Runtime and scalability are measured on a IBM SP-2.

Goertz et al. use 3D finite difference techniques to perform full wave field modeling of a complex fault zone. Synthetic benchmark data sets are used to enhance imaging techniques. Modeling of rock properties within the fault zone enables them to simulate 4D seismic monitoring experiments.

Pohl et al. compute the elastic wave equation solution on a irregular computational grid in order to reduce unphysical diffractions that can arise from the typical staircasing effect when applying conventional finite differences to a regularly gridded model. Examples of wave propagation in 2 dimensions are shown for a homogeneous medium using a irregular grid, as well as a 2-layer model, where the layer boundary exhibits topography.

Other Topics

Popov and Schitov present the results for the problem which models wave propagtion in anisotropic inhomogeneous media when the velocities of two qS waves coincide at a point. These results allow to anticipate that generally one qS wave being incident at such a point gives rise to two qS waves behind this point. The ray ansatz becomes singular in a vicinity of such points and cannot describe the wave phenomenon properly.

Tygel et al. review the basic derivations and results concerning the traveltime moveout formula of Gelchinsky and coworkers. This formula describes traveltimes of rays located around a fixed central ray and it is called multifocus moveout. They also present a new higher-order multifocus formula and provide an alternative form suitable for implementation.

M. Karrenbach et al. use the novel programming language Java in a computational interdisciplinary project between the geophysics and computer science. Basic seismic processing steps are programmed in Java and High Performance Fortran and their runtime, scalability measured on a wide variety of parallel high-performance computers and workstations. The Mobil AVO data set is used a benchmark data set to which some standard processing steps are applied.

M. Karrenbach reports on large-scale computational and visualization facilities that are available to conduct research in seismic algorithm development. The High Performance Computing Center at Stuttgart offers a variety of highly parallel computers as well as a 3D immersive virtual reality environment for analyzing seismic data and velocity models. Computational steering of large-scale simulations and processing runs are possible from within this environment. As oil companies install such environments more frequently, access of researchers to similar tools is important.

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The Wave Inversion Technology Consortium

The Wave Inversion Technology Consortium (WIT) was established in 1997 and is organized by the Geophysical Institute of the Karlsruhe University. Together with its five working groups at UNICAMP, Campinas, Brasil the Computer Science Department at Nancy, France, the FU Berlin and the Applied Geophysics Group of the University of Hamburg (AGG) it offers the following services to its sponsors.

- Research as described in the topic "Research aims" below and on the page " *Research.* "
- Deliverables.
- Technology transfer / training.

Research aims

The ultimate goal of the WIT Consortium is a most accurate and efficient target-oriented modeling and seismic imaging using seismic and acoustic methods.

Traditionally, exploration seismics aims at the delineation of geological structures that constrain and confine reservoirs. It then extrapolates the coarse structural features of logs into space. Today an understanding is emerging on how sub-wavelength features such as small-scale disorder, porosity, permeability, fluid saturation etc. influence elastic wave propagation and how these properties can be recovered in the sense of effective media.

The WIT consortium plans to have the following main research directions, which aim at characterizing and extrapolating fine grained properties of targets:

- Forward and inverse scattering in disordered media and composite materials.
- Seismic and acoustic methods in porous media.

- True-amplitude imaging, migration and inversion.
- Seismic image and configuration transformations. (Data mappings)
- Macromodel-independent multicoverage zero-offset simulations.
- Macromodel determination.
- Fast and accurate seismic forward modeling

Click here for a more detailed description of our research aims.

Steering committee

Internal steering committee:

- Robert Essenreiter
- Dirk Gajewski
- Peter Hubral
- Martin Karrenbach
- Andreas Kirchner
- Thilo Müller
- Claudia Payne
- Jörg Schleicher
- Sergei Shapiro
- Ekkehart Tessmer
- Martin Tygel
- Friedemann Wenzel

External steering committee (company representatives):

- Paolo Marchetti, AGIP
- Heinz-Jürgen Brink, BEB
- Josef Paffenholz, BHP
- Glyn M. Jones, Chevron
- Twain Dopkin, Cogniseis
- Claude Lafond, Elf
- Ralf Ferber, Geco Prakla
- David L. Hinkley, Mobil
- Paul Krajewski, Preussag
- Martin Widmaier, PGS Seres
- Wolfgang Apel, RWE-DEA

WIT public relations committee

Peter Hubral	
Claudia Payne	
Robert Essenreiter	*WIT Report and WIT Meeting Organization* *Contact to other WIT groups*
Matthias Riede	*WIT Report and WIT Meeting Organization* *Contact to other WIT groups*
Andreas Kirchner	*WIT Homepage Manager*
Tobias Müller	*WIT Seminar Organizer*
Jürgen Mann	*WIT Poster Organizer*
Kai-Uwe Vieth	*WIT Poster Organizer*
Thilo Müller	*Seminar Organizer*

Research groups

Research Group Karlsruhe (Hubral)

Macro-Model Independent Reflection Imaging

Group leader:

Peter Hubral

Boris Gelchinsky. Alexander von Humboldt prize winner, visiting professor.	*Teaching and developping the Homeomorphic Imaging method and new High-Resolution coherency measures*
M.Popov. Visiting professor.	*Teaching and developping the ray theory in complex media.*
Thilo Müller. Ph.D. student.	*Developping the Common Reflection Surface Stacking (CRS) method; assisting Prof. Hubral in giving lectures; supervising master students;*
Rainer Jäger. Master student.	*Special aspects of the CRS method*
German Höcht. Ph.D. student.	*Imaging with the CRP and the CRS Stack*
Patrick Majer. Research student.	
Kai-Uwe Vieth. Ph.D. student.	*Application and development of imaging and inversion techniques. Non-destructive localization of macroscopic cracks in fibre-reinforced composite materials*
Matthias Riede. Ph.D. student.	*Modeling by Demigration*
Thomas Hertweck. Research student.	
Jürgen Mann. Ph.D. student.	*Derivation and implementation of the Image Wave Theory and its application to seismic data*
Robert Essenreiter. Ph.D.student.	*Development of multiple identification and suppression techniques on the basis of neural networks.*
German Garabito Callapino.	*Zero Offset Imaging - responsible for*

Ph.D. student.	*FOCUS/Disco based processing*
Norcirio Pantoja Queiroz. Master student.	*True amplitude time migration without knowledge of velocities*

Research Group Karlsruhe (Wenzel)

Full Wave Form Modeling and Imaging with Fast Marching Schemes

Group leaders:

Martin Karrenbach
Friedemann Wenzel

Alexander Goertz. Ph.D. student.	*3D velocity model building using GOCAD and 3D Finite Difference seismic modeling in complex fault zones*
Linus Pasasa. Ph.D. student.	*High-resolution seismic imaging in waste disposal sites and applications of dynamic wave front tracing in prestack migration*
Melanie Pohl. Ph.D. student.	*Modelling of anisotropic features in the earth's crust and development of Finite Difference methods on irregular grids*
Robert Mauch. Master student.	*Coherency analysis of seismic data (Skills: SEPLIB, Fortran90)*
Bärbel Traub. Master student.	*3D Asymptotic Raytracing with a Wave Front Construction Method (Skills: SEPlib, Moser's recursive raytracing)*
Maren Scheidhauer. Research student.	*Testing of processing seismic algorithms (Processing Packages: FOCUS, SEPlib, SU, GMT)*
Robert Essenreiter. Ph.D.student.	*Development of multiple identification and suppression techniques on the basis of neural networks.*
Ingo Koglin. Research student.	*Computation and analysis of seismic attributes (skills: SEPLIB, Fortran90)*

Research Group Hamburg (Gajewski)

Applied Geophysics Group (AGG)

Group leader:

Dirk Gajewski	*High frequency asymptotics for imaging and modeling*

Research associates:

Ekkehart Tessmer	*Full wave form modeling.*
Tim Bergmann	*Effects of nonlinear elastic behaviour on wave propagation.*
N.N.	*Prestack migration and material parameter estimation in anisotropic media*

Ph.D. students:

Andree Leidenfrost	*Finite-Difference traveltime computation*
Claudia Vanelle	*Model independent time processing*
Elive Menyoli	*Prestack depth migration of converted waves*

Master students:

Maximilian Krüger	*AVO modeling of gas hydrates*
Sebastian Barth	*Processing and migration of wide angle observations*
Tina Kaschwich	*3D Wave front construction*
Nicol Linke	*3D Wave front construction*

Research Group Campinas (Tygel)

Modeling by Demigration, Kirchhoff Migration, Traveltime Inversion, Configuration Transforms, Edge Diffractions, 2.5-D Wave Propagation

Group leaders:

Martin Tygel,
Jörg Schleicher,
Lúcio Tunes Santos

PostDoc Researchers:

Ernesto Goldberg Birgin

Ph.D.Students:

João Luis Martins.	*Migration and Demigration in 2.5 Dimensions*

Maria Amélia Novais Schleicher.	*Modeling of Reflections and Diffractions by a unified Born-Kirchhoff approximation.*
Ricardo Biloti.	*Multiparameter Velocity Analysis*
Rodrigo Portugal.	*The 2.5D Acoustic Wave Equation*
Carlos Piedrahita.	*Multiparameter Inversion by Optimization*
Matthias Riede.	*Modeling by Demigration*

Master Sudents:

Angela Maria Vasquez	*True-amplitude MZO*
Claudio Guerra	*Kirchhoff-type multiple elimination.*

Research Students:

Thorvald Wetlesen.

Thomas Hertweck.

Vanessa Giuriati

Guliana Nascimento

Research Group Nancy/Karlsruhe/Berlin (Shapiro)

Permeability, Seismic Inversion, Random Media Wave Propagation

Group leader:

Sergei A. Shapiro

Andreas Kirchner. Ph.D. student.	*Forward and Inverse Born modelling. Stochastic characteriziation of faults and fractured zones.*
Micha Bahmann. Research student.	*Finite Difference modeling of elastic wave propagation.*
Tobias Müller. Ph.D.student	*Green Functions in statistically isotropic random media. Poroelasticity.*
Kai-Uwe Vieth. Ph.D. student.	*Application and development of imaging and inversion techniques. Non-destructive localization of macroscopic cracks in fibre reinforced composite materials.*

Erik Saenger. Ph.D. student.	*Simulation of elastic wave propagtion through heterogeneous and fractured media. Application of parallel computing devices.*
Pascal Audigane. Ph.D. student.	*3D inversion and modeling of permeability tensor.* *Affiliation: CRPG-CNRS, Nancy, France.*

Karlsruhe External Ph.D. students

Jörg Zaske. Ph.D. student, Tel Aviv	*Prediction and attenuation of multiples using wave-front characteristics of primary reflections*
Wolfgang Velten. Ph.D. student, Nancy	*Development of ray tracing algorithms in 3D blocked media with triangulated surfaces*

Computer facilities

The research project uses computer facilities that consist of mainly Hewlett-Packard and Silicon Graphics workstations. These are networked with a local computer server, a multi-processor SGI PowerChallenge. For large-scale computational tasks a 100-node IBM SP-2 is available on Campus. Additionally, we have access via ATM networks to the nearby German National Supercomputer Center with primarily a Cray T3e and NEC SX-4.

The Hamburg group has direct access to the German Computer Center for Climate Research (Deutsches Klimarechenzentrum, DKRZ). A Cray 916 and a Cray T3D (128 processors) are used for computationally intensive tasks.

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List of WIT Sponsors

BEB Erdgas und Erdl GmbH
Postfach 51 03 60
D-30633 Hannover
Contact: Mr. Heinz Jürgen Brink
Tel. 49-511-641-2164
Fax: 49-511-641-2403

BHP Petroleum
10810 Old Katy Road 205
Houston, TX 77043
USA
Contact: Mr. Josef Paffenholz
Tel. 1-713-465362
Fax. 1-713-465 2938

Chevron Petroleum Technology Co.
1300 Beach Blvd.
La Habra, CA 90631-6374
USA
Contact: Dr. Glyn M. Jones
Tel. 1-562-694-7137
Fax: 1-562-694-7063

Elf Exploration UK plc
30 Buckingham Gate
London SW1E 6NN
UK
Contact: Mr. Claude Lafond
Tel. +44 171 963 5005
Fax. +44 171 963 5061

ENI S.p.A.
AGIP Division
20097 San Donato Milanese MI
Italy
Contact: Mr. Serafino Gemelli
Tel. 39-02-520 63441
Fax: 39-02-520 63741

Geco Prakla UK Ltd.
Schlumberger House,
Buckingham Gate
Gatwick Airport
Gatwick, West Sussex RH6 0NZ
UK
Contact: Dr. Ralf Ferber
Tel: 44-1293-556802
Fax: 44-1293-556800

Mobil Technology Co.
P.O. Box 650232
Dallas, TX 75265-0232
USA
Contact: Mr. David L. Hinkley
Tel: 1-214-951-2839
Fax: 1-214-951-2098

PGS Seres AS
P.O. Box 354
Strandveien 4
1324 Lysaker
Norway
Contact: Mr. Martin Widmaier
Tel. 47-67526643
Fax: 47-67526640

Preussag Energie GmbH
Waldstr. 39
D-49808 Lingen
Contact: Mr. Paul Krajewski
Tel: 49-591-612-381
Fax: 49-1-591-6127000

RWE-DEA AG fuer Minerall und Chemie
Postfach 600449
D-22204 Hamburg
Contact: Mr. Wolfgang Apel
Tel: 49-40-6375-2349
Fax: 49-40-6375-3590

Research Personnel

Stephan Bojinski received his diploma in geophysics (1998) from Karlsruhe University. His research interests include wave propagation in random media, statistical wave inversion, and numerical modeling of elastic waves. He is also interested in smoothing methods of inhomogeneous media. Stephan passed a B.Sc.(geophysics) from Edinburgh University, and improved his knowledge of parallel programming during a research visit at CINECA Supercomputing Centre, Bologna. He is soon to start his PhD.

Robert Essenreiter received his M.Sc. in Geophysics from the University of Karlsruhe, Germany, in August 1996. His master thesis was on Geophysical Deconvolution and Inversion with Neural Networks. Currently he is a Ph.D. Student at the Geophysical Institute, University of Karlsruhe, Germany. His research interests include signal processing and artificial intelligence. In his current project he is working on a new approach for multiple attenuation using neural networks.

Norman Ettrich received his Diploma (1993) in geophysics from the Technical University of Clausthal and a PhD (1997) in geophysics from the University of Hamburg. Since 1996, he has been a research assistant at the University of Hamburg. His interests are ray tracing and seismic migration/inversion. He received EAEG's Van Weelden Award in 1995. He is a member of EAGE.

Joachim Falk received his Diploma (1994) in geophysics from the University of Hamburg. From 1994 to 1998 he has been a research associate at the University of Hamburg working on finite difference algorithms using adapted grids for the numerical modeling of acoustic, seismic and electro-magnetic wave propagation problems in complex media. In summer 1998 he received his PhD from the University of Hamburg. He left Hamburg (and WIT) and started his postdoc at the Delft University of Technology (Applied Geophysics Group of Prof Fokkema) where he is now working on inversion of time-lapse data. He is a member of the EAGE.

Dirk Gajewski received a diploma in geophysics in 1981 from Clausthal Technical University and a PhD from Karlsruhe University in 1987. Since 1993, he has been associate Professor (Applied Geophysics) at Hamburg University. After his PhD, he spent two years at Stanford University and at the Center for Computational Seismology at the Lawrence Berkeley Lab in Berkeley, California. From 1990 until 1992, he worked as an assistant professor at Clausthal Technical University. His research interests include high-frequency assymptotics, seismic modeling, and processing of seismic data from isotropic and anisotropic media. Together with Ivan Psenck, he developed the ANRAY program package. He is a member of AGU, DGG, EAGE, and SEG, and serves as an Associate Editor for Geophysical Prospecting (section anisotropy).

Alexander Goertz received his diploma in geophysics in 1998 from Karlsruhe University. Since 1998 he is a research associate with Karlsruhe University. His research interests include 4D modeling of geophysical systems with finite differences, imaging of complex fault zone structures and seismic sounding of lithospheric heterogeneities.

German Höcht received his diploma in geophysics in 1998 from Karlsruhe University. Since 1998 he is a research associate at Karlsruhe University. His interests are macro velocity model independent imaging methods. He is member of the SEG.

Peter Hubral received an M.Sc. in 1967 in geophysics from Clausthal Technical University and a Ph.D. in 1969 from Imperial College, London University. Since 1986, he has been a full Professor of Applied Geophysics at Karlsruhe University specialising in Seismic Wave Field Inversion. During 1970-73 he was with Burmah Oil of Australia and from 1974 to 1985 he was with the German Geological Survey in Hannover. He was a consultant in 1979 with AMOCO Research and, during 1983-1984, a PETROBRAS-sponsored visiting professor in the PPPG project at the Universidade Federal da Bahia in Brazil. In 1995-1996 he was an ELF- and IFP sponsored visiting professor at the University of Pau, France. He received EAEG's Conrad Schlumberger Award in 1978 and SEG's Reginald Fessenden Award in 1979. He is a member of DGG, EAEG and SEG. Peter Hubral is involved in most of WIT's activities, in particular those including research on image resolution, image refinement, image attributes, multiple suppression, incoherent noise suppression, true-amplitude imaging, interpretative processing, and image animation.

Martin Karrenbach received his “Vordiplom” in physics in 1985 from the University of Karlsruhe, West Germany, and his M.S. in geophysics from the University of Houston in 1988. He was with SEP from September 1988 through February 1995 when he received his Ph.D. in geophysics from Stanford University. He had summer employment with Siemens, BEB, Cogniseis and most recently with Chevron Oilfield Research Co. He is currently an Assistant Professor at Karlsruhe University, Germany. He is a member of the AGU and SEG.

Andree Leidenfrost received his Diploma (1995) in geophysics from the University of Hamburg. Since 1995 he has been a research associate at the University of Hamburg. His interests are travel time computation and seismic migration. He is a member of EAGE.

Thilo Müller received his diploma (1996) in geophysics from Karlsruhe University. Since then he is working as a research scientist on imaging techniques. He is particularly involved in the development of the Common Reflection Surface (CRS) Stacking Method. This is an imaging process that does not need any explicit knowledge of the velocity field and uses stacking surfaces that match the reflection response better than the ones of conventional methods.

M. Amélia Novais investigates the different aspects of Born and Kirchhoff forward modeling schemes, in particular with respect to amplitudes. She is also working on a combined scheme that incorporates the advantages of both methods.

Claudia Payne has been Peter Hubral's secretary for 8 years. She is in charge of all WIT administrative tasks, including advertising, arranging meetings, etc.

Linus Pasasa received his Drs (1989) and MS (1993) degree in geophysics from Bandung Institute of Technology (ITB), Indonesia. ¿From 1989 to 1994 he was a research geophysicist at ITB. Since 1995 he has been working towards a Ph.D. in geophysics at the University of Karlsruhe, Germany. His main research interests are related to prestack depth migration, traveltime calculation and shallow seismic.

Melanie Pohl is dealing with wave propagation in generally anisotropic 3D media. She is applying these schemes in lower crustal structure studies and in reservoir simulations.

Matthias Riede received his M.Sc. in Geophysics from the University of Karlsruhe, Germany, in 1997. Currently he is a Ph.D. Student at the Geophysical Institute, University of Karlsruhe, Germany. His research interests include signal processing, seismic imaging and modeling.

Erik Saenger received his diploma in Physics in 1998 from the University of Karlsruhe in March 1998. Since April 1998 he is a Ph.D. student at the Geophysical Institute at Karlsruhe University. Currently, he focuses on Finite Difference modeling. He is member of the EAGE.

Lúcio Tunes Santos received his BS (1982) and MS (1985) in Applied Mathematics from the State University of Campinas (UNICAMP), Brazil. In 1991 he earned his Ph.D. in Electrical Engineering also from UNICAMP. From 1985 to 1988 he was employed as a Teaching Assistant at the University of So Paulo (USP). Since 1988 he has been working for UNICAMP, first as a Teaching Assistant and since 1991 as an Assistant Professor. Between August 1994 and August 1995, he visited Rice University as a postdoc researcher. His professional interests include seismic modeling and imaging as well as nonlinear optimization. He is a member of SIAM and SBMAC (Brazilian Society of Applied Mathematics). His main areas of research are seismic modeling and true-amplitude imaging. He's also interested in nonlinear optimization algorithms and fractals. His present activities include MZO for variable velocity and modeling by demigration. Moreover, he's also working on exact penalty methods in nonlinear programming.

Jörg Schleicher received his "Diplom" (MSc equivalent) in Physics in 1990 and his "Dr. rer. nat." (Ph.D. equivalent) in Geophysics in 1993 from Karlsruhe University, Germany. After employment as a research fellow at the Geophysical Institute from February 1990 to September 1995, he became a visiting scientist at the Institute for Mathematics, Statistics, and Scientific Computing of the State University of Campinas (IMECC/ UNICAMP), Brazil, with a joint grant from the Brazilian National Council for Scientific and Technological Development (CNPq) and Alexander von Humboldt foundation. Since October 1996, he has been employed as an Associate Professor for Applied Mathematics at IMECC/UNICAMP. His research interests include almost all forward and inverse seismic methods. He is a member of SEG, EAGE, DGG, SBGf, and SBMAC. His main areas of research include true-amplitude imaging and ray tracing. He's also interested in any kind of seismic modeling or imaging theories and algorithms. His present activities include research on how to control amplitudes in different kinds of seismic imaging methods and on how to efficiently perform the true-amplitude imaging. Moreover, part of his research is directed towards the extraction of more useful image attributes from seismic data. In 1998, he received SEG's J. Clarence Karcher Award.

Sergei Shapiro received his M.Sc. in 1982 from Moscow University and the Ph.D. in 1987 from All Union Research Institute of Geoinformsystem (AURIG) in Moscow, both in Geophysics. During 1982-90 he worked for AURIG as a research geophysicist. Since 1991 he has been a senior research scientist at the Geophysical Institute of Karlsruhe University, Germany, the first two years as an Alexander von Humboldt fellow. From January to August 1997, he was a Heisenberg associate-research professor in Karlsruhe. Since September 1997, he has been a full professor in Applied Geophysics at the Nancy School of Geology, France, where he is cooperating with GOCAD consortium. His interests include exploration seismology, rock physics, and forward and inverse scattering problems. He is a member of SEG, EAGE, AGU, and DGG.

Ekkehart Tessmer received an MSc in 1983 in geophysics from Hamburg University and a PhD in 1990 from Hamburg university. Since 1990, he has been senior research scientist at the Institute of Geophysics at Hamburg university. Since 1994, he has a university staff position. His research interests include exploration seismology, seismic and electromagnetic wave propagation simulation, and migration. He is a member of DGG, EAGE, and SEG.

Baerbel Traub is dealing with calculation of traveltimes and greens functions in 3 dimensions. Her research interests include implementation and processing of large geophysical algorithms on massively parallel computers.

Martin Tygel received his BSc in physics from Rio de Janeiro State University in 1969, his M.Sc. in 1976 and Ph.D. in 1979 from Stanford University, both in Mathematics. He was a visiting professor at the Federal University of Bahia (PPPG/UFBa), Brazil, from 1981 to 1983 and at the Geophysical Institute of Karlsruhe University, Germany, in 1990. In 1984, he joined Campinas State University (UNICAMP) as an associate professor and since 1992 as a full professor in Applied Mathematics. Professor Tygel has been an Alexander von Humboldt fellow from 1985 to 1987. In that period, he conducted research at the German Geological Survey (BGR) in Hannover. Since 1995, he has been president of the Brazilian Society of Applied Mathematics (SBMAC). His research interests are in seismic wave propagation and processing, including imaging, migration and inversion. He is a member of SEG, SBGf, and SBMAC. His research combines wave propagation and seismic processing. This includes the development of imaging, migration and inversion algorithms, that possess a sound wave theoretical basis and can as well be applied to practical problems. His recent publications have been in the study of amplitude aspects of seismic data, namely true-amplitude depth migration and migration to zero offset (MZO). He is also working in kinematical imaging by stacking multi-coverage data, as for example by the common reflection element (CRE) method.

Kai-Uwe Vieth received his diploma in Geophysics in 1998 from the University of Karlsruhe in March 1998. Since April 1998 he is a Ph.D. student at the Geophysical Institute at Karlsruhe University. Currently, he focuses on imaging cracks/ reflections in heterogeneous media and on new applications using the CRS stack. He is member of the EAGE.

Friedemann Wenzel received a Ph.D. in geophysics from Karlsruhe University in 1985. Until 1988 he worked as research scientist in Karlsruhe and at Columbia University (U.S.), until 1990 as Associate Professor in Karlsruhe, until 1992 as Principal Research Scientist of CSIRO Division of Exploration Geosciences in Sydney (Australia), until 1994 as Director of the department 'Structure of the Earth' at GeoForschungs Zentrum Potsdam, and Professor of Geophysics at Potsdam University, since 1994 as Professor at the Geophysical Institute, Karlsruhe University. He is currently head of the Collaborative Research Center 461 (Sonderforschungsbereich) 'Strong Earthquakes - A Challenge for Geosciences and Civil Engineering' at Karlsruhe University. His research interests are in seismology, modeling of wave propagation, and seismic hazard assessment. He is a member of AGU, SEG, EGS, EUG, and SSA.