Wave Inversion Technology

Wave Inversion Technology
established 1997 in Karlsruhe

Annual Report

2000

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Wave Inversion Technology
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Wave Inversion Technology

WIT

Wave Inversion Technology
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Preface

The fourth WIT (Wave-Inversion-Technology) report gives a compilation of the 2000 WIT activities. The global WIT consortium with one group in Campinas (Brazil), one in Berlin, one in Hamburg and one in Karlsruhe continued to function effectively with the same amount of sponsors and researchers as in the previous three years. The WIT research in Karlsruhe in 2000 was reinforced by the visiting professor and Alexander von Humbolt Prizewinner Dr. E. A. Robinson (New York).

After Dr. Martin Karrenbach left, there will now only one WIT group remain in Karlsruhe. However, Martin's 2D/3D FD Modelling capabilities will remain to be offered to our sponsors.

The WIT consortium member S. A. Shapiro organized the EAGE/SEG sponsored workshop 'Seismic Signatures of Fluid Transport' (February 27-29, 2000 at Berlin) for which a Special Proceedings Volume with contributions will appear in Geophysics (Guest Editors: Shapiro and Gurevitch).

The WIT consortium members M. Tygel and P. Hubral also organized during February 14-16, 1999 the EAGE/SEG sponsored workshop 'Seismic True Amplitudes' in Karlsruhe. Finally I would like to mention that the manuscript of our forthcoming book 'Seismic True Amplitude Reflection Imaging' by Schleicher, Tygel and Hubral is now with the Special Editor Dr. Stolt to hopefully appear soon as a SEG Monograph.

Peter Hubral

Karlsruhe, February 21, 2001

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Reviews: WIT Report 2000

Responsible for compilation and layout: A. Mueller & M. Spinner [1]

Imaging

The Common-Reflection-Surface (CRS) stack as presented in the preceeding WIT reports assigns only one parameter set to each ZO sample to be simulated. **Mann and Gerst** now present an extended CRS stack strategy that is able to detect and characterize an arbitrary number of contributing events for each ZO sample. Thus, conflicting dip situations can be resolved to simulate the interference of intersecting events and to characterize the contributing events separately.

Koglin and Vieth present a 2-D velocity model that is exclusively data-driven. The common-reflection-surface stack attributes are used for the inversion. These are smoothed with a sophisticated algorithm to obtain a robust inversion.

Chira-Oliva and Hubral provide an analytic 2D CRS stacking formula for a curved measurement surface. A new analytic expression for the NMO-velocity has been found.

Garabito et al. present a new optimization strategy for determining the CRS parameters and simulating zero-offset section based on the CRS stack formalism. This is a three step in cascade process: 1) Two-parameters global optimization; 2) One-parameter global optimization; and 3) three-parameters local optimization.

Schleicher et al. investigate the asymptotic inverse Kirchhoff-Helmholtz integral under more realistic conditions and compare the results of this 'migration by demodeling' integral to those of conventional true-amplitude Krichhoff migration.

Schleicher and Santos study the resolving power of seismic migration as a function of source-receiver offset. In a simple numerical example, they compare the achieved resolution with the ray-theoretical prediction. They find that the region of influence after migration is well described by the difference between the time-domain Fresnel zone and its paraxial approximation.

Hertweck et al. present a seismic imaging tool which is based on the unified approach theory. With the help of Kirchhoff-type true-amplitude migration and demigration,

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they are able to perform various kinds of image and configuration transformations.

Goertz et al. show examples of true-amplitude PreSDM based on the Unified Approach theory (Hubral et al., 1996). By comparing the true-amplitude migrated results with Zoeppritz' equations, they show that the method is capable of performing AVO/AVA analysis in the depth domain with high precision. This is especially advantageous when trying to invert for fine-scaled amplitude variations below a complex verburden.

Coman and Gajewski present a wavefront oriented ray-tracing (WORT) technique for a fast computation of traveltimes and migration weights in a smooth 3D velocity model. In this method, we propagate a wavefront stepwise through the model and interpolate output quantities (ray quantities, e.g.,traveltimes, slownesses) from rays to gridpoints. In contrast to Vinje's wavefront construction method, our technique is based only on kinematic ray tracing.

Menyoli and Gajewski present a method for determining Poisson's ratio and updating S-wave velocity using converted wave migration incorporated in reflection tomography. The method based on eliminating residual moveout from migrated CRP gathers is fast and target oriented and does not assume flat reflectors or lateral invariance in model. The method is demonstrated using a synthetic 2D seismic section.

Rock Physics and Waves in Random Media

Shapiro et al. propose an extension of the SBRC approach to estimate the large scale permeability of reservoirs using seismic emission (microseismicity) induced by fluid injection. They show that in a homogeneous medium the surface of the seismicity triggering front has the same form as the group-velocity surface of the low-frequency anisotropic second-type Biot's wave (i.e. slow wave). The approach is generalized for a 3-D mapping of the permeability tensor of heterogeneous reservoirs and aquifers. An equation describing kinematical aspects of triggering front propagation in a way similar to the eikonal equation for seismic wavefronts is derived and used to invert for the hydraulic properties of rocks. The method is applied to several data sets and tested on numerical models.

Rindschwentner implemented a new algorithm for estimating a permeability tensor at reservoir scale using hydraulically induced seismicity. With the new algorithm data sets from Soultz-sous-Forêts (France), the KTB site (Germany) and Fenton Hill (USA) were reprocessed and thus the algorithm tested. The algorithm facilitates the interpretation of possible fluid flow paths.

Müller et al. propose a broad frequency range theory to describe seismic primaries (time harmonic and transient transmissivities) in statistically isotropic heterogeneous 3-D and 2-D media. This formalism is a 3-D analog of the O'Doherty and Anstey theory. It relates properties of the primaries to the first two statistical moments of the medium heterogeneities.

Müller and Shapiro use the formalism for primaries in 3-D statistically isotropic media (see the Mueller et al contribution) in order to explain seismic attenuation due to scattering. On the example of the German KTB data set they show that scattering attenuation has a significant impact on the wavefield propagation.

Saenger and Shapiro are able to model the effective velocities of fractured media using the rotated staggered finite difference grid. The numerical study of dry rock skeletons can be considered as an efficient and well controlled computer experiment. Based on this considerations we present analytical descriptions for effective elastic properties for fractured media.

The article by **Goertz and Kaselow** describes a high-frequency, high-resolution seismic experiment carried out by University of Karlsruhe last spring within a gallery system. The experiment was designed to measure hydraulic properties with seismic methods. The installations of the rather unique test site used for the experiment allows for the calibration of techniques for 4D seismic monitoring.

Modeling

Vanelle and Gajewski present a fast and efficient algorithm for traveltime interpolation. High accuracy is achieved because second order derivatives are taken into account. Examples including the highly complex Marmousi model demonstrate the quality of the method.

Vanelle and Gajewski developped a method to determine weight functions for a true-amplitude migration. Traveltimes on coarse grids are the only necessary input data, no dynamic ray tracing is required.

Coman and Gajewski present a hybrid method for computing multi-arrival traveltimes in weakly smoothed 3D velocity models. The hybrid method is based on the computation of first-arrival traveltimes with a finite-difference eikonal solver and the computation of later arrivals with the wavefront construction method. For a faster traveltime computation we implement a wavefront construction method without dynamic ray tracing.

Soukina and Gajewski present an FD eikonal solver scheme for general anisotropic media which is based on a perturbation method. Traveltimes are calculated for an elliptically anisotropic reference medium. The correction terms required for the traveltimes of the general anisotropic medium are then computed by a perturbation technique.

Buske presents a method for the computation of first-arrival traveltimes and amplitudes by a finite-difference solution of the eikonal equation and the transport equation. It is based on the formulation of these equations as hyperbolic conservation laws and their numerical solution using ENO upwind schemes. Highly accurate traveltimes and smooth amplitudes are obtained which is demonstrated for the Marmousi model.

Other Topics

The KBC and WHL methods are here compared and applied by **Leite et al.** to the multiple suppression of peg-legs related to upper low velocity layers (weathering zone), and to deeper high velocity layers (diabase sills).

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The Wave Inversion Technology Consortium

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. It consists of five working groups, two at Karlsruhe University and three at other universities, being the Mathematical Geophysics Group at Campinas University (UNICAMP), Brazil, the Seismics/Seismology Group at the Free University (FU) Berlin and the Applied Geophysics Group (AGG) of the University of Hamburg.The WIT Comsortium offers the following services to its sponsors.

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

Research aims

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

Traditionally, exploration and reservoir seismics aims at the delineation of geological structures that constrain and confine reservoirs. It involves true-amplitude imaging and the extrapolation of 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 true-amplitude imaging, inversion and effective media.

The WIT consortium has the following main research directions, which aim at characterizing structural and stratigraphic subsurface characteristics and extrapolating fine grained properties of targets:

1.
    - Macromodel-independent multicoverage zero-offset simulations.
    - Macromodel determination.
2.
    - Seismic image and configuration transformations. (Data mappings)

- True-amplitude imaging, migration and inversion.

3.

- Seismic and acoustic methods in porous media.
- Passive monitoring of fluid injection.

4.

- Fast and accurate seismic forward modeling
- Modeling and imaging in anisotropic media

Steering committee

Internal steering committee:

- Dirk Gajewski
- Peter Hubral
- Axel Kaselow
- Claudia Payne
- Matthias Riede
- Erik Saenger
- Jörg Schleicher
- Sergei Shapiro
- Ekkehart Tessmer
- Martin Tygel
- Kai-Uwe Vieth

External steering committee (company representatives):

- Paolo Marchetti, AGIP
- Heinz-Jürgen Brink, BEB
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- Glyn M. Jones, Chevron
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- Christian Henke, RWE-DEA
- Panos Kelamis, Saudi Aramco
- Norman Ettrich, Statoil
- Henning Trappe, Trappe Erdöl Erdgas Consulting

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Axel Kaselow	*WIT Homepage Manager*
Jörg Zaske	*WIT Seminar Organizer*
Jürgen Mann	*WIT Poster Organizer*
Kai-Uwe Vieth	*WIT Poster Organizer*

Research groups

Research Group Karlsruhe (Hubral)

Macro-Model Independent Reflection Imaging

Group leader:

Peter Hubral

Ph.D.students:

German Garabito Callapino	*Zero Offset Imaging - responsible for FOCUS/Disco based processing*
Thomas Hertweck	*Modeling by Demigration*
German Höcht	*Imaging with the 3D CRS stack*
Jürgen Mann	*Implementation of the CRS stack and its application to real seismic data*
Pedro Chira Oliva;	*3D CRS stack*
Matthias Riede	*Modeling by Demigration*
Kai-Uwe Vieth	*Application and development of imaging and inversion techniques. Non-destructive localization of macroscopic cracks in fibre-reinforced composite materials*
Jörg Zaske	*Prediction and attenuation of multiples using wave-front characteristics of primary reflections*
Yonghai Zhang	*3D-True Amplitude Imaging*

Master students:

Steffen Bergler	*CRS stack for common offset*
Christoph Jäger	*Seismic true-amplitude imaging*
Ingo Koglin	*Preparation and application of seismic wave field attributes obtained by the CRS stack.*

Research Group Hamburg (Gajewski)

Applied Geophysics Group (AGG)

Group leader:

Dirk Gajewski	*High frequency asymptotics for imaging and modeling*

Research associates:

Tim Bergmann	*Effects of nonlinear elastic behaviour on wave propagation.*
Ekkehart Tessmer	*Full wave form modeling.*

Ph.D. students:

Radu Coman	*Hybrid method for travel time computation in 3D complex media*
Elive Menyoli	*Prestack depth migration of converted waves*
Svetlana Soukina	*Material parameter determination in anisotropic media*
Claudia Vanelle	*Model independent time processing*

Master students:

Sebastian Barth	*Processing and migration of wide angle observations*
Christian Herold	*Processing of long spread reflection seismic data*
Tina Kaschwich	*3D Wave front construction*
Maximilian Krüger	*AVO modeling*

Research Group Campinas (Tygel)

Modeling by Demigration, Kirchhoff Migration, Traveltime Inversion, Configuration Transforms,Kirchhoff Modeling, AVO/A Analysis, CRS Stack,2.5-D Wave Propagation

Group leaders:

Lúcio Tunes Santos
Jörg Schleicher,
Martin Tygel,

Visting Professors:

Norman Bleistein	*Teaching and developing seismic reflector mapping methods*

Ph.D.Students:

Ricardo Biloti	*Multiparameter Velocity Analysis*
João Luis Martins	*Migration and Demigration in 2.5 Dimensions*
Rodrigo Portugal	*Configuration Transforms in 2.5D*
Carlos Piedrahita	*Seismic Ray Tracing in Blocked Media*
Matthias Riede	*Modeling by Demigration*
Maria Amélia Novais Schleicher	*Modeling of Reflections and Diffractions by a unified Born-Kirchhoff approximation.*

Master Sudents:

Sérgio da Silva Araújo	*CRS Processing*
Valéria Grosfeld	
Claudio Guerra	*Kirchhoff-type multiple elimination.*
Angela Maria Vasquez	*True-amplitude MZO*

Research Students:

Vanessa Giuriati

Thomas Hertweck

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Research Group Berlin (Shapiro)

Permeability, Seismic Inversion,
Random Media Wave Propagation

Group leader:

Sergei A. Shapiro

Research associates:

Stefan Buske	*Seismic modeling and inversion, deep seismic sounding and parallel programming*
Erik Saenger	*Simulation of elastic wave propagtion through heterogeneous and fractured media. Application of parallel computing devices.*

Stefan Lüth	*Refraction seismic data interpretation, seismic processing and integration of geophysical and geodynamic data.*
Robert Patzig	*Application of CRS stacking to seismic profiles from the northern Chilean coast.*
Ph.D.Students:	
Elmar Rothert	*3D inversion and modeling of permeability tensor .*
Tobias Müller	*Green Functions in statistically isotropic random media. Poroelasticity.*
Master students:	
Mi-Kyung Yoon	*Application of Kirchhoff Prestack Depth Migration to the ANCORP'96 data set*
Jan Rindschwentner	*In-situ estimation of the permeability tensor using hydraulically induced seismicity*
Oliver Krüger	*seismic modeling*
Christof Sick	*random media*

Computer facilities

In Karlsruhe, the research project uses computer facilities that consist of mainly Hewlett-Packard and Silicon Graphics workstations, and Linux PCs. These are networked with a local computer server, a multi-processor SGI PowerChallenge. For large-scale computational tasks a 256-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 512-node 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.

The Geophysical Department of the Free University of Berlin (Fachrichtung Geophysik, Freie Universität Berlin) has excellent computer facilities based on SUN- and DEC-ALPHA workstations and Linux-PCs. It has access to the parallel supercomputer CRAY-T3M (256 processors) of ZIB, Berlin.

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Research Personnel

Steffen Bergler received will receive his diploma in geophysics in February 2001. Currently, he is working on the CRS stack for common offset. He is member of DGG.

Tim Bergmann received his MSc (1995) in geophysics from the University of Kiel, Germany, and a PhD (1998) from the Earth Science Department of the Swiss Federal Institute of Technology (ETH) in Zuerich, Switzerland. Currently, he is a research associate at the Institute of Geophysics at the University of Hamburg. His research interests include seismic and GPR theory, wave propagation, and numerical methods. He is a member of AGU, EAGE, EEGS-ES, DGG, SIAM, and SEG.

Ricardo Biloti received his B.Sc.(1995) and M.Sc. (1998) in Applied Mathematics from the State University of Campinas (UNICAMP), Brazil, where he is a PhD student since 1998. In his PhD thesis he has been developing a macro-model velocity independent inversion method. He has worked with CRS (Common Reflection Surface) type methods and developed a technique to estimate some seismic attributes without the knowledge of macro-model velocity. He is also interested in fractals. He is a member of SIAM and SEG.

Stefan Buske received his diploma in geophysics (1994) from Frankfurt University. From 1994 until 1998, he worked as research associate at Frankfurt University, and from 1998 until 1999 he was with Ensign Geophysics Ltd. (Depth Imaging Department) in London. Since 1999 he is a university staff member at the Free University of Berlin. His research interests include seismic modeling and inversion, deep seismic sounding and parallel programming. He is a member of DGG and EAG

Radu Coman received his Diploma (1995) in geophysics from the University of Bucharest. From 1995 until 1996, he worked as research assistant at Geoecomar Bucharest and also specialized in geology at the University of Bucharest. After this, he spent two years at the Westfälische Wilhelms-Universität Münster. Since 1999 he is a Ph.D. student at the University of Hamburg. His interests are travel time computation.

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 Psencík, 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.

Thomas Hertweck received his diploma in geophysics in May 2000 from Karlsruhe University, Germany. Since August 2000, he has been a research associate at the Geophysical Institute, Karlsruhe University. His fields of interest are numerical analyses, development of seismic software, seismic ray theory, and seismic true-amplitude imaging. Currently, he focuses on an implementation of an efficient 2D and 3D true-amplitude migration and demigration tool.

German Höcht received his diploma in geophysics in 1998 from Karlsruhe University. Since 1998 he has been 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 received the first Foreign Geophysicist Award of the Brazilian Geophysical Society in 1999. He is a member of DGG, EAEG and an honorary member of the 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.

Christoph Jaeger has been a research assistent since 1999. Currently he writes his diploma thesis where he focuses on seismic true-amplitude imaging.

Axel Kaselow received his diploma in Geology focused on Hydrogelogy from the University of Karlsruhe in 1999. Since April 1999 he is a research associate at Karlsruhe University. Currently, he focuses on finite difference modeling of wave propagation in fluid-saturated porous media and fluid flow modeling at complex fault zones. He is a member of AGU.

Ingo Koglin is a diploma student. His thesis will focus on the preparation and application of seismic wave field attributes obtained by the CRS stack. He uses the attributes for inversion and to improve imaging.

L.W.B. Leite Professor of Geophysics at the Graduate Course in Geophysics, and member of the Department of Geophysics of the Federal University of Pará (Belem,Brazil). His main emphasis at the present time is seismic wave propagation in thin layers for deconvolution and inversion problems.

Stefan Lüth received his Diploma in geophysisics from the Technische Universität Clausthal in August 1996. His thesis was on numerical and methodical investigations on diving wave tomography. He is currently working as a Ph.D student at the Freie Universität Berlin. His research interests include refraction seismic data interpretation, seismic processing and integration of geophysical and geodynamic data.

Joao L. Martins is occupied with the development of fast and efficient Kirchhoff-type true-amplitude imaging methods for several different simpler types of media.

Jürgen Mann received his diploma in geophysics in 1998 from Karlsruhe University. Since 1998 he has been a research associate at Karlsruhe University. His fields of interest are seismic image wave methods and macro velocity model independent imaging methods. He is member of the EAGE and the SEG.

Elive M. Menyoli received his diploma in Physics with specialization in Geophysics in 1998 at the University of Goettingen. From April 1998 until November 1998, he was with the German Geological Survey in Hannover. Since December 1998 he is a Ph.D. student at the University of Hamburg. His research interest is in Kirchhoff migration of P-SV converted waves.

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.

Robert Patzig received his diploma in geophysics from Braunschweig. In the dipoma thesis he developed a digital filter for the detection of the Stoneley-wave (borehole seismics) by combination of a predictionfilter and the envelope of the wave. 1999 he received his Ph.D. for ”Local earthquake tomography in the region of Antofagasta (Chile)”. His actual research interest is the application of CRS stacking to seismic profiles from the northern Chilean coast.

Claudia Payne has been Peter Hubral's secretary for 9 years. She is in charge of all WIT administrative tasks, including advertising, arranging meetings, etc.

Carlos Piedrahita received a B.Sc. in mathematics from UNAL of Colombia,and the M.Sc. in mathematics from SUNY at Buffalo in 1986. Has worked in the laboratory of geophysics and the material science group of ICP,the research group of ECOPETROL since 1988. Currently is working toward his Phd at the State University of Campinas, Brasil. His thesis subject is ray tracing using continuation procedures trying to extend these methods to complex structures. His interests are in numerical methods and continuum mechanics.

Rodrigo Portugal received his B.Sc. (1995) and M.Sc. (1998) in Applied Mathematics from the State University of Campinas (UNICAMP), Brazil, where he is a PhD student since 1998. In his PhD thesis he is currently working on employing wave front construction based ray tracing in 2.5D migration, demigration, and other image transformations. His research interests are in numerical analysis, modeling, and imaging. He is a member of SEG.

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.

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