Introduction

Report 16 of the Consortium project "Seismic Waves in Complex 3–D Structures" (SW3D) summarizes the work done towards the end of the twelfth year and during the thirteenth year of the project, in the period June, 2005 — May, 2006. It also includes the compact disk with updated and extended versions of computer programs distributed to the sponsors, with brief descriptions of the programs, and with the copy of the SW3D WWW pages containing papers from previous reports and also from journals.

Our group working within the project during the thirteenth year has consisted of six research workers: Václav Bucha, Petr Bulant, Vlastislav Červený, Luděk Klimeš, Ivan Pšenčík and Václav Vavryčuk. Our PhD student Karel Žáček, working on the algorithm of Gaussian packet migration, defended successfully his PhD thesis on September 21, 2005, and finished his PhD studies at our Department under the supervision of Luděk Klimeš.

Henrik Bernth, Chris Chapman, Leo Eisner and Henk Keers (Schlumberger Cambridge Research, United Kingdom), Veronique Farra (Inst. Physique du Globe de Paris, France), Louis Fishman (MDF International, Slidell, USA), Klaus Helbig (Hannover, Germany), Tijmen Jan Moser (Horizon Energy Partners, 's-Gravenhage, Netherlands) and Peter Ciganik (Comenius University, Bratislava, Slovakia) visited us during the period June, 2005 — May, 2006. Peter Ciganik intends to begin his PhD studies at our Department under the supervision of Luděk Klimeš starting from October 1, 2006.

Ivan Pšenčík together with Vladimir Grechka and Klaus Helbig edited the abstracts from the 11th International Workshop on Seismic Anisotropy, held at St. John's, Newfoundland, Canada in 2004. The abstracts appeared in Geophysics, **71** (2006), 13JF–29JF. Ivan has just completed editing of the first part of the proceedings from the workshop "Seismic waves in laterally inhomogeneous media VI", held at Hrubá Skála, Czech Republic in 2005. The first part of the proceedings will appear in No. 3 of the Studia Geophysica et Geodaetica, **50** (2006). The second part will appear in No. 1 of the Studia Geophysica et Geodaetica, **51** (2007). Both mentioned issues of the Studia Geophysica et Geodaetica will be distributed to the Consortium members.

Research **Report 16** contains mostly the papers related to seismic anisotropy (11 of 14 papers). Report 16 may be roughly divided into five parts, see the Contents.

The first part, **Ray methods in isotropic and anisotropic media**, is devoted to the high–frequency methods in general, but does not contain the papers more specifically addressing problems of weak anisotropy or of anisotropic viscoelastic media, which have been postponed to the second and third parts. This part also contains two papers describing application of the SW3D ray tracing software distributed on the compact disk.

Manuscript "Ray tracing in the smoothed acoustic SEG/EAGE Salt Model. Part 2: Maps of reflections" by V. Bucha has been submitted for publication in the Journal of Seismic Exploration. The manuscript is an extended version of the paper which appeared in Report 14 (2004) and shows the application of the SW3D software to the construction of reflection maps on the bottom flat interface in the smoothed SEG/EAGE Salt Model with interfaces. The illumination of the large shadow area below the trunk of the salt body is discussed.

The second paper by V. Bucha is an extended and revised version of the paper from Report 15 (2005). The finite–difference seismograms in the elastic SEG/EAGE Salt Model are compared with the ray–theory travel times calculated using the SW3D software. The plots of travel times are more clear than plots of seismograms of individual elementary waves presented in Report 15. Two–point rays and travel times for three additional receiver configurations have been computed.

E. Iversen and I. Pšenčík propose an efficient ray tracing procedure for inhomogeneous anisotropic media of higher symmetry. Instead of working with all 21 elastic parameters, only the parameters specifying the considered symmetry and its orientation are considered. In contrast to algorithms based on interpolation of all 21 elastic parameters, the proposed algorithm preserves given anisotropic symmetry between interpolated points.

In the next paper of this part, V. Červený compares the dynamic ray tracing systems in ray–centred coordinates and in wavefront orthonormal coordinates. Both these systems consist of four linear ordinary differential equations of the first order. The systems, known form literature and derived independently, consist of equations expressed in different forms. The paper shows that both systems are fully equivalent and may be used alternatively.

The paper by V. Červený & T.J. Moser, submitted for publication to the Geophysical Journal International, discusses the ray propagator matrices in 3–D anisotropic inhomogeneous layered media. A simple and invertible transformation between the ray propagator matrices in ray–centred and Cartesian coordinates is proposed. Consequently, the ray propagator matrix in ray–centred coordinates can be computed by dynamic ray tracing in Cartesian coordinates, and vice versa. The 6×6 and 4×4 interface propagator matrices in ray–centred coordinates are also derived.

In the paper by T.J. Moser & V. Červený, accepted for publication in the Geophysical Prospecting, surface–to–surface paraxial matrices are studied. These 4×4 matrices define the transformation of paraxial ray quantities from one surface crossed by the reference ray, to another. The formalism of surface–to–surface paraxial matrices is based on conventional dynamic ray tracing in Cartesian coordinates along the reference ray. Applications of the proposed formalism in the paraxial ray methods are discussed.

In the paper by V. Vavryčuk, a new asymptotic formula for S waves propagating near the symmetry axis in transversely isotropic elastic media derived by Popov et al. [Wave Motion 42 (2005) 191–201] is discussed and commented. It is shown that the formula is a modification of the previously published formula by Vavryčuk [Geophys. J. Int. 138 (1999) 581–589]. The formula of Popov et al. (2005) is less accurate and is valid under more restrictive conditions than that of Vavryčuk (1999).

The second part, **Weak anisotropy**, addresses the problems relevant to weakly anisotropic media.

P. Bulant & L. Klimeš numerically test the equations for the anisotropic–common–ray approximation of the coupling ray theory in three smooth 1–D velocity models of differing degree of anisotropy. The numerical example from the paper of Report 15 (2005) has been supplemented by the synthetic seismograms obtained by both the isotropic–common–ray and anisotropic–common–ray approximations of the coupling ray theory. These seismograms are compared with the more accurate coupling–ray–theory

synthetic seismograms simulated by the second–order perturbation expansion of travel time from the anisotropic common rays.

The third part, **Anisotropic viscoelastic media**, is devoted to the problem of homogeneous and inhomogeneous plane waves propagating in anisotropic viscoelastic media.

In the paper by V. Červený and I. Pšenčík, the energy flux vector and other energy–related quantities (kinetic energy, strain energy, dissipated energy, energy supplied by internal sources) in inhomogeneous viscoelastic anisotropic media are investigated. For time–harmonic wave fields, both constituents of the energy–related quantities, namely the time–averaged and time–dependent ones, are discussed. Several forms of the energy balance equation are derived.

The fourth part, **Seismic sources**, is devoted to the forward and inverse problems of source mechanisms, which become increasingly important in reservoir monitoring, especially in connection with hydraulic fracturing.

The first paper of this part, by L. Eisner & P. Bulant, is devoted to the borehole deviation surveys. Not performing accurate borehole deviation surveys for hydraulic fracture monitoring and neglecting the effects of the borehole trajectory results in significant errors in the calculated fracture azimuth and other parameters. For common geometries, a 5° deviation uncertainty of monitoring or treatment boreholes can cause more than 40° uncertainty in inverted fracture azimuths. The errors caused by the deviation uncertainty should not be compensated by artificially adjusting the velocity model.

In the first paper by V. Vavryčuk, conditions for a successful inversion of complete moment tensors from borehole data observed in isotropic and transversely isotropic media are studied. It is shown that the moment tensors can be retrieved from the amplitudes of P waves, provided receivers are deployed in three boreholes at least. Using the amplitudes of P and S waves, two boreholes are, in principle, sufficient. It is also investigated by numerical simulations how sensitive the moment tensor inversion is to noise in the data.

In the next paper, V. Vavryčuk studies non–double–couple (non–DC) mechanisms produced by shear faulting in anisotropic rocks. It is shown that the non–DC mechanisms can combine the isotropic and compensated linear vector dipole components. The formulas for percentages of the non–DC components are advantageously expressed in terms of the Thomsen's weak anisotropy parameters.

V. Vavryčuk, M. Bohnhoff, Z. Jechumtálová, P. Kolář & J. Šílený study moment tensors of microearthquakes that occurred during the 2000 injection experiment at the KTB deep–drilling borehole (Germany). They show that the moment tensors contain significant non–DC components. The DC is on average 60% and the non–DC is 40%. A detailed analysis indicates that a part of the non–DC components is produced by anisotropy in the focal area.

The contribution by D. Rössler, F. Krüger, I. Pšenčík & G. Rümpker is an extension of the contribution, which appeared in Report 15 (2005). The algorithm proposed there is applied to retrieval of the source mechanism of a selected event from the 2000 West Bohemia earthquake swarm. Inversion yields a stable and significant indication of a tensile faulting, which, in turn, seems to indicate a role of fluids in the triggering of the studied event.

The fifth and final part, **CD–ROM with SW3D software, data and papers**, contains the CD–R compact disk SW3D–CD–10.

Compact disk SW3D–CD–10, edited by V. Bucha & P. Bulant, contains the revised and updated versions of the software developed within the Consortium research project, together with input data related to the papers published in the Consortium research reports. A more detailed description can be found directly on the compact disk. Compact disk SW3D–CD–10 also contains over 240 complete papers from journals and previous reports in PostScript, PDF, GIF or HTML, refer to the copy of the Consortium WWW pages on the compact disk. Compact disk SW3D–CD–10 is included in Report 16 in two versions, as the UNIX disk and DOS disk. The versions differ just by the form of ASCII files.

This Introduction is followed by the list of members of the SW3D Consortium during the thirteenth year of the project. We are very pleased to welcome a new Consortium member, Schlumberger Cambridge Research Limited (Cambridge, U.K.). We hope that Schlumberger Cambridge Research will find the membership in our Consortium profitable.

The Research Programme for the current, thirteenth year of the Consortium project comes after the list of members. The Research Programme for the next year will be prepared after the discussion at the Consortium meeting, June 19–20, 2006. More detailed information regarding the SW3D Consortium Project is available online at "http://sw3d.mff.cuni.cz".

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