Special Section

Seismic Anisotropy — Introduction

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This special section is dedicated to seismic anisotropy, which is playing an increasingly more important role in our understanding and modelling of the subsurface. Most papers published in this section were presented at the 14th International Workshop on Seismic Anisotropy (IWSA), which was held on 12–16 April 2010 in Hillarys, Perth, Western Australia. The main organizers of the workshop were Andrej Bóna and Boris Gurevich from Curtin University and Greg Ball from Chevron. This workshop continued the tradition of biennial meetings of anisotropists, which began in 1984.

The workshop was dedicated to the memory of Mike Schoenberg, one of the most prominent and inspirational members of the anisotropic community, who died of cancer in 2008 shortly after attending the 13th IWSA in Colorado, U. S. A. Celebration of Mike's contribution to the geophysical community was particularly fitting for a workshop held in Perth, where Mike gave a lasting inspiration to colleagues and students during a number of his sabbatical visits to Curtin University, CSIRO, and University of Western Australia.

The 14th IWSA was generously sponsored by CGGVeritas, Woodside Energy, WesternGeco, Curtin University, and Santos Energy. The sponsorship helped reduce the cost for the participants and offered travel grants for overseas students who otherwise would not have been able to attend the workshop. Seed funding from the organizers of the previous IWSA greatly eased the planning of the workshop; similar seed funding will be forwarded to organizers of a future IWSA.

There were 71 overseas and local participants from academia, research organizations, and industry, 13 student participants and 31 day participants. The program consisted of 42 oral presentations, seven posters and concluded with a short course "Seismic Anisotropy: What interpreters need to know" presented by Leon Thomsen. The participants chose the location for the next workshop, 15th IWSA, to be Bahrain, which was proposed by Abdul-fattah Al-Dajani on behalf of the Dhahran Geoscience Society.

The 17 papers chosen for this special section are presented alphabetically by title within the following categories: imaging, modeling and inversion, experiments, and rock physics.

IMAGING

Zhang et al. propose a stable tilted transverse isotropic (TTI) acoustic wave equation that does not add numerical complexity and can be solved by either a pseudospectral method or a high-order explicit finite-difference scheme. They demonstrate on field-data examples that the method provides stable and high quality TTI reverse-time migration images.

Takanashi and Tsvankin discuss P-wave nonhyperbolic moveout inversion for horizontally layered VTI models that include a thin isotropic lens and demonstrate that such lenses can cause significant distortions in the NMO velocity and the anellipticity parameter η. They propose several criteria to delineate the area influenced by the lens and then devise an efficient algorithm for removing lens-induced traveltime shifts from prestack data.

Wang and Tsvankin develop a 3D parameter-estimation algorithm for layered TTI media that operates with P-wave NMO ellipses, zero-offset traveltimes, and reflection slopes supplemented by borehole data. If the symmetry axis is perpendicular to the bottom of each layer, the only necessary borehole constraint is reflector depth, while in the more general case of arbitrary axis tilt, it is necessary to include wide-azimuth walkaway VSP traveltimes.

Alkhalifah develops numerical solutions for the transversely isotropic eikonal equation based on perturbations in anellipticity parameter η and the symmetry axis angles from an elliptically anisotropic inhomogeneous background model. These solutions

are simpler and more efficient than the conventional ones, and they allow for straightforward semblance-like analysis of these perturbation parameters in a generally inhomogeneous background medium.

MODELING AND INVERSION

Bernth and Chapman compare several grids for anisotropic, elastic finite-difference modeling. The authors conclude, in particular, that for smooth models, the Lebedev grid has lower computational cost than the rotated staggered grid.

Pšenčík and Červený derive and discuss exact expressions for the boundary attenuation angle of an inhomogeneous plane wave propagating in a dissipative anisotropic medium. They show that the use of the attenuation angle as a free parameter of the inhomogeneous plane wave may lead to serious errors in attenuation analysis, particularly if the attenuation angle is chosen close to or greater than the boundary attenuation angle.

Dubos-Sallée and Rasolofosaon use time-lapse seismic monitoring over the geological storage site of Sleipner (North Sea) to follow the displacement of the injected CO_2, considered as a permeability tracer. This leads to the estimation of the depth dependence of the permeability anisotropy (strength and direction).

Tsuji et al. measure the V_P/V_S ratio and S-wave splitting from active-source seismic data recorded by ocean bottom seismometers along the survey line extending from the trench to the seismogenic zone in the Nankai plate subduction zone southwest of Japan, to estimate variation of stress state and sediment consolidation associated with subduction process. The results clearly demonstrate that V_P/V_S is abruptly changed at the trough axis (deformation front of the accretionary prism), and the S-wave splitting is significant at the seismogenic fault.

EXPERIMENTS

Lebedev et al. introduce a method for laboratory measurements of the velocities and polarizations of compressional and shear waves in rock samples using a laser Doppler interferometer. They conclude that incorporating these polarizations into the estimation of anisotropy improves the accuracy compared to estimation based only on traveltimes.

Nadri et al. study the stress-dependent seismic anisotropy of the overburden shale in an oil field on the North West Shelf of Western Australia. They invert the ray velocities from measurements of ultrasonic P-wave velocities in 132 directions for confining pressures from 0.1 to 400 MPa on a spherical shale sample to estimate the Thomsen parameters V_{P0}, ε, and δ using a very fast simulated re-annealing algorithm.

Dewhurst et al. use microstructural techniques tied to experimental geomechanical and ultrasonic testing to investigate the impact of stress magnitude and stress orientation on shale anisotropy. They note that fabric orientation with respect to stress orientation governs the anisotropic response of these rocks and report the results in terms of the Thomsen anisotropy parameters ε, γ, and δ.

Nihei et al. present a new experimental apparatus, the phased array compaction cell, for measuring the TI elastic properties of clay-rich sediments under uniaxial strain consolidation conditions. Several novel features of this apparatus are the use of a phased array to synthesize plane waves for the estimation of c13, and the ability to measure the five TI elastic constants during compaction of the sediment, without the need for sample unloading, recoring, or reorienting.

ROCK PHYSICS

Gurevich et al. present an analytical model for seismic anisotropy caused by application of a small uniaxial stress to an isotropic rock modeled as an isotropic linearly elastic solid permeated by an isotropic distribution of cracks or compliant crack contacts. The model yields analytical expressions for the Thomsen anisotropy parameters, which can be used to distinguish stress-induced from fracture-induced anisotropy.

Krzikalla and Müller unify the theory of interlayer flow and the Backus averaging rules for layered porous media in a new poroelastic theory. The theoretical model describes the attenuation and dispersion of P-SV-waves for different angles of incidence in layered fluid-saturated sediments.

Pervukhina et al. develop a model for transversely isotropic media that describes stress sensitivity of all five elastic coefficients with four meaningful fitting parameters; the model is used to parameterize elastic properties of 20 shales obtained from laboratory measurements and the literature. The four fitting parameters, namely, specific tangential compliance of a single crack, ratio of normal to tangential compliances, characteristic pressure, and crack orientation anisotropy parameter show moderate to good correlations with the depth from which the shale was extracted.

Sil et al. perform analysis of fluid substitution in a porous and fractured medium. They observe variation of seismic anisotropy due to changes in porosity and fluid saturation of the medium. This analysis may help in better interpretation of observed seismic anisotropy from a fractured reservoir.

Rasolofosaon proposes a unified model that synthesizes the most robust mechanical behaviors of porous rocks, namely the frequency dependence, nonlinearity with possible hysteresis, and anisotropy. It predicts, in addition to the classical elastic hysteresis of the stress-strain curves, the existence of a second type of hysteresis, or hydraulic hysteresis, of the curve fluid pressure versus fluid content due to the hysteresis in the porous network geometry at different stress levels. This phenomenological model, complementary to microstructural models, is corroborated by experimental data in a sandstone sample and useful for the design of future experiments.