COURSE NUMBER AND NAME

GPGN651: Advanced Seismology. Offered online via Canvas, Spring semester.

INSTRUCTOR

Prof. Ilya Tsvankin
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Office hours: Friday, 3:00 – 4:00 pm

COURSE OBJECTIVE

To introduce students to modern seismology of anisotropic, heterogeneous media.

WELCOME TO ADVANCED SEISMOLOGY

Please watch the welcome video posted on Canvas. This is an advanced course for graduate students and professional geophysicists enrolled in the GP Certificate Program. The course is designed to provide an in-depth discussion of elastic wave propagation and seismic processing methods for realistic heterogeneous, anisotropic subsurface models. The students are expected to significantly improve their understanding of wave-propagation processes and develop physical insight into the relationship between recorded seismic wavefields and properties of geologic formations. The course requires the students to go beyond some paradigms taught in lower-level classes.

Topics include the influence of anisotropy on plane-wave properties and point-source radiation, seismic signatures for transversely isotropic (TI) and orthorhombic models, moveout analysis of 2D and wide-azimuth reflection data, parameter-estimation and imaging methods for TI media, joint processing and inversion of PP- and PS-waves, geometrical spreading for layered media, and amplitude-variation-with-offset (AVO) analysis for TI and azimuthally anisotropic models.

Prerequisites: GPGN552 and GPGN553 or consent of instructor.

Credits: Three semester hours.

Textbooks (available as e-books from Arthur Lakes Library):
I. Tsvankin, 2012, "Seismic signatures and analysis of reflection data in anisotropic media," Society of Exploration Geophysicists (3rd edition), ISBN 978-1-56080-299-0.
I. Tsvankin and V. Grechka, 2011, "Seismology of azimuthally anisotropic media and seismic fracture characterization," Society of Exploration Geophysicists, ISBN 978-1-56080-228-0.
Additional text:
K. Aki and P.G. Richards, 2002, "Quantitative seismology," University Science Books (2nd edition), ISBN 0-935702-96-2.
Several additional references are listed on Canvas.

COURSE CONTENTS
(schedule is posted on Canvas)

Wave propagation in anisotropic media

- Anisotropic wave equation, generalized Hooke's law, stiffness tensor for various symmetries
- Plane waves, Christoffel equation for arbitrary anisotropy, polarization vectors
- Phase and group velocities, relation between slowness surface and wavefront
- Basic properties of point-source radiation
- Anisotropic ray tracing

Seismic signatures for transversely isotropic (TI) models

- Solutions of Christoffel equation for P-, SV-, and SH-waves
- Thomsen notation and its application for weak and strong anisotropy
- Analytic description of body-wave velocities and polarizations
- Anisotropy parameters of sedimentary rocks

Moveout analysis of reflection seismic data

- Normal-moveout (NMO) velocity for TI media with vertical (VTI) and tilted (TTI) symmetry axis
- Generalized Dix equation for NMO velocity
- 3D description of normal moveout, notion of NMO ellipse
- Quartic moveout coefficient and nonhyperbolic moveout analysis
- P-wave moveout equation for layered VTI models

Velocity analysis and processing of P-waves for TI media

- Two-parameter description of time-domain processing
- Estimation of parameter η from nonhyperbolic and dip moveout
- Basics of migration velocity analysis and depth imaging
- Case studies of time and depth processing

Converted waves and joint processing of PP and PS data

- Properties of mode-converted waves and PP + PS = SS method
- Joint moveout inversion of PP- and PS-waves for VTI and TTI media
- Case studies of velocity analysis and imaging of multicomponent data

Notation and signatures for azimuthally anisotropic media

- Thomsen-style notation for orthorhombic and HTI (TI with horizontal symmetry axis) models
- Adaptation of VTI equations in symmetry planes
- NMO ellipses and nonhyperbolic moveout in orthorhombic/HTI media

Amplitude analysis and VSP inversion for anisotropic media

- Reflection/transmission coefficients of plane waves
- Amplitude-variaton-with-offset (AVO) analysis of P-, SV-, and SH-waves for VTI media
- Moveout-based geometrical-spreading correction
- Principles of azimuthal AVO analysis for orthorhombic/HTI media
- Processing of wide-azimuth P-wave data from a fractured reservoir (case study)
- Estimation of local parameters using VSP (vertical seismic profiling) data

LEARNING OUTCOMES

- Apply appropriate medium parameterization when operating with seismic data for typical anisotropic symmetry systems
- Apply moveout and amplitude inversion to P-wave and multicomponent surface seismic data
- Analyze anisotropy-induced distortions in velocity model-building and seismic imaging
- Evaluate the performance of seismic modeling methods for different types of subsurface structures and choose the most efficient option

- Evaluate the influence of anisotropy on kinematic and dynamic signatures of reflected waves
- Create approximations linearized in the anisotropy coefficients to gain insight into the properties of surface seismic data from anisotropic media
- Create optimal combinations of surface seismic data with borehole information to accurately estimate the parameters of anisotropic media

For the corresponding assessments, see the descriptions of the course modules on Canvas.

OREDIGGER PROMISE

Orediggers climb together and look out for each other. It takes a shared commitment from each and every one of us to stop the spread of COVID-19, keep the campus open, and be together at Mines this year. We take great pride in being a top engineering and applied sciences university and we will strive to be exemplary in preventing the spread of COVID-19 in a university setting.

Therefore, as a member of the Oredigger community, I promise to protect classmates and colleagues, our families and neighbors, and myself by adopting the practices and attitudes summarized at the Mines website.

DIVERSITY AND INCLUSION

At Colorado School of Mines, we understand that a diverse and inclusive learning environment inspires creativity and innovation, which are essential to the engineering process. We also know that in order to address current and emerging national and global challenges, it is important to learn with and from people who have different backgrounds, thoughts, and experiences. Our students represent every state in the nation and more than 90 countries around the world, and we continue to make progress in the areas of diversity and inclusion by providing Diversity and Inclusion programs and services to support these efforts.

DISABILITY SUPPORT SERVICES

Colorado School of Mines is committed to ensuring the full participation of all students in its programs, including students with disabilities. If you anticipate or experience any barriers to learning in this course, please feel welcome to discuss your concerns with me. Students with disabilities may also wish to contact Disability Support Services (DSS) to discuss options to removing barriers in this course, including how to register and request official accommodations. Please visit their website at disabilities.mines.edu for contact and additional information. If you have already been

approved for accommodations through DSS, please meet with me at your earliest convenience so we can discuss your needs in this course.

Accessibility within Canvas:
Read the Accessibility Statement from Canvas to see how the learning management system at the Colorado School of Mines is committed to providing a system that is usable by everyone. The Canvas platform was built using the most modern HTML and CSS technologies, and is committed to W3C's Web Accessibility Initiative and Section 508 guidelines.

WRITING CENTER

The Writing Center is a free academic support service available to all members of the campus community including undergraduate and graduate students. The Center can assist you at any stage of the writing process, from brainstorming to final revisions. You do not need a complete draft to make an appointment. Consultants working for the Center have expertise in a variety of composition and communication fields, providing support as you work on projects such as lab reports, essays, collaborative papers, scholarly publications, thesis chapters, and oral presentations. Whether you are focusing on organization or sentence structure, the Center can evaluate your individual needs and tailor each appointment so that you become a more effective and efficient communicator. To learn more or to make an appointment, please visit "writing.mines.edu".

POLICY ON ACADEMIC INTEGRITY/MISCONDUCT

Colorado School of Mines affirms the principle that all individuals associated with the Mines academic community have a responsibility for establishing, maintaining, and fostering an understanding and appreciation for academic integrity. In broad terms, this implies protecting the environment of mutual trust within which scholarly exchange occurs, supporting the ability of the faculty to fairly and effectively evaluate every students academic achievements, and giving credence to the universitys educational mission, its scholarly objectives and the substance of the degrees it awards. The protection of academic integrity requires clear and consistent standards, as well as confrontation and sanctions when individuals violate those standards. CSM desires an environment free of any and all forms of academic misconduct and expects students to act with integrity at all times. Academic misconduct is the intentional act of fraud, in which an individual seeks to claim credit for the work and efforts of another without authorization, or uses unauthorized materials or fabricated information in any academic exercise. Student academic misconduct arises when a student violates the principle of academic integrity. Such behavior erodes mutual trust, distorts the fair evaluation of academic achievements, violates the ethical code of behavior upon which education and scholarship rest, and undermines the credibility of the university. Because of the serious institutional and individual ramifications, student misconduct

arising from violations of academic integrity is not tolerated at Mines. If a student is found to have engaged in such misconduct, sanctions such as change of a grade, loss of institutional privileges, or academic suspension or dismissal may be imposed. The complete policy can be found online.

Expectations of online etiquette/netiquette, grading policy, coursework return policy, and expectations for participation are posted on Canvas.