USC University of Southern California

GEOL 534L: Mechanics of Lithospheric Deformation

Description

Units: 3.0
Term-Day-Time: TBD
Location: ZHS 118
Instructor: Sylvain Barbot (sbarbot@usc.edu)
Office: ZHS 105

Holidays and recess:
Martin Luther King's Birthday: Monday, January 16.
President's Day: Monday, February 20.
Spring Recess: March 12-19

Course Description

The deformation of the solid Earth is controlled by various micro-mechanical processes that operate at different length and time scales. This class will focus on the deformation of the lithosphere and asthenosphere at time scales relevant to the seismic cycle, i.e., from milliseconds to thousands of years. As a foundation, we will first discuss elasticity, stress, and strain in the lithosphere. We will introduce the mathematical tools to describe these quantities in three dimensions with scalars, vectors, and tensors. Consideration of momentum conservation will lead us to the governing equations of elasticity: Navier's equation and the wave equation in three dimensions. Modeling of long strike-slip faults and subduction megathrust motivates writing these equations in two dimensions. Equipped with these fundamentals, we will review the constitutive properties of rocks at various temperature conditions. We will first describe the origin of friction and how it governs faulting, probably best described by the Anderson theory of faulting and the Mohr-Coulomb failure criterion. Because of its relevance to earthquakes, we will describe the kinematic aspects of friction and the stability of frictional sliding. This will be an occasion to learn how to solve nonlinear differential equations and to introduce deterministic chaos. We will then describe the visco-elasto-plastic properties of rocks relevant to lower-crustal and asthenosphere conditions, including poro-elasticity and thermo-elasticity as special cases. We will review various mechanisms of ductile flow, i.e., diffusion creep, dislocation creep, and dislocation glide. Considering frictional strength in the brittle layer and ductile strength in the viscoelastic lower crust and asthenosphere yields strength profiles of the lithosphere. We will end the course with discussions on how to derive the governing equations for lithosphere deformation and solve then analytically, semi-analytically, or numerically using various numerical methods. We will introduce Fourier methods, the boundary-integral method, and explicit solvers for ordinary differential equations. At the end of this class, you will be have a thorough understanding of rock mechanics relevant to the lithosphere and you will be able to model geodetic data.

Learning Objectives

By the end of this course, the students will know many important mechanisms of deformation of rocks in the lithosphere-asthenosphere system, including elastic (reversible) deformation, poro-elasticity, thermo-elasticity, visco-elasto-plasticity, and frictional sliding. The students will be able to derive the governing equations for time-dependent deformation from first principle. The students will be introduced to solution methods to model geodetic data.

Prerequisite(s):

This is a General Education class and there are no prerequisites.

Description and Assessment of Assignments

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There will be no home assignment. The students will present a relevant paper during class during the semester. For final evaluation, the students will apply the concepts or methods learned towards their own research project, write, and present a term paper.

Grading Breakdown

There will be 1 oral paper presentation mid-semester (20%) and 1 final term paper and presentation (30%). Attendance counts for the remaining 50%.

Assignment	% of Grade	Extra Credit (%)
Lecture attendance and participation	50	
Field trip participation	20	
Term paper and presentation	30	
Total	100	

Course evaluation

Course evaluation will be conducted with 1 oral paper presentation at the time of lectures and one final paper and presentation. Each student will lead a 30 minutes presentation on the topic of his/her term paper. Preliminary version of the final paper should be shown to the instructor for approval at least two weeks beforehand. Students should prepare a handout to be distributed in the class at the time of the presentation.

Lecture outline

approx. # of lectures

I. Elasticity — 4
   a. Stress and strain
   b. Invariants
   c. Scalars, vectors, tensors
   d. Momentum and mass conservation
   e. Navier's equation
   f. Plane strain, anti-plane strain

II. Friction — 10
   a. Static and kinematic friction
   b. Faults, folds
   c. Anderson theory of faulting
   d. Faults and surface deformation
   e. Stability of fault slip
   f. Dynamics of frictional sliding

III. Visco-elasto-plasticity — 4
   a. Spring-dashpot assemblies
   b. Thermo-elasticity and poro-elasticity
   c. Postseismic relaxation
   d. Constitutive equations

e. Strength of the lithosphere
f. Dynamics of visco-elastic flow

IV. Numerical methods for lithosphere deformation 10
a. Fourier methods
b. Green's functions
c. Numerical quadrature
d. Boundary integral method
e. Ordinary differential equation solver

Lecture content is subject to change without warning.

Field trip

We will spend a few days in the field to explore some of the geological wonders of Southern California. The field trip will expose you to faulting and folding processes of deformation and volcanic activity (lava tubes, lava lakes, cinder cones). We will also look for 500 My-old fossils of vertebrates. This will involve two nights of camping in the desert. Transportation is with department vehicles.

Recommended reading

Paul Segall, Earthquake and volcano deformation, Princeton University Press, 2010.

Donald L. Turcotte, Gerald Schubert, Geodynamics, Cambridge University Press, 2002.

David Berkovici, The Origins of Everything in 100 Pages (More or Less), Yale University Press, 2016.

Robert M. Hazen, The Story of Earth, Penguin Books, 2013.

William H. Press, Saul A. Teukolsky, William T. Vetterling, Numerical Recipes 3rd Edition: The Art of Scientific Computing, 2007.

Attendance

We will accommodate students who give advance notice of religious observation. In each case, we will work with you to find another date to schedule your oral presentation or term paper due date.

Classroom norms

Student participation during lecture and laboratories and encouraged. Always feel free to ask questions and clarifications. The comments that you make (asking for clarification, sharing critiques, expanding on a point) should reflect that you have paid attention to the instructor comments.

Communication

Regular communication will be conducted through Blackboard (https://blackboard.usc.edu). The lectures will be written on the board during class. It is the student's responsibility to take appropriate notes. We will not provide more study material.

Statement on Academic Conduct and Support Systems

Academic Conduct:

Plagiarism – presenting someone else's ideas as your own, either verbatim or recast in your own words – is a serious academic offense with serious consequences. Please familiarize yourself with the discussion of plagiarism in *SCampus* in Part B, Section 11, "Behavior Violating University Standards" policy.usc.edu/scampus-part-b. Other forms of academic dishonesty are equally unacceptable. See additional information in *SCampus* and university policies on scientific misconduct, http://policy.usc.edu/scientific-misconduct.

Support Systems:

Student Counseling Services (SCS) – (213) 740-7711 – 24/7 on call
Free and confidential mental health treatment for students, including short-term psychotherapy, group counseling, stress fitness workshops, and crisis intervention. engemannshc.usc.edu/counseling

National Suicide Prevention Lifeline – 1 (800) 273-8255
Provides free and confidential emotional support to people in suicidal crisis or emotional distress 24 hours a day, 7 days a week. www.suicidepreventionlifeline.org

Relationship and Sexual Violence Prevention Services (RSVP) – (213) 740-4900 – 24/7 on call
Free and confidential therapy services, workshops, and training for situations related to gender-based harm. engemannshc.usc.edu/rsvp

Sexual Assault Resource Center
For more information about how to get help or help a survivor, rights, reporting options, and additional resources, visit the website: sarc.usc.edu

Office of Equity and Diversity (OED)/Title IX Compliance – (213) 740-5086
Works with faculty, staff, visitors, applicants, and students around issues of protected class. equity.usc.edu

Bias Assessment Response and Support
Incidents of bias, hate crimes and microaggressions need to be reported allowing for appropriate investigation and response. studentaffairs.usc.edu/bias-assessment-response-support

The Office of Disability Services and Programs
Provides certification for students with disabilities and helps arrange relevant accommodations. dsp.usc.edu

Student Support and Advocacy – (213) 821-4710
Assists students and families in resolving complex issues adversely affecting their success as a student EX: personal, financial, and academic. studentaffairs.usc.edu/ssa

Diversity at USC
Information on events, programs and training, the Diversity Task Force (including representatives for each school), chronology, participation, and various resources for students. diversity.usc.edu

USC Emergency Information
Provides safety and other updates, including ways in which instruction will be continued if an officially declared emergency makes travel to campus infeasible. emergency.usc.edu

USC Department of Public Safety – UPC: (213) 740-4321 – HSC: (323) 442-1000 – 24-hour emergency or to report a crime.
Provides overall safety to USC community. dps.usc.edu