GEOL 321 Structural Geology and Tectonics

Geology 321 Structure and Tectonics will be given in Spring 2017. The course provides a general coverage of the structures produced by brittle and ductile rock deformation at scales from the hand-specimen to plate boundaries, and an insight into the relationships between the deformational structures and plate tectonic settings. The emphasis will be on the description and interpretation of structures seen in the field, and the course includes an introduction to the techniques of geological mapping in a structurally complex terrain, and the interpretation of geological maps and sections. Lab exercises will involve calculations and graphical exercises, but a basic math preparation is sufficient to follow the course.

There will be two day trips and two weekend trips, including a mapping trip in the Inyo Mountains. The weekend trips are provisionally scheduled for February 24-27 and April 15-17: in both cases we will try to leave as early as we can on the Friday, and return late Sunday. The day trips will be scheduled on Thursdays, and will be arranged in class.

Lectures (11.00 - 12.25 T, Th), Labs (TBA). 2 weekend field trips and 2 day trips. Assessment is based on lab assignments, field trip reports, and a final examination.

Flow chart for course:
Plate tectonics → tectonic regimes → structural geometry → mechanics → rheology → fault rocks → ductile structures → mylonites → rift zones → strike-slip zones → thrust belts.

Schedule
Classes start: Monday January 9
Martin Luther King's Birthday: Mon January 16
President's Day: Mon February 20
Spring Recess: March 12-19
Classes end: Friday April 28

Field exercise 1: Southern California tectonics (day trip, February)
Field exercise 2: Death Valley (weekend trip February 24-27)
Field exercise 3: Field methods in structural geology (day trip, March)
Field exercise 4: Mapping in the Inyo Mtns (weekend trip, April 15-17).

Note: the sequence of lectures and lab exercises shown below is provisional. There will be additional lectures and labs related to the field trips, and a review session at the end of the semester.

Plate tectonics and tectonic regimes

Reading: Davis & Reynolds chapter 10.
Lecture 1: The Earth as a mechanical system.

- Heat flow and the global energy budget

- Conduction and convection
- Compositional boundaries within the Earth
- Lithosphere and asthenosphere. Thermal and mechanical boundary layers.
- Decompression melting and the origin of the oceanic crust
- Isostasy, gravity and topography

Lecture 2: Continental drift and plate tectonics
- Geometrical and geological evidence for continental drift
- Apparent polar wander paths
- Distribution of seismicity
- Sea-floor magnetic anomalies
- Geometrical concept of plate tectonics.

Lab exercise 1: Introduction to geological maps

Reading: Moores & Twiss, sections 5.1 - 5.5.
Lecture 3: Divergent plate boundaries and transform faults
- Topographic and structural expression of mid-ocean ridges
- Subsidence history of oceanic lithosphere
- Magmatism at mid-ocean ridges
- Magmatic structure of oceanic crust as revealed in ophiolite sequences
- Kinematic behaviour of transform faults
- Seismicity and topographic expression of transform faults

Lecture 4: Convergent plate boundaries
- Benioff seismic zones
- Surface structure: Accretionary wedge – forearc basin – magmatic arc – back-arc
- Introceanic and continental arcs
- Continental collision zones

Lab exercise 2: Introduction to geological maps (continued)

Reading: Moores & Twiss, sections 7.1 – 7.4
Lecture 5: Geometrical aspects of plate motion
- Euler's theorem
- Relative velocities and poles of rotation
- Kinematic and geometrical characteristics of plate boundaries
- Triple junctions

Lecture 6: Continental rift zones and the evolution of passive continental margins
- Structure of continental rifts. East African Rift as an example
- Initiation of continental breakup. Red Sea as an example
- Evolution of passive continental margins: Atlantic margin of eastern US as an example.

Lab exercise 3: Plate kinematics

Structural Geometry

Reading: Davis & Reynolds, p. 269-296
Lecture 7: Faulting

- Description of deformation in terms of geometry, kinematics, and dynamics.
- Geometrical description of faults. Slip and stratigraphic separation on faults.
- Methods for determining the slip vector on a fault.

Lecture 8: Fault rocks and small-scale structures in fault zones.

- Fault rocks: fault breccia, cataclasite, mylonite, pseudotachylite
- Slickensides and slickenlines
- Gouge fabrics, Riedel shears
- Wear grooves, fibre lineations, solution grooves
- Sense of shear indicators in fault zones.

Lab exercise 4: Day field trip and field-trip follow-up.

Reading, week 5: Davis & Reynolds, p. 373-403
Lecture 9: Geometrical description of folds

- Fold hinge, axis, axial surface, fold crest
- Inclined folds and plunging folds
- Fold asymmetry, enveloping surface of a fold train
- Fold style: parallel, concentric, similar, kink geometries.

Lecture 10: Folds and rock fabrics

- Axial plane cleavage in folds.
- Linear fabric elements in folds.
- Use of folds, cleavages and lineations in structural analysis

Lab exercise 5: Introduction to the equal-area projection

Introduction to Structural Mechanics

Reading: Davis & Reynolds, p. 98-134
Lecture 11: Stress

- Force and stress
- Stress on a surface: tractions and the stress vector
- Stress field in 3-D; Principal stresses
- Hydrostatic and deviatoric stress
- Mohr equations and the Mohr construction for stress

Lecture 12: Fracture mechanics

- The Coulomb fracture criterion.

- Use of the Mohr construction to represent fracture mechanics
- Failure envelope
- Effect of fluid pressure on fracture

Lab exercise 6: Geometrical analysis of folds

Reading: Davis & Reynolds, p. 38-74
Lecture 13: Strain
- Displacement gradients, rotation, and strain.
- Elongation, stretch, shear strain, volumetric strain
- Incremental strain and strain-rate

Lecture 14: Strain analysis
- Strain analysis using spherical objects
- Center-to-center method
- Rf/phi method
- Mohr construction for strain
- Strain analysis using deformed fossils

Lab exercise 7: The Mohr construction for stress and its use in fracture mechanics

Ductile deformation

Reading: Davis & Reynolds, p. 143-149, 424-436, 456-471
Lecture 15: Ductile deformation
- Rheology
- Elastic, viscous and plastic deformation
- Rheological analogues
- Deformational mechanisms in rocks

Lecture 16: Ductile deformational fabrics
- Planar deformational fabrics: cleavage, schistosity, gneissic foliation, mylonitic foliation, crenulation cleavage.
- Linear deformational fabrics: intersection lineation, stretching lineation, crenulation lineation.

Lab exercise 8: Strain analysis

Reading: Davis & Reynolds, p. 493-523, 404-413
Lecture 17: Ductile shear zones
- Boundary conditions limiting nature of flow in ductile shear zones
- Geometry of simple shear
- Foliation geometry in ductile shear zones
- Mylonites
- Sense of shear criteria in mylonites

Lecture 18: Mechanics of folding 1

- Fold style in terms of the geometry of the folded layer
- Mechanical theory of buckle folding in single layers.

Lab exercise 9: Day field trip and field trip follow up

Lecture 21: Mechanics of folding 2

- Folding in multilayers; flexural slip folds
- Kinks.
- Similar folds and flow folds

Lecture 22: Analysis of polyphase deformation

- Superposed folds
- Interference structures
- Folded foliations and superposed foliations
- Folded lineations

Lab exercise 10: Field trip follow up

Tectonics

Lecture 23: Tectonic styles in zones of strike-slip faulting

- Patterns of folds and faults in strike-slip fault zones
- Flower structures
- Releasing and restraining bends
- Pull-apart basins
- Vertical-axis rotations in in strike-slip fault zones
- Deep structure of strike-slip fault zones

Lecture 24: Tectonic styles in zones of normal faulting

- Conjugate sets of normal faults
- Horst and graben structure
- Detachment faults
- Rotation of normal faults above listric faults and detachments
- Rolling hinge model for detachment faults

Lab exercise 11: Structures and fabrics in rocks

Lecture 23: Tectonic styles in zones of thrust faulting

- Thin-skinned and thick-skinned thrust belts
- Ramp and flat structures
- Ramp anticlines and footwall synclines
- Fault propagation folds
- Frontal imbricate fan

- Duplex structure
- Culminations
- Backthrusts and pop-up structures

Lecture 24: Construction and restoration of balanced sections

Lab exercise 12: Construction and restoration of balanced sections

FINAL EXAMINATION: Tues May 9, 11-1.