California Institute of Technology
GE 106 STRUCTURAL GEOLOGY (Winter 2023)

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Office Hours: Tu 3:30-4:30PM

or make special appointment

LECTURE: Meets Th 5:00-8:00PM in Arms 251 (includes ~20-minute break)

LABORATORY: Meets Tu 4:30-7:30PM in Arms 251 (includes ~20-minute break);
Some lab meetings to be supplanted by field trips (see schedule below for details)

Prerequistes: None

Required Text: Fossen, Haakon, Structural Geology, Cambridge University Press, (2nd editions)

No Laboratory Manual Is Required; Pertinent materials will be provided. Stereonet plotting procedures are summarized in Appendix B of Fossen. Two good references for field techniques are:

- Coe, Angela L., Argles, Dr. Tom W., Rotherey, Dr. David A., and Spicer, Robert A., 2010. *Geological Field Techniques*. John Wiley & Sons.
- Compton, Robert R., 1985. *Geology in the Field*. John Wiley & Sons

Required Field Trips: See suggested dates and times listed in schedule below. I presume some students may have Friday time conflicts so hopefully Saturdays and/or Sundays will work. The schedule is flexible enough to adapt to poor weather conditions. The Saturday Jan 14 trip to the San Gabriel Mountains is a relatively short drive. The Feb 18-20 trip to Anza-Borrego will involve two nights camping out and cooking in remote areas.

Field Trip Logistics: A logistics sheet explaining details of each trip will be provided to students a few days prior to scheduled field work. The field trips will visit remote sites. Rugged and primitive conditions are likely to be encountered. Should students have concerns or require special accommodations please contact Dr. Nourse a few days prior to departure.

Required Equipment: Calculator, protractor, ruler, colored pencils, 2H, 3H, and 4H pencils with erasers, high quality black ink pen, graph paper, tracing paper, stereonet assembly, clipboard or hinged map board, field notebook, heavy duty shoes or boots, magnifying lens, rock hammer, basic camping gear. Brunton compasses and GPS receivers will be checked out in the field.

Learning Outcomes:
Upon completion of this course, students shall have attained working knowledge of content areas and developed practical skills as listed below:
1. Understand the rule of V's as applied to interaction of topography with variably oriented rock layers
2. Construct true scale geologic cross sections from a geologic map base
3. Recognize, describe, and accurately measure various classes of geologic structures (including bedding, unconformities, intrusive contacts, faults, fault striations, foliation, lineation, folds, fold hinges, axial planes, etc.) in their natural field setting
4. Plot various types of structural orientation data on stereonet diagrams
5. Interpret the 3-dimensional geometry of structures plotted on stereonet diagrams
6. Understand geometric relationships between three main classes of faults and orientations of the principle stresses

7. Apply the strain ellipsoid concept to measurement and interpretation of 3-dimensional strain in naturally deformed rock masses
8. Utilize drawings of progressive deformation to illustrate fundamental differences between coaxial plane strain (pure shear) and noncoaxial plane strain (simple shear)
9. Understand Mohr-Coulomb theory of rock failure and its application to earthquake faulting
10. Recognize and describe various classes of kinematic indicators associated with ductile shear zones
11. Classify fold geometries in terms of inter-limb angle and orientations of hinges and axial planes.
12. Relate the concept of cylindrical folding to stereonet representations of structures associated with folded surfaces
13. Understand geometric relationships of S folds, Z folds, W folds, M folds, and axial plane cleavage/foliation to larger scale folds in folded terrain

Evaluation: Because lecture, laboratory, and field trip concepts are intimately related, scores in lecture and laboratory will be combined into one grade worth 4 units. Both examinations will be lengthy (3-4 hrs) to allow sufficient thinking and work time. Grades are calculated as follows:

Laboratory and Field Exercises	40%
Midterm Exam (lecture and lab combined)	30%
Final Exam (lecture and lab combined)	30%

Final Grades follow the standard schedule derived from percentages of total points earned: 100%-90% = A; 80%-90% = B; 70%-80% = C; 60%-70% = D; <60% = F. A modest curve may be applied to adjust grades upward, but this is at the discretion of the instructor and should not be expected.

- **No makeup exams or field trips without a documented emergency or prior consultation.**
- **Please submit all work on time. My late policy is as follows: 15% grade deduction per week of class meeting that work is submitted late.**
- **Attendance is required in lecture and laboratory. You will be held responsible for all missed lab or lecture sessions. This course is very lab-intensive and the pace will be quite rapid, so make every effort to keep up with the reading assignments and homework.**
- **Class time is our learning time. Stay focused on your instructor and be prepared to take notes. No cell phone interruptions or texting, please.**

TENTATIVE LECTURE AND LABORATORY SCHEDULE:

(Pertinent readings from 2nd edition of text are in *bold italics* below)

Week 1 (January 5—Introductory Lecture): Course Logistics; Intro to themes in Structural Geology; Primary vs. Secondary geologic structures (Photographic examples); 3-D Principle stress geometries associated with conjugate extensional, compressional and strike-slip faults;
Read Chapter 1; Start Reading Chapters 4 and 5

Week 2 (Jan 10, 12):
Laboratory #1 (Tues Jan 10): Fundamental three-dimensional construction techniques; Construction of geologic cross sections; Apparent dip calculations; The classic *3-point problem*; *Strike, Dip, and the Rule of V's*; Projection of dipping contacts or veins across canyons or arroyos
Lecture (Thurs Jan 12) Geothermal gradient and the brittle-ductile transition; Structures formed in extensional, and compressional tectonic environments; Half grabens and block rotations during normal faulting; Thrust faults and duplexes; Continental tectonic examples ***Read Chapters 17 and 18***

Lab #2 (Saturday Jan 14 8AM –5PM): Field Trip to Cow Canyon Saddle and San Dimas Canyon-- measurement of dikes, veins foliation, faults and fault striations; brittle fault kinematic indicators
****Please reserve Saturday, Jan 21 for rain makeup****

Week 3 (Jan 17, 19):

Lab #3 (Jan 17): Stereographic projection and stereonet plotting techniques**; analysis of Lab #2 field data**

Lecture *Please read Appendix B and download Richard Allmendinger's Stereonet and FaultKin programs*

(Thurs Jan 19) Transform faults and strike-slip faulting; Transtension vs. transpression; Rotating blocks in strike-slip tectonic regimes; Continental tectonic examples. ***Read Chapter 19,***

Week 4 (Jan 24, 26):;

Lecture (Tues Jan 24) The Mohr stress circle; Introduction to Rock Mechanics as applied to geologic problems; Byerlee's Law; Anderson-Coulomb fault-fracture theory; Exceptions to the 30 degree rule; ***(Read Chapters 7, 8, 9, 10.2; focus on p. 92-98;)***

Lab #4 (Thurs Jan 26): Applications of the Mohr stress circle to earthquake faulting, Rock mechanics and related experiments

Week 5 (Jan 31, Feb 2):

Lab #5 (Tues Jan 31): Ductile strain and the strain ellipsoid; 3-dimensional Strain Analysis--measurement of stretched pebbles; Quantification of strain parameters (principle longitudinal strains and stretches; Flynn diagrams); Harmonic mean approximation techniques

Lecture (Thurs Feb 2) Strain analysis, continued: Geometric relationship of strain ellipsoid to *Foliation* (cleavage, schistosity, gneissosity, etc) and *Stretching Lineation*; L-Tectonites, S-Tectonites, and L-S Tectonites; ***Read Chapters 2, 3; Chapter 13, 14***

Week 6 **(Feb 7, 9): **Midterm Exams—to be administered during class meeting times**

Week 7 (Feb 14, 16)

Lab will not meet Tuesday, Feb 7--

Lecture (Thurs Feb 16) Coaxial Strain vs Noncoaxial Strain and Shear Strain; Pure shear vs. Simple shear; Fundamental Plane Strain equations; ***Reread Ch 2.14 through 2.30; Begin reading Chapter 16***

Lab #6 (Saturday Feb 18, 8AM through Sunday Feb 20, 2PM): Weekend Field Trip to Anza Borrego State Park—Investigation of Quaternary transpressional structures near Clark Fault in Coachwhip Cyn; measurement of S-C fabric in mylonites at Glorieta Cyn; overview of extensional half graben at Hawk Cyn

****Please reserve Friday Feb 24 through Sunday Feb 26 for poor-weather makeup****

Week 8 (Feb 21, 23):

Lab will not meet Tuesday, Feb 21--

Lecture (Thurs Feb 23) Noncoaxial brittle-ductile deformation zones (Shear Zones) and associated S-C fabrics; Quantitative shear zone analysis using hand specimens; Review of meso- and microscopic S-C fabrics

Week 9 (Feb 28, Mar 2):

Lab will not meet Tuesday, Feb 28--

Lecture (Thurs Mar 2) ***Folds*****:** Description, classification, and associated lineation; Relationship of folds to local and regional strain fields; Parasitic folds: flexural slip folding and *S, Z, W, M* folds; Stereographic representation of folds: pi diagrams ***Read Ch 12, 16***

Week 10 (Mar 7, 9):

Lab #7 (Tues Mar 7): Fold analysis-- measurement and analysis of refolded fold system

Lecture (Thurs Mar 9) ***Folds continued*****:** Stereographic representation of various fold geometries, continued; Bedding/cleavage relations in folded terrain; Exploration techniques: projecting folds into the subsurface ***Reread Chapters 13, 14,***

Week 10 (Mar 16): ** Final Exam—to be administered during class meeting time