Professor: Jan Tullis — Office GC033; phone 31921; email: Jan_Tullis@brown.edu
Office hours: Tues 3–4 PM & by appt.

Graduate TA: Amanda Getsinger — Office GC 042 (Amanda_Getsinger@brown.edu) hrs TBA

Undergrad TA: Helen Doyle — Office GC028 (Helen_Doyle@brown.edu) office hrs TBA

Textbook: *(see back side)*
The textbook by van der Pluijm & Marshak (2nd ed) is modern and complete in its coverage of structural geology, from a description of the geometry of structures, to a determination of their kinematics (strain) and interpretation of their dynamics (stress and rheology). It also does a good job of showing how outcrop scale structures fit into larger-scale tectonics. I have prepared Guides to the readings to provide an overview and help link the text to class coverage. ***Skim the assigned reading before class, including the figures & photos, to get an idea of the topics & terms***, then do a more detailed reading after lecture.

Class meetings:
The goal of class meetings is not primarily content delivery, but rather active and deep learning. Class meetings will include some lecture, but also pair–share discussion and problem solving; active examination and discussion of rock samples, color images, maps and animations; and model demonstrations.

For everyone's benefit, I expect that everyone will arrive to class on time (with cell phones turned off), prepared to participate actively. In turn I commit to end on time.

This class includes people with somewhat different backgrounds and interests. That is good, because we can all learn from one another. In order that the course provide an effective learning environment for everyone, it is very important that everyone contribute to the questions as well as to the 'answers'.

Writing & oral assignments:
There will be one short 'warm–up' writing assignment, one very short abstract, one slightly longer one (~2 pages) with brief class presentation, and a brief class presentation of a model/demonstration. The writing assignments are designed to give you practise and feedback. You will probably want to revise all of these at least once; only the final version will be graded.

- ♦The 1st exercise is a chance to review pertinent content from Geo 220 and to practise organizing moderately complex ideas into a logically clear and concise paragraph.
- ♦The 2nd assignment is to write an abstract (one paragraph) for a short article in the research literature that relates closely to the lecture topic (dates on syllabus). This assignment will involve peer review.
- ♦The 3rd assignment involves reading a research article illustrating the application of 'structural geology' to another area that interests you (such as hydrology or glaciology), writing a brief (~2–3 p) summary, and giving a 5 min class presentation with one–page handout highlighting one key idea or result.

- ♦Working in pairs or individually, everyone will prepare and present briefly (~10 mins) to the class a model or demonstration pertinent to various topics during the semester (see syllabus). For each, a one page class handout should be prepared in advance, and a one page report on 'how it worked' afterward.

Labs and field trips:
There will be 8 labs (the last one extending over 3 weeks) and 2 field trips (1 half day, 1 full day). Labs are 2 hrs long; you are expected to be there for the whole time so you can benefit from the TAs and from your fellow students. Labs are due the following week at the beginning of lab. Some weeks you may almost finish in lab; other weeks you will need to come for a short time to finish up.

Grading: The grading for the course will be approximately as follows:

First & 2nd hourly exams	15% each	Writing/oral assignments	15%
Labs and field trips	30%	Final exam	25%

Discover and integrate new information about structural geology

Basic factual knowledge is obviously one important component of any science course; you cannot formulate reasonable hypotheses unless you know some facts. Some facts pertinent to structural geology will obviously be introduced by your professor and TAs; however, providing 'facts' is not our most important function, and memorizing 'facts' should not be your most important goal. You should aim to connect facts, via concepts and processes, into new knowledge that is firmly tied to your existing knowledge base.

The textbook is obviously one good source of structural geology information and illustrative examples. Other sources of information about structural geology that you should plan to make use of include:

- ♦ the maps on the GC walls; the books, journals, & maps in GeoChem & Sci Li; & web resources;
- ♦ some colloquium and/or lunch bunch speakers this semester;
- ♦ other faculty (e.g. Greg Hirth, Peter Gromet), post docs and grad students;
- ♦ undergrads & grad students who have taken a summer field course or done a field–based REU.

Develop skills (e.g., writing, speaking, quantitative analysis, estimating)

There are a number of skills particular to structural geology you will develop during the semester, eg:

- ♦ use of the Brunton compass for making field measurements of attitude
- ♦ methods of estimating finite strain magnitudes & directions.

Some skills are also pertinent to a number of other science fields, eg:

- ♦ use of stereo nets for representing 3D orientations of features;
- ♦ use of Mohr circles for stress analysis.

In addition, however, we will focus on a number of skills which are important for any endeavor in life, eg:

- ♦ ability to visualize complex phenomena in 3D;
- ♦ ability to think across vast ranges of time and space scales
- ♦ ability to make order-of-magnitude estimates;
- ♦ effective written and oral communication.

Some of the specific skills will be taught in the lab sessions. However we will work on many of the communication, analysis, and visualization skills during the regular class meetings as well. The professor and TAs cannot 'give' you knowledge or skills, but we will try to be good coaches. Your active engagement and participation in class is very important for everyone's learning.

Only those who remain silent never utter nonsense.

Develop conceptual & intellectual tools (e.g., critical thinking, synthesis)

Perhaps most importantly, we hope that during the semester we can help you to develop your ability to do higher order or critical thinking, including:

- ♦ pattern recognition and interpretation,
- ♦ identification of unstated assumptions,
- ♦ critical reading and unraveling arguments,
- ♦ data evaluation, and formulating and testing hypotheses.

These abilities will allow you to go beyond memorization of 'facts' so that you will be a self-learner, able to solve totally new problems on your own – including those not directly related to structural geology.

Critical thinking involves skepticism, reason, logic, and argumentative discourse, and provides the means to personally evaluate the quality of ideas and knowledge (eg wisdom, see below). We hope to create an environment in which these components are encouraged in several different ways.

- ♦ First, class meetings will not just consist of passive (for the student) lectures; they will involve active debate, analysis, and problem solving, often done in small groups (the way real research is done).
- ♦ Second, writing exercises will stress critical analysis as well as effective communication.
- ♦ Third, exams and lab exercises will stress reasoning in addition to the correctness of the 'answers'.

The greatest risk is not taking one.

Where is the wisdom we have
lost in knowledge;
Where is the knowledge we
have lost in information. *(T S Elliot)*

Two final goals: (1) to become more aware of your own learning process (metacognition), and (2) to recognize and enjoy the esthetics of beautiful rock structures! ***(see over)***

Geol. Sci. 1450 – STRUCTURAL GEOLOGY – spring 2011

Jan Tullis

Amanda Getsinger, Helen Doyla

DRAFT Syllabus

	Date	Lecture topic	Reading in P&M	Lab topic
1	Jan. 27 (Th)	Introductions; scope of structural geology; ***Writing Assignment #1: review of brittle, ductile, strength***	Ch. 1 (&14)	**(no lab)**
2	Feb. 1 (Tu)	Introd. to brittle deformation ***WA #1a due***	2.1–2.2; skim 7.1–7.4; 8.1–8.4	**Intro to 3D visualization & representation**
3	Feb. 3 (Th)	Stress ***WA#1a returned***	3. 1–3.11 (omit 3.8)	
4	Feb. 8 (Tu)	Mohr circles for stress ***WA#1b due***	3.8 & handout	**3D continued, with stereo net plots**
5	Feb. 10 (Th)	Brittle failure processes & criteria ***WA #1b returned*; Demo #1: photoelastic stress concentration**	6.1–6.7	
6	Feb. 15 (Tu)	Effect of fluids on brittle deformation **Demo #2: cornstarch joints** ***WA#1b revision due; WA #2: one par. abstract***	6.8–6.9; Ch. 7	**Using Mohr circles to find stress on faults**
7	Feb. 17 (Th)	Stress in the crust & fault mechanics	3.12–3.14; 8.2; 8.5–8.8	
	Feb. 22 (Tu)	**Holiday**		
8	Feb. 24 (Th)	Determining stress magnitudes & directions **Demo #3: dike propagation** ***WA#2 due & exchange; small group discussions***	2.4 & handout	**Faults on geol. maps & in hand samples**
9	Mar. 1 (Tu)	Review, stress & brittle deformation ***peer reviews due (including JT)***		**Field sketch & Brunton compass measurements**
10	Mar. 3 (Th)	**FIRST HOUR EXAM**		
11	Mar. 8 (Tu)	Structures at compressive plate boundaries **Demo #4: accretionary wedge**	17.2.3,17.3,17.4.4,17.5–6 18.1–2,18.8; skim 18.3–18.7	**Structures & landforms from air photos**
12	Mar.10 (Th)	Structures at rift & transform boundaries ***WA#2 revisions due Friday***	16.1–3;skim 16.4–5 &16.8; 19.1–19.4	
13	Mar. 15 (Tu)	Introduction to ductile deformation **Demo #5: strike–slip fault in clay**	(10.1–10.5), 4.1-4.3 & 4.7; p. 67–69	**Folds on geol. maps & in hand samples**
14	Mar. 17 (Th)	Processes of ductile def: solution transfer ***WA #3: research paper review or field work***	handout; 7.7 (9.1–9.5)	

Sat Mar. 19 Field Trip to Purgatory *(save Sun too as a back-up in case of rain)*

15	Mar. 22 (Tu)	Strain path & measurement; FT preparation **Demo #6: computer strain path**	Ch. 4 (except 4.8)	**(no lab)**
16	Mar. 24 (Th)	Processes of ductile def: dislocation creep ***WA#3 topic choice deadline***	handout (9.3.2, 9.4, 9.6–9.9)	

– – – – – – (Spring Break) –

17	Apr. 5 (Tu)	Foliations & lineations	Ch. 11	**Microstructures** **Demo #7: analog deformation**
18	Apr. 7 (Th)	Folds and foliations	10.1–10.6	
19	Apr. 12 (Tu)	Review: Fault mechanics; ductile deformation		**(no lab; review)**
20	Apr. 14 (Th)	**SECOND HOURLY EXAM**		
		(Apr. 14–17 Spring Weekend)		
21	Apr. 19 (Tu)	Rheology **Demo #8: viscosity**	5.1; handout	**Cross section and geologic history**
22	Apr. 21 (Th)	Mechanics & kinematics of folds **Demo #9: folding model;** ***draft WA#3 due***	10.7–10.10	
		(Apr 24 Easter)		
23	Apr. 26 (Tu)	Diapirs & ductile shear zones **Demo #10 diapir model;** ***WA#3 feedback returned***	2.3; 12 (omit 12.5)	**Cross section (con't)**
24	Apr. 28 (Th)	Appalachians		

Sat. Apr. 30 Field Trip to Beavertail ***(all day; save Sun as backup)***

25	May 3 (Tu)	Overview of western US tectonics & 5 min presentations of WA#3	handout	**Cross section (con't)**
26	May 5 (Th)	Review of crustal deformation & 5 min presentations of WA#3	handout	
27	May 10 (Tu)	**Cross section viewing and celebration**		
	May 13 (Friday) 9 AM	**FINAL EXAM**		

Geo 1450 **Augmented Syllabus** **spring 2011**

Class # topic title Motivating questions to be addressed

1. Scope of structural geology: What processes and phenomena does it encompass, and what range of time and space scales does it include? What is the logical order this course will follow, & how do the various course activities contribute to the whole?

2. Introduction to brittle deformation: What evidence of brittle deformation do we observe on hand sample to outcrop to regional scales? What geometry and patterns are common? How do brittle rock structures affect landforms and human activities?

3. Stress: How is stress distinct from force? Why do geoscientists need to use stress in order to understand permanent deformation of rocks? What is the significance of normal stress, shear stress and principal stress?

4. Mohr circle representation of stress: How can we use the graphical Mohr circle construction to solve stress problems and why is a 2D representation sufficient for most problems involving brittle deformation? How can we use Mohr circles to determine the normal and shear stresses on fractures and faults?

5. Brittle failure processes and criteria: What grain-scale processes lead to macroscopic brittle deformation? How can cracks open under all-compressive loading? How is the brittle failure criterion represented on a Mohr diagram, and how can it be used to make interpretations as well as predictions?

6. Effects of fluids on brittle deformation: Why and how does pore pressure affect the formation of fractures and sliding on faults, and how can we represent these effects on a Mohr diagram? What are some implications for human activities such as dams, geothermal energy and CO_2 sequestration?

7. Stress in the crust and fault mechanics: How can we calculate or constrain the values of the vertical and horizontal stresses in different tectonic settings in the crust, and how do these constraints relate to the 3 major types of faults? How can we determine the actual offset on recent and older faults?

8. Determining stress magnitudes and directions: How can we measure present day stress magnitudes, and how do they relate to plate boundaries and earthquake triggering? What is the relation between local and regional stresses and how do igneous intrusions map out these transitions?

9. Review: How is stress as the 'cause' of brittle deformation related to fractures and faults as the 'result', in different parts of the crust? What are the effects of rock properties and P, T, fluid conditions on the expression of brittle deformation?

10. Hourly exam

11: Relation of structures to tectonics; compressive plate boundaries: What is the plate tectonic setting and time history of thrust fault systems? Mechanically why do such systems form with a wedge geometry, whether they are soft sediments or consolidated rock layers?

12. Relation of structures to plate tectonics; extensional & transform boundaries: What is the mechanical paradox of listric normal faults, and what are current theories? What is the mechanical paradox for the weak San Andreas fault, and what is the recent evidence?

13. Introduction to ductile deformation: What evidence of ductile deformation do we observe on hand sample to outcrop to regional scales? What geometry and patterns are common? How do we quantify the geometry and amount of finite strain that occurred, and how does strain relate to stress?

14. Grain-scale processes of ductile deformation, solution transfer: How do point defects in mineral grains undergo solid state diffusion and how is this diffusion affected by fluids and by directed stress? How does solution transfer accomplish cementation of sediments as well as shape change of rock masses? How can you recognize the operation of this process in hand samples and outcrops, and how can you use the microstructures to infer the operative stress directions?

15. Strain history (path) and measurement, & field trip preparation: What is the strain history under the end member cases of pure shear and simple shear, and for what situations can you infer the strain path from the final strained object? What objects in nature can be used to provide a measure of all or some components of the strain magnitude?

16. Grain-scale processes of ductile deformation, dislocation creep: How do line defects (dislocations) in minerals differ from point defects? How do dislocations move under directed stress and how do they accomplish finite strain? In what way is slip on a fault analogous to dislocation slip within a single mineral grain? How can you recognize the operation of this process in hand samples and outcrops, and how can you use the microstructures to infer the operative stress directions?

Spring Break!

17. Foliations & lineations: What deformation processes produce planar and linear structures in ductilely deformed rocks? What stress and/or strain information do these structures provide? How do these structures affect subsequent deformation?

18. Geometry of folds & foliations: What conditions favor similar or parallel styles (geometry) of folding? How do different geometries relate to grain-scale deformation mechanisms and to associated foliations? How can you use limited outcrop information to infer the regional folding structure?

19. Review: Fault mechanics and ductile deformation: What is well understood and what are the current controversies concerning the mechanics of thrust, normal and strike slip faults? What are the grain-scale mechanisms that produce ductile deformation, what are the diagnostic microstructures from which we can infer their operation, and how can we determine the geometry and magnitude of strain they produce?

20. Hourly exam

21. Rheology: What are the flow laws or constitutive relation between stress and strain rate for the various grain-scale deformation mechanisms? How are flow laws determined experimentally? How do geoscientists use flow laws for interpretation of natural structures and for prediction of tectonic relations?

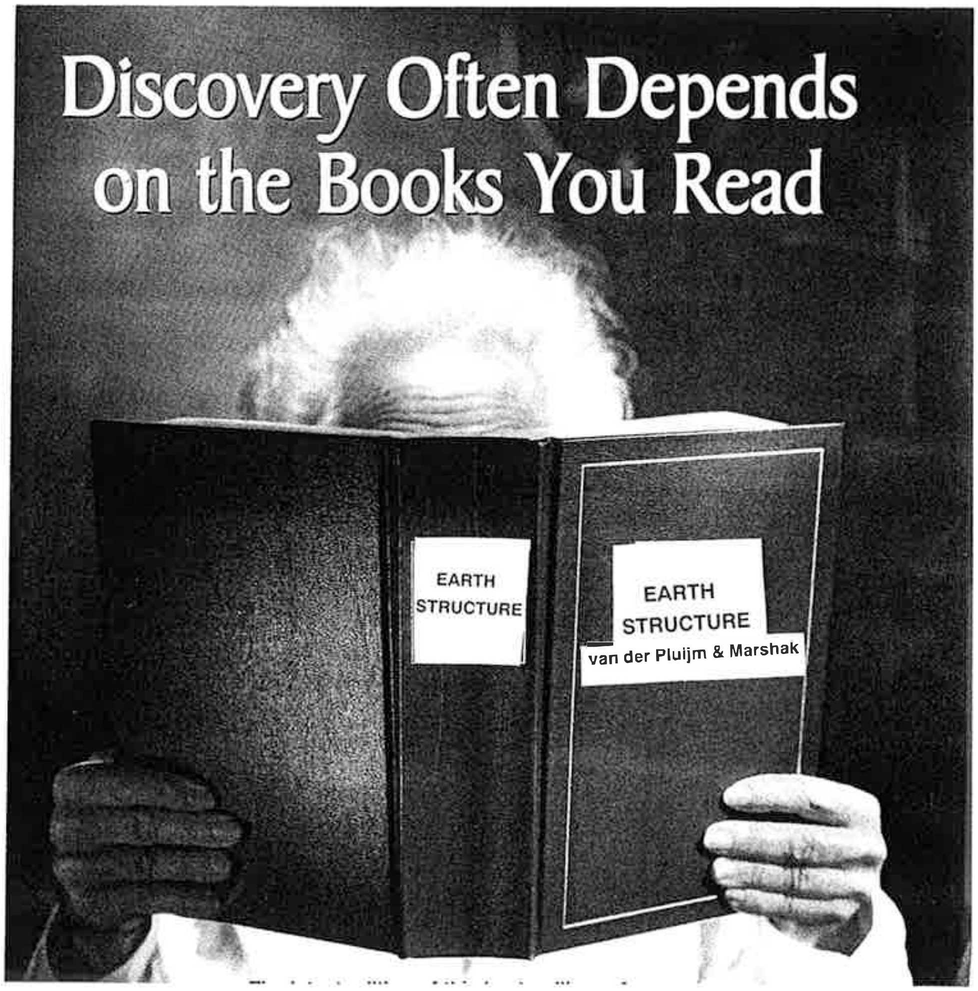
22. Mechanics and kinematics of folding: Why do folds tend to develop a dominant wavelength? What strain distribution is observed in different styles of folds and how do they match theoretical predictions based on different inferred flow laws? What do theoretical models predict about the relation between instantaneous stress and finite strain during folding, and how do these predictions match observed foliations and microstructures?

23. Diapirs and ductile shear zones: Under what circumstances do salt diapirs develop? How does the development of a dominant spacing between diapirs relate to the dominant wavelength of folds? What circumstances and processes lead to localized rather than homogeneously distributed ductile deformation? What are the implications for the strength distribution in the continental crust?

24. Tectonic history of Appalachians & field trip preparation: What evidence have we used to infer the tectonic history of the northern Appalachian Mountains, and how do our field trip sites relate to this history?

25. Tectonic history of western US: How and why is the style and history of deformation in the Rockies different from that in the Appalachians, and how does this history inform our interpretation of the cross section?

26. Review of crustal deformation: How has our understanding of brittle and of ductile deformation changed over the course of the semester?How are brittle and ductile deformation distributed and manifested in the crust? How are they related to igneous, metamorphic and sedimentary processes? How do earlier deformation events affect subsequent deformations?


Discovery Often Depends on the Books You Read
EARTH STRUCTURE
EARTH STRUCTURE
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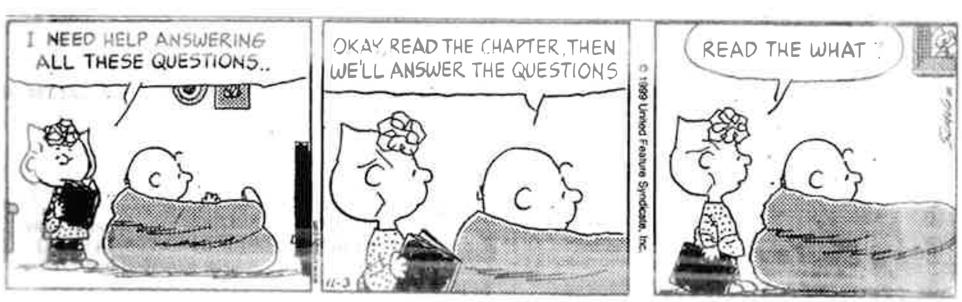
I NEED HELP ANSWERING ALL THESE QUESTIONS..
OKAY, READ THE CHAPTER, THEN WE'LL ANSWER THE QUESTIONS
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READ THE WHAT ?