GEOL 275-375 Rock Deformation:

Outline of Paper 2017.

Details of content may change depending on class progress.

Communication: will be through blackboard.

Breadth: It will be impossible to cover all areas of rock deformation in 13 weeks! Topics covered in this paper will include:

- The geometry, kinematics and dynamics of rock deformation.
- Stress and strain.
- Faults and shear zones.
- Strain paths and ductile fabrics.
- Folds.
- Rock rheology.
- Experimental rock deformation.
- Deformation mechanisms and microstructure.

Learning Outcomes: Students should leave this paper with a level of knowledge of rock deformation which include the specific skills listed below:

- Ability to characterise and quantify the geometry of common geological structures (faults, folds, shear zones, fabrics) on a range of scales from maps, through outcrop and hand samples to microscopic.
- Understand the basic physics of rock deformation including stress-strain relationships and how they may be measured.
- Ability to develop kinematic models from geometrical data. Understanding of what is needed to develop a dynamic model.
- Ability to design their own structural investigation of deformed rocks.
- Appreciation of observational science, including fieldwork, experimental approaches and modeling as tools to understand rock deformation.
- Quantitative techniques and problem solving.
- Scientific literacy

Objective of lectures. The lectures are designed primarily to interest students in the subject area, to outline what is important to know and understand and to help students' understanding of issues that they would otherwise find difficult. The lectures will not be the primary source of knowledge for students.

Objective of reading. The reading of book chapters, scientific papers and some other media provides the primary source of knowledge for students and support for understanding. The content of reading material will not be repeated in lectures although aspects of assigned reading that students find difficult to understand may be discussed. Exam questions will require students to include material from reading that has not been covered in lectures or practical classes.

Objective of laboratory practical classes. The laboratory practical classes are designed to reinforce understanding of issues covered in the lectures and in reading through the analysis of data and the construction of analytical, numerical and analogue models. Hopefully they will also be fun!

Field Trip. There will be a one day field trip to Brighton. This will be on Saturday 12th August or Sunday 13th August.

Assessment.

1. An A3 graphic poster to illustrate multi-scale geometry and kinematic interpretations of the Otago Schist outcrops at Brighton. Individual exercise. ***10%*** of paper.
2. An interactive powerpoint (or equivalent) showing the results of sandbox experiments to investigate fault and fold geometry and kinematics. Group exercise. ***10%*** of paper.
3. A lab-book with all the details of a series of ice creep experiments conducted by an individual group. Groups will also submit tables of data for each experiment they conduct. Group exercise. ***10%*** of paper.
4. An A2 poster to show a mechanical and microstructural analysis of the ice creep data from the whole class (all groups experiments). Individual exercise. ***20%*** of paper.
5. An examination. Students will choose to answer three questions from a selection of five in 2 hours. 375 students will be expected to show a broader range of knowledge and a deeper understanding. It is expected that exam answers will demonstrate knowledge and understanding gained from reading, lectures and laboratory classes. The exam is worth ***50%*** of the paper.

Groups.

These will be assigned, based on a skills audit.

Reading Material.

I will give specific advice on reading. You will need to balance breadth and detail.

Course text book. "Structural Geology" by Haakon Fossen.

Online resources for this book at: http://folk.uib.no/nglhe/StructuralGeoBook.html.

A very useful website: https://www.uwgb.edu/dutchs/structge/labman.htm

Assigned scientific papers: see list below

Elected scientific papers: Students need to choose some extra papers, in three particular topics, based on citations to or from assigned reading or based on other search mechanisms.

- 275 students will need to select five extra papers in each topic. At least one of these should relate to a New Zealand example, one to an experimental study and one to a numerical modeling study.

- 375 students will need to select ten extra papers in each topic. At least two of these should relate to a New Zealand example, two to an experimental study and two to a numerical modeling study.
- Topics for 2017: 1) Fault geometry and kinematics. 2) Foliation and lineation. 3) Microstructure and rheology. Students will be required to send lists of elected scientific papers by given deadlines.

Assigned scientific papers. I will give some guidance on what to try and get out of these:

Bell, T. H., and Rubenach, M. J., 1983, Sequential porphyroblast growth and crenulation cleavage development during progressive deformation: Tectonophysics, v. 92, no. 1-3, p. 171-194.

Bestmann, M., and Prior, D. J., 2003, Intragranular dynamic recrystallization in naturally deformed calcite marble: diffusion accommodated grain boundary sliding as a result of subgrain rotation recrystallization: Journal of Structural Geology, v. 25, no. 10, p. 1597-1613.

Burgmann, R., and Dresen, G., 2008, Rheology of the lower crust and upper mantle: Evidence from rock mechanics, geodesy, and field observations, Annual Review of Earth and Planetary Sciences, Volume 36, p. 531-567.

Cobbold, P. R., and Quinquis, H., 1980, Development of sheath folds in shear regimes: Journal of Structural Geology, v. 2, no. 1-2, p. 119-126.

Gibbs, A. D., 1983, Balanced cross-section construction from seismic sections in areas of extensional tectonics: Journal of Structural Geology, v. 5, no. 2, p. 153-160.

-, 1984, Structural evolution of extensional basin margins: Journal of the Geological Society, v. 141, no. JUL, p. 609-620.

Gillam, B. G., Little, T. A., Smith, E., and Toy, V. G., 2013, Extensional shear band development on the outer margin of the Alpine mylonite zone, Tatare Stream, Southern Alps, New Zealand: Journal Of Structural Geology, v. 54, p. 1-20.

Hickman, S. H., 1991, Stress in the lithosphere and the strength of active faults: Reviews of Geophysics, v. 29, p. 759-775.

Hirth, G., Teyssier, C., and Dunlap, W. J., 2001, An evaluation of quartzite flow laws based on comparisons between experimentally and naturally deformed rocks: International Journal of Earth Sciences, v. 90, no. 1, p. 77-87.

Hubbert, M. K., and Rubey, W. W., 1959, Role of fluid pressure in mechanics of overthrust faulting .1. mechanics of fluid-filled porous solids and its application to overthrust faulting: Geological Society of America Bulletin, v. 70, no. 2, p. 115-166.

Hudleston, P. J., and Treagus, S. H., 2010, Information from folds: A review: Journal of Structural Geology, v. 32, no. 12, p. 2042-2071.

Kohlstedt, D. L., Evans, B., and Mackwell, S. J., 1995, Strength of the lithosphere - constraints imposed by laboratory experiments: Journal Of Geophysical Research-Solid Earth, v. 100, no. B9, p. 17587-17602.

Law, R. D., 1990, Crystallographic fabrics: a selective review of their applications to research in structural geology, *in* Knipe, R. J., and Rutter, E. H., eds., Deformation Mechanisms, Rheology and Tectonics, Volume 54: London, Geological Society of London, p. 335-352.

Ramsay, J. G., 1980, Shear zone geometry - a review: Journal of Structural Geology, v. 2, no. 1-2, p. 83-99.

Sibson, R. H., 1977, Fault rocks and fault mechanisms: Journal of the Geological Society, v. 133, p. 191-213.

Sibson, R. H., 1989, Earthquake Faulting as a Structural Process: Journal of Structural Geology, v. 11, no. 1-2, p. 1-14.

Stipp, M., Stunitz, H., Heilbronner, R., and Schmid, S. M., 2002, The eastern Tonale fault zone: a 'natural laboratory' for crystal plastic deformation of quartz over a temperature range from 250 to 700 degrees C: Journal of Structural Geology, v. 24, no. 12, p. 1861-1884.

Toy, V. G., Prior, D. J., and Norris, R. J., 2008, Quartz fabrics in the Alpine Fault mylonites: Influence of pre-existing preferred orientations on fabric development during progressive uplift: Journal Of Structural Geology, v. 30, no. 5, p. 602-621.

Toy, V. G., Prior, D. J., Norris, R. J., Cooper, A. F., and Walrond, M., 2012, Relationships between kinematic indicators and strain during syn-deformational exhumation of an oblique slip, transpressive, plate boundary shear zone: The Alpine Fault, New Zealand: Earth and Planetary Science Letters, v. 333, p. 282-292.

Walsh, J. J., and Watterson, J., 1989, Displacement gradients on fault surfaces: Journal of Structural Geology, v. 11, no. 3, p. 307-316.

Wilson, C. J. L., Peternell, M., Piazolo, S., and Luzin, V., 2014, Microstructure and fabric development in ice: Lessons learned from in situ experiments and implications for understanding rock evolution: Journal Of Structural Geology, v. 61, p. 50-77.

					Total time in term (hours) 163 Time left for revision 17					Expected Time involved in: (Hours)			
										24	80	40	19
	Date	**Lec 08:00**	**Lec 12:00**	**Lab**	**Fossen: Structural Geology**	**Other Reading**	**Extra Reading: Abstract and pictures. 375: 10 papers. 275: 5 papers. At least one NZ, one experimental, one numerical modelling**	**Other things**	**Assement: Deadlines (Weds 4pm)**	Lectures	Practical	Reading	Hand ins and Assesment
Week 1	Thursday, 13 July 17	Introduction: Geometry, Kinematics, Dynamics. Expectations and Literature.	Stress: Mohr circle	Stress and Friction	CH4 Stress. CH5 Stress in the Lithosphere	Hickman, 1991. Hubbert & Rubey, 1959	https://www.uwgb.edu/dutchs/structge/labman.htm			2	3	4	
Week 2	Thursday, 20 July 17	Fracture vs friction. Pore pressure effective stress.	Griffith cracks. Stress trajectories. Andersonian Faulting.	Fault displacements and Separations	CH7 Fracture and Brittle Defm. CH8 Faults.	Walsh & Watterson, 1989; Sibson, 1989;	**1. Fault geometry and kinematics**	Skills audit info Due		2	3	4	1
Week 3	Thursday, 27 July 17	Equations from Mohr, Brittle-Ductile, Shear Zones	Conjugates, Shear zones continued	Displacements distributions on individual and neighbouring faults.	CH3 Strain in Rocks. CH2 Deformation.	Ramsay, 1980; Toy et al 2012		List of papers for 1 due		2	3	6	1
Week 4	Thursday, 3 August 17	Deformation, Strain tensor, Strain Ellipsoid and Ellipse	Longitudinal and shear strain. Practical strain measurement. Finite vs Infinitesimal. 3D- Flinn diagram	Shear Box. Strain Analysis	CH11 Folds and folding.	Cobbold & Quinquis, 1980; Hudleston & Treagus 2010				2	3	3	
Week 5	Thursday, 10 August 17	Brittle shear zones- tension gashes	Data on stereonets. Conical distributions	Analysis of regional orientation data sets: stereonet contouring and statistical descriptions.	CH12 Foliation and Cleavage. CH13 Lineations.	Bell & Rubenach, 1983	**2. Foliations and lineations**			2	3	3	
	Sat/Sun 12th/13th August			1 day Field Trip to Brighton							8		
Week 6	Thursday, 17 August 17	Fold vergence	Shear senses, deformation mechanisms	Fold Vergence	CH15 Shear Zones and Mylonites.	Sibson, 1977; Gillam et al 2013			**Field Poster**	2	3	3	
Week 7	Thursday, 24 August 17	Folds and Faults: thrusts and extension.	Critical Wedges	Sandbox Experiments	CH16 Contractional regimes. CH17. Extensional regimes. CH20 Balancing and restoration.	Gibbs 1983; Gibbs 1984		List of papers for 2 due		2	15	7	
	Thursday, 31 August 17	Mid Semester Break	Mid Semester Break	Mid Semester Break									
Week 8	Thursday, 7 September 17	Rheology	Ice	Ice Creep: setting up experiments	CH6 Rheology	Hirth et al., 2001			**Sandbox Interactive PPT**	2	10	2	4
Week 9	Thursday, 14 September 17	Defects, Dislocation Glide	Dislocation Climb and Recovery	Ice Creep: Sample extraction. Preliminary mechanical results	CH10 Deformation at the microscale	Stipp et al 2002; Wilson et al 2014	**3. Microstructure and rheology**			2	10	3	
Week 10	Thursday, 21 September 17	Recrystallisation	Recrystallisation	Ice Creep: Combining the results of experiments				List of papers for 3 due	**IceExperiments Lab-Books**	2	10		1
Week 11	Thursday, 28 September 17	Crystallographic Preferred Orientation	Grain size sensitive creep	Ice and quartz microstructures: more data reduction		Bestmann & Prior, 2003; Toy et al., 2008; Law et al 1990		Visits to SEM		2	3	3	2
Week 12	Thursday, 5 October 17	backup if needed	Strength of the Lithosphere	Ice Microstructures: more data reduction: Revisions		Burgmann & Dresen, 2008. Kohlstedt et al 1995;		Visits to SEM		1	3	2	
Week 13	Thursday, 12 October 17	backup if needed	The exam	Revision 01					**Ice Deformation Poster: Monday 9th**	1	3		10