COURSE OUTLINE

ERTH 3060 APPLIED STRUCTURAL ANALYSIS: UNDERGROUND AND SURFACE TECHNIQUES

1st Semester 2 units

Geometric, kinematic & microstructural analysis of complexly deformed rocks, regions, & shear zones. Field, mine, & digital map techniques applied to real geological problems.

Course Coordinator: Assoc.Prof. Rod Holcombe.
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Course Home page: http://www.earth.uq.edu.au/~rodh/courses/ERTH3060/

The full course profile (with Graduate Attributes, etc) can be found on the web at: http://www.earth.uq.edu.au/

The home page also contains up-to-date news about the course material, links to class notes and additional material, and announcements for students. Please check this regularly during the semester.

Class contact hours: 1L1C3P

Assumed Background

This course follows directly on the second level lectures/practicals in structural geology (ERTH2004) and field mapping course (ERTH2050). Students should be totally familiar with terms, concepts, and practice introduced at that level. Refer to the ERTH2004 course outline for details of this background (http://www.earth.uq.edu.au/~rodh/courses/ERTH2004/).

Course Goals:

The aim of ERTH3060 is to enable you to understand and deal with multiply or complexly deformed metamorphic rocks and shear zones. The course is based on teaching you to recognise and use metamorphic/structural fabrics to interpret the structure and structural history of any area of multiply deformed rocks. Although the course emphasises the interpretation of structures in metamorphic rocks, it is designed to develop general structural analytical and deductive skills.

By the end of the course, you should have:

- a basic understanding of the physical flow and deformation processes that produce the structures and fabrics in shear zones and complexly deformed metamorphic rocks;
- an introductory understanding of how to analyse strain and the kinematics of flow in such rocks;
- developed techniques for analysing the geometry of complex structures from the microscopic to the macroscopic scale;
- a good understanding of how to interpret the fabrics that occur in both low and high strain plane-strain shear zones;
- a good understanding of how to interpret microstructures and to determine the timing of deformation fabrics relative to metamorphic reactions and processes (i.e. one aspect of PTt paths);
- an introduction to rheology and microscopic deformation mechanisms and the inference of the physical conditions (P, T, strain rate, fluids) from microstructures;
- An elementary introduction to complex shear zones;

In each topic emphasis will be placed on:

- training you to recognize and extract useful observations from a sea of data. Structural data are generally derived in the field, where you are confronted with a much wider selection of possible data than can ever be introduced in a classroom;
- training you to see through geological noise. That is how to recognize, within a complex map or irregular data set, the stylised problems (and their solutions) introduced in 1st and 2nd year;

- training you take deductive reasoning, based on geometrical constraints, as far as possible before having to rely on genetic models (that is, knowing when to start arm-waving based on an understanding of theoretical processes).

The latter goals are based more on experience than on textbook theory, and it is for that reason that attendance at lectures and practicals is a requirement for passing the course.

Teaching Mode

ERTH3060 consists of 25 lecture/contact periods and 12 practical classes, and a 2 days of a 5-day field trip. About 16 of the lecture periods will comprise formal lectures; the remainder will be used as tutorial sessions associated with pracs and assignments. In general, the morning lecture before the afternoon prac class will be slightly less formal and will pertain to the practical session of that afternoon. The structural field trip (details below) will be a component of a 5 day field trip (held probably in association with other classes). Note that lectures are only intended to be a guide to your total learning in the course. You are expected to become completely familiar with the assigned text material and you will be examined on your understanding of the course, not on your ability to simply memorise lecture notes. Satisfactory completion of the practical material is a prerequisite for passing the course. Because a significant learning component in this course involves the transfer of years of subtle practical experience from the lecturer to the student, attendance at **all** lecture and practical classes is required unless a satisfactory explanation is tendered. A component of the marks, as set out below, will reflect attendance and satisfactory lab performance.

Practical sessions will be under the supervision of the lecturer and a tutor.

Practical classes will consist of microscopy, hand specimen evaluation, and geometrical exercises. You will require basic drawing instruments (as for second level: good ruler, compass, protractor, **sharp** pencils, drawing paper, some transparent tracing paper (thin bond will do), and drawing pins). You will also be required to have, and to use, a 10x hand lens when necessary.

Practical material that is not completed within the timetabled period must be completed in your own time. **The completed practical exercises of the previous practical class must be available for inspection or handing in for evaluation at the beginning of each practical session.**

Exercises from each week will be assigned a mark out of 5, with 5 reserved for excellent work; 3 for just-OK; 1 for entirely unsatisfactory; and zero for non-attendance. A zero can be subsequently upgraded if a reasonable and satisfactory explanation is tendered and the work completed satisfactorily by the following class.

Satisfactory completion of all lab exercises is a **requirement** for passing the course. "Satisfactory" means that work must be complete, and as neat and precise as possible.

ASSESSMENT:

(Note: this assessment schedule may change after consultation and class approval)

Theory (1 hour Departmental exam) -	35%
Practical:	
Satisfactory attendance and completion of lab exercises	10%
Field Trip performance and exercise	10%
Cape Clairault exercise and associated practical classes	25%
Practical examination (2 hour Departmental exam)	20%

(Note that students must obtain at least 50% of the Attendance/completion mark to pass the course)

Theory Examination

The theory examination will consist of a 1-hour closed-book essay on a single topic. This must be in a logical essay form, not a set of point notes. The available topics span each of the major theory themes of the course and can be chosen in advance from the list below:

a) the fabric and structures associated with high strain shear zones.
b) microstructural timing relationships in metamorphic rocks and the analysis of PTtD paths
c) the development of fabrics (foliations and lineations) in deformed metamorphic rocks.
d) the relationship between microstructure, deformation mechanisms and the physical conditions of deformation in metamorphic rocks.
e) deformation, flow, and strain in deforming rocks. Include in your discussion the concepts of pure shear, simple shear, general shear, transpression, transtension, and strain partitioning.

Effectively you are asked to choose one of the major theoretical components of the subject and show that you completely understand the topic. The purpose of the exam mode is to remove uncertainty from the exam process, but to replace it with an expectation of in-depth understanding of the chosen topic. The three sets of criteria used to evaluate each essay will be the **rigour and accuracy** of each statement that you make, the **scope and adequacy** of your discussion, and the **clarity, organisation, and grammar** of your presentation. You are restricted to one hour so you need to give considerable prior thought to the last two aspects.

Practical Examination

The practical examination will be a two-hour Departmental examination and will involve both a structural geometrical exercise and thin-section/specimen interpretation.

Assignment:

A major component of the assessment comes from a major structural synthesis project (Cape Clairault project). This project is designed to develop broader geological deductive skills in addition to structural geology. Although a final report is required, important elements of the assignment will be collected at regular intervals throughout the semester. These will be marked, and feedback given, so that your final report is based on correct deductions.

Assignment due dates:

Field trip exercise:	Thursday, May 13th.	
Cape Clairault assignment:	Question 1:	**Beginning** of prac, April 1
	Question 6:	April 19 **(to office)**
	Question 2 & 3:	**Beginning** of prac, May 6
	Question 10 & 12:	May 24 (**to office)**
	Final report: Monday, June 7th (**to office**).	

SYLLABUS

Week	Topic	Lecture/Exercise
Week 1 *Lec*	*Intro to Structural Analysis*	*Introduction to course. Introduction to multiple deformation structures and fabrics.*
Lec	*Recognition of fabrics*	*Single generation fabrics: Primary fabrics, slaty cleavage, fabrics in psammite.*
Prac 1	**Thin section recognition of fabrics**	**Identification of multiple generation fabrics: slaty cleavage vs crenulation fabrics. Analysis of real sequence (Ducktown, Tenn).**
Week 2 *Lec*	*Recognition of fabrics*	*Problem of schistosity-crenulation cleavage-schistosity sequence in thin-section. The geometric concept of "fabric generations" versus the tectonic concept of a "deformation event".*
Pre-lab Tut	*Overprinting criteria*	*Mesoscopic and microscopic overprinting criteria.*
Prac 2	**Hand specimen/outcrop recognition of fabrics**	**Recognition of deformation history in hand specimens. Hand specimen identification of various types of foliations and lineations. Recognition and discrimination of stretching vs intersection lineations. Assignment of fabric labels.**
Week 3 *Lec*	*Strain Analysis*	*Measuring strain. Strain analysis techniques.*
Lec	*Strain and fabrics*	*Review of strain, strain magnitude and strain type. Estimation of "intensity of deformation". Types of tectonites.*
Prac 3	**Strain Analysis**	**Estimation of type and intensity of strain from rocks**
Week 4 *Tut*	*Geometrical Analysis*	*Basic "rules" of structural analysis. Geometrical relationship between original layer orientations, fold orientations, axial plane orientations.*

Pre-lab	*Geometrical Analysis*	*Refolded fold geometries and interference patterns. Interpretation of outcrop and map patterns. Departures from theoretical refolding geometries.*
Prac 4	**Geometrical Analysis**	**Multiple deformation geometry. Mt Barker refold. Lineation exercise.**
Week 5 *Lec*	*Geometrical Analysis*	*Geometry of 3D fold interference. Stereographic projection fabric diagrams. Folded lineation trajectories.* *Synopsis of structural data in macroscopic analysis.*
Lec	*Shear fabric*	*Displacement across shear zones. Incremental, finite strain patterns, fabrics and structures. Strain history and kinematics of shear zones. High strain shear zones and fabrics. Mylonite.*
Prac 5	**Geometrical analysis**	**Delineation of cylindrical subareas. Gibbs Reward problem. Osicka Flat problem.**
Week 6 *Lec*	*Shear fabrics*	*Kinematic sense-of-shear criteria.*
Pre-lab	Shear fabrics	Recognition of shear fabrics
Prac 6	**Shear fabrics and sense of shear**	**Hand specimen and thin-section recognition of shear fabrics and mylonite.**
	Easter Break	
Week 7 *Lec/tut*	*Deformation/ metamorphism timing criteria.*	*Introduction to structural-metamorphic timing criteria. Timing criteria in PTt paths. Concepts of pre-, syn-, and post-kinematic growth. Metamorphic growth vs fabric generation plots. The geometry of a helicitic porphyroblast. Zwart, and Passchier criteria for porphyroblast timing. Correct identification of the external fabric (the problem of schistose 'crenulation' fabrics).*
	Deformation/ metamorphism timing criteria (cont).	*Possible origins of curved inclusion trails within porphyroblasts. Ambiguous and non-ambiguous porphyroblast/fabric relationships. Difference between syn-kinematic and syn-tectonic - the problem of fabric reactivation. Problems of deformation partitioning.*
Prac 7	**Structural/Met. history analysis**	**Thin-section analysis of timing relationships between structural fabrics and metamorphic growth.**
Week 8 *Lec*	*Introduction to fieldtrip:*	*Blueschist/greenschist/accretionary prism terranes of SE Qld*
Pre-lab *Lec*	***Field-trip***	
Prac	**Field-trip**	
Weekend	**Field trip**	**Field Trip to Mt Mee-Kilkivan area**
Week 9 *Tut*	*Rheology, microstructures, and deformation mechanisms*	*P, T. t, fluid controls on rheological behaviour of rocks. Stress-strain, strain-time curves. Concept of rock strength: brittle failure, plastic yield. Rheological models.*
	Microstructures and deformation mechanisms (cont.)	*Diffusional and dislocation glide processes. Dislocation climb. Dislocation interaction and the formation of subgrains.*
Prac	**Field trip analysis**	**Thin-section analysis of fabric and timing from field trip area**
Week 10 *Lec*	*Microstructures and deformation mechanisms (cont.)*	*Recovery-recrystallization processes. Strain hardening; strain softening, and dynamic recrystallization textures. Superplasticity processes. Deformation mechanism maps.*

	Theory wrap-up	*Relationship of kinematics, strain, and structure. Discrimination of types of flow. Transpressional (and transtensional) flow. Deformation partitioning.*
Prac	**Geometrical Analysis**	**Synthesis of structural data. Lerida exercise.**
Week 11 *Tut*	*Structural Synthesis*	*Introduction to the Cape Clairault area: Rock, unit identification*
Tut	*Structural Synthesis*	*Cape Clairault analysis and synthesis (cont): map analysis*
Prac	**Structural Synthesis**	**Cape Clairault area analysis and synthesis (cont). Porphyroblast timing**
Week 12 *Tut* *Tut* **Prac**	*Structural Synthesis* *Structural Synthesis* **Structural Synthesis**	*Cape Clairault analysis and synthesis (cont)* *Cape Clairault analysis and synthesis (cont)* **Cape Clairault area analysis and synthesis (cont).**
Week 13 Tut		*Revision & questions*
Tut **Prac**	**Prac exam**	Revision period

FIELD TRIP DETAILS

1. A) 2-DAY/WEEKEND FIELD TRIP

A 2-day field trip into the northern D’Aguilar ranges will be held (in conjunction with other classes). The structural component of the trip will primarily examine blueschist and greenschist facies metamorphic structures associated with an exhumed accretionary complex.

Aim & Products

To analyse structures and fabrics and produce field maps and sketches of selected areas in multiply deformed Devonian-Carboniferous accretionary terrane rocks of the North D’Aguilar Block. Details of the required tasks and their assessment will be handed out before the trip and after the trip details have been finalised.

Itinerary (tentative)

Thursday morning, April 29th: meet at 12 noon (or earlier if possible) and travel to Kilkivan via Mt Mee, Kilcoy, Jimna and Gallangowan. This field trip will link in with the field trips held in conjunction with ERTH3001 and ERTH3205.

Organisation

Organisational details will be made available after the start of the semester. Probably we will take a couple of UQ vehicles – depends on number of students. Students who wish to make their own travel arrangements may do so but must notify me well in advance so that we can plan the trip efficiently. Students travelling by private vehicle do so at their own risk. They should take all appropriate care that the vehicle is safe, that it is not overloaded, and that they drive safely.

OR

B) FIELD MAPPING PROJECT

(only for students unable to attend the weekend field trip)

Students unable to complete the structural component of the weekend field trip will be assigned a structural mapping project in the local Brisbane area to undertake on an individual basis in their own time. Students in this situation should see me as soon as possible. The area and required tasks will be assigned after consideration of individual travel capabilities and time constraints.

TEXT

Microtectonics, Passchier & Trouw, 1996, Springer-Verlag. This text (which does not cover the entire scope of the course) is the best modern text covering deformation mechanisms, microstructures, and shear zone kinematics and structures.
In addition the following references may be useful:

OTHER REFERENCES:

General introductory Structural Geology theory texts

Earth Structure - An Introduction to Structural Geology and Tectonics

Ben A. van der Pluijm & Stephen Marshak. 1997; McGraw-Hill
Although this book is now out of print it is still an excellent introductory text for ductile structures. The material from this text that is new and directly applicable to the ERTH3060 lectures are:

Chapter	Topic
Ch.5	Rheology and deformation mechanisms theory
Ch 9	Ductile deformation processes
Ch 11	Fabrics, foliation and lineations (not new – but very pertinent).
Ch 12	Ductile Shear zones.
Ch 13	D-P-T-t paths

Foundations of Structural Geology; Park;2nd ed. 1989; Blackie.
This text contains a very concise (and accurate) summary of the elements of structural geology.

Structural Geology of Rocks and Regions George Davis & Stephen Reynolds; 2nd ed. 1996; John Wiley and Sons. This is the alternative 2nd level text. Chapters that are pertinent to this course, and have not been covered previously, are:

- Ch.2 (70-79) Advanced strain theory..
- Ch.4 Deformation mechanisms and microstructures
- Ch.8 (382-492) Strain measurement.
- Ch.9 Shear zones

Principles of Structural Geology John Suppe; 1985; Prentice-Hall. This is one of the older second level texts. Ch 4 is a good alternative reference for deformation mechanisms and rheology.

Structural Geology, Robert J. Twiss, Eldridge M. Moores. 1992. New York : W.H. Freeman

References useful for deformation theory and reading rocks in outcrop

The Techniques of Modern Structural Geology; Ramsay and Huber; Academic Press.
Vol.1: Strain Analysis; 1983. (Chapters 1 to 3 will be used in the practical sessions on strain, and the material is examinable in the theory exam. Chapters 5 to 8 are excellent references for practical strain measurement). **Vol.2: Folds and Fractures**; 1987. (Chapters 21 to 26 are pertinent to this class). (Both these volumes are crammed with an overwhelming amount of material on detailed structural geology. They make excellent long-term references, and if read and understood then they would give a superior theoretical background in practical structural geology). There is a third volume in this series that concentrates on kinematics of flow and mathematical and computer modelling of deformation. However, it contains a seriously flawed chapter on shear zones and shear fabrics that makes it less useful as a teaching reference.

Folding and Fracturing of Rocks; Ramsay, McGraw-Hill, 1967. This is one of the cornerstone textbooks in modern structural geology. Although now more than 35 years old, it still retains a wealth of still-valid information. It introduces in precise detail the strain-based approach to understanding deformation that forms the basis of this course (and my approach to structural geology). It may appear at first sight to be dauntingly mathematical, but it is written in such a way that the mathematics merely forms a background to the discussion. However, these old texts must be read in the understanding that very little was known then about the structures and fabrics of non-coaxial deformation (shear zones).

Structural Geology: Fundamentals and Modern Developments; Ghosh, Pergamon; 1993. Is a more modern book modelled on the Ramsay,1967, approach.

Field Geology of High-Grade Gneiss Terrains; Passchier, Myers, and Kröner, Springer-Verlag, 1990. This is a useful book for dealing with gneissic and migmatitic terranes. It is overly brief and serves more to point out the pitfalls of reading rocks in such terranes rather than being a full manual.

Continental Transpressional and transtensional tectonics; Holdsworth, Stachan and Dewey, eds. 1998. The initial 5 papers in this monograph serve as a useful introduction to the problems of general deformation and flow (as opposed to the end members of pure shear and simple shear). It is a starting point for where one area of modern research is headed.

References useful for the geometrical analysis of metamorphic rocks

(There are not very many of these, hence the class notes will attempt to fill the gaps).

Stereographic Projection Techniques in Structural Geology; Leyshon & Lisle; Butterworth-Heinemann; 1996. A cookbook approach to the stereographic projection solution to simple geometrical relationships in rocks.

Structural Analysis of Metamorphic Tectonites; McGraw-Hill, 1963; this book was one of the first texts to describe in characteristically precise detail the techniques (and shorthand notation) now fundamental to modern geometrical analysis (as opposed to conventional stratigraphy-base mapping analysis). It is in two parts, and it is only the first part that continues to hold considerable value. It contains a precise description of the structural geometrical relationships in deformed rocks and the statistical stereographic projection approach to solving their geometry. Because it was written at a time when very little was known about shear zones, it must be treated with some caution.

Structural Geology of Folded Rocks, E.H.Timothy Whitten; Rand-McNally, 1966; is another old text that contains a wealth of good material (with some reservations). In this case it is an excellent and complete reference to the early structural geology literature, and contains a considerable expansion on some of the geometrical techniques described by Turner & Weiss (above).

N.B. Some of the techniques described in Chapter 16 of **Marshak & Mitra** (below) for dealing with polydeformed rocks are a little misleading as they are based on simplifying assumptions that are not stated in the text (and yet are fully explored in the earlier texts given above).

References useful for general practical structural geometry

Geol Soc London Handbook series: The mapping of geological structures: Ken McClay
This is a useful text to have in the field. It is a summary both of basic structural concepts and of field techniques.

Basic Methods of Structural Geology; Marshak and Mitra; Prentice-Hall; 1988
[This text must be used with caution and under guidance. Although major parts of it are excellent, it contains an enormous number of errors (that should have been trapped during editing) and over-simplifications].
The material in chapter 15 is pertinent to strain analysis and theory. The construction of block diagrams is described in chapter 13. Chapters 8, 10, 11, and 16 are pertinent to various other practical sessions.

Structural Analysis and Synthesis (2nd Edition), Stephen Rowland & Ernest Duebendorfer; 1994; Blackwell Scientific

Structural Geology: an introduction to geometrical techniques (3rd ed**.),** Ragan
Reasonable basic reference for standard geometrical techniques.

3-D Structural Geology: Richard Groshong Jr.
An excellent and concise text with emphasis on on cross-section and interpretation techniques in petroleum geology.

Applied Subsurface Geological Mapping, Tearpock and Bishke
This is a text of petroleum-style structural geology. It takes many of the relatively simple mapping techniques developed in first and second level courses to advanced levels.