COURSE OUTLINE

ERTH 2004 DEFORMATION AND STRUCTURAL GEOLOGY

1st Semester 2 units

Analysis of ductile and brittle deformation structures. Stress theory. Dynamics of folding and faulting. Fracture analysis. Geological map, mine, and subsurface interpretation.

Course Coordinator: Assoc.Prof. Rod Holcombe.
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Consultation hours: Mon 2-4; Tues 11-1; Wed 2-4
Lab Tutor: Megan Packer
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Course Home page: http://www.earth.uq.edu.au/~rodh/courses/erth2004/
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: 2L, 3P

Assumed Background

This course follows directly on the lectures in structural geology and the mapping practicals in ERTH1001. Students should be totally familiar with terms and concepts introduced at that level. **Pertinent terms and concepts that should form prior knowledge for the course are summarised at the end of this outline.** Re-read the explanatory notes that accompany the 1st Level mapping practicals before the first ERTH2004 practical session. Any of this assumed geological background is also examinable in this course. The course also assumes competency in basic Mathematics, particularly trigonometry.

Course Goals:

The aim of ERTH2004 is to introduce you to the array of structures that deform the Earth's crust, and to the basic tools required to produce maps of such structures and to solve their 3-D geometry. The course is based on teaching you to be able to deal with areas that have been deformed once, such as in simple fold and thrust belts. The emphasis will be on understanding the underlying theory of how simple structures form, and on how they are mapped and analysed by professional geologists.
On completing this course, students will:
Have a basic introduction to the spectrum of structures that exist in deformed rocks in a variety of geological environments;
Have a basic understanding of the concepts of stress, strain, and kinematics (movement paths) in understanding how some of these structures form;
Understand and be able to deal with geological structures associated with a single episode of deformation, no matter how intense.
Learn practical techniques for field mapping and data collection in such areas;
Learn an array of geometrical techniques required to analyse geological structures in maps and cross-sections from such areas.
The approach is slightly biased toward structures associated with thin-skinned tectonics and high-level deformation - the more complex metamorphic structures of thick-skinned tectonics and multiple deformation are dealt with in ERTH3060.

Teaching Mode

ERTH2004 consists of 24 lectures and 13 three-hour practicals, including a field trip held during one of the practical classes. In addition, you will be assigned two projects during the semester to be completed in your own time. One of these will be a laboratory-based exercise to be completed individually, and the other will be a field-based team exercise.

The lectures are intended to be a guide and a supplement to your reading and understanding of the assigned text material and provided class notes. Emphasis in examination will be on your understanding of the course, not on your ability to simply memorise lecture notes. Several lectures, toward the end of the semester, will include material based on personal professional experience and case histories. This material is not available from any other source, so attendance at lectures is strongly advised.

Practical classes will concentrate on developing tools to interpret geological maps, and to draw viable, accurate cross-sections. Lab classes will be under the supervision of the lecturer and a demonstrator. Practical material that is not completed within the timetabled period must be completed in your own time.

The completed practical exercises (maps, etc.) of the previous practical class must be available for inspection, or handing in for evaluation, at the beginning of each practical session. *Satisfactory* attendance and completion of all lab exercises is a **requirement** for passing the course (see Assessment). Exercises from the initial 3 practical classes will be assigned a simple OK/not-OK grade. The exercises from each subsequent 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 satisfactory explanation is tendered and the work completed satisfactorily by the following class.

ASSESSMENT:

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

Theory (2 hour central exam) - 50%

Practical:

Satisfactory attendance and completion of lab exercises		10%
Lab Project		15%
Field Project	(Initial 8%; Final 17%)	25%

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

Assignment due dates:

Field Project Initial: Monday, April 14th; Final: Monday, June 2nd.

Lab Project: Friday May 2nd

Assessment criteria

Theory examination

The theory examination will be assessed in terms of the extent to which the student demonstrates an ability to:

- Define the array of geological structures covered in the course and to recognise the field characteristics of each;
- Define, explain and interrelate the key concepts involved in the course;
- Recognise the appropriate theory required to solve an observed problem;
- Relate basic theory to the structures observed in real rocks.

Laboratory and project reports

Laboratory and project reports will be assessed in terms of the extent to which the student demonstrates an ability to:

- Draw on a theoretical understanding of the array of geological structures to interpret them in rocks and maps;
- Recognise the appropriate theory required to solve an observed problem;
- Present results of that analysis in a professional manner.

Precision and accuracy are extremely important professional attributes in structural geology. Imprecise cross-sections or maps can cause major cost overruns. Thus "satisfactory" as an assessment criteria means that work must be as neat and precise as possible. Most classes will consist of cross-section construction exercises for which you will require basic drawing instruments (good ruler, compass, protractor), **sharp** pencils, drawing paper, and a supply of transparent tracing paper (thin bond will do). Constructions done with unsharpened pencils, or with thick ink pens, or without using precision aids such as ruler, protractor, or compass will be marked as unsatisfactory.

Assessment policy

Unless previously discussed with the course coordinator, a penalty of 20% (of the maximum score) per day (or part thereof, and including holidays) applies for late submission of project assignments.
Extensions and the possibility of re-submission can be granted for medical reasons and on other exceptional circumstances, to be discussed with the course coordinator before the due date for submission.
No specific policy applies to the use of pocket calculators in examination.
Students should be familiar with the rules that relate to assessment in their degrees as well as general university policy such as found in the General Award Rules. These are all set out on the Program and Course Information page on the UQ website http://www.uq.edu.au/student/courses/.

Plagiarism

See the course profile for the complete policy on plagiarism and for definitions of what constitutes plagiarism.
When a student knowingly plagiarises someone's work, there is intent to gain an advantage and this may constitute misconduct.
In this course, student's assessed work must be entirely their own. This includes laboratory assignments and project reports, except where indicated for the field-based project.
Informal group work is permitted within the practical classes exercises. That is, students may query and assist one another but the final work presented must be formulated and written by themselves.
The laboratory-base project is to be carried out entirely independently. Student who require help with the project should consult with the course coordinator or the tutor, rather than one another.
The field-based project is in two parts: in the group part, the group are expected to work together to produce a group effort. In those parts indicated as 'individual', the work presented must be the student's own analysis of the problem.
Students are encouraged to study together and to discuss ideas, but this should not result in students handing in the same or similar assessment work. Do not allow another student to copy your work.
While students may discuss approaches to tackling a practical or assignment problem, care must be taken to submit individual and different answers to the problem. Submitting the same or largely similar answers to an assignment or tutorial problem may constitute misconduct.
If an act of plagiarism is proven, the results of the assessment may be annulled and other action may be taken as is considered appropriate in the circumstances of the case.

Program of work for the semester:

LECTURE AND PRACTICAL TOPICS

Class	Topic
1	Introduction to course syllabus. Revision of compass, map and orientation conventions.
2	Statistical analysis of fracture arrays. Frequency, length, & traverse histograms; sample bias correction; filtering; rose diagrams; stereographic projection plots; π- & β-diagrams; contouring.
Prac 1	**Equal angle stereographic projections for geometrical calculations. Drill hole calculations.**
3	Introduction to deformation and flow in rocks. Relationship between forces (stresses), body geometry and properties, flow, instantaneous and finite strain, and observed structures. Flow paths controlled by material properties and boundary constraints. Demonstration of pure shear and simple shear flow (coaxial and non-coaxial deformation strain histories) using shear box and computer models. Intro to transpression/transtension terms.
4	Elements of strain theory. Concept of directions of stretching and directions of contraction within a deformed rock. Definitions of longitudinal, shear, and dilational strains. Assign strain exercises.
Prac 2	**Markland criteria for failure analysis. Stereographic problems involving rotation.**
5	Principal axes, and planes, of strain. Strain ellipsoid. Homogeneous versus inhomogeneous strain. Foliations/lineations as finite strain trajectories.

6 **Prac 3**	Measures of deformation intensity. (Flinn/Ramsay plots). Types of strain - plane, flattening, constrictional. Incremental vs finite strain. L, S, and L-S tectonites fabrics. Answers to assigned strain questions. **Net-slip determination of faults. Piercing point constructions.**
7 8 **Prac 4**	Introduction to stress theory. Stress vectors across a plane. State of stress at a point. Principal stresses and planes. Mean and deviatoric stresses. Stress units and natural stress magnitudes. Assign stress exercises. Mohr circle representation of the state of stress at a point. The concept of stress trajectories to represent the stress field in an area. Introduction to fracture theory. Mohr failure envelope. Answers to assigned stress questions. Assign fracture exercises. **Cross-section techniques in areas of simple folding: Buskian and "kink" methods.**
9 10 **Prac 5**	Coulomb, Griffith failure theories. Orientation of fractures. Tensile versus shear fractures. Tensile strength. Cohesive shear strength. Effects of fluids. Hydraulic fracturing. Fluid over-pressuring. Sliding criteria versus fracture criteria. Introduction to faults and faulting. Thrust geometry. Thrust propagation and fault-bend folds. Imbrication. Duplexes. Dip spectral analysis. **Fault bend folds and balanced cross-sections.**
11 12 **Prac 6**	Extensional faults. Listric vs bookshelf sliding. Décollement and detachment faults. Inversion faults. Wrench faults and wrench regimes. Releasing bends and restraining bends. Transpression-transtension. Flower structures Strain associated with fault systems. Linked fault systems. Fault transfer zones. Conjugate shears, fractures, and kink bands. Kinematic and dynamic analysis. Anderson stress theory. Allmendinger kinematic analysis technique. **Cross-section techniques in areas of disharmonic or strong folding. Axial plane control in areas of horizontal folds. Projection techniques in areas of plunging folds.** Down structure viewing.
	INTRASEMESTER BREAK (Easter)
13 14 **Prac 7**	Brittle, ductile, and brittle-ductile shears/faults. Structures associated with faults. Riedel shears. Ductile shears and mylonites. Introduction to folds and folding. Fold style classifications. Stereographic projection signatures. Dip isogons and Ramsay classification of fold style. **Regional map interpretation – Hill End Sofala area.** Control of the shape and depth of folded rocks in cross-sections
15 16 **Prac 8**	ANZAC DAY Holiday Factors that affect the type of structures (and cross-sections) in real areas. Disharmonic folding as the norm in real folded sequences. Problems associated with disharmonic folding. Transposition as an end product of disharmonic folding. Map interpretation and cross-section restrictions in areas of disharmonic folding. **Wednesday Morning Field trip to Shorncliffe project area. Revision of Field Project map. (Leave UQ at 10 a.m. sharp. Back by 1:50pm)**
17 18 **Prac 9**	**Labour Day** Begin outline of deformation/folding sequence in a shortened crustal slice. Factors that control the size, shape, and orientation of folds. Folding mechanisms - buckling, flow models and associated structures. **Regional map interpretation: Bundalla area exercise**
19 20 **Prac 10**	Recognition of structures associated with different folding mechanisms. Accommodation structures. Limits of buckling and transfer of deformation to the grain scale. Consequences on fold shape, tightness, and layer thicknesses. Deformation sequence continued. Transfer of deformation to grain scale. Formation of grain-shape fabrics. Imposed fabric elements. Axial plane foliation and fold geometry. **Regional map interpretation: Bundalla area exercise (cont). Map analysis and interp – Broken River area**
21 22 **Prac 11**	Classification and interpretation of axial plane foliations and fabrics. Geometry and types of lineations - imposed (stretching) lineations. **Broken River area (cont)**
23 24	Geometry and types of lineations - composite (intersection) lineations. Use of fabrics and small scale structures in mapping and mesoscopic analysis.

Prac 12	**Eifel area cross-section using vergence relationships**
25	Stratigraphic younging criteria in sedimentary and igneous rocks
26	Recognition of structures in maps. Practical applications of theory. Structure contour maps, trend surface maps, trend 'contour' maps.
Prac 13	**Exam outline and practice. Questions answered**

ASSIGNMENT DETAILS

Lab Project: Extensional fault specimen analysis 15%

The project consists of two specimens and photographs of blocks of rock from the Mt Isa lead-zinc mine. Project due date (at the Earth Science Office) is shown on the first page of this profile. Late submittal will lose marks at the rate of 3 marks per day (ie. it will be assessed at 0% after five days).

This project is to help you think about and understand concepts of strain and the geometry of structures and the processes involved in brittle-ductile deformation. Via a series of questions (see lab manual) you are asked to closely describe and analyse these specimens. Apart from learning about extensional faults and folding, the purpose of the exercise is to teach you to how much detail you can get from detailed observation of an outcrop or specimen. You will have to consult the text or other references to answer some of the theoretical questions. Other questions introduce you to the process of research, in that you have to draw theoretical conclusions about rock behaviour from your own detailed observations. The project should help you read and understand the theory outlined in the assigned text by providing a real example. This project is for examination and the work must be entirely your own. If you have problems see me (RJH), or the tutor, rather than a fellow student.

Field Project: Field mapping and interpretation exercise 8% + 17%

The class will be assigned a small area in the Brisbane area (Shorncliffe peninsular) to map in detail, construct appropriate geological sections, and interpret. Submission of the project will be in two parts: an initial submission based on your own field work; then, closely following a class field trip to the area, a final version is to be re-submitted. Project due dates (at the Earth Science Office) are shown on the first page of this profile. Students may work in groups of two (only) to conduct the mapping but must complete the cross-sections and interpretation on their own. Please state your field partner on your project.

- Note that a component of your assessment will be on professionalism of presentation and scientific writing style.
- Late submittal will lose marks at the rate of 20% per day (ie. it will be assessed at 0% after five days).

The detailed criteria for assessment of the project are outlined in the project handout.

TEXTS AND REFERENCES

PRIMARY TEXT: Structural Geology of Rocks and Regions

George Davis & Stephen Reynolds; 2nd ed. 1996; John Wiley and Sons

Chapter		Topic
Ch.1	**all**	Overview of Structural Geology
Ch.2	**38-70;79-97**	Kinematics and strain theory
Ch.3	**all**	Stress theory; rheology.
Ch.4	**3rd level**	Deformation mechanisms and microstructures
Ch.5	**all**	Joints and fractures - theory and analysis
Ch 6	**all**	Faults
Ch 7	**all**	Folds
Ch 8	**424-482;**	Foliation and lineation
Ch 9	**3rd level**	Shear zones
Ch 10	**3rd level**	Tectonics

Ch 11	**all**	Practical aspects. This chapter is examinable in ERTH2004 but contains many aspects that are applicable to ERTH1001 and ERTH2050 as well as ERTH2004.

Alternative Text Earth Structure - An Introduction to Structural Geology and Tectonics. (This was the preferred text, but is now out of print)

Ben A. van der Pluijm & Stephen Marshak. 1997; McGraw-Hill

All material indicated below in this text is examinable in ERTH2004.

Chapter	Relevant Pages for ERTH2004	Topic
Ch.1	**all**	Overview of Structural Geology
Ch.2	**-**	Primary structures. Read, but not examinable in detail.
Ch.3	**all**	Stress theory
Ch.4	**52-61;65**	Strain theory
Ch.5	**78-81;92-96**	Rheology theory
Ch 6	**99; 112-120**	Brittle deformation processes
Ch 7	**123;126-127**	Joints and veins
Ch 8	**all**	Faults and Faulting
Ch 9	**3rd level**	Ductile deformation processes
Ch 10	**207-220;226-237**	Folds and folding
Ch 11	**all**	Fabrics, foliation and lineations
Ch 12	**277-281**	Ductile Shear zones. Remainder 3rd level
Ch 13	**3rd level**	D-P-T-t paths
Ch 15	**323-332**	Extensional tectonics
Ch 17	**all**	Fold-thrust belts
Ch 18	**392-399**	Strike-slip tectonics
Ch 19	**404-415**	Regional geology

Other References

Principles of Structural Geology, John Suppe; 1985; Prentice Hall.
This was a previous text and is still an excellent reference.
Structural Geology, Robert J. Twiss, Eldridge M. Moores. 1992. New York : W.H. Freeman.
Foundations of Structural Geology; Park;2nd ed. 1989; Blackie.
This text contains a very concise (and accurate) summary of the structural geology topics covered in this course.
The Techniques of Modern Structural Geology: (Vols. 1&2: Folds and Fractures); Ramsay and Huber; 1987; Academic Press. There is also a volume 3 – but it is not a particularly good reference. Both volumes in this series are extremely good. Each chapter is arranged as a group of of questions followed by a detailed analysis of the answers, although its treatment is much more detailed than covered in this course. Some of the illustration materials used in the lectures are from these volumes.
Geol Soc London Handbook series: The mapping of geological structures: Ken McClay
This is an excellent summary both of basic structural concepts and of field techniques.
Basic Methods of Structural Geology, Stephen Marshak & Gautam Mitra; 1988; Prentice Hall
This was previously the text for the laboratory work. It is an excellent reference book, particularly with some of the more advanced concepts, but many of its exercises are rife with errors and because of this is unusable as a class text.
Structural Analysis and Synthesis (2nd Edition), Stephen Rowland & Ernest Duebendorfer; 1994; Blackwell Scientific
This reference is excellent for the practical classes in the first half of the semester. The major problem with this text is its universal use of parochial American quadrant notation for directions (although you **are** required to become familiar with quadrant notation).

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 to advanced levels that are not covered in this or the third level course. Material from the sections on fault-related folding and balanced sections are used in the class lectures.

ASSUMED KNOWLEDGE BASE

ERTH2004 is built upon introductory lectures in Earth Sciences, particularly introductions to topics in physical geology, Earth deformation, Earth structures, and Plate Tectonics. At the University of Queensland these topics are covered in ERTH1001.
The following structural geology terms should be familiar, at an introductory level, to all students starting ERTH2004.

TERMS AND CONCEPTS USED IN ERTH1001 STRUCTURAL GEOLOGY

Theory

stress terms: tension, compression, shear stress
strain terms: extension, contraction, shear strain
rheology terms: elastic deformation, plastic deformation, fracture, flow
brittle behaviour, ductile behaviour; competent rocks, incompetent rocks
tectonics: uplift, orogeny, mountain building, crustal thickening
craton, orogen (mobile belt, fold belt)
crustal extension, crustal thinning
plates, slab, subduction, collision
folds: antiform, synform, anticline, syncline, monocline
limb, hinge, axis, axial plane
upright, plunging, overturned, recumbent
fault bend fold, drape fold
gentle, closed, tight, isoclinal
parallel/similar, symmetric/asymmetric,
concentric/rounded/angular/chevron, kink band
foliation, rock cleavage, lineation
buckling, bending, passive flattening/amplification, shear folding
faults: fault block, hangingwall, footwall
strike-slip fault, dip-slip fault, normal fault, reverse fault, domino fault, listric fault
horst, graben, ramp, décollement, detachment fault
thrust, nappe, imbrication, separation, slip , throw, heave
fault breccia, fault gouge, slickensides, slickenlines
fault scarp
joints and veins: systematic and non-systematic joints,
joint patterns in different rock types,
cooling/columnar joints, sheeting joints, unloading
fractures as aquifers, landscape controls, karst topography
geotechnical/engineering aspects of fractures, modes of failure
veins, en echelon (gash) veins

Practical

Be able to interpret basic topographic and geological maps, and to construct topographic profiles and geological cross-sections from them**.**
Understand what is meant by: beds, strata, layers, Members, Formations, Groups, contacts, disconformities, unconformities, structure contours and be able to recognize them on maps. Be able to recognise igneous flows, plugs, dykes, sills (laccoliths), and plutons.
Understand the terms: dip, strike, dip direction, plunge, plunge direction, azimuth, apparent dip, easting, northing, latitude, longitude, true north, magnetic north, grid north.
Basic techniques: Understand and interpret the map patterns of homoclinal planes across topography. Be able to determine strike and dip of such planes from the map pattern. Understand and be able to construct structure contours from such data. Be able to reconstruct the map pattern of such planes given the strike and dip. Be able to construct map contours from any point data values.
Be able to incorporate simply horizontal folds and simple faults in cross-sections. Understand the map pattern of plunging folds on horizontal surfaces.

ERTH 2004 SYLLABUS TOPICS

The following topics and terms are covered in ERTH2004. These are built upon the Assumed Knowledge from the ERTH1001 syllabus, and thus the latter is also examinable in ERTH2004

Topics and terms

Deformation theory

- Relationship between stress, flow, instantaneous strain, finite strain, and structures
- Flow theory
    - Coaxial and non-coaxial flow (strain accumulation)
    - Instantaneous (incremental) vs finite strain
    - Plane, transpressional and transtensional flow
- Strain theory
    - Longitudinal, shear and dilational strain definitions.
    - Strain ellipse/ellipsoid. Principal strains/stretches. Stretch calculations.
    - Measures of strain intensity and type (Plane, Flattening, and Constrictional strains)
    - Strain and shape fabrics. L-, S-, and LS-tectonites.
- Stress theory
    - Stress vectors across a plane (tractions)
    - State of stress at a point (principal planes and axes of stress)
    - Stress trajectories across a volume of rock
    - Mohr circle representation of stress
    - Interpretation of Mohr circle and Mohr envelope diagrams for fracture and for sliding

Brittle deformation, Fractures, Faults, and faulting

- Failure and fracture theory
    - Empirical failure theory (Mohr envelope)

Mathematical approximations of failure envelope and theories of failure (Coulomb, Griffith)
Sliding failure
Effects of fluids (hydraulic fracturing)

- Fault geometry
    - Types of faults (normal, reverse, strike-slip, transpressional, transtensional)
    - Linked faults and structures. Tear faults, transfer faults, detachments/décollements, accommodation faults, relay zones.
    - Types of structures associated with fault zones (Riedel shears, P & X shears, slickensides/slickenlines/slickenfibres, gash veins, folds, fabrics, mylonites, pseudotachylite.
    - Geometry and structures associated with thrust faults, normal faults, strike-slip faults. Duplexes. Fault-bend folds. Crustal scale detachment faults/core complexes.
- Fault kinematics and dynamics
    - Anderson models of faults relative to principal stress orientations
    - Kinematic analysis of instantaneous strain axes (e.g. Allmendinger method) for linked fault systems

Folds, folding, and ductile deformation

- Fold geometry and style. Precise description terms.
- Folding mechanisms and associated structures
    - Buckling theory and implications (wavelength-thickness/competence relationship; minor congruent folds; partial and complete transposition)
    - Limits of buckling. Implications of the passive flattening phase of folding/deformation
- Fabric geometry and theory
    - Foliations
        - Geometry and description
        - Formation modes
    - Lineations (Intersection vs Stretching)
        - Formation modes

Maps, mapping, and cross-section interpretation

- Stereographic projections
    - Geometrical calculations
    - Statistical Analysis
        - Joint/fracture analysis; rose diagrams; bias correction; Markland failure criteria.
        - Statistical fold analysis
    - Fault slip/separation determination

    - Piercing point constructions for net slip. Throw/heave components of dip separation
- Cross-section techniques for areas characterised by kink-folds, concentric folds, and plunging folds. Faults and fault-bend folds in cross-section.
- Techniques for dealing with the effects of disharmonic folds, transposition, etc
- Use of vergence and bedding/cleavage relationships
- Interpretation of igneous body shapes in cross-section
- Recognition and handling of unconformities and faults, both planar and folded
- Field mapping and analysis techniques.
- Younging criteria.

Types of structural areas, case histories