THE UNIVERSITY OF SYDNEY

School of Geosciences

GEOS3101-3801 EARTH STRUCTURE & EVOLUTION

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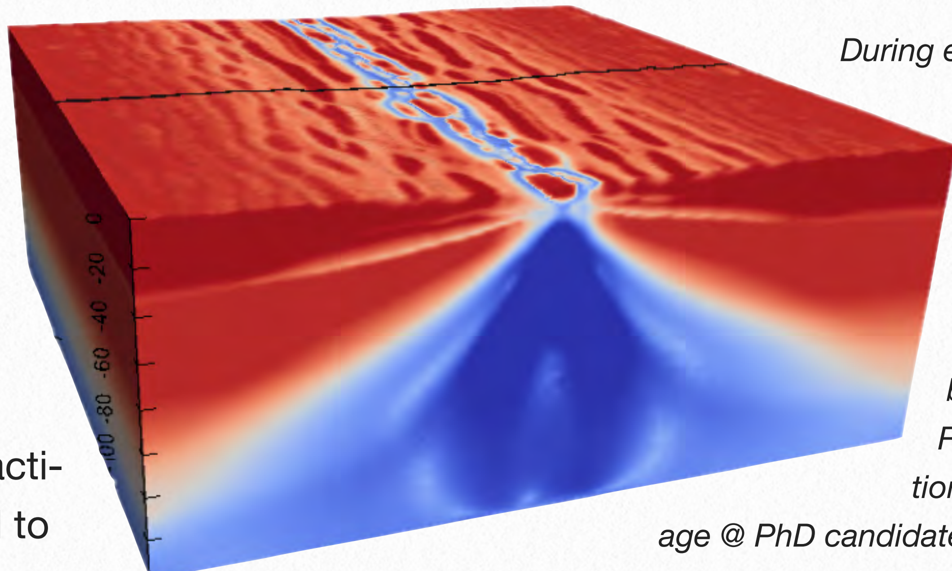
Course synopsis

GEOS3101: The Earth's continental crust is the product of tectonic, metamorphic and magmatic processes operating since Earth's formation. This unit focuses on the body of knowledge and techniques that enable an understanding of these processes. GEOS3101-3801 is divided into metamorphic petrology and processes (weeks 1–5), and tectonic processes (weeks 6–13), with a component of fieldwork (13th to 16th April) and a group 4-minute video presentation (week 12). No lecture or practical in week 9, to make up for time spend in the field. The main topics presented in this unit include: analysis of igneous and metamorphic rocks and minerals under the microscope; textural analyses; subduction and extreme metamorphism, mechanisms of heat and mass transfer, the mechanical behavior (i.e. rheology) of Earth materials, and causes and consequences of lithospheric deformation. Practical classes are designed to enable students to be competently and independently identify the common crystalline rocks in hand-specimen; to gather and interpret the structural field data which enables the determination of the structural style and deformational history presented in particular tectonic settings, and to understand and interpret petrological and structural data in terms of thermal and mechanical processes. The concepts and content presented in this unit are essential knowledge for geologists and geophysicists and provide a conceptual framework for their professional practice. Students wishing to specialize in the field and become professional geologists will normally need to expand upon the knowledge gained from this unit and either complete an honours project or progress to post-graduate coursework in this field.

The use of a laptop/tablet (with the MATSCOPE, app for microscope work) is strongly encouraged. Students are invited to use, during the practicals, their knowledge of Matlab or Mathematica, or their open source equivalents: Octave, SciLab, Python or R.



During extensional tectonics, the Earth lithosphere breaks and the asthenosphere rises, advecting heat to shallow levels. Decompression melting of the hot asthenospheric mantle beneath Mid-Oceanic-Ridges explains the formation of the oceanic crust. (image @ PhD candidate L. Mondy).

GEOS3801: It has the same objectives and is suitable for students who wish to pursue aspects of the subject in greater depth. Entry is restricted and selection is made from the applicants on the basis of their performance at the time of enrollment. Students who elect to take this unit are required to pursue independent work to meet unit objectives.

Learning outcomes & graduate qualities

Learning outcomes: Provided that students attend all classes and complete all required work, it is expected that students will be able to:

• 1/ identify common rock forming minerals (magmatic and metamorphic) in hand specimen and thin sections; interpret common mineral textures, finite strain fabrics, kinematic indicators, and the relative timing of mineral growth and fabric development;

•2/ understand the tectonic, metamorphic and geochemical processes involved in key geodynamic settings, their products and be aware of assumptions underlying their interpretation;

•3/ explain why the temperature at a particular location in the continental crust may change through time; know the various terms defining the steady-state geotherm; explain the impact of temperature on the density and the strength of rocks;

•4/ analyse surface geology to identify the various tectonic regimes and how they may affect the temperature and pressure evolution of the continental crust;

•5/ apply the principle of isostasy to calculate the gravitiational force acting between two regions; understand and calculate the tectonic forces acting on the Earth's lithosphere;

•6/ reflect on why earthquakes tend to be over represented in the upper crust, and demonstrate how this observation relates to the rheology of rocks.

•7/ when presented with a geological problem, observe and interpret the key geological data and relationships and provide a valid explanation or interpretation;

•8/ use computers effectively to process, visualize and analyze data, and perform simple numerical calculation;

•9/ work collaboratively in a multicultural team environment;

•10/ write concise technical reports; present engaging scientifc oral presentations; design and deliver effective multimedia podcasts.

Magmatic foliation is a granite. The long potash feldspar is about 6 cm long. (image @ P. Rey, Finland).

Learning outcomes & graduate qualities

Graduate Qualities – what are they and why are they important?

The six Graduate Qualities promote deep knowledge of students' chosen field or disciplines of study and well-developed skills for critical thinking, problem solving, communication and teamwork. They also promote student capabilities for continuous learning, for updating their knowledge and skills in information literacy, and for the flexibility and breadth of perspective to interact productively and creatively across cultural, disciplinary and professional boundaries. For further details refer to this Science faculty website.

A Depth of disciplinary expertise: To excel at applying and continuing to develop disciplinary expertise.

Deep disciplinary expertise is the ability to integrate and rigorously apply the knowledge, understanding and skills of a recognised discipline defined by scholarly activity, as well as familiarity with evolving practice of the discipline.

B Broader skills: To increase the impact of expertise, and to learn and respond effectively and creatively to novel problems

Critical thinking and problem solving: Critical thinking and problem solving are the questioning of ideas, evidence and assumptions in order to propose and evaluate hypotheses or alternative arguments before formulating a conclusion or a solution to an identified problem.

Communication (oral and written): Effective communication, in both oral and written form, is the clear exchange of meaning in a manner that is appropriate to audience and context.

Information and digital literacy: Information and digital literacy is the ability to locate, interpret, evaluate, manage, adapt, integrate, create and convey information using appropriate resources, tools and strategies.

Inventiveness: Inventiveness is generating novel ideas and solutions.

C Cultural competence: To work productively, collaboratively and openly in diverse groups and across cultural boundaries

Cultural competence is the ability to engage ethically, respectfully and successfully in intercultural settings.

D Interdisciplinary effectiveness: To work effectively in interdisciplinary (including inter-professional) settings and to build broader perspective, innovative vision, and more contextualised and systemic forms of understanding

Interdisciplinary effectiveness is the integration and synthesis of multiple viewpoints and practices, working effectively across disciplinary boundaries.

E An integrated professional, ethical and personal identity: To build integrity, confidence and personal resilience, and the capacities to manage challenges and uncertainty

An integrated professional, ethical and personal identity is understanding the interaction between one's personal and professional selves in an ethical context.

F Influence: To be effective in exercising professional and social responsibility and making a positive contribution to society

Influence is engaging others in a process, idea or vision.

Assessment & Special consideration

Assessment: The assessment for this course is based on ***formative*** *and* ***summative*** *assessements*. Late assignments are penalized 10% per day (weekends and holidays included).

To satisfactorily complete the course, *all formative and summative assessments, including fieldwork, have to be completed to a minimum grade of Pass to avoid an Absent Fail*.

** Faculty policy: In cases where a student fails to submit a compulsory task and/o fail to get a Pass, the final marks awarded should be the maximum that the student is entitled to,* ***up to 49****. This attracts an "Absent Fail" grade.*

	Assessment types*	Indiv. / Group	Due date	Return date (in days)	%	Learning outcomes
Week 1a	Skills based evaluation	Individual	end of session	7	4%	1, 7, 10
Week 1b	Assignment	Individual	Week 2	7	1%	1, 2, 10
Week 2	Assignment	Individual	Week 3	7	1%	1, 2, 10
Week 3	Skills based evaluation	Individual	end of session	7	4%	1, 2, 7, 10
Week 4	Assignment	Individual	Week 5	7	1%	1, 2, 10
Week 5	Skills based evaluation	Individual	end of session	7	4%	1, 2, 7, 10
Excursion	Demonstrations	Group (2 st.)	end of session	14	15%	1, 2, 7, 9,10
Week 7	Assignment	Individual	Week 10	7	1.5%	3, 4, 8
Week 8	Assignment	Individual	Week 9	7	1.5%	5, 8
Week 9	*No assignement*					
Week 10	Assignment	Individual	Week 11	7	1.5%	6, 8
Week 11	Assignment	Individual	Week 12	7	1.5%	6, 8
Week 12	Demonstrations	Group (3 st.)	Week 12	NA	7.5%	8, 9, 10
Week 13	Small test	Individual	end of session	7	14%	3, 4, 5, 6, 10

**All reports are compulsory and due either at the end of the practical session or at the START (first 10 mn) of the practical class of the following week.*

Compulsory Attendance & Pre-lecture work: Attendance to lectures and practicals is compulsory unless there is a clash with other USyd UoS, or unless special consideration has been granted. Students must come to the lecture prepared by reading the lecture notes and completing pre-lecture activities.

Assessment & Special consideration

Special Consideration - Students who have a serious illness, or have experienced misadventure which may affect their academic performance in this Unit of Study, may request that they be given *Special Consideration*. Brief illness and minor misadventure will not warrant *Special Consideration*.

Application for *Special Consideration* must be submitted within three working days of the due date of the assessment or examination for which consideration is being sought.
Special Consideration request are lodged to and processed by the Student Administration Services (SAS) with little to no input from Lecturers and Tutors. To lodge a SP request follow this weblink: Student Administration Services:

Please note that *simple extensions will not be granted* in this course.

Kyanite-bearing schist from the Entia gneiss dome (Harts Range, central Australia). @ P. F Rey

Marking criteria

Marking and Distribution of Grades: Marks for the assessment tasks and grades awarded for the unit will conform to the University's assessment policies and procedures. A recent change to this policy requires that marks be awarded relative to a set of standards that describe a graduated hierarchy of the levels of achievement. The marks assigned to the various grades pass, credit, distinction, high distinction remain as they were prior to the change in the policy. The grades are described below along with the criteria that will be used to identify the various levels of achievement. Note the acknowledgement of the several sources (e.g. SLS 2014) from which these grade descriptors were modified; given below, see section on plagiarism).

In reference to these grades students should note that:

a) all marked assessment tasks, with the possible exception of practicals, will normally contain at least one item that will enable the full range of achievement levels (PS to HD) to be demonstrated, although students should note that some, and perhaps the majority of the individual items, activities or questions presented in each of the assessment tasks will be intended to establish that students have achieved a PS or CR level of achievement.

b) DI and HD would normally only be awarded to students who have performed at a high level in all assessment tasks – in this context 'performed at a high level in all assessment tasks' means that distinction students will have achieved a credit minimum in all individual items of assessed work and will have achieved a distinction level of achievement (or better) for the majority (>75%) of the assessment tasks. High distinction students will have achieved a distinction minimum in all individual items of assessed work and will have achieved a high distinction level of achievement for the majority (>75%) of the assessment tasks

Fail (Below 50%)

Work may fail for any or all of the following criteria

- No answer or response is provided
- Does not address or otherwise answer the question
- Contains numerous minor errors or presents a significant misconception
- Presents irrelevant material
- No evidence of research or analysis
- Presents a significantly inaccurate or flawed argument
- The answer is incomprehensible or difficult to understand due to significant problems with grammar, expression or structure

Pass (Between 50% and 64%)

Work awarded a passing grade will usually achieve the following minimum standards or present the described characteristics

- An appropriate but superficial answer or response is provided
- Presents relevant material in a superficial manner or in a simplistic descriptive style
- Correctly identifies key point or points (facts) but does not develop an appropriate explanation or argument if this is required
- Contains some minor errors or presents minor inaccuracies and misconceptions
- Little or no evidence of in-depth analysis or deep understanding of the concept

- Answers can be understood but may be poorly worded or somewhat flawed due to poor grammar, expression or structure

Credit (Between 65% and 74%)

Work awarded a credit grade will usually achieve the following minimum standards or present the described characteristics

- An appropriate, accurate and reasonable detailed answer or response is provided
- Appropriate key point or points (facts) and/or concepts clearly presented without significant errors or misconceptions
- Presents relevant material concisely with facts clearly integrated into the explanation
- Accurate quotation and/or source identification when appropriate.
- Evidence of some independent research or critical analysis of concept or problem
- Answers are easily understood with both clear expression and structure if appropriate

Distinction (Between 75% and 84%)

Work awarded a distinction grade will usually achieve the following minimum standards or present the described characteristics

- Accurately answers the question in a convincing, confident manner
- Presents relevant material accurately in a concise manner or with the facts well-integrated into a comprehensive explanation or argument
- Accurate quotation and/or source identification when appropriate.
- Evidence of extensive independent research
- Evidence of extensive critical analysis of concept, and/or innovative perspective on the topic, and/or deep understanding of problem
- Answers are well written, with clear structure and cogent expression

High Distinction (Above 85%)

- Work awarded a distinction grade will usually achieve the following minimum standards or present the described characteristics

In the deep crust, metamorphic processes of and deformation processes feed into each others. Deformation affects the orientation of pre-exisiting minerals and controls the orientation of new metamophic minerals to form finite strain fabrics such as foliations and lineations. In turns, metamorphism change the mineralogy of rocks and therefore their physical properties including their strength which affects how they deform (image @ D.L. Whitney).

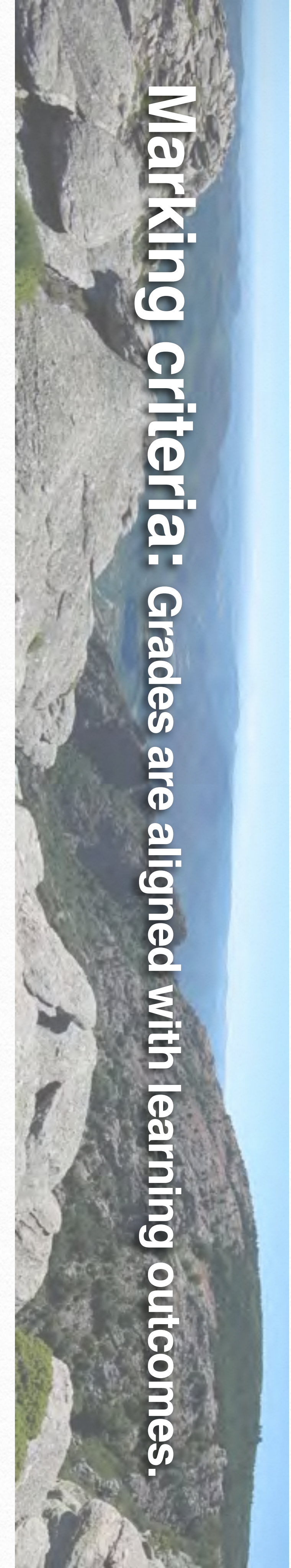
- Accurately answers the question in an impressive, compelling, or highly persuasive manner
- Presents relevant material accurately in a thoroughly convincing or forceful manner or with the facts well-integrated into an extended and comprehensive explanation or argument
- Accurate quotation and/or source identification when appropriate.
- Evidence of exhaustive independent research
- Evidence of extensive critical analysis of concept, and/or innovative perspective on the topic, and/or deep understanding of problem
- Answers demonstrate striking originality, an innovative approach, or impressive analytical skill
- Answers are exceptionally well written, with excellent structure expression
- Is otherwise exceptional in some way

The completion of all of the assignments contributes to the *Graduate Attributes* set by the University of Sydney:

Graduates of the Faculty of Science will be able to create new knowledge and understanding through the process of research and inquiry, use information effectively in a range of contexts, work independently and sustainably, in a way that is informed by openness, curiosity and a desire to meet new challenges, hold personal values and beliefs consistent with their role as responsible members of local, national, international and professional communities, recognise and value communication as a tool for negotiating and creating new understanding, interacting with others, and furthering their own learning. The assessment tasks of this unit are intended to collectively enhance the above graduate attributes.

Thin sections of metapelitic rocks under the microscope showing kyanite (on the left), andalusite (center), and garnet-staurolite and chloritoid (on the right).

Recumbent fold from King Oscar Fjord (Norway), from the Caledonides orogeny (490-380 Ma).



Marking criteria: Grades are aligned with learning outcomes.

Criteria	***Pass***	***Credit***	***Distinction***	***High Distinction***
Rock and mineral identification	Be able correctly identify and describe common minerals and mineral associations forming common igneous and metamorphic rocks1.	As for pass, and be able predict and account for whole rock compositional depencies on mineral assemblage.	As for credit, and correctly interpret nuanced relationships (timing and growth, igneous petrogenesis, metamorphic grade variations).	As for distinction, and show a flair in the interpretation of nuanced relationships (timing and growth, igneous petrogenesis, metamorphic grade variations).
Petrographic analysis	Correctly interpret textural and whole rock geochemical relationships in common igneous and metamorphic rocks1, basic petrogenetic dependencies and the effects of metamorphic facies variation on mineral assemblage.	As for pass, and be able to interpret the timing of mineral growth stages including prograde, peak and retrograde metamorphic stages.	As for credit and include accurate detail. An advanced level of achievement will be indicated from careful accurate work indicating a high level of understanding of complex relationships.	As for distinction. An exceptional level of achievement will be indicated from detailed and accurate work, and demonstrate an exceptional level of understanding of complex relationships. Evidence of independent reading and initiative will be shown.
Mineral and rock geochemistry	Demonstrate the ability to account for major geochemical distinctions between Earth's core, mantle and crust, and the major processes leading to elemental variation in common crustal rocks.	As for pass, and be able to demonstrate a critical understanding of geochemical methods bearing on models for upper mantle and crustal geodynamic processes.	As for credit, with accurate detail, and the structure will be well constrained with an appropriate amount of data. An advanced level of achievement will be indicated.	As for distinction. An exceptional level of achievement will be indicated from accurate work and the resolution of complex relationships.
Tectonic context	Demonstrate the capacity to identify and interpret rock associations reflective of common tectonic environments.	Correctly discriminate rock associations reflective of common tectonic environments.	As for credit, with accurate detail, lithological variation will be well constrained with an appropriate amount of data. An advanced level of achievement will be indicated from accurate work.	As for distinction. An exceptional level of achievement will be indicated from accurate work and the resolution of complex relationships. Evidence of independent reading and initiative will be shown.
Logic in incomplete datasets	Demonstrate the capacity to resolve a best case argument pertaining to common igneous, metamorphic and tectonic issues and present a coherent argument bearing on a case study.	Correctly resolve a best case argument pertaining to common igneous, metamorphic and tectonic issues and present a coherent argument bearing on a case study.	As for credit, with accurate detail, a considered and well presented argument at an advanced level of achievement.	As for distinction. An exceptional level of achievement will be indicated from accurate work and the resolution of complex relationships. Evidence of independent reading and initiative will be shown.
Heat transfer	Demonstrate an understanding of Earth's thermal structure and the possible range of temperature at the Moho. Be able to: calculate the steady state continental geotherm and the temperature and heat flow at any depth, and follow a mathematical recipe to solve temperature problems.	As for Pass, and be able to explain: the significance of various parameters related to the definition of the steady state geotherm; the difference between steady state and transient geotherms; and use a given mathematical recipe to solve a heat problem.	As for Credit, and be able to explain: how the geotherm evolves following a tectonic event and predict PTt paths followed by various part of the continental crust; and independently figure out the mathematical solution to solve a heat transfer problem.	As for Distinction, and be able to write critical, well-articulated and illustrated reports, calling upon knowledge from other sources (other Unit of Study, research publications, books ...).
Dynamics	Demonstrate an understanding of Earth's density structure and to know the maximum magnitude of tectonic forces on Earth. Be able to: draw the various tectonic forces and gravitational volume force on a realistic sketch; and follow a mathematical recipe to solve dynamic problems.	As for Pass, and be able to explain: the origin of the various tectonics forces AND the origin of gravitational volume forces, AND to be able to explain how these forces can oppose or enhance each other; in which circumstances extensional tectonics can be coeval with contractional tectonics; and use a given mathematical recipe aimed at solving a dynamic problem.	As for credit, and be able to: calculate the various forces AND to be able to predict whether or not these forces can drive deformation; mathematically derive the value of the gravitational forces from application of the principle of isostasy; explain how the geotherm may impact on tectonic and gravitational forces; and independently figure out the mathematical solution to solve a dynamic problem.	As above.
Rheology	Demonstrate an understanding of Earth's viscosity structure. Be able to : list the various rheological behaviours, AND to be able to use simple analogue models to illustrate them; and follow a mathematical recipe to solve mechanical problems	As for Pass, and be able to explain: the various rheological behaviours using concept of strain, strain rate and stress, AND to be able to explain the sensitivity of the various rheological behaviours to pressure, temperature, fluids, etc; and explain and to use a given mathematical recipe aiming at solving a mechanical problem.	As for Credit, and be able to: construct the rheological profile for continental and oceanic lithospheres AND be able to evaluate their respective integrated strength; explain the concept of brittle-ductile transition, AND to be able to explain how this transition changes with temperature and strain rate; and independently establish a mathematical solution to a rheological problem.	As abov

Course schedule

GEOS - 3101/3801 - LECTURE OUTLINE		
WEEK	**LECTURES - Two 1-hour lecture per week** **Mondays: 10.00 am to 12.00 pm** **Carslaw room 408**	**LABS - One 2-hour session per week** **Mondays - 1 to 3 pm** **Madsen Lab 332 or 336**
Module 1: Mineralogical & Petrological Evolution - Tim Chapman		
Week 1	**Introduction; asymmetry in petrology**	**Mineral textures in crystalline rocks**
Week 2	**Petrofabrics: Metamorphis & deformation**	**Metapelitic rocks**
Week 3	**Elemental clues to Earth history**	**Integrating field relationships**
Week 4	**Equilibria reactions and equilibria**	**Subduction metamorphism**
Week 5	**Extreme metamorphism and melt dynamics**	**Fractionation effects**
Week 6	**South Coast Excursion: Friday 13th April to Monday 16th April**	
Module 2: Tectonic and Tectonophysics - Patrice Rey & Vasilis Chatzaras		
Week 7	**The Earth's Geotherm**	**Heat generation and transfer**
Week 8	**Isostasy and gravitational forces**	**Isostasy and gravitational forces**
Week 9	***Week off in lieu of field excursion***	
Week 10	**Tectonic forces**	**Tectonic forces**
Week 11	**Notions of rheology**	**Notions of rheology**
Week 12	**Video Presentation**	
Week 13	**Practical Exam (summative assessment)**	

Submitting reports - When submitting your reports via email : 1/ Use your USyd email address. 2/ In the email *subject* please refer to the UoS and the practical ID (e.g. GEOS-3101 Report Week 8). 3/ Send your reports as PDF (Portable Document Format). PDF was invented to facilitate the sharing of documents across platforms via the Internet. 4/ Reduce the size of your PDF document before sending it. 5/ Instead of naming your report “practical_report” choose this format “UniKey_UoS_Lab_nb” e.g “prey_geos3101_Lab3”. 6/ When using the assignment box, write the date of submission, otherwise penalty will be counted from the due date up to the date when your report was collected.

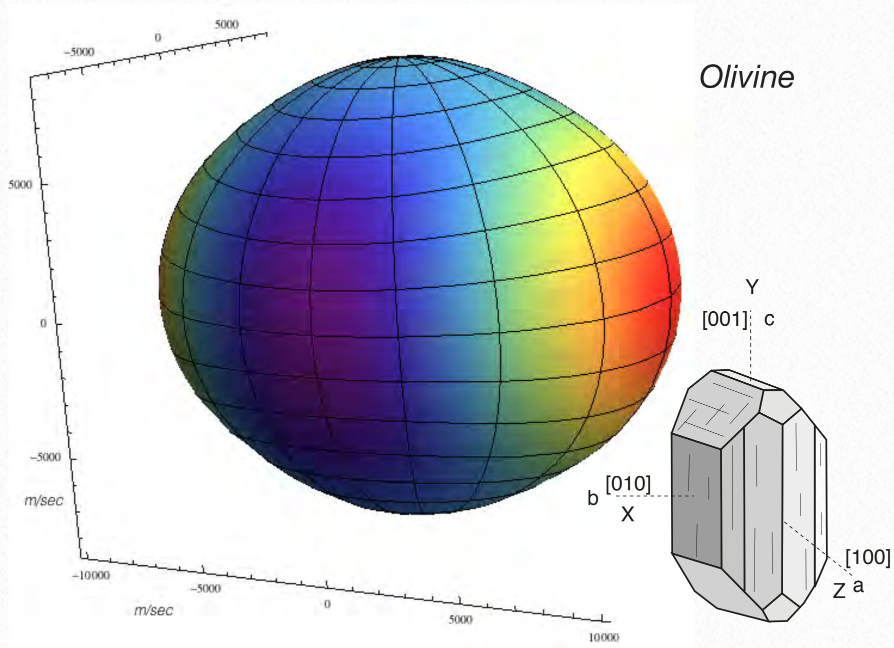
Plagiarism policy & Academic honesty

PLAGIARIMS POLICY- Please ensure you have read the University of Sydney Plagiarism Policy which can be accessed from the following website: https://sydney.edu.au/students/academic-dishonesty-and-plagiarism.html

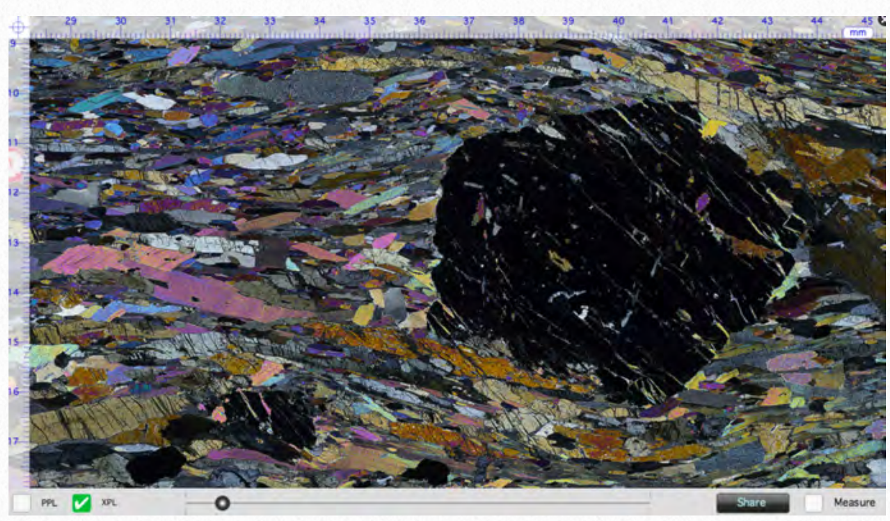
Hardcopy submissions must include a signed copy of the Student Plagiarism: Coursework - *Policy and Procedure Compliance Statement* form which can be downloaded from the School of Geosciences website: http://www.geosci.usyd.edu.au/undergrad/ug_acahon.shtml

All electronic assignment submissions must include the text provided in the *Student Plagiarism: Coursework - Policy and Procedure Compliance Statement* form. The text must be unchanged except for the students' name(s) and submission date and must appear on the first page of any electronically submitted assignment in order for the assignment to be considered acceptable. The form is available as a word document from the School of Geosciences website: http://www.geosci.usyd.edu.au/undergrad/ug_acahon.shtml

NB: Mandatory use of Turnitin- The University has mandated the use of text-based similarity detecting software (Turnitin) for all text-based written assignments.



Understanding crystallography is paramount to understand the physical properties of rocks. The elastic properties of olivine, which makes > 60% of the Earth's mantle, largely control the propagation of seismic waves through the Earth interior. This image shows the speed of P-waves propagating inside a crystal of olivine. The fast direction (red) corresponds to the [100] crystallographic axis, whereas the slow direction (purple) is the axis [010] (image @ P. F. Rey).



@ virtualmicroscope.org

Cross-polar view of a metamorphic schist from European Alps (Val D'Aosta, Italy). The mineral assemblage consists in glaucophane, phengite, garnet, clinozoisite and rutile. You explore this thin section here: http://www.virtualmicroscope.org/rock_sample?asset=p32011a/index.html?x=23.46&y=11.54&zoom=0&s=0

ACADEMIC HONESTY- While the University is aware that the vast majority of students and staff act ethically and honestly, it is opposed to and will not tolerate academic dishonesty or plagiarism and will treat all allegations of dishonesty seriously.

All students are expected to be familiar and act in compliance with the relevant University policies, procedures and codes, which include:

- Academic Honesty in Coursework Policy 2015
- Academic Honesty Procedures 2016
- Code of Conduct for Students
- Research Code of Conduct 2013 (for honours and postgraduate dissertation units)

They can be accessed via the University's Policy Register: http://sydney.edu.au/policies (enter "Academic Honesty" in the search field).

Students should never use document-sharing sites and should be extremely wary of using online "tutor" services. Further information on academic honesty and the resources available to all students can be found on the Academic Integrity page of the University website: http://sydney.edu.au/elearning/student/EI/index.shtml

Academic Dishonesty and Plagiarism- Academic dishonesty involves seeking unfair academic advantage or helping another student to do so.

You may be found to have engaged in academic dishonesty if you:

- Resubmit (or "recycle") work that you have already submitted for assessment in the same unit or in a different unit or previous attempt;
- Use assignment answers hosted on the internet, including those uploaded to document sharing websites by other students.
- Have someone else complete part or all of an assignment for you, or do this for another student.
- Except for legitimate group work purposes, providing assignment questions and answers to other students directly or through social media platforms or document ("notes") sharing websites, including essays and written reports.
- Engage in examination misconduct, including using cheat notes or unapproved electronic devices (e.g., smartphones), copying from other students, discussing an exam with another

person while it is in progress, or removing confidential examination papers from the examination venue.
• Engage in dishonest plagiarism.

Plagiarism means presenting another person's work as if it is your own without properly or adequately referencing the original source of the work.

Plagiarism is using someone else's ideas, words, formulas, methods, evidence, programming code, images, artworks, or musical creations without proper acknowledgement. If you use someone's actual words you must use quotation marks as well as an appropriate reference. If you use someone's ideas, formulas, methods, evidence, tables or images you must use a reference. You must not present someone's artistic work, musical creation, programming code or any other form of intellectual property as your own. If referring to any of these, you must always present them as the work of their creator and reference in an appropriate way.

Plagiarism is always unacceptable, regardless of whether it is done intentionally or not. It is considered dishonest if done knowingly, with intent to deceive or if a reasonable person can see that the assignment contains more work copied from other sources than the student's original work. The University understands that not all plagiarism is dishonest and provides students with opportunities to improve their academic writing, including their understanding of scholarly citation and referencing practices.

USE OF SIMILARITY DETECTION SOFTWARE

All written assignments submitted in this unit of study will be submitted to the similarity detecting software program known as Turnitin. Turnitin searches for matches between text in your written assessment task and text sourced from the Internet, published works and assignments that have previously been submitted to Turnitin for analysis.

There will always be some degree of text-matching when using Turnitin. Text-matching may occur in use of direct quotations, technical terms and phrases, or the listing of bibliographic material. This does not mean you will automatically be accused of academic dishonesty or plagiarism, although Turnitin reports may be used as evidence in academic dishonesty and plagiarism decision-making processes.

The Team

Staff Contact Information

Lecturers	Room	Tel	Email
Patrice Rey	Rm 408 Madsen Bld	9351 2067	patrice.rey@sydney.edu.au
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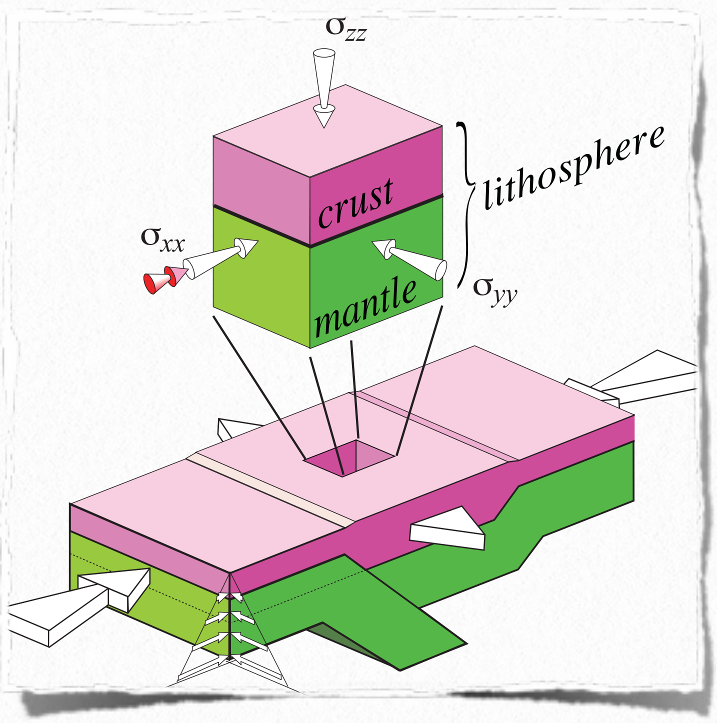
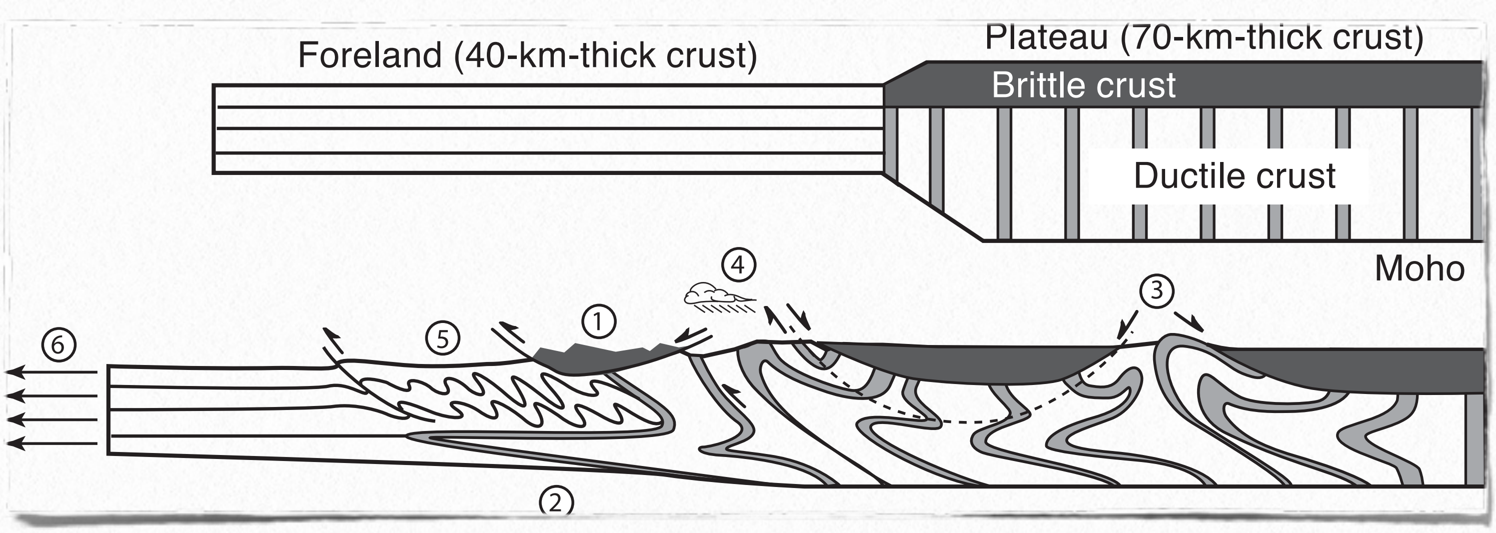


The formation of moutain belts and orogenic plateaux is the result of orogenic processes occurring during and after the convergence between lithospheric plates. These processes includes oceanic and continental subduction, and collision between continental lithospheres. They led to crustal thickening responsible for the higher elevation of moutain belts and plateaux. Other processes also contribute to the high topographic elevation of orogenic domains including the removal of thickened lithospheric mantle , and deep mantle upwelling. Following these orogenic processes, and even after convergence has ceased, other processes unfold contributing to warming-up the orogenic domain and its waekening to the point where the orogenic domain collapses under its own weight. The spreading of orogenic plateaux contributes to the exhumation of deep crustal rocks (often partially melted) into gneiss domes, and it also contribute to the shortening of adjacent regions (images @ P. F. Rey).



Recommended books and more ...

Ben van der Pluijm and Stephen Marshak, 2004. Earth Structure An Introduction to Structural Geology and Tectonics. WW Norton & Company. Second Edition.

Bucher, K. & Frey, M., 1994. Petrogenesis of Metamorphic Rocks. Springer.Comprehensive rewrite of Winkler's dated but valued text.

Deer, Howie & Zussman,1992. An Introduction to the Rock Forming Minerals, 2nd edition. Longman.Standard reference for mineralogy and mineral chemistry.

Dickin, Radiogenic Isotope Geology. Cambridge.Recent text for isotopic petrology and geochronology.

Kearey & Vine, 1990. Global Tectonics. Blackwell.Excellent summaries of geodynamics, though a rewrite will be released in 2008 (Kearey, Vine & Klepeis).

Marshak, S., 2008. Earth, Portrait of a Planet, 3rd edition. Norton & Co., New York.This is the recommended first year text and covers many basic issues very well.

Rollinson, H.1993. Using geochemical data. Longman.Great summaries of isotopic petrology, geochemistry and the uses of trace element data in petrology.

Spear, F.S., 1993. Metamorphic Phase Equilibria and P-T-t paths. Mineralogical Society of America, Monagraph.Detail on what the title suggests, but this will take some time for you to get in.

Van Der Pluijm, B.A. & Marshak, S., 2004. Earth Structure: An Introduction to Structural Geology and Tectonics. A great book for undergraduates.

Vernon, R.H., 2004. A practical guide to rock microstructure. Cambridge.

Vernon, R.H. & Clarke, G.L., 2008. Principles of Metamorphic Petrology. Cambridge.You received a preliminary copy of Chapter 1 last year, attached is Chapter 2.

Wilson, M. 1989. Igneous Petrogenesis, A Global Tectonic Approach. Chapan & HallChapters 1-3 provide an excellent petrologic background.

Winter, 2001. Igneous and metamorphic Petrology.Good coverage of some fundamental issues.

Yardley, B.W.D., 1989. An Introduction to Metamorphic Petrology. Longman.An excellent and compact reference.

http://www.virtualmicroscope.org

http://www.iucr.org/education (in the search engine enter education to find didactic papers)

http://www.smorf.nl/ (interactive 3D crystal models and more)

https://www.rockptx.com/thin-section-scans/ (Thin sections of metamorphic rocks).

South Coast Excursion

Introduction- The objective of this excursion is to introduce you to advanced techniques in the analysis of sedimentary, igneous and metamorphic rocks at the outcrop scale. The South Coast of New South Wales between Moruya and Bega offers some spectacular exposures of Early to Middle Devonian igneous suites, Ordovician turbidites and complexly deformed Cambrian to Devonian sedimentary sequences. Together they form the Late Ordovician Namoora accretionnay complex of the Lachlan Orogen. The excursion involves 3 intensive days of analytical exercises designed to improve your skills at outcrop analyses and the interpretation of geological processes at the mesoscale.

Physical requirements are similar to those expected for daily walks in a National Park in a coastal region. This includes walking 4 to 6 hours per day on sandy beaches and uneven terrains, climbing steep hills and walking down steep slopes.

Exercises- Group and individual exercises will include the following:
• Analysis of igneous minerals, igneous rocks and igneous processes at Bingie Bingie Point.
• Analysis of sedimentary facies, depositional environments (and possibly exotic terranes) in rocks at Potato Point and Narooma.
• Analysis of superposed structural fabrics in deformed greywackes at Bermagui.
• Critical interpretation of rock relationships on a macroscopic scale.

Assessment - This excursion is an important part of the GEOS3101 course (15% of final mark) and attendance is mandatory unless a *Special Consideration* is granted. You will be divided into groups to complete some exercises, but assessed individually. Each working day will involve specific exercises. Your assessment for the exercises will be based on the following: (1) participation in the exercises and discussions, (2) quality of the map, sections, sketches and written interpretations produced for each exercise. Bingie Bingie (35%), Potato Point (20%), Narooma (10%), Bermagui (35%).

... South Coast Excursion ...

TIME TABLE
Friday 13th April- AM: Depart from Bombo train station (South Coast Line) 11:00 am. Travel to Narooma in minibuses, anticipated arrival time: ~4 pm. PM: Visit of outcrops on Narooma beach and grocery shopping in Narooma.
Saturday 14th April- Bring field lunch AM-PM: Mapping & analysis of plutonic rocks of the Moruya batholith at Bingie Bingie Point
Sunday 15th April- Bring field lunch AM-PM: Mesoscopic structural analysis of superposed fabrics and folds at Bermagui
Monday 16th April- Bring field lunch AM: Stratigraphic analysis of rock exposures at Potato Point. PM: Return to Helensburgh station; estimated arrival at Sydney Central - 6 pm.

Accommodation- We will stay in cabins at the Island View Beach Resort. Please bring a warm sleeping bag or your own bed linen. Cooking facilities will be available but you must provide your own food - opportunities for shopping will be arranged.
Island View Beach Resort, 7323 Princes Highway Narooma NSW 2546 ph: 1800 465 432, http://www.islandview.com.au/ Coordinates: Lat: -36.246085; Long: 150.141151

Accommodation & transport fee- The cost of the trip ($250 inc GST), click here to **pay online.**

Equipment to bring- Stout boots are required for fieldwork, daypack, 2 litre water bottle, hat, sun glasses, sun screen, lip balm, rainjacket. Be prepared for working in cold weather, wind and rain. In the field, long-sleeved shirts and pants offer better protection than T-shirts and shorts. It is NOT acceptable to wear thongs or sneakers whilst completing fieldwork. Field notebook, color pencils, erasers and protractor, for taking note in the field. Quality Estwing hammer ($90), geological compass ($20), hand lens x10 ($40), and safety goggles (10$) can be found on ebay.com.au or prospectors.com.au. When using a geological hammer you will have to wear your own safety goggles. Some of the areas we will visit are in National Parks where no hammer is allowed.

...South Coast Excursion

Assumed Knowledge - To successfully complete this field excursion you should be familiar with the following concepts and tasks:

• Measuring strike, dip and dip direction, and plunge and plunge direction with a compass.
https://www.youtube.com/watch?v=gggTySc234Y

• Plotting lines & planes on a stereonet canvas, and analyse of their angular relationships.
https://www.youtube.com/watch?v=kCvqSsgyCS8&list=PLDE65FA626DC9E4A1

• Identification and classification of main igneous rocks.
https://www.youtube.com/watch?v=Zbz4e-9pjY4

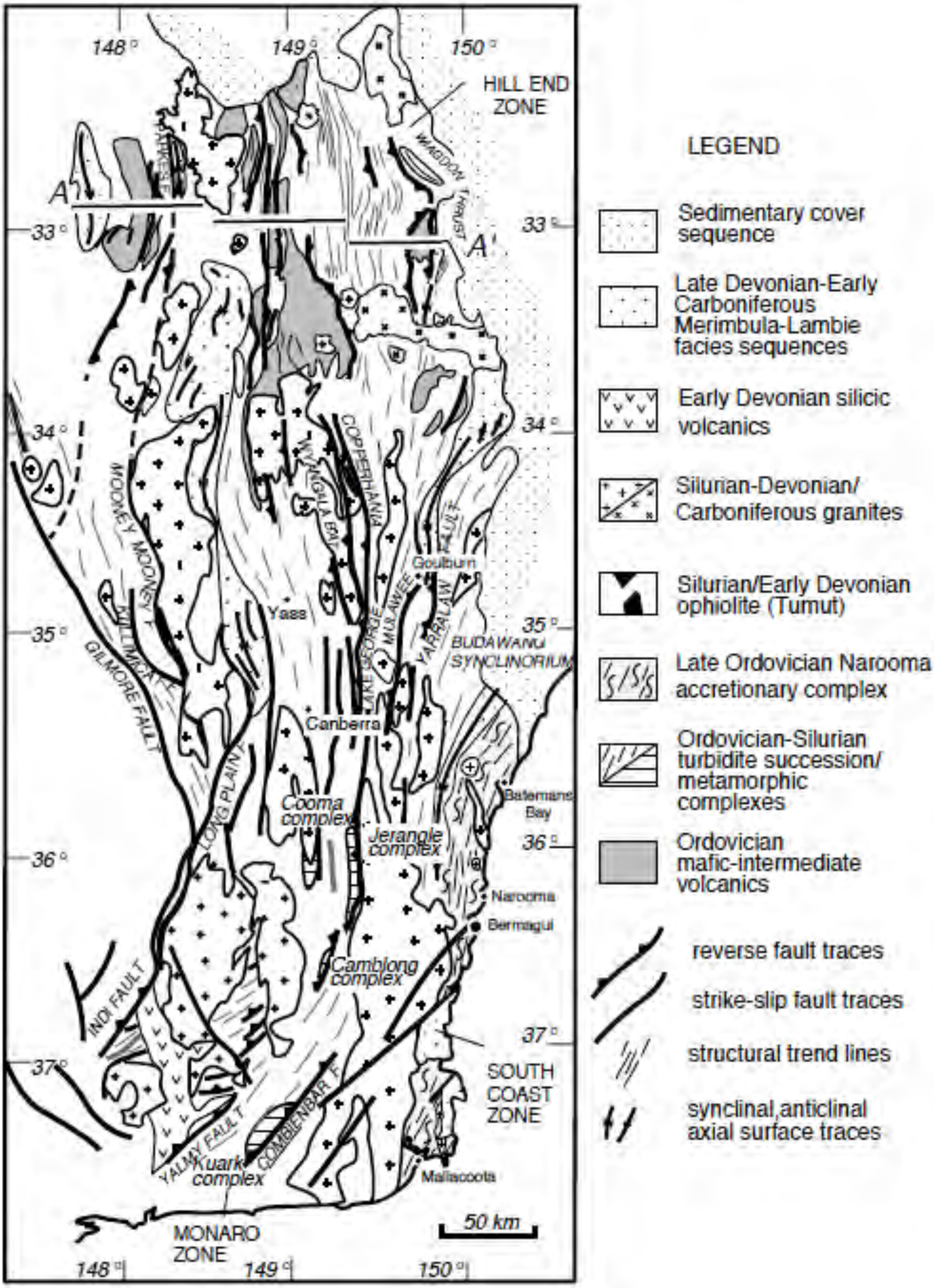
• Indification and interpretation of sedimentary rocks.
https://www.youtube.com/watch?v=uozyWZ6XQzM
https://www.youtube.com/watch?v=B3EnKjDrXHc

• Indification and interpretation of metamorphic rocks and fabrics.
https://www.youtube.com/watch?v=Ncr-46YX-N0

• Identification of turbidites, Bouma sequences and palaeocurrent indicators.
https://www.youtube.com/watch?v=jeY6Z-3mTVQ

• Folds, folds systems and fold related fabrics and microstructures.
https://www.youtube.com/watch?v=shu9ZOYc5DU

NB: Common igneous rocks: those defined in the IUGS classification of igneous rocks (Le Bas & Streckeisen, Journal of the Geological Society of London, 148, 825–833, 1991). Common metamorphic rocks: refer to glossary from Vernon & Clarke (2008) given on Blackboard site. Common minerals: those forming common igneous and and metamorphic rocks, as examined in practical exercises.



148°
149°
150°
HILL END ZONE
WAGGON THRUST
A
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33°
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35°
36°
37°
COPPERHANIA
MOONEY MOONEY
GILMORE FAULT
Goulburn
Yass
LAKE GEORGE
MULWAREE
YARRALAW
BUDAWANG SYNCLINORIUM
Canberra
LONG PLAIN
Cooma complex
Jerangle complex
Batemans Bay
Narooma
Bermagui
Cambalong complex
INDI FAULT
YALMY FAULT
COMBIENBAR F
Kuark complex
Mallacoota
SOUTH COAST ZONE
MONARO ZONE
50 km
LEGEND
Sedimentary cover sequence
Late Devonian-Early Carboniferous Merimbula-Lambie facies sequences
Early Devonian silicic volcanics
Silurian-Devonian/ Carboniferous granites
Silurian/Early Devonian ophiolite (Tumut)
Late Ordovician Narooma accretionary complex
Ordovician-Silurian turbidite succession/ metamorphic complexes
Ordovician mafic-intermediate volcanics
reverse fault traces
strike-slip fault traces
structural trend lines
synclinal,anticlinal axial surface traces

Video Presentation Week 12

In week 12, students working in group of 3 will deliver a 4 to 5 mn-long video presentation on a subject of particular interest to them but relevant to GEOS3101-3801.

1. INTRODUCTION - Don't be fooled by the short length of the video which is requested from you. To produce a meaningful 4 to 5 mn-long video you will have to go through, understand and digest a relatively large volume of information. Only then, you will be able to present your topic in an engaging, concise and articulate manner. Please, keep in mind that these videos aim at senior undergraduates, not first year students.

Your video must be delivered, in an Internet-compatible format, on a USB (Universal Serial Bus) key, along with a one-page summary. To be safe, please provide your video in various formats (avi, mpeg, mov, etc). A webcam, a basic movie editor and some imagination are all you need to build an engaging podcast presentation.

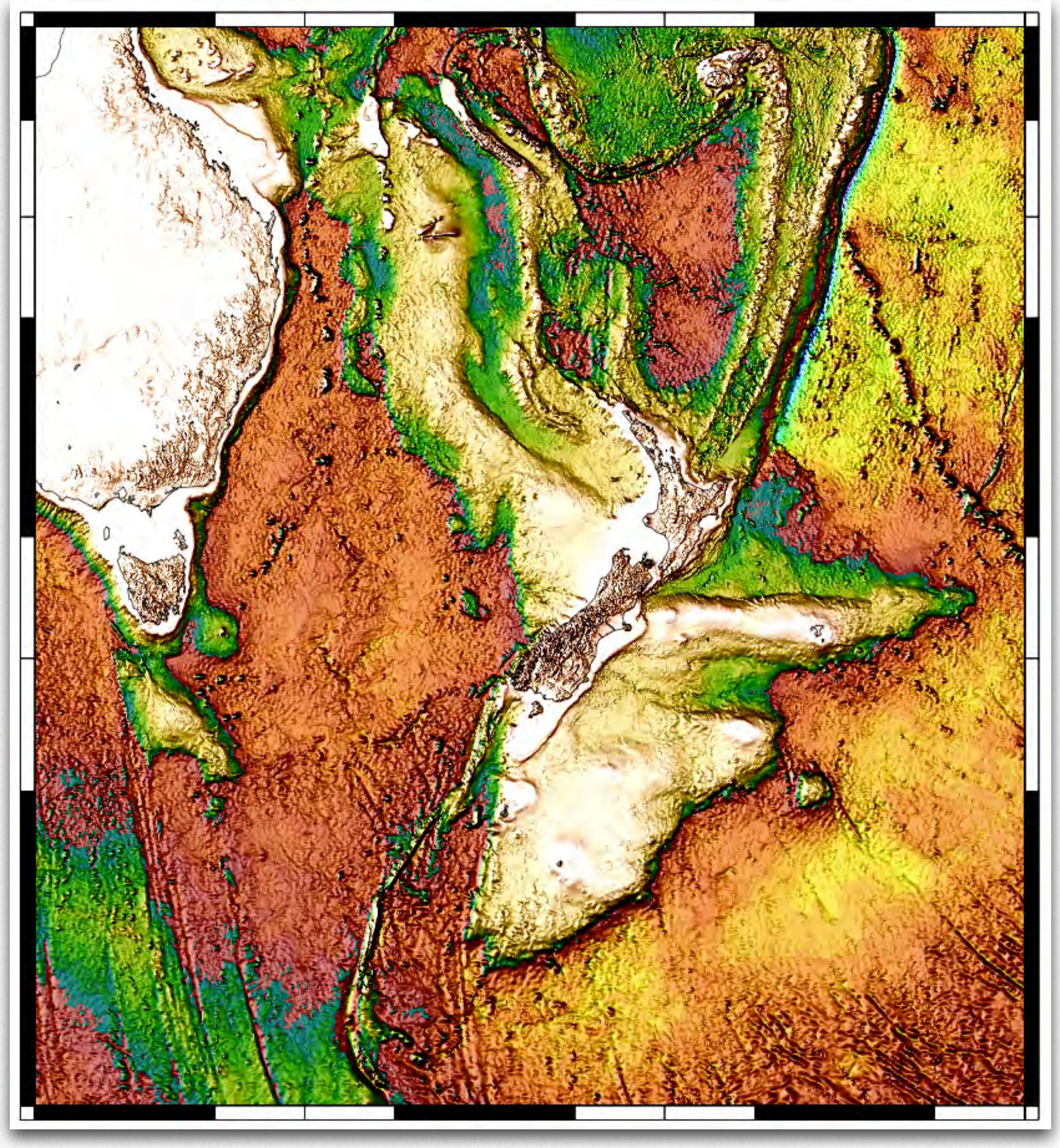
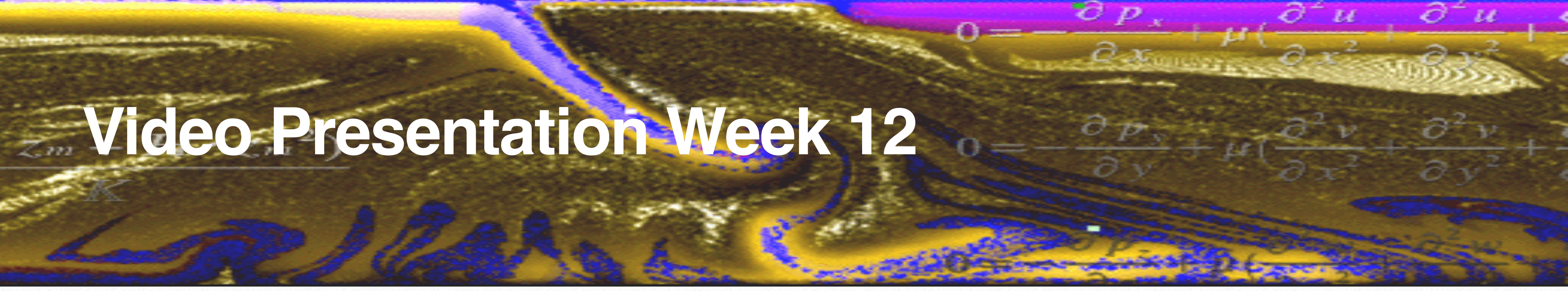


Plate margin fragmentation and the detachment of continental ribbons can be seen as the product of mantle wedge dynamics.

2. ASSESSMENT CRITERIA

A: GENERAL PRESENTATION (30%)

1/ Introduction - effective in laying the groundwork, its significance 5 %
2/ Delivery - well-articulated, effective transitions, smooth and well paced 10 %
3/ Grammar and word choice 5 %
4/ Timing: Finish in time allowed 5 %
5/ Summary/conclusion - reinforced key points 5 %



Video Presentation Week 12

B: VISUAL AIDS (20%)

1/ Could you read / comprehend them? 10 %
2/ Sequence - was it appropriate? 5 %
3/ Effectiveness in supporting conclusions 5 %

C: CONTENT & ORGANIZATION (40%)

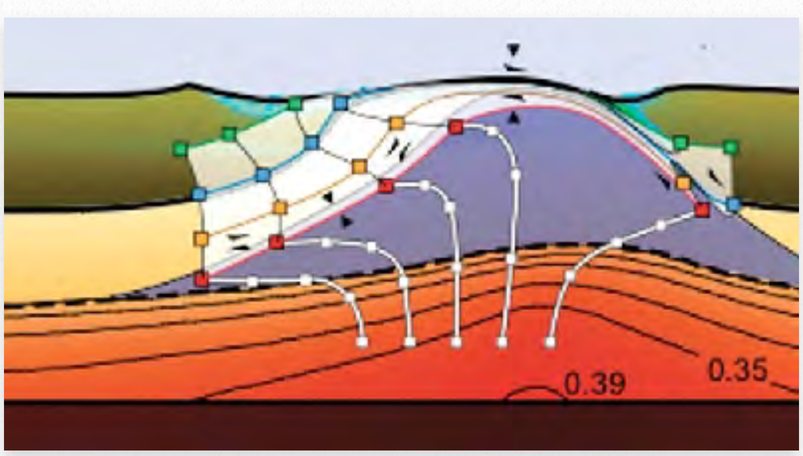
1/ Logic- logical and smooth progression from problem through study to result 10 %
2/ Significance - new and useful contribution? 10 %
3/ Relevance- of presented material to the task 10 %
4/ Conclusions - well-supported and documented 10 %

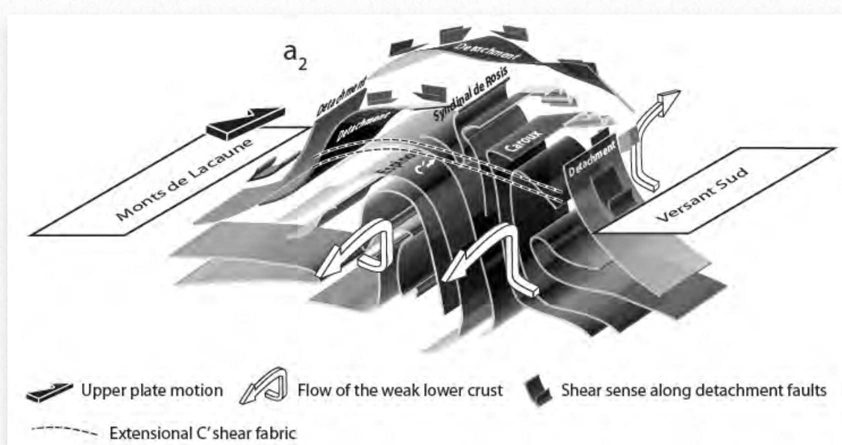
D: AUDIENCE RESPONSE (10%)

1/ Questions - Measure the audience interest 5 %
2/ Replies - well handled 5 %

NB: Humor is one way to engage the audience. Keep in mind however that the prime objective of this exercise is not solely to entertain your audience, but to teach and learn.

Choose your your topic carefully (see list in the next section) and send to Patrice (patrice.rey@sydney.edu.au) the title of the topic you have chosen and the name of your teammates.





Video Presentation Week 12

3. PRESENTATION TOPICS

Each individual chapter from "Van Der Pluijm, B.A. & Marshak, S., 2004. Earth Structure: An Introduction to Structural Geology and Tectonics" can used as a basis for a 4-5 mn video podcast, in addition to the following broader topics:

Mantle Convection and Mantle Dynamics

Tackley, 2000: Mantle Convection and Plate Tectonics: Toward an Integrated Physical and Chemical Theory. Science, v.288, 2002-20007

Romanowicz, B, Yuancheng Gung, 2002: Superplumes from the Core-Mantle Boundary to the Lithosphere: Implication for Heat Flux. Science, v. 296, 513-516.

Zhong, S, and M. Gurnis, 1995: Mantle Convection with Plates and Mobile, Faulted Plate Margins. Science, v.267, 838-843.

Scoppola, B, D. Boccaletti, M. Bevis, E. Carminati and C. Doglioni, 2006: The Westward Drift of the Lithosphere: A rotational drag? G.S.A. Bulletin, v.118, 199-209.

Conrad, C. and C. Lithgow-Berteloni, 2002: How Mantle Slabs Drive Plate Tectonics, Science, v. 298, 207-209.

Cizkova, H., J. van Hunen, A. P. van den Berg, 2002: The Influence of Rheological Weakening and Yield Stress on the Interaction of Slabs with th 670 km discontinuity. Earth Planetaru Scince Letters, v.199, 447-457.

van den Berg, A., P. E.S.G., Rainey and D. A., Yun, 2005: The Combined Influences of Variable Thermal Conductivity, Temperature- and Pressure-Dependent Viscosity and Core-Mantle Coupling on Thermal Evolution. Earth Planetary Science Letters, v. 149, 259-278.

Coltice, N., B.R., Phillips, H. Bertrand, Y. Ricard and P. Rey, 2006: Global Warming of the Mantle at the Origin of Flood Basalts over Supercontinents. Geology, 35, 391-395.

Continental Break-Up and Sedimentary Basins

Gernigon, L., S. Planke, J.C. Ringenbach and B. Le Gall, 2006: Tectonic and Deep Crustal Structures along the Norwegian Volcanic Margin: Implications for the "Mantle Plume or Not" debate. www.MantlePlumes.org

Video Presentation Week 12

Gernigon, L., J.C. Ringenbach, S. Plank, and B. Le Gall, 2004: Deep Structures and Breakup along Volcanic Rifted Margins: Insights from Integrated Studies along the outer Vøring Basin (Norway). Marine and Petroleum Geology, v. 21, 363-372.

Gernigon, L., F. Lucazeau, F. Brigaud, C. Ringenbach, S. Plank, and B. Le Gall, 2006: A Moderate Melting Model for the Vøring Margin (Norway) Based on Structural Observations and a Thermo-kinematical Modelling: Implications for the Meaning of the Lower Crustal Bodies. Tectonophysics, v.412, 255-278.

Geoffroy, L. 2005: Volcanic Passive Margins. Comptes Rendus Geoscience, v.337, 1395-1408.

Corti, G., M. Bonini, S. Conticelli, F. Innocenti, P. Manetti and D. Soukoutis, 2003: Analogue Modelling of Continental Extension: a Review Focussed on the relations Between the Patterns of Deformation and the Presence of Magma. Earth Science Reviews, v.632, 169-247.

Corti et al., 2003, Geophysical Research Letters

Wijns, C., Weinberg, R., Gessner, K. & Moresi, L. 2005: Mode of crustal extension determined by rheological layering. Earth Planetary Science Letters v. 236, 120-134.

Rey, P. 2001: From Lithospheric Thickening and Divergent Collapse to Active Continental Rifting. in Miller, J.A., Buick, I.S., Hand, M., and Holdsworth, R.E., (eds), Continental Reworking and Reactivation, Journal of the Geological Society of London, v.184.

Mountain Belts Processes

Wittlinger G., P. Tapponnier, G. Poupinet, Jiang Mei, Dhi Danian, G. Herquel and F. Mason, 1998: Tomographic Evidence for Localized Lithospheric Shear along the Altyn Tagh Fault. Science, v. 282, 74-76.

Shapiro, N.M., M.H. Ritzwoller, P. Molnar and V. Levin, 2004: Thinning and Flow of Tibetan Crust Constrained by Seismic Anisotropy. Science, v.305, 233-236

Royden L. H. B. C. Burchfield, R. W. King, Erchie Wang, Zhiliang Chen, Feng Shen and Yuping Liu, 1997: Surface Deformation and Lower Crustal Flow in Eastern Tibet, Science, v. 276, 788-790.

Rey, P., O. Vanderhaeghe, and C. Teyssier, 2001: Gravitational Collapse of the Continental Crust: Definition, Regimes and Mode. Tectonophysics, v. 342, 435-449.

Boutelier, D., A. Chemenda and C. Jorand 2004: Continental Subduction and Exhumation of High-Pressure rocks: Insights form Thermo-mechanical Laboratory Modelling. Earth Planetary and Science Letters, v. 222, 209-216.

Stockhert, B., and T. V. Gerya, 2005: Pre-collisional high-pressure metamorphism and nappe tectonics at active continental margins: a numerical simulation. Terra Nova, v.17, 102-110.

Tikoff, B., C. Teyssier, C. Waters: 2002. Clutch tectonics and the partial attachment of lithospheric layers. EGU Stephan Mueller Special Publication Series, 1, 57–73.

Rey, P. and N. Coltice, Geology, 2008: Neoarchean lithospheric strengthening and the coupling of Earth's geochemical reservoirs. Geology, v.36, 635-638.

Duclaux, G., Rey, P., Guillot, S., and Ménot, R.P., 2007, Orogen-parallel flow during continental convergence: Numerical experiments and Archean field examples: Geology, v. 35, p. 715–718.

Rey P., and G. Houseman, 2006: Lithospheric scale gravitational flow: the impact of body forces on orogenic processes from Archaean to Phanerozoic. In Buiter, S. J. H. & Schreurs , G. (eds) 2006. Analogue and Numerical Modelling of Crustal-Scale Processes. Geological Society, London, Special Publications, 253, 153–167.

Heat Generation and Heat Transport

Anderson, D. 2005: Energetics of the Earth and the Missing Heat Source Mystery. www.MantlePlume.org

Burg J.P. and T.V. Gerya, 2005: The role of viscous heating in Barrovian metamorphism of collisional orogens: thermomechanical models and application to the Lepontine Dome in the Central Alps. J. Metamorphic Geology. v.23, 75-95.

Rey, P., P. Philippot and N. Thébaud, 2003: Contribution of mantle plumes, crustal thickening and greenstone blanketing to the 2.75–2.65 Ga global crisis Precambrian Research, v.127, 43-60.

Coltice, N., B.R., Phillips, H. Bertrand, Y. Ricard and P. Rey, 2006: Global Warming of the Mantle at the Origin of Flood Basalts over Supercontinents. Geology, 35, 391-395.

Rheology of the Continental and Oceanic Lithospheres (2 topics)

Behr, W.M., and Platt, J.P., 2014, Brittle faults are weak, yet the ductile middle crust is strong: Implications for lithospheric mechanics: Geophysical Research Letters, v. 41, p. 8067–8075,

Behr, W.M., and Hirth, G., 2014, Rheological properties of the mantle lid beneath the Mojave region in southern California: Earth and Planetary Science Letters, v. 393, p. 60–72,

Chatzaras, V., Tikoff, B., Newman, J., Withers, A.C. and Drury, M. R., 2015. Mantle strength of the San Andreas fault system and the role of mantle-crust feedbacks. Geology, v. 43, 891-894.

Kohlstedt, D.L., B. Evans and S.J. Mackwell, 1995: Strength of the Lithosphere: Constraints Imposed by Laboratory Experiments. Journal of Geophysical Research, v.100, 17587-17602.

Fernandez, M. and G. Ranalli, 1999: The role of rheology in extensional basin formation modeling. Tectonophysics, v. 282, 129-145.

Burov, E.B. and A.B. Watts, 2006: The Long-Term Strength of Continental Lithosphere:"Jelly Sandwich" or "Crème Brûlée"? G.S.A. Today, v.6, 4-10.

Jackson, J. 2002: Strenght of the Continental Lithosphere: Time to Abandon the Jelly Sandwich? GSA Today, v. Sept, 4-9.

Pysklywec, R. N. and A. R. Cruden, 2004: Coupled crust-mantle dynamics and intraplate tectonics: Two-dimensional numerical and three-dimensional analogue Modeling. Gcubed, v.5, 1-22.

Unworth, M.J., A.G. Jones, W. Wei, G. Marquis, S.G. Gokarn, J.E. Spratt, and the INDEPTH-MT team, 2005: Crustal rheology of the Himalaya and Southern Tibet inferred from magnetotelluric data. Nature, 438, 78-81.

Watts, A.B. and S. Zhong, 2000: Observations of ¯exure and the rheology of oceanic lithosphere. Geophys. J. Int. v.142, 855-875.

Dyksterhuis, S., P. Rey, D. Müller and L. Moresi, 2007: Effects of initial weakness on rift architecture. In Karner, G. D., G. Manatschal, and Pinheiro, L. M. (eds) Imaging, Mapping and Modelling Continental Lithosphere Extension and Breakup. Geological Society, London, Special Publications, 282, 443 – 455.

Demouchy, S., Tommasi, A., Ballaran, T. B. & Cordier, P, 2013. Low strength of Earth's uppermost mantle inferred from tri-axial deformation experiments on dry olivine crystals. Phys. Earth Planet. Inter. 220, 37–49.

van der Werf, T., Chatzaras, V., Kriegsman, L. M., Kronenberg, A., Tikoff, B., and Drury, M.R., 2017. Constraints on the rheology of the lower crust in a strike-slip plate boundary: evidence from the San Quintín xenoliths, Baja California, Mexico. Solid Earth, v. 8, 1211-1239.

Zhong, S. & Watts, A. B., 2013. Lithospheric deformation induced by loading of the Hawaiian Islands and its implications for mantle rheology. J. Geophys. Res. 118, 1–24.

Tectonic Forces and Body Forces

Wittlinger G., P. Tapponnier, G. Poupinet, Jiang Mei, Dhi Danian, G. Herquel and F. Mason, 1998: Tomographic Evidence for Localized Lithospheric Shear along the Altyn Tagh Fault. Science, v. 282, 74-76.

Hammond W.C. and W. Thatcher, 2004: Contemporary tectonic deformation of the Basin and Range province, western United States: 10 years of observation with the Global Positioning System. Journal of Geophysical Research, v.109, 1-21.

Hammond W.C. and W. Thatcher, 2005: Northwest Basin and Range tectonic deformation observed with the Global Positioning System, 1999 – 2003, Journal of Geophysical Research, v.110, 1-12.

Flesch L.M., W.E. Holt, A.J. Haines and Bingming Shen-Tu, 2000: Dynamics of the Pacific-North American Plate Boundary in the Western United States. Science, v.287, 834-836.

Lallemand S. and A. Heuret, 2005: On the relationships between slab dip, back-arc stress, upper plate absolute motion, and crustal nature in subduction zones. G-Cubed, v.6, 1-18.

Huisman R.S., Y. Y. Podladchikov, and S. Cloetingh, 2001: Transition form Passive to Active Rifting: Relative Importance of Asthenospheric Doming and Passive Extension of the Lithosphere. Journal of Geophysical Research, v. 106, 11271-11291.

Davis and Kuznir, 2002: Are buoyancy forces important during the formation of rifted margins?. Geophys. J. Interior, v. 149, 524-533

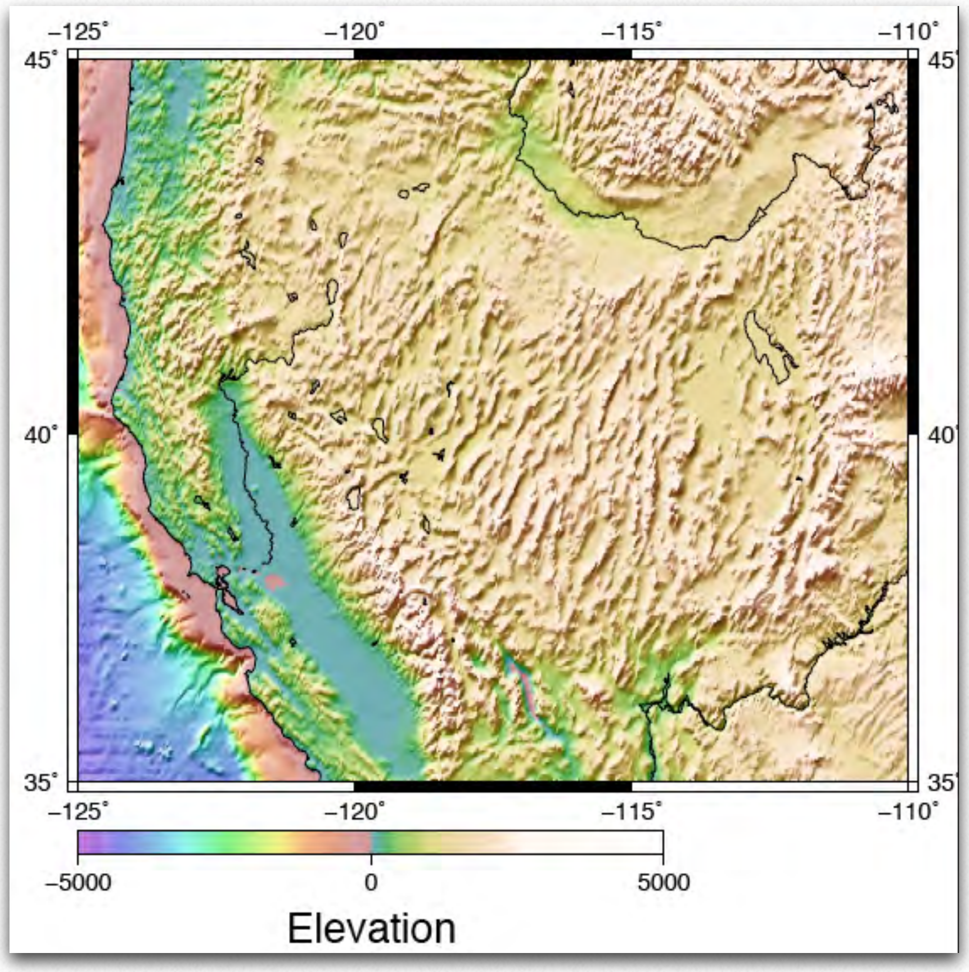
Husson, L. and Y. Ricard, 2004. Stress balance above subduction: Application to the Andes. Earth Planetary Science Letters, 222, 1037-1050.

Rey, P. 2001: From Lithospheric Thickening and Divergent Collapse to Active Continental Rifting. in Miller, J.A., Buick, I.S., Hand, M., and Holdsworth, R.E., (eds), Continental Reworking and Reactivation, Journal of the Geological Society of London, v.184.

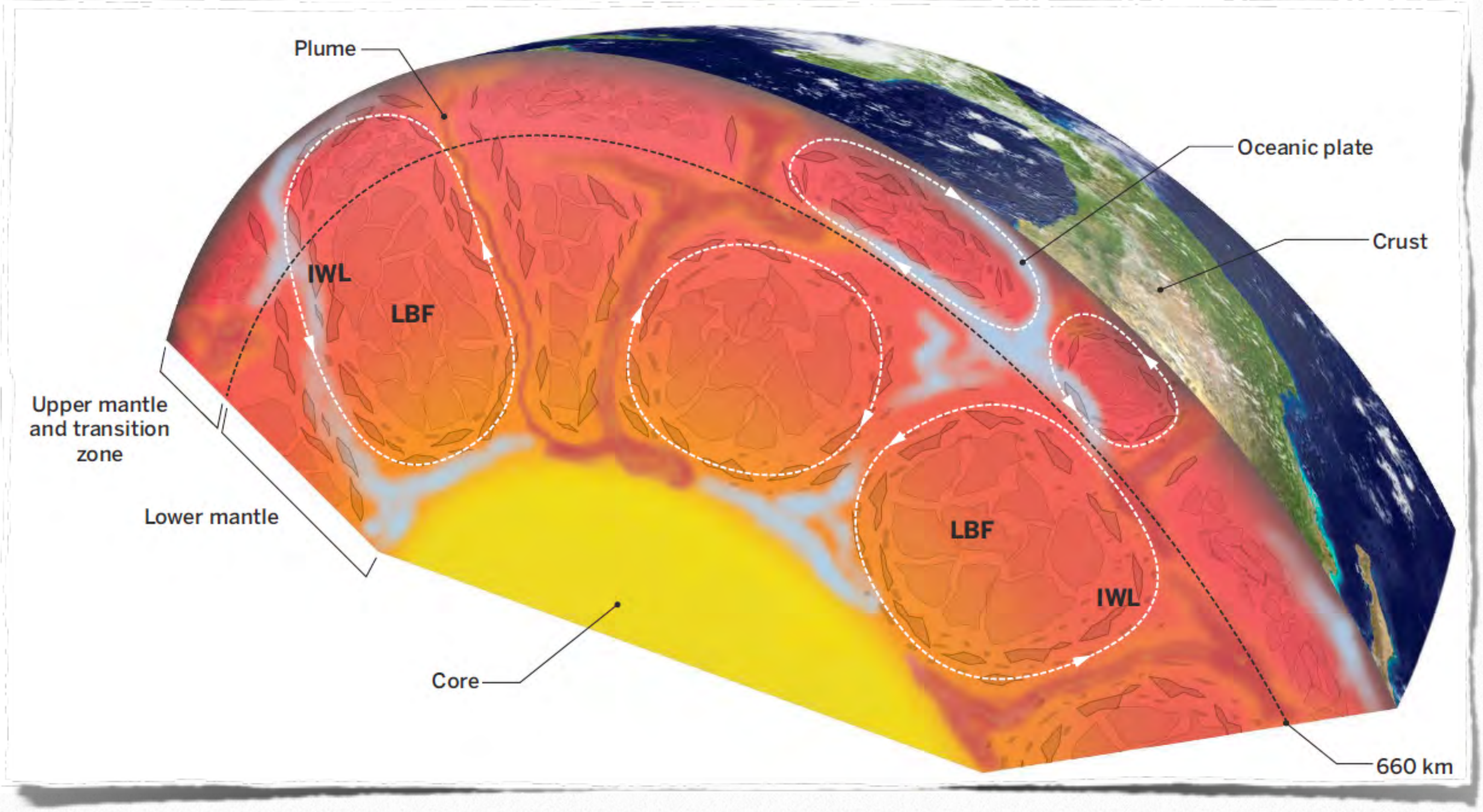
Rey P., and G. Houseman, 2006: Lithospheric scale gravitational flow: the impact of body forces on orogenic processes from Archaean to Phanerozoic. In Buiter, S. J. H. & Schreurs , G. (eds) 2006. Analogue and Numerical Modelling of Crustal-Scale Processes. Geological Society, London, Special Publications, 253, 153–167.

Rey, P., O. Vanderhaeghe, and C. Teyssier, 2001: Gravitational Collapse of the Continental Crust: Definition, Regimes and Mode. Tectonophysics, v. 342, 435-449.

Duclaux, G., Rey, P., Guillot, S., and Ménot, R.P., 2007, Orogen-parallel flow during continental convergence: Numerical experiments and Archean field examples: Geology, v. 35, p. 715–718.



Earth's Structure ...



Jiahua Chen, Science 8 Jan. 2016: Subducting slabs bring oceanic plates (blue) into the deep mantle. The slabs deflected at the 660-km discontinuity form layered convection within upper mantle and transition zone. The slabs penetrating into the lower mantle reaching the core-mantle boundary form whole-mantle convection. Plumes (red) rise from the core-mantle boundary, bringing materials that are enriched in incompatible elements relative to the expected mantle average back to the 660-km discontinuity. Some of them penetrate through the discontinuity, whereas others are deflected and may produce secondary upper-mantle plumes. Shear localization induces interconnected weak layers (IWL) along the slabs or plumes as well as the top and bottom of the lower mantle, yielding a less efficient mixing for the central LBF (load-bearing framework) part of the lower mantle (the reason for long-lived geochemical reservoirs). Illustration: C. Bickel/Science