Practical 4: The Rheology of the Continental Lithosphere

Aim: The purpose of this practical to get up close and personal with the rheology of the continental lithosphere.

- Outcomes: To develop a deeper understanding of the rheology of the continental lithosphere, in particular the notion of brittle-ductile transition and the dependency of the rheology to strain rate.
- Generic skills: Problem solving ability, computational skills, and analytical skills.
- Assumed background knowledge: Basic knowledge on frictional failure theory and viscosity law. As always year 12 Mathematics is a must.
- Tools you may want/need to use: MatLab, Mathematica, LiveMath, Excel spreadsheet, calculator...
- Reading: Van den Pluijm and Marshak: Earth Structure.

Submission details: *Individual practical reports are due next week and will be collected at the beginning of the practical class. Should you hand-in your report later, do not forget to write the date of return on the front page. This is a report, not an answer sheet, so please give enough details so the assessor can understand your solution. Hand written reports are acceptable, but please write clearly.*

Some fundamentals:

The rheology of rocks: The rheology of Earth material (the way they deform when submitted to stress) depends on which deformation mechanism requires the least energy. At low temperature and/or high strain rate and/or high-pore pressure, frictional sliding is the mechanism that requires the least energy. Frictional sliding gives rise to faulting (brittle deformation). This mode of deformation is described by a Mohr Coulomb criterion or a Byerlee law (for rocks with pre-existing weak fractures), both law states that the yield stress increasing linearly with the effective normal stress (ie the difference between the confining pressure and the pore pressure, cf. rheology). At higher temperature and/or low strain rate, viscous flow lead to the development of foliation and lineation (ductile fabrics). Viscous flow is strongly dependent on temperature and therefore depth. The brittle-ductile transition refer to the depth at which there is a switch between frictional sliding to viscous flow.

Exercise- We consider an orogenic plateau (*fc*=2, *fl*=1) for which the thickness of the reference (ie. undeformed) crust is 40 km, its density is 2700 kg.m^{-3} and independent of temperature. In the continental crust, the temperature gradient is 14.5ºC/km. The conductivity of the mantle is 2 W.m^{-1}.K^{-1}, its heat capacity is 1000 J.kg^{-1}.K^{-1}, and the mantle heat flow at the base of the lithosphere is 0.012 W.m^{-2}. The density of the mantle is 3300 kg.m^{-3} and independent of temperature.

1/ Plot on one graph, the Byerlee frictional law in the case of extensional tectonics, assuming a/ a zero pore pressure, b/ a pore-pressure equal to one third of the confining pressure (ca. hydrostatic gradient), and c/ a pore pressure equal to 80% of the confining pressure (over-pressurized fluid).

2/ Let us assume that the Byerlee frictional law accurately represents the rheology of the brittle crust. Now consider two situations: i/ the continental crust is above sea level; ii/ the continental is below sea level. In which case is the stress required to deform the continental crust larger, and why?

3/ On the same graph, plot the power law for viscous creep for strain rates of 1e-15 s^{-1}, 1e-14 s^{-1} and 1e-13 s^{-1}. We will use the viscous rheological parameters (*A, n, Q*) listed in slide 09 of the Rheology lecture module.

4/ Analyse the depth of the brittle-ductile transition(s) as a function of pore pressure and strain rate. Comment.

5/ A gravitational force acting between the orogenic plateau and its surrounding is exerted over a column starting at the plateau surface down to the Moho of the thickened crust. The magnitude of this force is 12.5 TN/m. Assuming a strain rate of 1e-15 s^{-1} and a hydrostatic pore pressure, compare this gravitational force to the integrated strength of the thickened continental crust and discuss your findings.

6/ We have considered a linear geotherm for the continental crust. Assuming that the temperature at the Moho remains the same, discuss the effect of radiogenic heat production on the integrated strength of the continental crust for a given strain rate and hydrostatic pore pressure.

7/ Advanced students: How would you proceed to calculate the strain rate at which the orogenic plateau deforms?