Examination Paper: GEO3-1302

Continuum mechanics and rheology of the crust and mantle
PART II (SPIERS)

29-01-2010, 13.00-16.00, Room C.008 (C.010?)

N.B. - The exam paper consists of 5 questions. **Answer 4 of the 5 questions.**
- Take about 45 minutes to answer each question.
- Answer in English or in Dutch
- Identify all mathematical symbols you use

Good Luck!!!

Question 1

a) Describe the essential characteristics of the elastic behaviour of crystalline materials. Make use of sketches of typical stress-strain and strain-time diagrams.

b) Explain briefly the atomic scale basis for elastic behaviour.

c) The 3-D elastic behaviour of dense isotropic rock, or of dry rock with zero pore fluid pressure is given by the equation

$$2G\,\varepsilon_{ij} = \sigma_{ij} - \frac{1}{3}(1 - 2G/3K)\,\sigma_{kk}\,\delta_{ij}$$

Define fully all of the quantities (variables and parameters) appearing in this equation.

d) Use the above equation to calculate the strains undergone, at room temperature, by a cube of granite (G = 15 GPa, K= 40 GPa at 22 °C) subjected to a stress state defined by the principal stresses σ_1 = +20 MPa, σ_2 = 0 and σ_3 = -20 MPa. Illustrate your answer with a simple diagram. (N.B. Take compressive stress as positive).

e) Suppose that you subject the above cube of granite to the same stress state, but at 200 °C instead of room temperature. How would the resulting strain response then change, and why would it change?

Question 2

a) Explain what is meant by the terms "uniaxial compressive strength" and "failure criterion" for brittle rock, and indicate typical values of the uniaxial compressive strength for sedimentary and igneous rocks.

b) Write down criteria for the two main modes of brittle failure that can occur in regions of the Earth's crust where pore fluid is present at a pressure P_f. Make sure you identify all terms appearing and indicate any restrictions on the orientation of the failure planes involved.

c) Seismic events in an area of regional tectonic compression indicate reactivation of healed thrust faults at a depth of h ≈ 3000 m. Assuming (i) that the pore pressure at this depth takes a value equal to 40% of the lithostatic pressure (ρgh), (ii) that σ_3 is near-vertical and equal to the lithostatic pressure (ρgh), and (iii) that the local fault rocks are characterized by a (healed) cohesive shear strength of 4 MPa and a coefficient of internal friction of 1/3, obtain an estimate of the value of the horizontal stress (σ_1) associated with faulting.

* Take the density (ρ) of the overburden to be 2500 kg/m^3 and g = 10 ms^{-2}.

Question 3

a) Draw simple 3-D diagrams illustrating the key differences between an edge and a screw dislocation. Label all of the important vectors, directions and planes associated with the dislocations and their glide motion. Add a rough scale bar also!

b) Explain what is meant by the terms
(i) dislocation loop
(ii) dislocation node
(iii) dislocation density
(iv) dislocation self-energy

c) Explain the operation of the Frank-Read source of dislocations. Make sure you mention the various competing forces involved and the equilibrium condition required to activate such a source. Explain also how this equilibrium condition relates to the plastic yield behaviour of single crystals.

d) Explain what is meant by the terms "work hardening" and "recovery" and how these can lead to steady state flow of rock materials by dislocation processes.

Question 4

a) Explain what is meant by the term "steady state flow" and describe what deformation mechanisms are capable of producing such behaviour in the mid-lower crust and mantle.

b) Explain the concept of the deformation mechanism map, illustrating your answer with a schematic labelled diagram.

c) Explain how a deformation mechanism map is constructed and indicate the significance of the field boundaries appearing in such a map.

d) Explain what is meant by dynamic recrystallization and what it's effect is expected to be on the rheology of initially coarse grained rocks deformed to large strains in an environment such as a lower crustal shear zone. Use sketches of appropriate deformation maps to illustrate your answer.

Question 5

a) Write down and explain what is meant by Byerlee's law.

b) Indicate what deformation mechanisms and what type of constitutive equations are usually used to describe the ductile flow of quartz in the mid-lower crust and of olivine in the upper mantle.

c) Given Byerlee's law and suitable laboratory equations for the ductile flow behaviour of quartz and olivine, list the steps that you would take to construct a strength profile for a section of continental lithosphere undergoing rifting, assuming a uniform extensional strain rate of say 3 x 10^{-15} s^{-1}?

d) Finally, list and explain the main problems or weaknesses that you see in the classical approach to constructing a strength profile for a portion of lithosphere. Feel free to give your own ideas on this !!

HPT Lab Tour and Beer Award Borrel

All members of the class are invited for a tour of the HPT Lab and beer award "ceremony"/borrel (with final grades evaluation) on Monday, 8 March, 17.00. Assemble in the onderwijshal and I will meet you there. CHRIS