Examination Paper: GEO3-1302

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

01-02-2012, 13.30-16.30 (Educ Megaron)

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

Question 1

a) List the key features of the elastic behaviour exhibited by rock materials.

b) Explain briefly the atomic scale basis for elastic behaviour in crystalline materials

c) Write down a set of equations giving the 3-D strain response of an isotropic elastic solid subjected to a stress defined by the principal stresses σ_1, σ_2, σ_3, defining all terms.

d) A block of dense olivine rock (Young's modulus $E = 5 \times 10^{11}$ Pa, Poisson's Ratio $\nu = 0.3$) is subjected to the stress

$$\sigma_{ij} = \begin{bmatrix} +300 & 0 & 0 \\ 0 & +260 & 0 \\ 0 & 0 & +240 \end{bmatrix} MPa$$

where compression is taken positive. Calculate the state of strain and the volumetric strain relative to stress free conditions.

e) If the temperaure of this block of rock is increased from the initial value by say 300 °C, without changing the stress state, how would the state of strain change and why would it change - from both sample and an atomic scale perspectives?

Question 2

a) Explain what is meant by the term "failure criterion" for brittle rock.

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 = 5000 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 10 MPa and a coefficient of internal friction of 2/3, obtain an estimate of the value of the horizontal stress (σ_1) and the differential stress associated with faulting. Take the overburden density (ρ)to be 2500 kg/m^3 and g = 10 ms^{-2}.

d) If the region was one of extension not compression, would earthquakes sourced at 5 km depth be associated with a smaller or larger differential stress and would they be smaller or bigger?

Question 3

a) Draw a simple block diagram illustrating the essential features of an edge dislocation.

b) Define the terms "dislocation self energy" and "dislocation density"? Illustrate your answer with appropriate formulas, identifying all terms.

c) Explain what is meant by the term "slip system" and write down an expression for the force (per unit length) on a dislocation lying within its slip system in a stressed crystal.

d) 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.

e) The Frank-Read source produces dislocation loops. What does a dislocation loop enclose, and what happens to a small crystal if a dislocation loop expands under stress until it jumps out of the surfaces of the crystal?

Question 4

a) 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.

b) Describe what other deformation mechanisms are capable of producing steady state flow in the crust and mantle, and how they work.

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

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

e) Explain how a deformation map for quartz could help you decide on a flow law to use to model the ductile shearing behaviour of a fault zone, containing fine-grained quartz mylonite, exposed in lower crustal rocks characterised by specific metamorphic minerals.

Question 5

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

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.

Beer Award Borrel

All members of the class are invited for the beer award ceremony and borrel (with an evaluation of your final grades) on Monday, 11 March, 17.00. Assemble in the old onderwijshal and I will meet you there. CHRIS