Examination Paper: GEO3-1302

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

03-02-2012, 13.30-16.30 (Educ Mu)

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

b) Define the quantities "Youngs Modulus" and "Poisson's Ratio" used to specify the elastic behaviour of isotropic materials. Illustrate your answer with simple diagrams!!!!!!

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.

d) Use these equations plus your general knowledge about the elastic stiffness of rock to estimate the strains undergone by a block of dense quartzite (Poisson's Ratio $\nu = 0.3$) subjected to the stress

$$\sigma_{ij} = \begin{bmatrix} +80 & 0 & 0 \\ 0 & +45 & 0 \\ 0 & 0 & +60 \end{bmatrix} MPa$$

where compression is taken positive.

e) How would you expect the response of the quartzite to be modified by the presence of
i) randomly oriented intergranular pores, and
ii) planar microcracks lying in the plane normal to the x_1 direction?

Question 2

a) Explain what is meant by “uniaxial compressive strength” and “failure criterion”.

b) What are typical values of uniaxial compressive strengths for rocks (sed. to igneous)?

c) Write down the Coulomb criterion for shear failure of dry rock and an expression giving the orientation (angle θ) of the failure plane normal with respect to the principal compressive stress σ_1 (identify ALL terms appearing and indicate any restrictions on the value of θ).

d) The state of stress in a 50 m-thick bedded anhydrite formation overlying a reservoir sandstone (depth to top 3 km), from which natural gas is being actively produced, is estimated (from numerical modelling) to be evolving with time t (years) in the following manner:

σ_1(vertical) = 80 MPa (constant)
σ_2(North-South) = (80 – $a.t$) MPa where a = 0.3 MPa/year
σ_3(East-West) = (80 – $b.t$) MPa where b = 1.5 MPa/year

* Assuming that these relations continue to hold and that the anhydrite behaves in a brittle manner on the timescale of interest, determine when (i.e. at what value of *t*) faulting can be expected to begin in the anhydrite. Laboratory tests have shown that the anhydrite has a cohesive shear strength of 5 MPa and a coefficient of internal friction of 0.5.
* Draw a realistic geological cross section showing the orientation of the faults which are expected to form in the anhydrite, and indicate the sense of shear on the faults.
* What do you think the consequences of faulting in the anhydrite might be?

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.
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) Derive Orowan's equation for the plastic shear strain rate $d\gamma/dt$ resulting from the glide of a steady state population of mobile edge dislocations in a single crystal subjected to a shear stress τ. Hint: consider a cube of material (with edge dimension L) containing a single slip system with slip planes aligned parallel to the top and bottom of the cube.

Question 4

a) Explain in detail what is meant by the term "static recrystallization". Illustrate your answer with simple diagrams.
b) Go on to describe the process of "dynamic recrystallization" mentioning the principal end-member mechanisms and illustrating typical microstructures with simple diagrams.
c) In what geological situations is dynamic recrystallization important?
d) How can dynamically recrystallized microstructures be used to evaluate the stress and associated with the development of a major mylonitic shear zone encountered in a field study?
e) How could the stress determined in (d) then be used to estimate the strain rate in the shear zone?

Question 5

a) Explain what is meant by Byerlee's law and indicate for what portion of the continental lithosphere it is expected to apply.
b) Indicate what deformation mechanisms and constitutive equations are thought to describe the solid state flow behaviour of quartz in the mid-lower crust and of olivine in the upper mantle.
c) Explain how you would construct a strength profile for a section of continental lithosphere assuming a uniform extensional strain rate of say 10^{-14} s^{-1}?
d) How and why would this profile become modified if extension were to be concentrated into a localized shear zone making up 1% of the width of the section considered?

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, 12 March, 17.00. Assemble in the onderwijshal and I will meet you there. CHRIS