Examination Paper: GEO3-1302

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

29-01-2009, 13.00-16.00 hours
Room C.008, Earth Sciences Building

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

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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) Define the quantities "Young's Modulus", "Poisson's Ratio" and "Shear Modulus" used to specify the elastic behaviour of isotropic materials.

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

e) Use these equations plus your general knowledge about the order of magnitude of the elastic stiffness of rock to estimate the strains undergone by a cube of granite (Poisson's ratio 0.3) subjected to a stress state defined σ_1 = +30 MPa, σ_2 = 0 and σ_3 = -30 MPa. Illustrate your answer with a simple diagram. (N.B. Take compressive stress as positive).

Question 2

a) Write down the Coulomb criterion for shear failure of dry isotropic rock and an expression giving the orientation of the failure plane normal. (N.B. identify all terms appearing and indicate any restrictions on the orientation of the failure plane).

b) Show how the Coulomb criterion is represented in a Mohr diagram for 2-D stress, and write down the 2-D stress equations for the normal and shear stresses on an arbitrary plane.

c) Show how the Coulomb criterion is modified when pore fluid is present at a pressure P_f.

d) Production of natural gas from a 50m-thick sandstone reservoir (depth-to-top given h = 2500 m) leads to changes in the local stress state and hence to the development of small normal faults in the reservoir. This results in minor sesmicity located in the uppermost part of the reservoir formation (i.e. at h = 2500 m). The gas pressure in the reservoir at the moment the earthquakes started was 15 MPa.

- If the strength of the fault rock is characterized by a cohesive shear strength of 6 MPa and a coefficient of internal friction of 0.5, calculate the principal stress difference (σ_1 - σ_3) associated with the triggering of the seismic activity associated with normal faulting.

- Comment on possible consequences of production-induced faulting

Hint: assume that σ_1 at the hypocentre was near vertical and approximately equal to the overburden pressure (ρgh). Take the density (ρ) of the overburden to be 2500 kg/m^3 and g = 10 ms^{-2}.

Question 3

a) Draw a 2-D diagram of an edge dislocation in a simple cubic structure, showing the Burgers vector and the directions of glide and climb motion.

b) Explain what is meant by the terms
(i) slip system
(ii) Schmid factor
(iii) critical resolved shear stress (CRSS).
(iv) dislocation self-energy

c) In an unstressed crystal, a straight segment of edge dislocation is pinned between two obstacles, separated by a distance L, lying in the dislocation slip plane. In the region between the obstacles, the dislocation can glide in its slip plane. Explain how this configuration can act as a so-called Frank-Read source of dislocations (use diagrams). Be as quantitative as you can in your answer!

d) Building upon your answer to (c), obtain an equation for the critical shear stress required to activate a Frank-Read source, stating what equilibrium condition this equation represents. Use this equation and background knowledge obtained from the course to estimate the yield stress of a crystal containing pinned dislocation segments of length L = 10 μm.

Question 4

a) Explain what is meant by the term steady state creep (= steady state flow), illustrating your answer with sketches of stress-strain and strain-time diagrams.

b) List the main mechanisms by which steady-state creep can occur in rock materials, and describe the mechanical characteristics (i.e. the flow behaviour) and microscale nature of each mechanism. Be as quantitative as you can in your answer.

c) Go on to explain the concept of the deformation mechanism map, illustrating your answer with a <u>schematic</u> <u>labelled</u> <u>diagram</u>.

d) Explain how such a map is constructed and explain the significance of the field boundaries.

<u>Question 5</u>

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

b) Indicate what deformation mechanisms and <u>what</u> <u>type</u> 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 <u>laboratory</u> <u>equations</u> for the ductile flow behaviour of wet quartz and wet olivine, <u>list the steps</u> that you would take to construct a strength profile for a section of continental lithosphere assuming a quartz dominated crust and an olivine dominated upper mantle. For each step listed, indicate the additional assumptions made.

d) Sketch the form of the strength profile that you would expect to obtain, and explain the main problems 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 16 February, 17.00. Assemble in the onderwijshal and I will meet you there.

CHRIS