Examination Paper: GEO3-1302

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

29-01-2008, 13.00-16.00, Room C.008/010

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 stress-strain relations for an isotropic elastic solid are often written in the form:

$$\varepsilon_1 = \frac{\nu}{E}\left[\frac{\sigma_1}{\nu} - \sigma_2 - \sigma_3\right] \quad \varepsilon_2 = \frac{\nu}{E}\left[\frac{\sigma_2}{\nu} - \sigma_1 - \sigma_3\right] \quad \varepsilon_3 = \frac{\nu}{E}\left[\frac{\sigma_3}{\nu} - \sigma_1 - \sigma_2\right]$$

Define all symbols appearing in these equations, illustrating your definitions of E and ν with appropriate diagrams.

d) Use the above stress-strain relations to derive equations describing how the principal stresses will change in a stress-free granite erosion surface that gets buried to a depth h in a filling basin. Assume that the maximum principal stress (σ_1) is vertical and equal to the overburden pressure ($\rho g h$) during burial, and that the lateral strains ($\varepsilon_2, \varepsilon_3$) are always zero (i.e. that the rock does not spread sideways as it becomes buried).

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 any 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 20 MPa.

i) 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.

ii) Comment on possible consequences of production-induced faulting.

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

Question 3

a) Draw a 2-D diagram of an edge dislocation in a simple cubic structure. Label all of the important vectors, directions and planes associated with the dislocations and their glide and climb motion. Add a rough scale bar also.
b) Explain what is meant by the terms **i)** slip system, **ii)** Schmid factor, **iii)** critical resolved shear stress (CRSS) and **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 condition relates to the plastic yield behaviour of 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 creep" (= steady state flow), illustrating your answer with sketches of stress-strain and strain-time diagrams.
b) What are the similarities and differences between the steady state flow of rock materials and the flow of a Newtonian fluid.
c) List the main mechanisms by which steady-state creep can occur in rock materials, describing the mechanical characteristics and microscale nature of each mechanism.
d) Go on to explain the concept of the deformation mechanism map, illustrating your answer with a schematic labelled diagram.

Question 5

a) Write down and explain what is meant by Byerlee's law, defining all symbols appearing.
b) Indicate what type of deformation mechanisms and constitutive equations are thought to describe homogeneous (non-localized) flow of quartz in the mid-lower crust and of olivine in the upper mantle.
c) List in detail the steps you would take to construct a strength profile for a section of continental lithosphere assuming a uniform extensional strain rate of say 5×10^{-15} s^{-1}? For each step you list, indicate any additional assumptions made and whether you think these are reliable or not.
d) How and why might this profile, and the assumed constitutive equations, become modified if extension were to be concentrated into a localized shear zone making up 1% of the width of the section considered?

HPT Lab Tour and Beer/Tequilla 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 Tuesday 19 February, 17.00. Assemble in the onderwijshal and I will meet you there. CHRIS