Resit Examination Paper: GEO3-1302

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

10-03-2016, **17.00-19.30**, Unnik 204

Note: an extra half hour is available to students who have registered special needs in advance

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N.B.
- This exam paper consists of 5 questions. **Answer 4 of the 5 questions.**
- Take 35-40 minutes to answer each question; each question carries equal points
- Answer in English or in Dutch
- Identify all mathematical symbols you use
- If you do not understand the English used in a question, raise your hand for help

Tip: - Read the questions carefully and answer what is asked. Check answers before leaving!

Good Luck!!!

Question 1

a) Describe the essential characteristics of the elastic behaviour of dry rock, illustrating your answer with sketches of i) stress-strain and ii) strain-time diagrams.

b) The elastic response of isotropic, porous rock containing a pore fluid at pressure P_f is given by the "poro-elastic" equation

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

where σ_{ij} and ε_{ij} represent the states of stress and strain respectively. Define the quantities G, K, K_g, δ_{ij} and σ_{kk} **fully.**

c) An isotropic reservoir sandstone located at 3 km depth in a large, new gasfield, experiences a state of total compressive stress defined by the tensor

$$\sigma_{ij} = \begin{pmatrix} 65 & 0 & 0 \\ 0 & 40 & 0 \\ 0 & 0 & 40 \end{pmatrix} MPa$$

where σ_{11} is the vertical stress and $\sigma_{22} = \sigma_{33}$ are the horizontal stresses. The gas pressure in the reservoir before production is 35 MPa. Assuming that the stress state remains constant, and taking G = 5 GPa, K = 10 GPa and K_g = 50 GPa, use the poro-elastic equation to calculate the **change** in the state of poro-elastic strain in the reservoir if the pore fluid pressure is reduced by gas production to 2 MPa.

d) If the reservoir is 150 m thick, estimate the displacement of the reservoir top and hence the surface subsidence that would accompany the above reduction in gas pressure due to poro-elastic deformation.

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.

p.t.o.

c) Seismic events in an area of regional tectonic compression indicate reactivation of healed thrust faults at a depth of $h \approx 5000$ 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 cohesive shear strength of 5 MPa and a coefficient of internal friction of 6/10, 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 tend to be smaller or bigger in magnitude?

Question 3

a) Draw simple diagrams illustrating the key features of an edge dislocation.

b) Define the term "dislocation self-energy" and "dislocation density".

c) 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 write down the equilibrium condition required to activate such a source.

e) If a population of Frank-Read sources in a stressed crystal is emitting dislocations in a fixed density and moving at a fixed average velocity, what will the strain rate be?

Question 4

a) Explain what is meant by the term steady state creep, 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 crystalline materials, indicating the essential characteristics of each mechanism.

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

d) What is the significance of the field boundaries in a deformation mechanism map?

e) Assuming deformation at geological strain rates, how would you use a deformation mechanism map to estimate the flow behaviour of an olivine mylonite, which contains specific minerals that define the temperature during deformation?

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 rule and laboratory equations for the 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 at a uniform strain rate of say 10^{-15} s^{-1}.

d) Identify and explain one key probelm that you see in the classical approach to constructing a lithospheric strength profile.

Beer Awards Borrel: New date to be announced soon via Blackboard
CHRIS

intergranular stress.

grain boundary sliding

Thermal vibrations