GEO4-1410, Deformation Mechanisms and Transport in Rocks.

Tentamen:

Transport and Effects of Fluids

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Instructions:

- Read all questions through, thoroughly, before answering.
- Answer question **1** plus any **3** from the remaining questions, (*i.e.* answer a total of **4** questions, including question **1**).
- Clearly label your answers with the question number.
- Use S.I. units, unless stated otherwise.
- Show any calculation steps clearly and use annotated diagrams where appropriate.
- Write your name clearly on each separate answer sheet.
- Duration of examination: 3 hours

Questions:

1.

a) In geological formations, what processes can drive fluid flow through porous rock? Where can fluid be stored or sourced? Give examples of such sources and sinks.

b) Write Darcy's law in terms of hydraulic head, hydraulic conductivity and specific discharge (Darcy velocity) and state the units of each parameter? Give the relation between hydraulic conductivity and permeability.

c) What are the requirements for Darcy's law to be valid as a description of fluid-flow in porous media? In what geological settings are validity problems likely to be encountered and why?

d) A rock has a permeability of 3×10^{-16} m^2 to water with dynamic viscosity 1 mPa.s. What will the permeability of this rock be to oil with a higher viscosity of 10mPa.s and lower density of 800kg.m^{-3}?

* e) What relation is often used, in models of porous media, to link local flow velocities at the grain scale to macroscopic bulk flows as described by Darcy's law?

f) What laboratory methods could be used to measure the low permeability ($<10^{-18}$ m^2) expected for reservoir-caprock seals and underground formations suitable for hazardous waste containment? What are the advantages of these methods over simple steady state Darcy flow-through determinations?

g) Show the general structure of the permeability tensor for both an isotropic and an anisotropic porous medium, giving geological examples of each medium.

h) What is meant by the term representative elementary volume (REV), in descriptions of transport properties used for thermo-hydro-mechanical-chemical modelling?

i) Define tortuosity. What role does tortuosity play in the formulation of Darcy's law from simple models of connected microscopic flow elements (capillaries, etc.)?

j) Why is the degree of connectivity taken to be more important than tortuosity in explanation of the critical permeability versus porosity behaviour seen in poorly connected, low permeability, materials?

2.

a) What modern geometrical theory may be applied to poorly connected systems and how does it help with estimates of permeability?
b) What tests can be applied to systems of poorly connected elements of transport paths to estimate their degree of connectivity?
c) What is a fractal object?
d) The probable strength (P) and rate of growth of through-connection for site or bond clusters in percolation, by random addition of sites or bonds at occupation-probability p, is given by critical-growth power laws such as $P = (p\text{-}p_c)^\beta$, just above the percolation limit p_c. For "2D" percolation systems $\beta = 5/36$. The sizes of percolation clusters S_∞, near the percolation threshold, grow as $S_\infty \propto L^D$. Where D = 91/48 for "2D" percolation systems and L is the length scale of interest. What are the important properties of percolating systems near the percolation limit which could explain why maps of fracture systems in some hydrothermal fields often exhibit fractal geometry with fractal dimensions in the range 1.8-1.9? Why should the geometry of hydro-fractures be determined by their connectivity?
e) Explain, by listing the process steps and connections, how the dehydration rate of certain rocks, that undergo prograde thermal metamorphism, may be used to estimate the time to failure by hydrofracture and thus to formation of mineral veins.

3.

a) Show how pore fluid pressure affects shear failure of porous rocks by change of effective stress. Use Mohr diagrams to illustrate this.
b) How are rock pore fluid pressure "lambda" values defined? How can strength profiles for the lithosphere be affected by these lambda values?
c) Why do thrust faults generally occur deeper in major fault systems than normal faults?
*d) What parameters control the surface slope angle of accretionary wedges at convergent plate margins and what are their individual effects?
e) How can gravity-driven sliding of regional scale rock units occur on low angle slopes of less than 5°, when the angle of friction for most dry crustal materials is greater than 30°? Which scientists solved this problem in the 1950's?

4.

a) What are seismic pumping and fault valve behaviour?
b) At what stage in a seismic faulting cycle are extensional veins likely to form? Describe the geometry of extensional veins that are associated with thrust faulting.
c) What processes give rise to crack-seal veins?
d) How can fluid flow be maintained in fractures that have a natural tendency to close at deep crustal levels?
e) Why do deep crustal rocks, in orogenic metamorphic belts, often show evidence for very high integrated fluid fluxes whilst their permeability is too low for pore-fluid recycling by convection and must only allow single-pass fluid expulsion?

5.

a) Explain why the bulk physical properties of fluids may not be applicable to thin films and narrow pores in deeper meta-sedimentary rocks. What are the consequences of these different fluid properties for deformation process models?
b) What is a supercritical fluid and explain the significance of aqueous fluid phase properties for quartz transport and precipitation?
c) What is disjoining pressure and where would it be likely to be encountered in rock deformation processes?
d) What can equilibrium pore geometry and fluid/rock dihedral angle studies tell us about permeable connectivity in deep crustal rocks and to what degree can laboratory measurements of permeability, on such texturally equilibrated rocks, provide us with values of permeability associated with past deformation and metamorphism?
e) What other methods can be used to determine the fluid transport properties of porous rocks besides direct permeability measurement?

6.

a) What are the stages of progressive hydration after fracture of a quartz crystal in a humid environment? Illustrate your answer with a diagram of surface energy versus hydration.
b) Why should the ionic concentration of a hydrous solution affect the ease of crack formation in stressed rock samples submerged in the solution?
c) Describe three limitations to sub-critical crack growth that relate to the fluid transport properties of the host material and the crack-filling-fluid properties.
d) How could changes in pore fluid pressure that accompany earthquakes lead to changes in telluric currents monitored by geophysical electrical potential surveys?
e) What other property of fluid filled fractures, associated with earthquake faults, could be utilized as an earthquake prediction tool using long term seismic monitoring?