Structural Analysis of Deformed rocks (GEO4-1411) --- Exam 02-02-2006

Time: 09.00 – 12.00 hr.
Place: AW – C.108

Answer 4 out of the 5 questions (make your own choice)

Please read carefully!

Question 1 – On inhomogeneous and homogeneous deformation of rocks

Geologists more often have to deal with multilayers (e.g. sedimentary sequences) than with single layers (e.g. dykes in a massive host rock). Various theories (e.g. 'Biot') exist that constrain the first increment of buckling of a multilayer.

a) Give a short overview *and explanation* of the factors that may control wavelength in a multilayer. Make sure you indicate what is meant with 'multilayer' and, if possible, use theoretical relationships to underpin your answer.

In a recent MSc project of a Utrecht student, so-called flanking structures have been studied. These are deflections (folds) of foliations of a rock against the margin of a cross cutting element like a vein or fault. Their geometry depends, amongst others, on the vorticity of flow. For one of the experiments, the following Velocity Gradient Tensor **L** has been defined to describe the deformation, assuming bulk homogeneous flow.

$$\mathbf{L} = \begin{pmatrix} 2x10^{-8} & -3x10^{-8} \\ -7x10^{-8} & -2x10^{-8} \end{pmatrix} \quad [s^{-1}]$$

b) Explain briefly what is meant with vorticity of flow and what the difference is with the kinematic vorticity number.

c) Make a Mohr circle representation of L. Label all axes and explain what the intersections of the Mohr circle and the axes mean. Also, determine the mean instantaneous stretching rate and the kinematic vorticity number.

d) Fig. 1.1 (next page) is a drawing of the bulk flow pattern describing the experiment. Is L the correct tensor for this flow pattern? Give arguments.

e) (bonus question) If you would have to give one *general* comment on the use of a Velocity Gradient Tensor in a study of folds, what would it be?

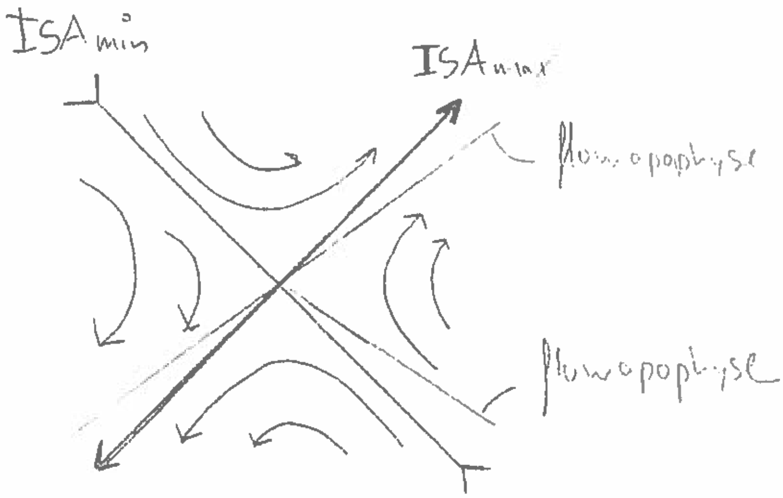


Fig. 1.1

<u>Question 2</u> – On mechanical instabilities and structure development

a) Geological structures are an expression of non-uniform deformation. From this starting point, list the main factors that can lead to geological structure development within a deforming rock mass. Illustrate each factor that you list with a simple diagrammatic example.

b) Explain the essential characteristics of an unstable deformation process and explain why rock materials with a non-linear rheology are more prone to localized deformation than those with a near Newtonian rheology.

c) Use the concept of 'positive feedback' to outline different ways in which ductile shear zones can dynamically localize in a deforming rock mass.

<u>Question 3</u> On paleostress Analysis

a) Explain in some detail what the basic assumptions are behind stress analysis using fault slip data. Be sure to include the role of the 'stress shape ratio' in your answer.

b) You are given the task to analyse the stress history of calcite rocks that are now exposed at the surface, but that have been buried more than 15 km at one point during their evolution. Present a plan of your approach to the project; what to look for in the field or under the microscope, what approach to follow in the data analysis?

Q3 continued

c) Give a general overview of the pros and cons ('voors en tegens') of determining stress using dislocation densities.

Fig. 3.1 (from Stipp *et al.*, 2002) shows flow stresses calculated from recrystallized grain sizes (natural quartzites deformed at known temperature *T*) using different piezometric relations (laboratory calibrated). GBM, SGR and BLG refer to different recrystallization mechanisms.

d) Give a summary of the various ways in which the diagram can be interpreted. Start by explaining what a recrystallized grain size – stress piezometer is.

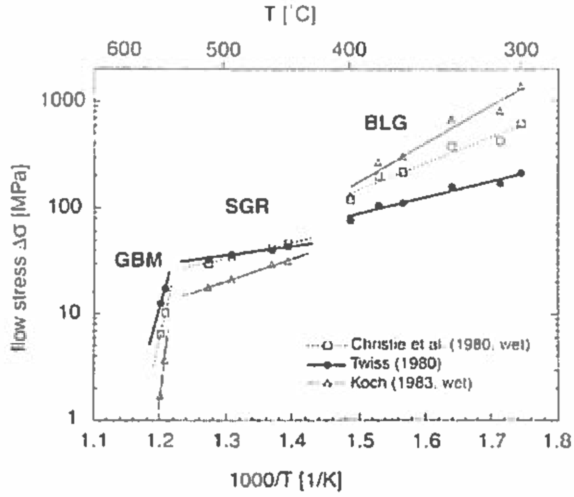
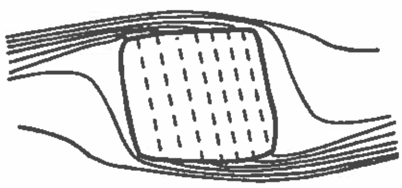


Fig. 3.1

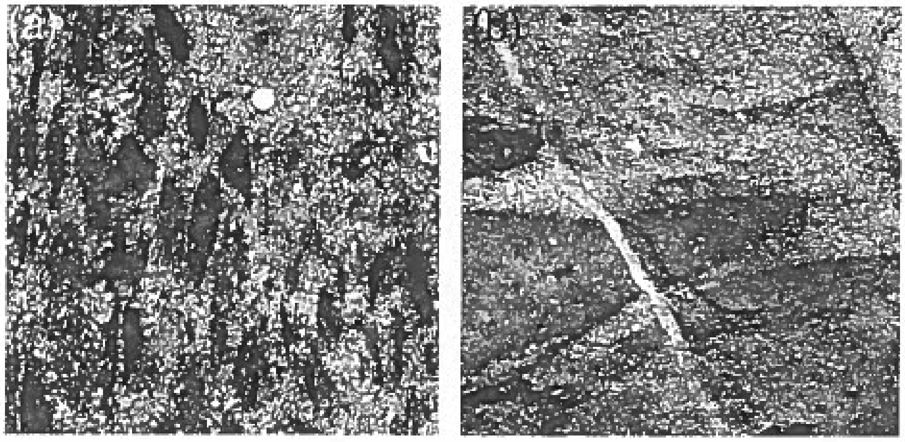
Question 4 On the analysis of tectonic and thermal histories.

a) Describe two ways that a spiral inclusion pattern can be developed in a garnet porphyroblast.

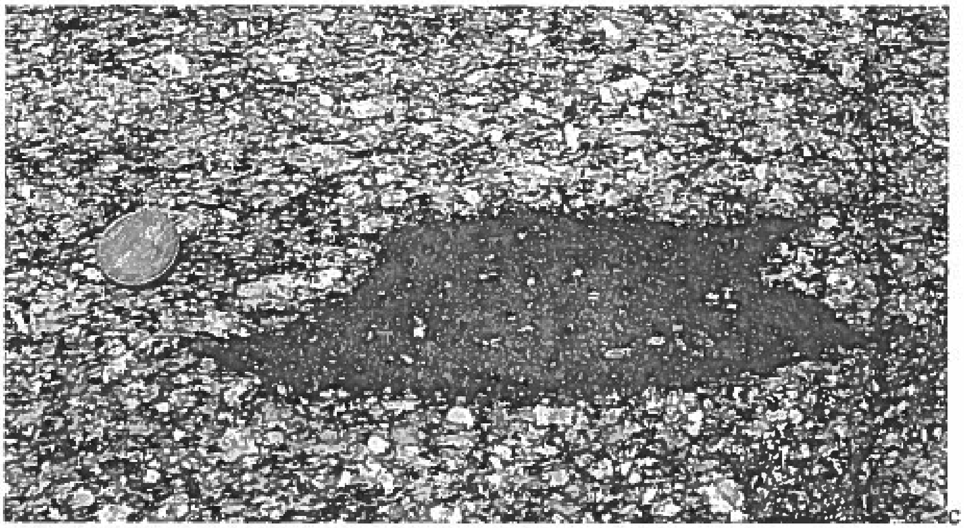
b) The image below shows the internal foliation in a porphyroblast and the external foliation. What information does this geometry give about the shear sense during deformation and the timing of mineral growth with respect to the deformation history?



c) How can foliations produced by magmatic flow be distinguished from foliations produced by sub-solidus deformation? The images below shows field photographs of structures in the Rosas granodiorite. Are the structures formed by magmatic or sub-solidus deformation? Note that the white aplite dykes are formed late in the crystallization of the granodiorite.



a&b



c

d

d) Many terranes of basement rocks contain structures formed during several phases or deformation events. For example in the Moine schists of NW Scotland four deformation phases can be reconized on the basis of overprinting relationships. Is it reasonable to correlate every "deformation phase" found on the outcrop scale with crustal scale tectonic processes such as collision or terrane accretion?

Question 5 - On Structural Analysis of Long-Lived deformation zones.

a) What criteria are used to describe different types of fault-zone rocks? What type of fault rocks are shown in the images below and what deformation processes are involved in the formation of these fault rocks?

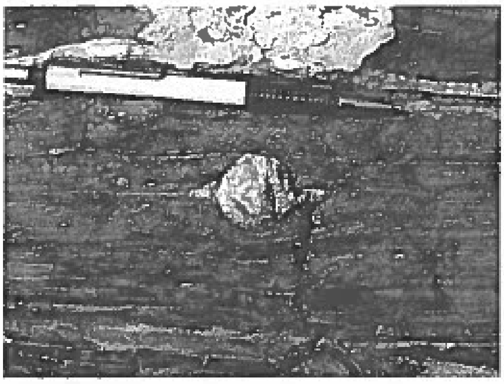


Figure 5a-1

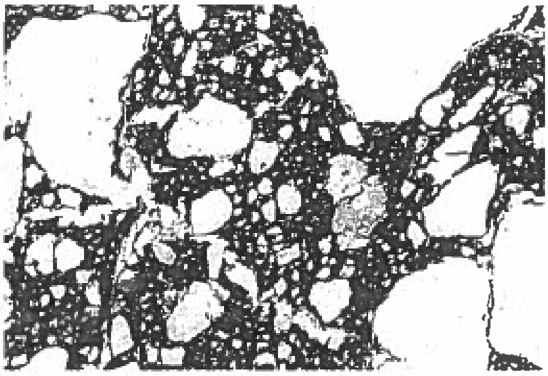


Figure 5a-2 (light microscope image)

b) Describe the structure of a typical exhumed thrust fault zone, such as the Outer Isles Thrust in NW Scotland or the Alpine fault zone in New Zealand. Discuss how these exhumed sections have been used to develop a model for the depth structure of major crustal fault zones.

c) How can episodes of fault zone re-activation be recognized from field and other types of data?

d) How can the shear sense within upper mantle shear zones exposed in orogenic peridotites of ophiolites be determined? (Note that at high temperature T> 1000°C the easy slip system in olivine is [100](010), i.e. slip in the [100] direction on the (010) plane).