Structural Analysis of Deformed Rocks (GEO4-1411) - Exam 30-01-2007

Time: 14.00 – 17.00 hr.
Place: AW – C.008

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

Please read carefully!

Question 1 – On Flow in Rocks

a) Flow parameters for deformed rocks can be reconstructed on the basis of vein systems, if present. Give a summary of what is needed in terms of observations (what do you need?) and assumptions (what do you *have* to assume?) in order to come to a successful analysis.

After a lot of work, geologists from Utrecht concluded that the flow of granites with pegmatite veins near Albanchez, southern Spain, can best be described by the following Velocity Gradient Tensor **L**:

$$\mathbf{L} = \begin{pmatrix} 2x10^{-13} & -3x10^{-13} \\ -7x10^{-13} & -2x10^{-13} \end{pmatrix} \quad [s^{-1}]$$

b) Explain briefly what is meant with the i) kinematic vorticity number and ii) the dilatancy number.

c) Make a Mohr circle representation of **L**. Carefully (!) 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) On the right (Fig. 1.1), a drawing is given of the bulk flow pattern belonging to **L**, according to the Albanchez researchers. Were they right? Explain your answer.

e) Dream up a sketch of the exposure of the granite, with appropriate orientation and geometry of the veins. Make sure the result is, at least to a first order, in agreement with your answers above.

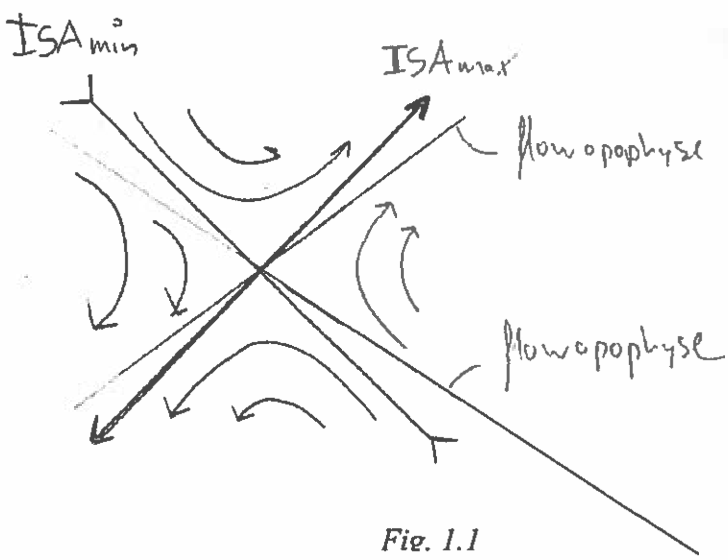


Fig. 1.1

Question 2 On the Analysis of Layered Rocks

a) Fig. 2.1 shows structures in phyllitic/silty rocks at Trearddur Bay, Anglesey, North Wales. Give a high-quality description of what you observe. No interpretations!

b) Give a succinct overview *and explanation* of the factors that may, in general, control wavelength in a multiplayer like shown in Fig. 3.1. Where possible, use theoretical relationships to underpin your answer. What specific element of the rock of Fig. 3.1 is complicating an analysis of wavelengths?

c) Let's assume the deformation temperature was sufficiently high to allow plastic deformation to occur during folding. What could you do to obtain an estimate of the stress magnitude during deformation? Explain and be critical!

d) The layers in the folded structure do not show cleavage refraction. In general, however, cleavage refraction can give quantitative information on viscosities (Treagus, 1998), if present: i) How does that work? and ii) why would it have been problematic in the case of Fig. 2.1, taking a) and c) into account?

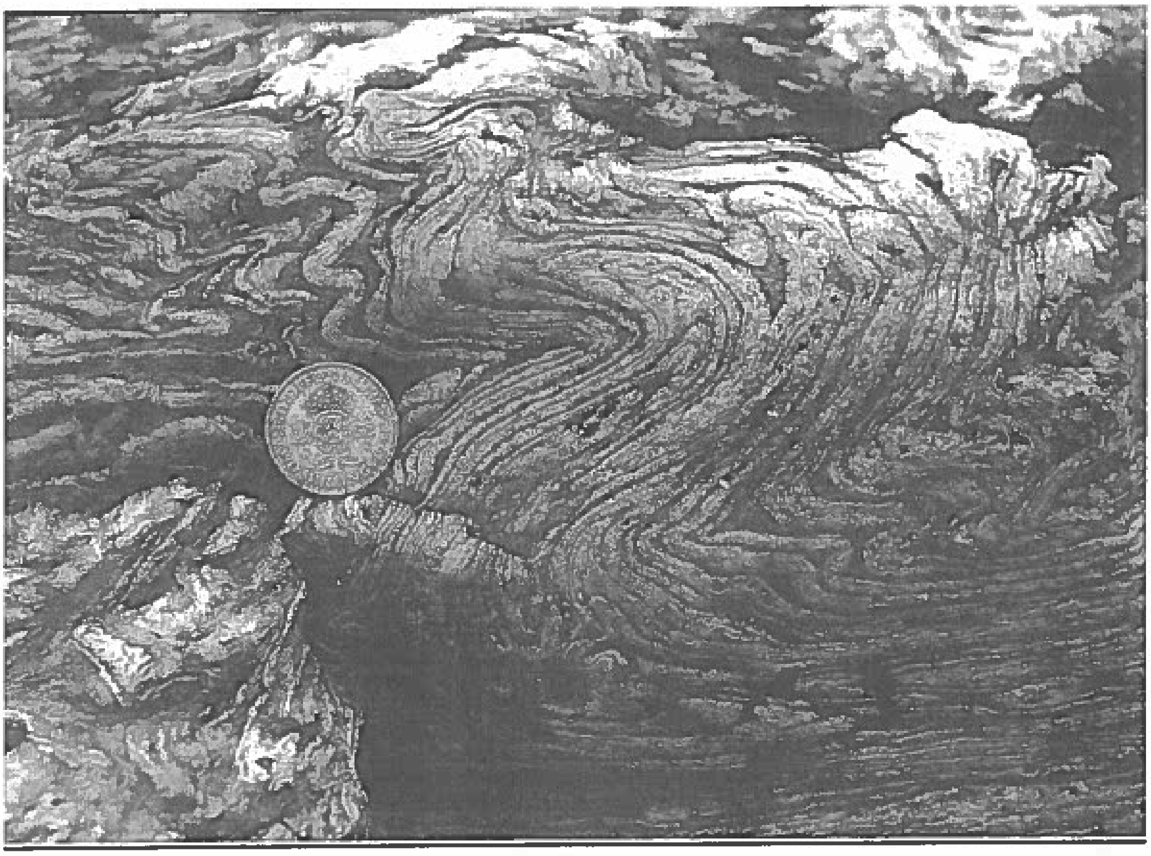


Fig. 2.1 Folds in phyllites and siltstones at Trearddur Bay, Anglesey, North Wales.

<u>Question 3</u> – On Mechanical Instabilities and Structure Development

a) Explain in detail what is meant by the terms
   - unstable deformation process
   - stable deformation process
   - stability analysis

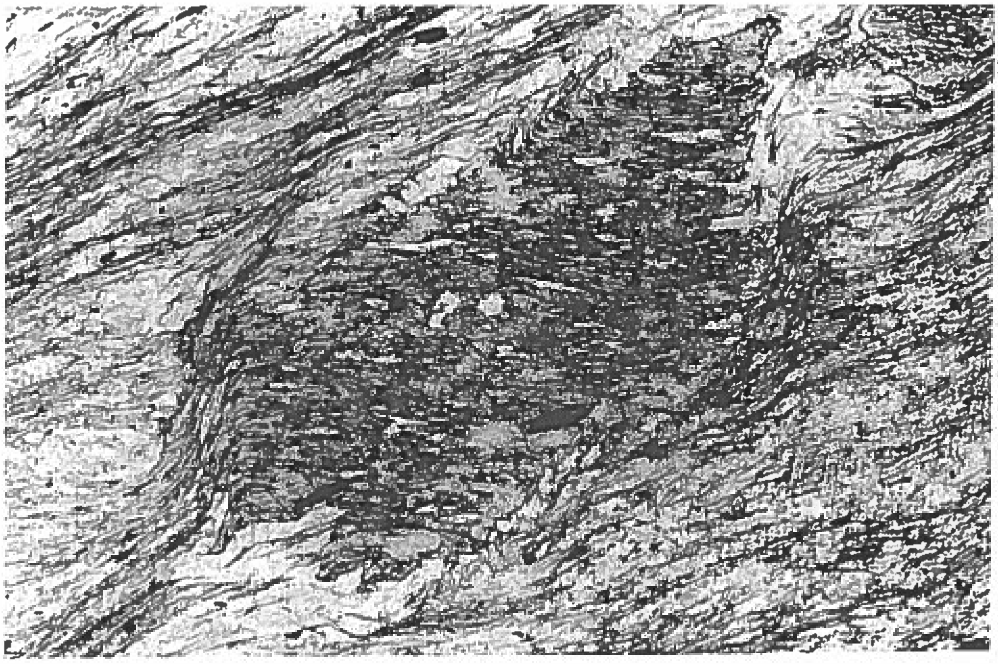
b) Explain with the aid of a feedback diagram why rock materials deforming by a dislocation creep process are expected to be more prone to localized deformation than those deforming by diffusion creep.

c) Describe the main characteristics of the following structures (illustrate with simple diagrams) and offer an explanation of how these structures can develop:
   - Pinch and swell
   - Regularly spaced diapiric salt domes

d) Define the term "ductile shear zone" from the point of view of a structural geologist working in the field.
   - Go on to use the concept of "positive feedback" to outline the different ways in which ductile shear zones can dynamically localize in a deforming rock mass.
   - What features might you look for in the field to determine how a given ductile shear zone formed (i.e. localized)?

Question 4 On the Analysis of Deformation Histories.

a) The figures below show the microstructures in and around some staurolite porphyroblasts in a sample from the Lukmanier Pass in the Pennine zone of the Alps.



Comment on the timing of staurolite growth with respect to the deformation history and discuss if there is any evidence for, or against, porphyroblast rotation (with respect to the instantaneous stretching axes of deformation) during the last deformation event?

b) In the Pennine zone of the Alps three main deformation phases can be recognised on the outcrop scale. Is it reasonable to correlate every "deformation phase" found on the outcrop scale in this example with crustal scale tectonic processes such as plate collision, nappe stacking or terrane accretion?

c) Describe how and why some deformation or recrystallization microstructures in minerals like quartz, calcite and olivine, can be used to indirectly estimate the temperature during a deformation event. Explain how the olivine recrystallized grainsize in mantle rocks can be used to distinguish deformation in the lithosphere and asthenosphere.

d) Discuss how primary fold structures formed in sedimentary basins or magmatic intrusions can be distinguished from tectonic structures formed in solid-state rocks.

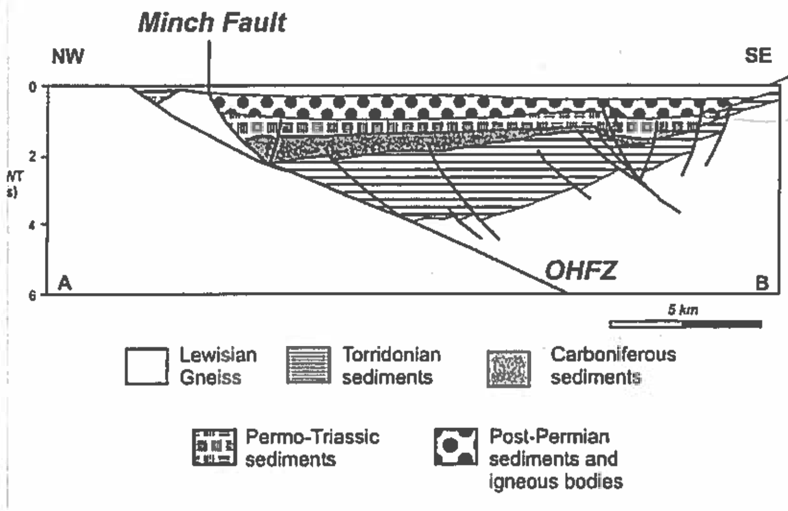
<u>Question 5</u> - On Structural Analysis of Long Lived Fault zones

a) What criteria are used to describe the different types of fault-zone rocks? What type(s) of micro-scale deformation mechanisms can result in the formation of mylonites in ductile shear zones?

b) Describe the structure of a typical exhumed thrust fault zone, such as the Outer Hebrides fault zone 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 fault zones in quartz-feldspar dominated crustal rocks.

c) The figure below shows an interpreted section of the Outer Hebrides fault zone (OHFZ) in NW Scotland based on a deep seismic reflection survey.

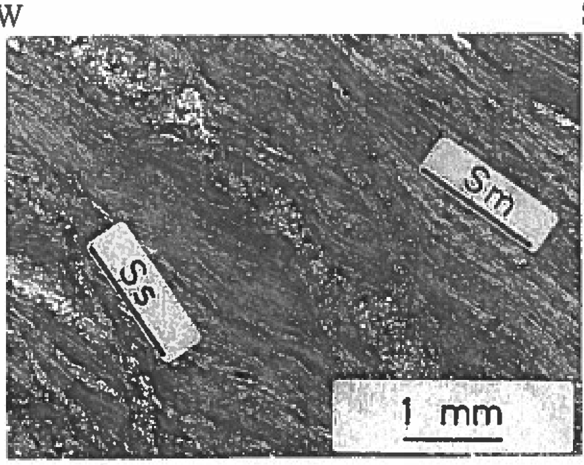
Work out a history of fault movement for the OHFZ from this section. Note the main sequence of exposed fault rocks (cataclasite, crush-breccia, mylonites) was formed between 400 to 420 Ma.



Lewisian (2.5-1.7 Ga), Torridonian (1000-750 Ma), carboniferous (360-300Ma).

An anastamosing network of phyllonites occurs within the crush breccias and mylonites of the OHFZ. The light micrograph below (from White 1998) shows a shear band foliation (Ss) and main foliation (Sm) in one of the phyllonite zones.

NW SE



What shear sense does this structure indicate and what this suggest for the timing of phyllonite formation?

d) The figure below shows a section through the St Barthelemy massif in the Pyrenees. A major shear zone is exposed in the basement rocks of the massif (the main mylonite band).

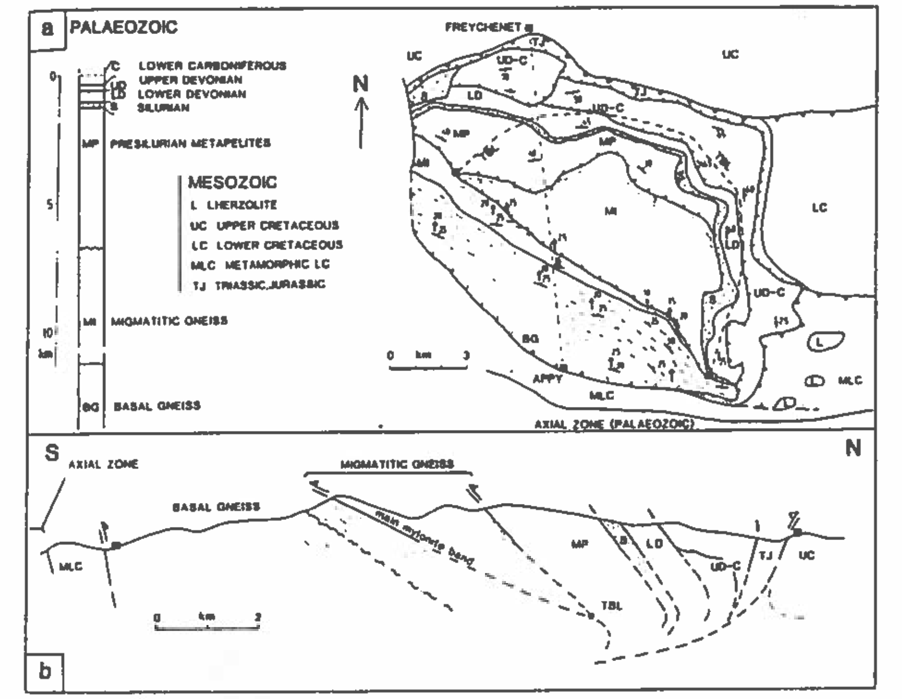
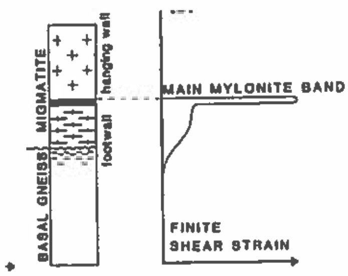


Figure 3. (a) Simplified map of the Saint-Barthélemy Massif. The lithologic column indicates thickness of units at the peak of Variscan metamorphism. TBL – trailing branchline (buried). Striping indicates extension of mylonitic deformation; open barbs: thrusts; closed barbs: tilted internal fault zone. (b) Cross-section through the massif parallel to transport direction in the mylonite zone.

An analysis of shear sense criteria in the main mylonite zone indicates a "hanging wall towards the south" shear sense. The figure below shows an exhumed section of undeformed rocks in the hanging wall and ductile mylonites in the footwall.



Is this exhumed shear zone an exhumed thrust, extensional detachment or strike slip zone?

Helpful Note: think about the original orientation of the Triassic-Jurasic sediments.....