Structural Analysis of Deformed rocks (GEO4-1411) - Exam 27-01-2009

Time: 13.00 – 16.00 hr.
Place: C.108

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

Please read carefully!

<u>Question 1</u> – On flow in rocks

Ten Grotenhuis *et al.* (2002) investigated the influence of strain localization on the rotational behaviour of rigid objects in experimental shear zones. Their laboratory set-up allowed modelling of different vorticity. See Fig. 1.1 below.

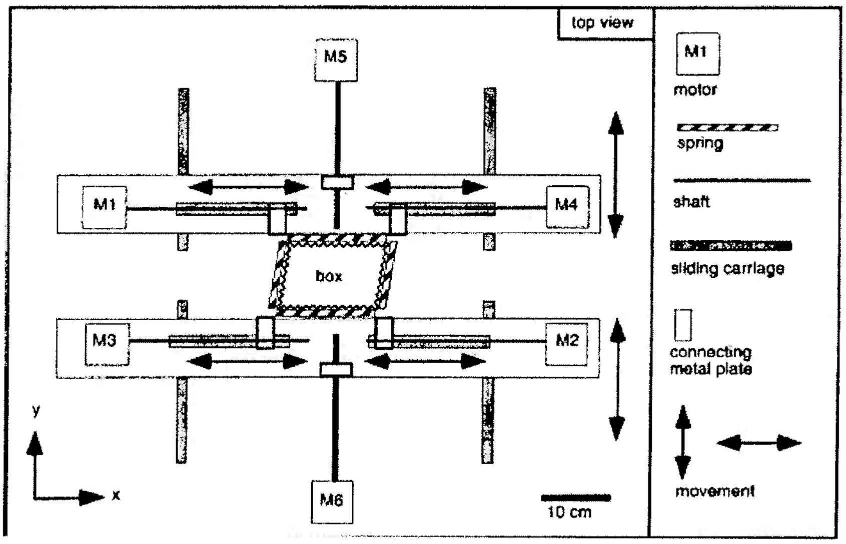


Fig. 1.1

The results of two experiments are shown In Fig. 1.2, for kinematic vorticity numbers of 1.0 (left) and 0.6 (right). The photographs are taken from the central part of the sample located within the box. Dark bands denote highest strain zones.

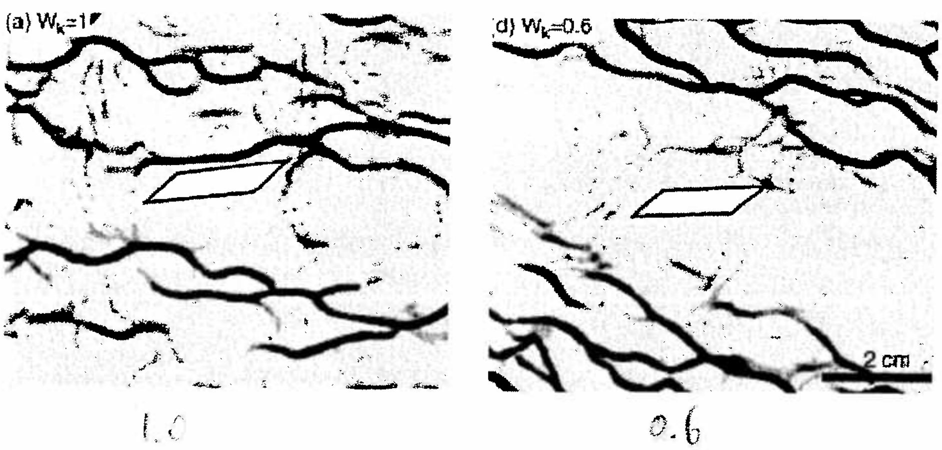


Fig. 1.2

A master student from Utrecht analysed the experimental data and photographs and came up with the following velocity gradient tensor **L** to describe the flow for the right hand photo:

$$\mathbf{L} = \begin{pmatrix} 3x10^{-6} & -1x10^{-6} \\ -8x10^{-6} & -4x10^{-6} \end{pmatrix} \quad [s^{-1}]$$

$$(a,-c) = (3,8)\cdot 10^{-6}\,s \qquad (d,b) = (-4,-1)\cdot 10^{-6}\,s$$

a) Explain in a few words what is meant with "vorticity" and what the advantage is of using the "kinematic vorticity number" rather than "vorticity".

b) Look at the set-up of Fig. 1.1. Explain how one can vary the kinematic vorticity number from one experiment to the next.

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 <u>stretching rates along the flow apophyses</u>.

d) Demonstrate whether or not tensor **L** indeed fits an experiment of the type mentioned above for a kinematic vorticity number of 0.6. Make a drawing of the bulk flow pattern corresponding to **L** to substantiate your conclusion. [tip: pay attention to the reference frame used to define **L**]

<u>Question 2</u> On the analysis of layered rocks and paleostress

a) Present a high quality description of the folded cherts of Fig. 2.1. Use appropriate terminology.

b) Give a succinct overview *and explanation* of the factors that may, in general, control wavelength in a multilayer like shown in Fig. 2.1. Where possible, use theoretical relationships to underpin your answer. What specific element of the rock of Fig. 2.1 is complicating an analysis of wavelengths?

c) Explain briefly what the basic assumptions are behind stress analysis using fault slip data. What is the role of the 'stress shape ratio' in this respect?

d) The density of dislocations in plastically deformed minerals is one of the paleostress indicators using microstructures.
   - First, explain the principle.
   - Then, give a general overview of the pros and cons ('voors en tegens' in Dutch) of determining stress using dislocation density.

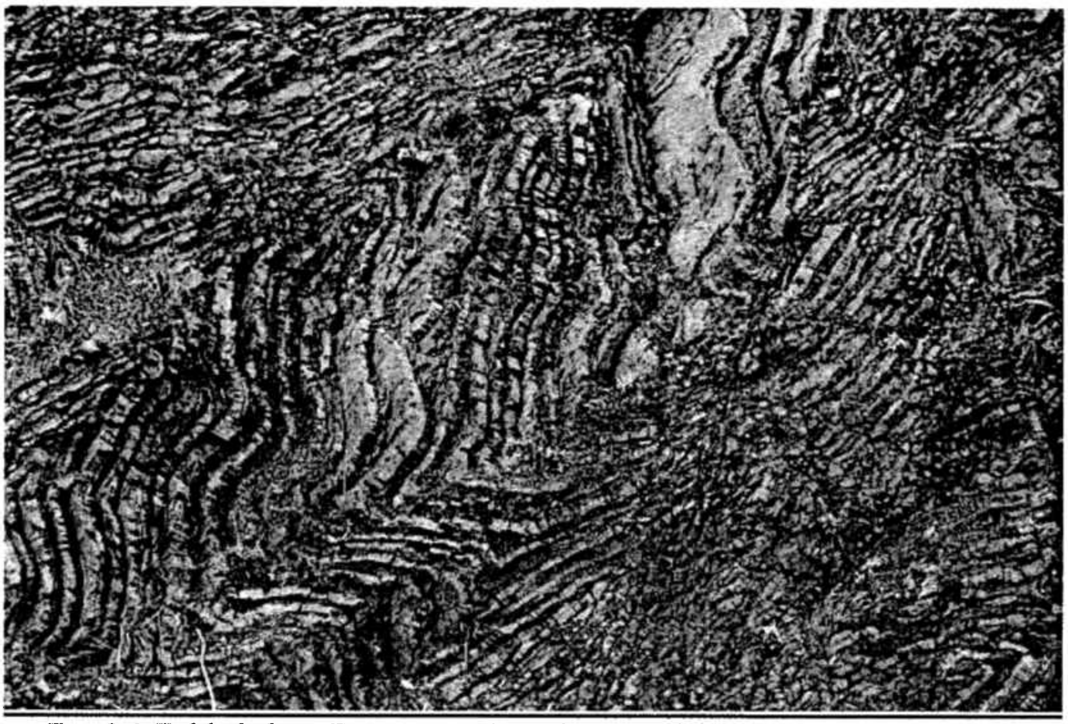


Fig. 2.1 Folded chert Franciscan Complex at California's Marin Headlands

<u>Question 3</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.

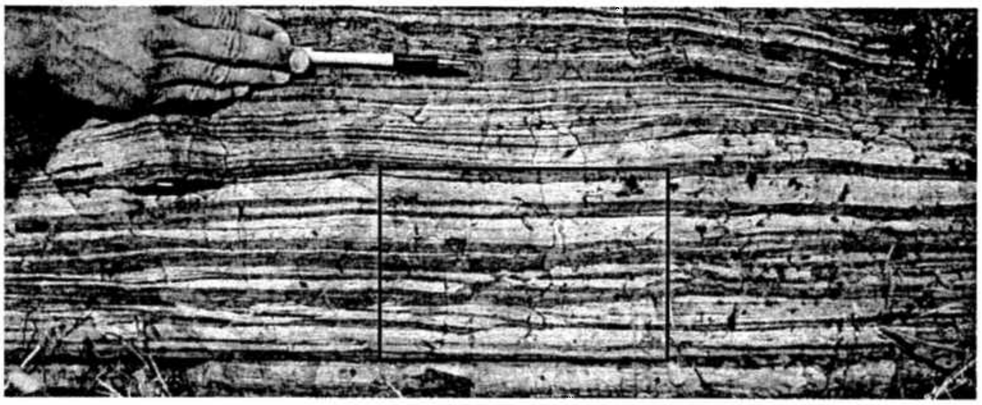
b) Explain the essential characteristics of an unstable deformation process and explain why rock materials with a non-linear rheology are more prone to highly unstable, localized deformation than those with a near Newtonian rheology.

c) Outline the ways in which the following geological structures can dynamically develop:
- Brittle faults in crystalline basement, with associated pseudotachylite veins
- Crenulation cleavage in a foliated quartz-mica rock with metamorphic segregation
- A ductile shear zone in calcite marbles, characterised by a grain size which is much finer than the surrounding, less-deformed marbles.

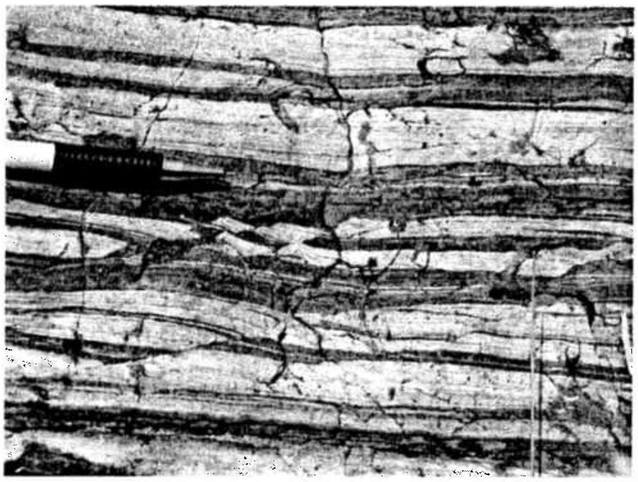
d) Explain briefly how the concept of stability analysis can be applied to assess whether the salt domes are of diapiric origin or related to tectonic deformation. Go on to list the assumptions made in applying stability analysis to salt diapirism and indicate how robust you think these assumptions are (with supporting arguments).

<u>Question 4:</u> On the analysis of Deformation Histories.

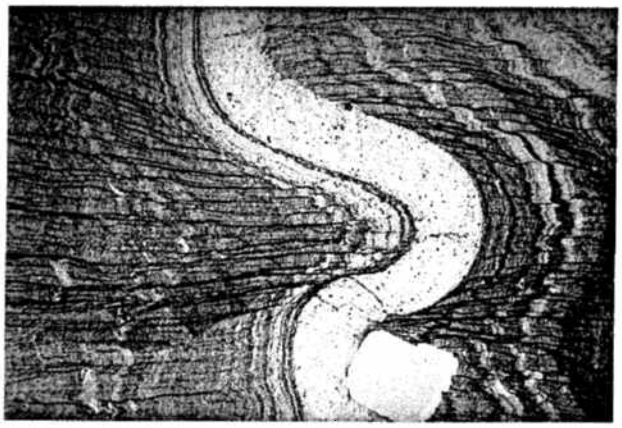
a) Shows some extensional faults in meta-sediments from the Cap de Creus area. Image a) shows an overview of the compositional layering and image and b) a close up view of the faults. Are these structures formed by "soft-sediment" deformation or by solid-state deformation?



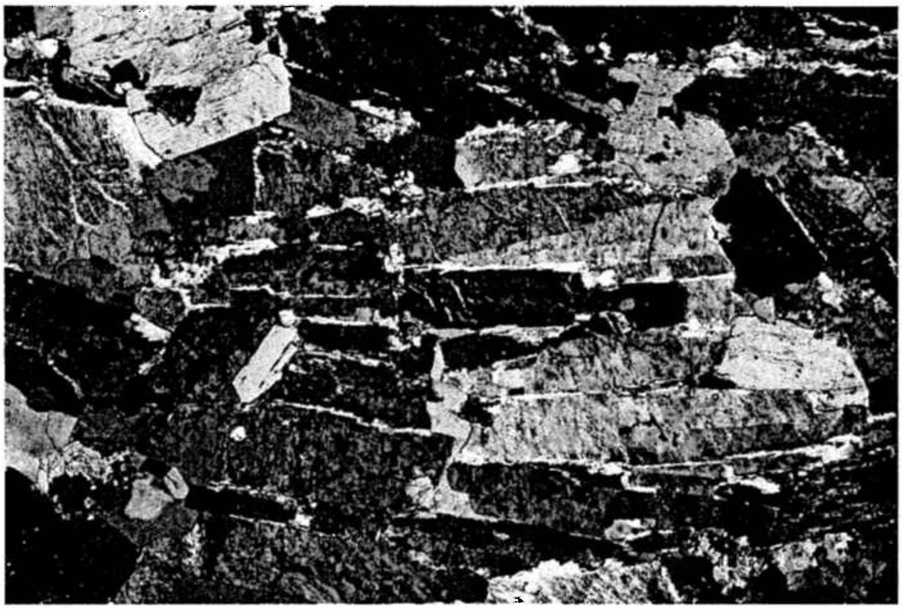
b)



c) The micrograph shows a view of a fold structure in a sedimentary rock. Is this structure formed by "soft-sediment" deformation or by solid-state deformation? What general criteria can be used to distinguish soft sediment from other structures?



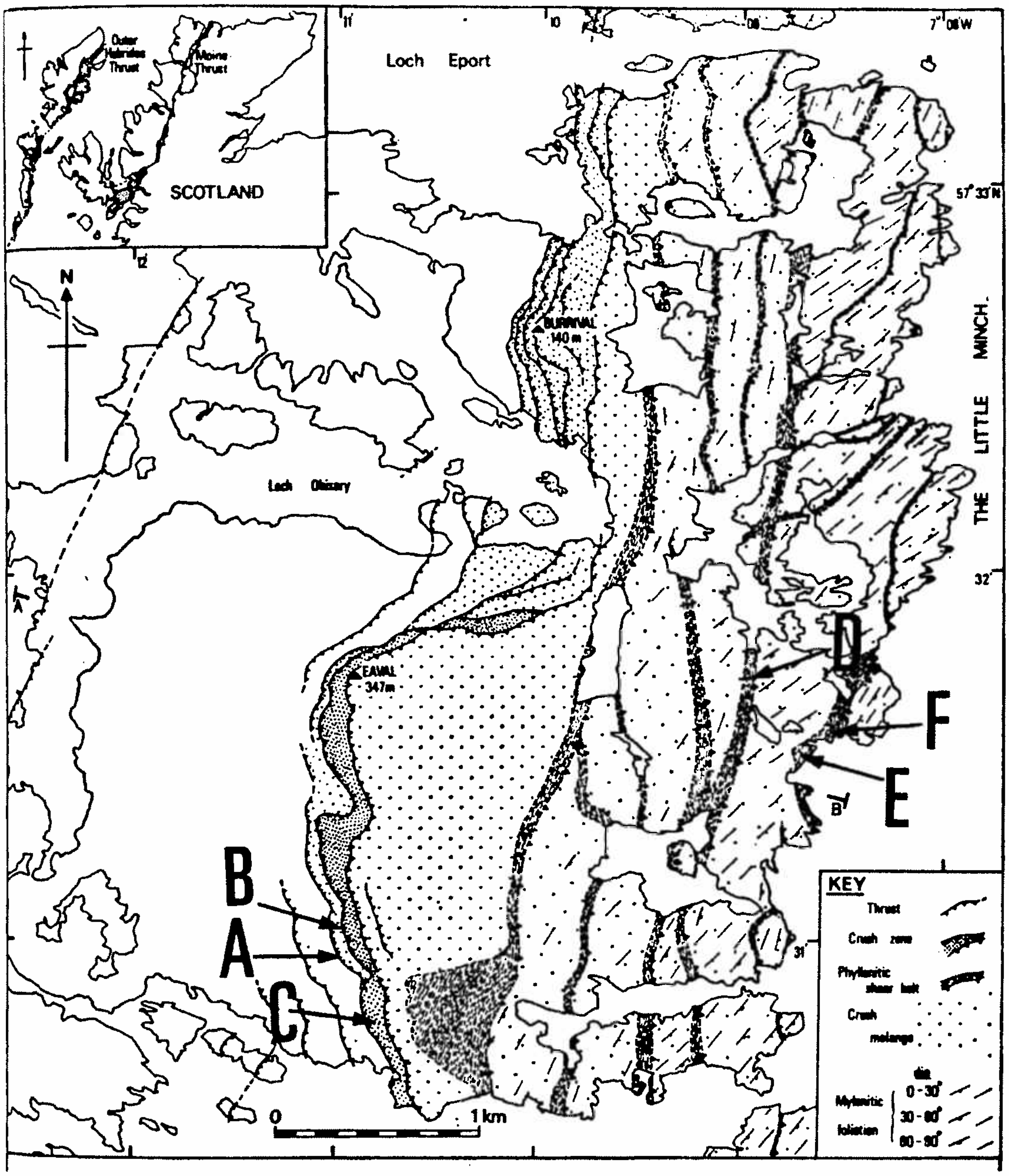
d) The micrograph shows a foliation in a quartz syentite intrusion from Brazil. Is this a magmatic, sub-magmatic or solid-state foliation?



e) The micrograph shows staurolite porphyroblasts in a schist from the Lukmanier pass, Switzerland. Describe the development of the microstructure and the timing of staurolite growth and deformation. Evidence of two deformation phases can be seen in the image. Can deformation events identified at thin section or outcrop scale be up-scaled to work out the tectonic history of the crust?

Question 5 - **On Structural Analysis of crustal and mantle terranes**

a) The map from Sibson (1977) shows exhumed fault rocks exposed at the Outer Hebrides Fault zone, in NW Scotland. Draw a sketch cross section of this structure and describe the model for crustal shear zones that is partly based on such exhumed structures.

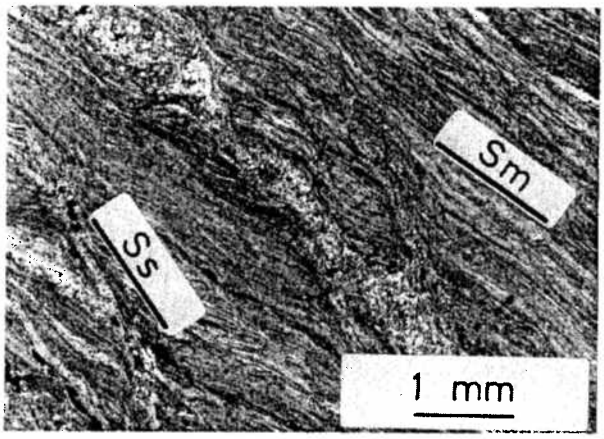


b) Subsequent studies have found new information that suggests a more complex history for the OHFZ. Use the information below to work out the movement history of this exhumed crustal fault zone.

i) The mylonites have down-dip stretching lineations (azimuth SE), while the phyllonite belts have horizontal lineations (azimuth N) parallel to the foliation strike.

ii) As shown in the image below, phyllonite zones in the western part of the exhumed section overprint the crush melange.

iii) As shown below, the phyllonites have extensional crenulation cleavages (Ss) that overprint the phylonite foliation (Sm). Ss dips more steeply to the east that Ss.



iv) Deep seismic reflection surveys show that the OHFZ acts as a bounding fault to several sedimentary sequences in the Minch basin. Lewisian (2.5-1.7 Ga), Torridonian (1000-750 Ma), carboniferous (360-300Ma).