Structural Analysis of Deformed rocks (GEO4-1411) - Exam 30-01-2012

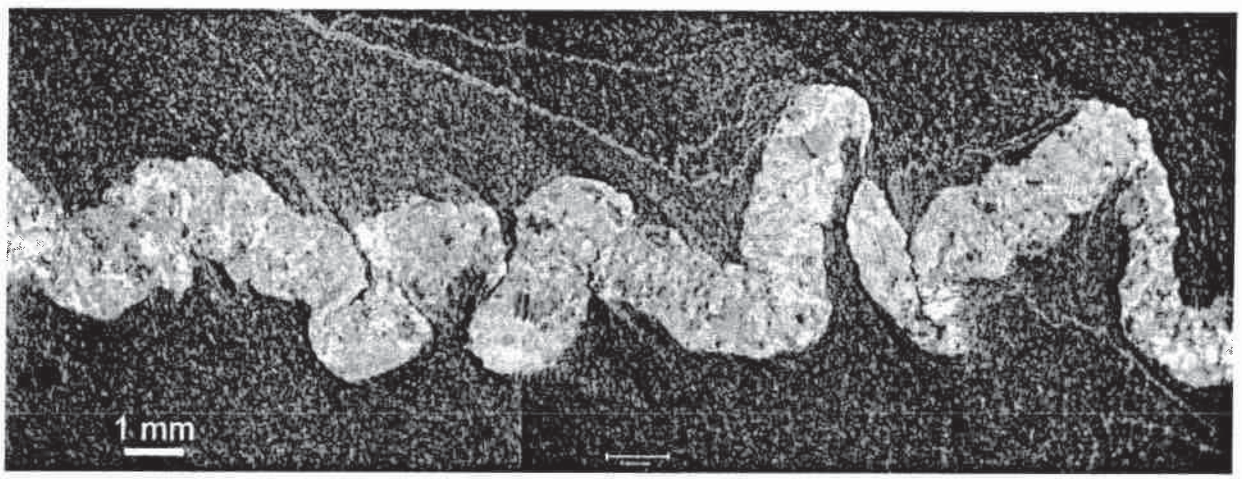
Time: 13.30 – 16.30 hr.
Place: BBL.023

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

Please read carefully! Answer every question on a separate page. DO NOT answer 5 questions!

Question 1 – On flow in rocks

Short and Johnson (2006) studied deformed calcite veins in limestones exposed in the Appalachians, central Maine, USA. Aim of the study was to determine vorticity and flow parameters for the deformed rock. The analysis resulted in a kinematic vorticity number of 0.67. Below, a photo is shown of a shortened vein in the limestone. The matrix foliation that is visible is determined by the authors as S_3.



a) Describe the structure as seen in the photo using appropriate terminology. Also, give an interpretation of the history of the vein, on the basis of your observations.

b) Assume a reader is not familiar with the concept of "vorticity". Explain to this reader what the statement "The analysis resulted in a kinematic vorticity number of 0.67" means. Be complete and very clear.

c) The photograph given above is not enough to determine a kinematic vorticity number. Describe what is needed to come to a full vorticity analysis of rocks containing veins. Put special emphasis on outlining what assumptions have to be made.

Let's assume that the flow of the Appalachian limestone can be described by the following velocity gradient tensor L:

$$\mathbf{L} = \begin{pmatrix} 1.0x10^{-14} & -1.0x10^{-14} \\ -8.0x10^{-14} & -4.5x10^{-14} \end{pmatrix} \qquad [s^{-1}]$$

d) 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 stretching rates along the flow apophyses.

e) Discuss whether or not tensor **L** could indeed fit the flow of the veined limestones of Maine. Make a drawing of bulk flow pattern belonging to **L** to substantiate your conclusion.

Question 2 – On the analysis of layered rocks and paleostress

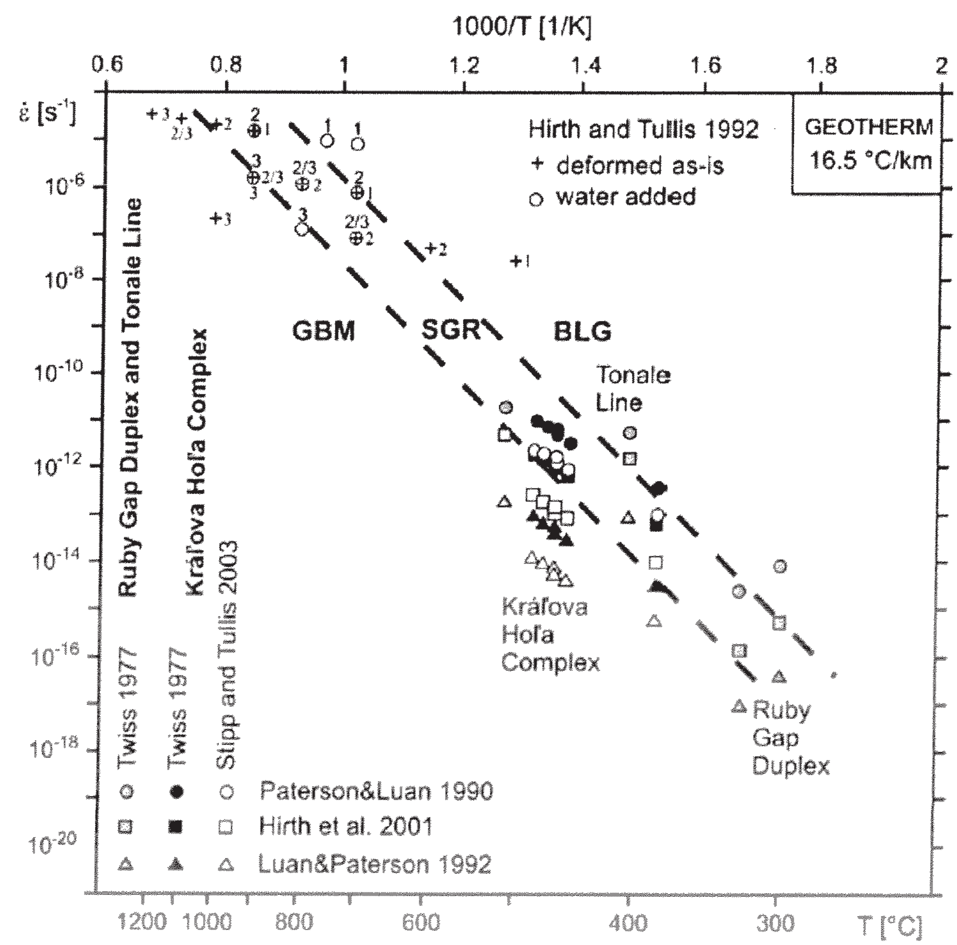
a) Explain why the concept of "material foliation" and "non-material foliation" is of importance when dealing with a differentiated crenulation foliation.

b) Consider stress analysis using dislocation density: i) explain briefly what the basic assumptions are behind this type of analysis, and ii) list pro's and con's ("voors en tegens" in Dutch) of the method.

Below, a strain rate vs. temperature diagram is given for quartzo-feldspathic rocks from the western Carpathians (Jeřábek *et al.*, 2007). The diagram shows laboratory data (Hirth & Tullis) as well as natural data (Ruby Gap and Král'ova from the Carpathians; Tonale line from the Alps). The dashed lines show the limits of three recrystallization regimes: bulging (BLG), subgrain rotation (SGR) and grain boundary migration (GBM).

c) The recrystallized grain size piezometer for quartz has been used to construct the diagram, but stress itself is not included as a variable. Give a plausible explanation of the way the piezometer has been applied to calculate the strain rate – temperature relations. Include in your explanation the assumptions the authors had to make.

d) The area shows small and large scale folding as well as shear zone development. Make an overview of the aspects you would need to take into account when performing stress analysis of such complex area.



Question 3 – On mechanical instabilities and structure development

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

  (6 points)

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.
  (6 points)

c) Describe the main characteristics of the following structures (illustrate with simple diagrams) and explain how these structures can develop:
  - Pinch and swell
  - Crenulation cleavage with metamorphic segregation in a slate.

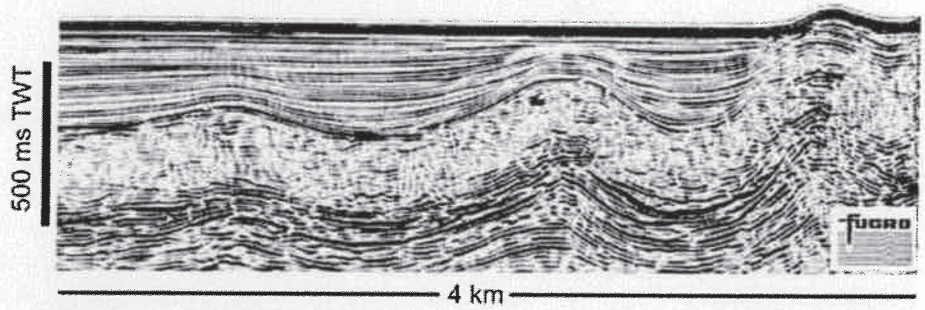
  (6 points)

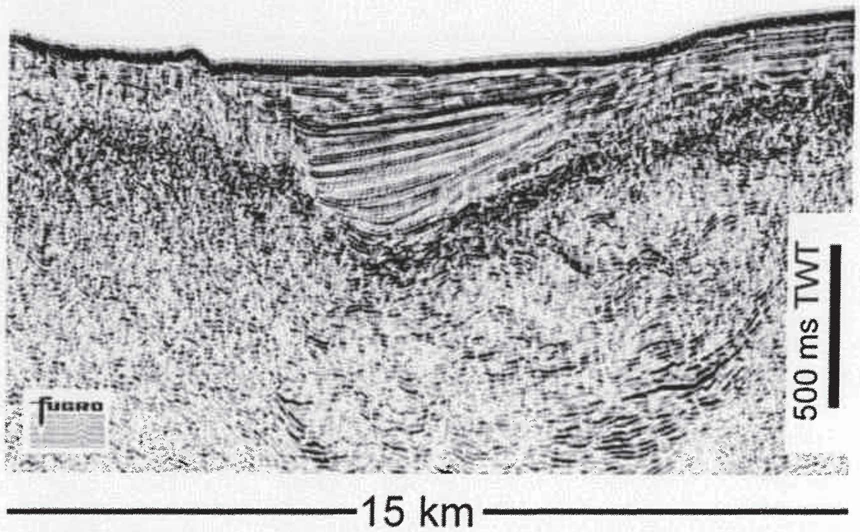
d) Define the term "**brittle fault zone**" from the point of view of a structural geologist working in the field.
  - Go on to use the concept of "positive feedback" to outline three different ways in which **brittle/frictional fault zones** can dynamically localize in a deforming rock mass.
  - What features would you look for in the field to verify which of these localization mechanisms might be responsible for the formation of a given **brittle/frictional** fault zone?

  (7 points)

Question 4: **On the analysis of Deformation Histories.**

a) The images show below show some reflection seismic sections of sediments in the Ionian Sea. Draw a structural interpretation of these sections and discuss the timing of deformation and sedimentation.

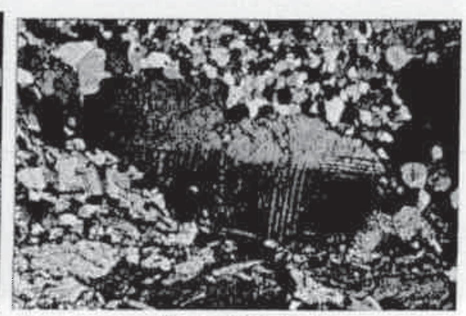




b) What general criteria can be used to distinguish soft-sediment faults and folds from solid-state deformation structures in the field?

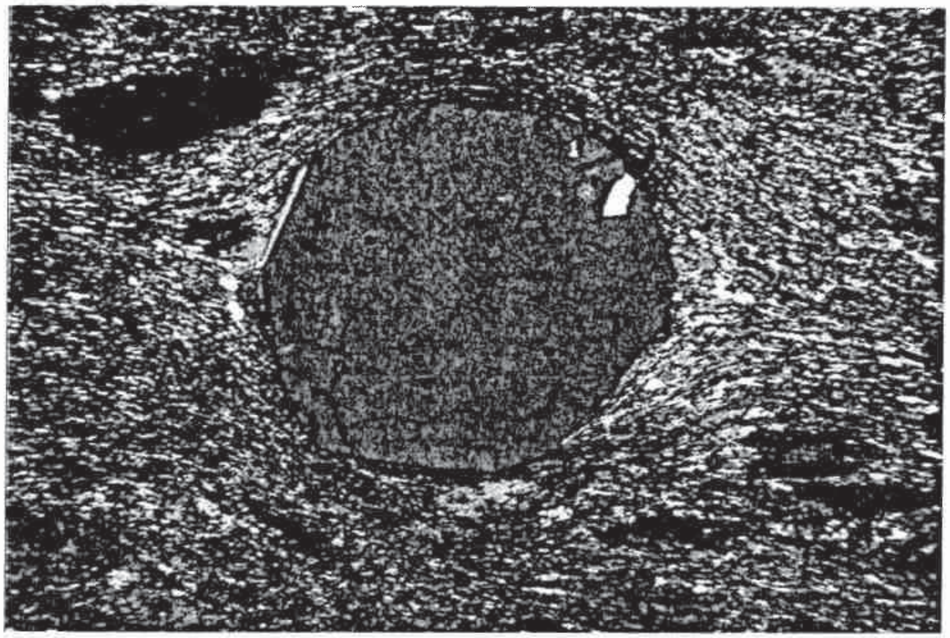
c) How can foliations produced by magmatic flow be distinguished from foliations produced by sub-solidus deformation? Are the structures shown in the images below formed by magmatic or sub-solidus deformation?

i) Granite from Corsica.

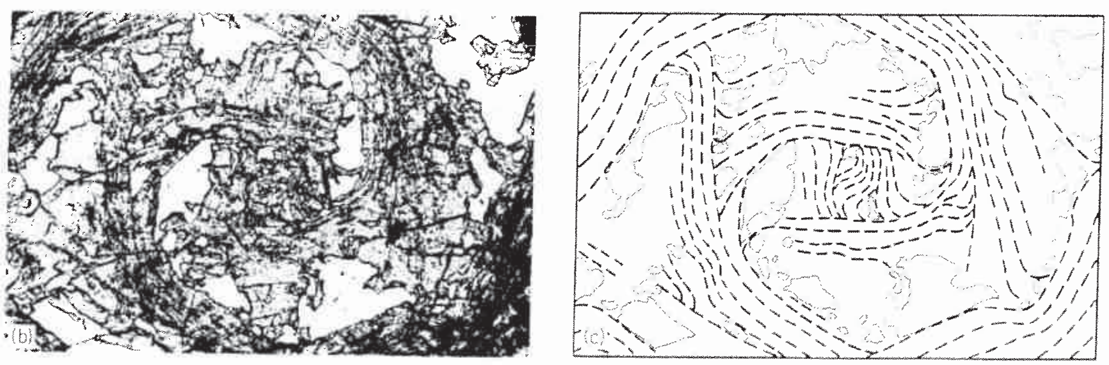


ii) Granite from Zimbabwe.

d) Comment on the timing of crystal growth and deformation in the example shown below. Micrograph of garnet porphyroblast in schist.



e) The figure below shows the pattern of mineral inclusions inside a garnet porphyroblast from Vermont, USA. An interpretation of the microstructure is shown on the right from Bell and Johnson 1989. First of all do you think that the researchers have made a good interpretation? Second, describe some possible deformation and mineral growth histories that can explain this type of inclusion pattern.



Question 5 - On Structural Analysis of Faults and Shear Zones

a) What criteria are used to describe different types of fault- rocks? Describe the Sibson (1977) and the IUGS (2007) classifications.

b) What type of fault rocks are shown in the images below and what deformation and grain size reduction processes are involved in the formation of these rocks?

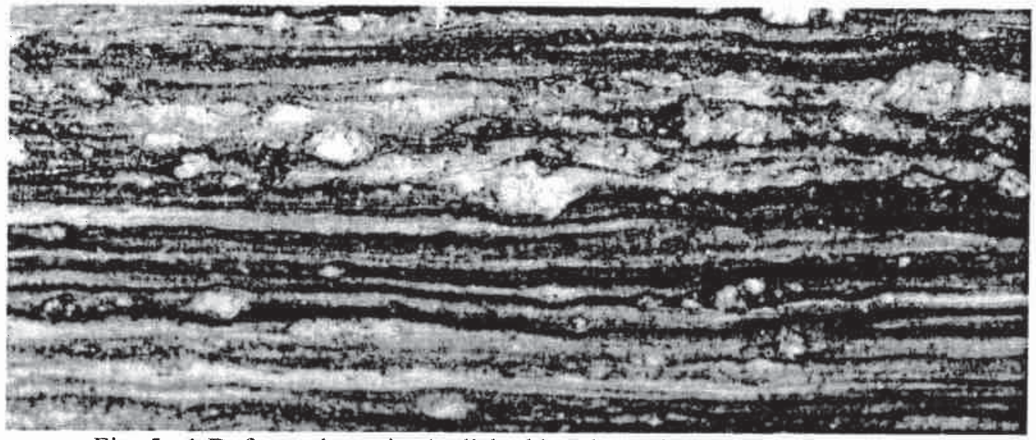


Fig. 5a-1 Deformed granite (polished hand-specimen).

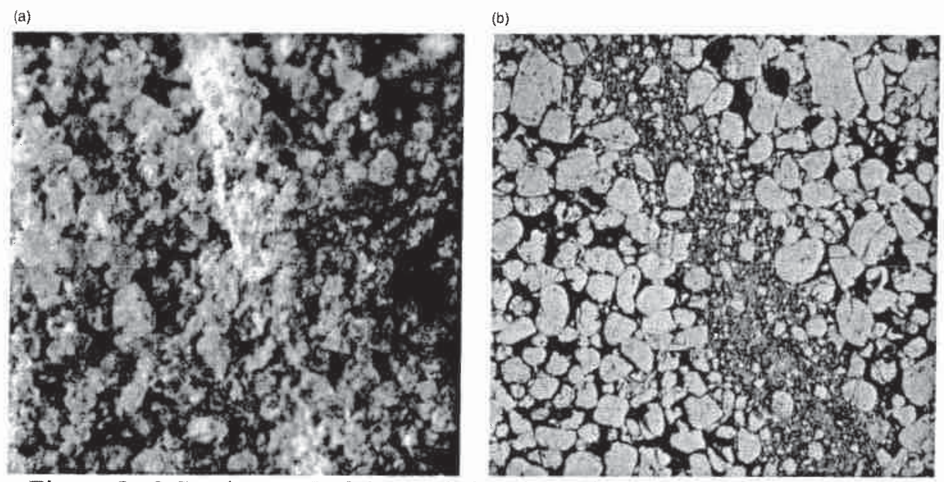


Figure 5a-2 Sandstone. Left image is hand-specimen, right image is microscope image with pores filled with dark resin.

c) 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.

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

e) 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).