Let's assume that the flow of the Chinees Zhangbaling schist can be described by the following velocity gradient tensor L:

$$\mathbf{L} = \begin{pmatrix} 1.0x10^{-12} & -1.0x10^{-12} \\ -8.0x10^{-12} & -4.5x10^{-12} \end{pmatrix} \quad [s^{-1}]$$

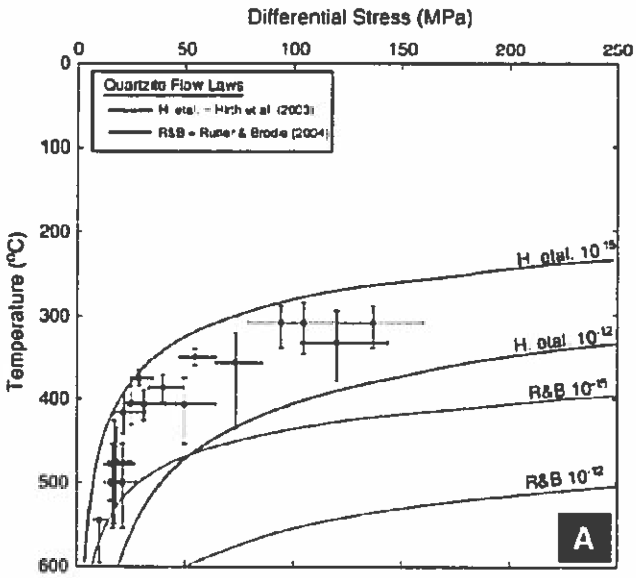
c) (7 points) Make a Mohr circle representation of **L**. Carefully (!) label all axes and explain what the intersections of the Mohr circle and the axes mean. Also, determine the mean instantaneous stretching rate and the stretching rates along the flow apophyses.

d) (6 points) Discuss whether or not tensor **L** could indeed fit the flow of the schist. Start by indicating what information regarding the flow is included in the tensor.

Question 2 – On the analysis of paleostress and layered rocks

a) (6 points) Consider stress analysis using fault slip data:
   i) explain briefly what the basic assumptions are behind this type of analysis,
   ii) discuss what the role is of the 'stress shape ratio',
   iii) why is it not possible to determine stress *magnitudes* on the basis of fault slip data?

Behr and Platt (2011) combined paleopiezometry and thermobarometry to construct a stress profile for the middle crust. Paleopiezometry was carried out using dynamically recrystallized grain sizes of quartz, applying the lab-calibrated relationship of Stipp and Tullis (2003 – the one form the home assignment). Thermobarometry puts constraints on the temperature during deformation. The diagram below shows the resulting stress profile (the data points with error bars) and allows a comparison of the data with predictions based on experimentally determined flow laws for quartzite (lines; numbers refer to strain rates in s^{-1}).



b) (6 points) Make a list of pro's and con's ("voors en tegens") regarding the use of dynamically recrystallized grain size to estimate paleostress.

c) (7 points) Analyse the diagram of Behr and Platt. Use your knowledge of flow laws (creep, viscosity) and piezometric relations for dynamical recrystallization to respond to the following statements:
   i) The diagram does not form proof that the size of dynamically recrystallized grains is temperature dependent.
   ii) The diagram does, however, suggest that the dynamically recrystallized grain size is not simply related to stress, but also depends on the flow behaviour of the material.

d) (6 points) Assume that the flow behaviour of "H.etal." and "R&B" belongs to two different types of quartz rocks, with slightly different viscosities. Also assume that the two rock types can be found in a folded multilayer. How would such a folded multilayer look in outcrop. Explain your drawing.

<u>Question 3</u> – On mechanical instabilities and structure development

a) (6 points) List the main factors that can lead to localized deformation, hence geological structure development, in deforming rock masses. Illustrate your answer with simple diagrams.

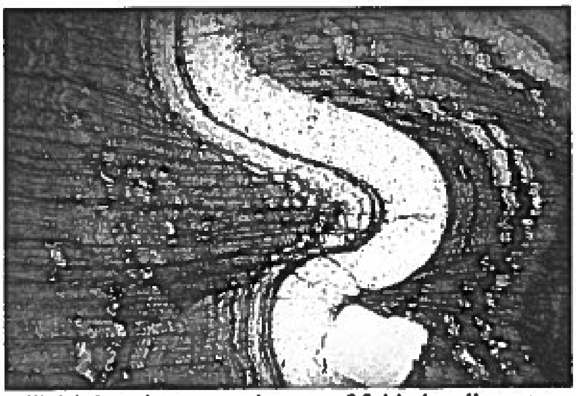
b) (6 points) Explain what is meant by the term "unstable deformation process". Go on to explain what "stability analysis" is, and specify the basic steps followed in conducting a standard stability analysis. Choose any structure you like as an example to illustrate the steps taken in performing such an analysis.

c) (6 points) 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.

d) (7 points) You are in the field and discover a semi-brittle fault zone, around 5m thick, that shows a high concentration of weak clay minerals, compared with the surrounding rocks. The surrounding rocks are very low grade meta-sediments, consisting mainly of siltstones. These siltstones are significantly richer in quartz cement and in quartz-filled veins on one side of the fault than on the other side of the fault, though there is some enrichment in quartz on both sides. Far away from the fault, the siltstones typically contain 15-20% clay – more or less the original sedimentary composition.
   - Make a sketch of the fault and its surroundings.
   - Propose an explanation of the observed pattern of clay versus quartz enrichment.
   - Go on to use the concept of "positive feedback" to offer an explanation of how the fault localised. Feel free to propose a <u>sequence</u> of feedback loops if needed

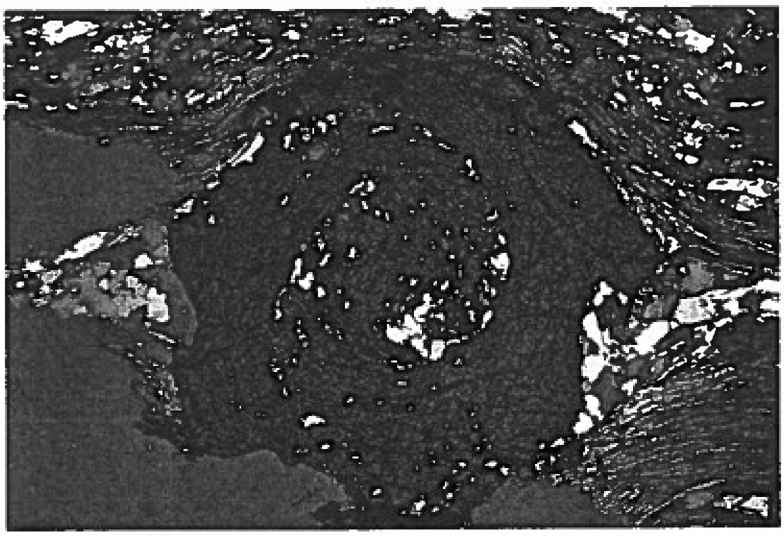
c) (5 points) Are the folds in the two images formed by soft-sediment flow or solid-state deformation?

i) Field image of folded sediments



ii) Light microscope image of folded sediments.

d) (5 points)Micrograph of garnet porphyroblast in schist. Comment on the timing of crystal growth and deformation.



<u>Question 5</u> - On Structural Analysis of Faults and Shear Zones

a) (5 points) What criteria are used to describe different types of fault- rocks? Describe the Sibson (1977) and the IUGS (2007) classifications.

b) (10 points) Images of highly deformed rocks from a major exhumed crustal shear zone are shown below.

i) What type of fault rocks are shown and what deformation and grain size reduction processes are involved in the formation of these rocks?
ii) Identify any kinematic indicators and the associated shear sense.
iii) Identify the relative depth level of the rocks within the fault zone.

Fig. A) light microscope image of deformed granodiorite intruded into major crustal shear zone.

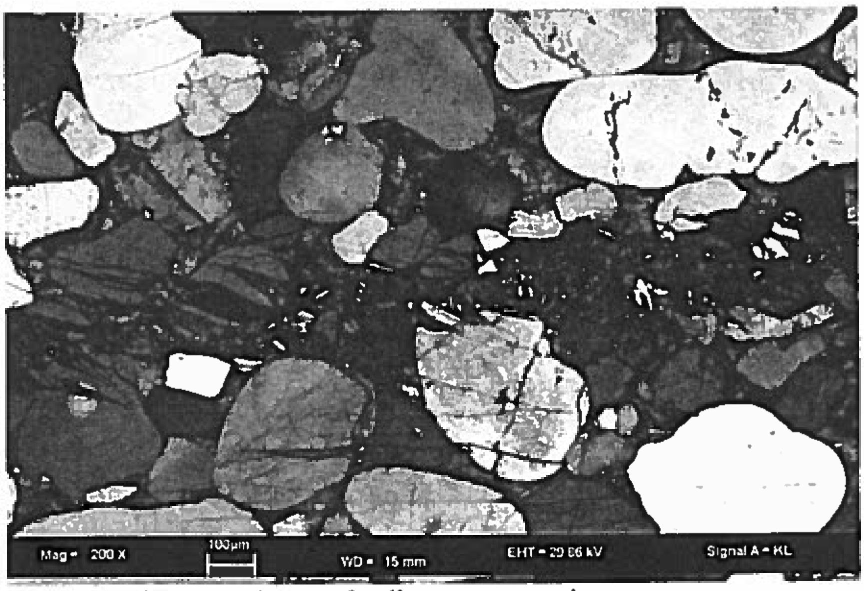


Fig. B) SEM cathode luminescence image of sedimentary quartzite.

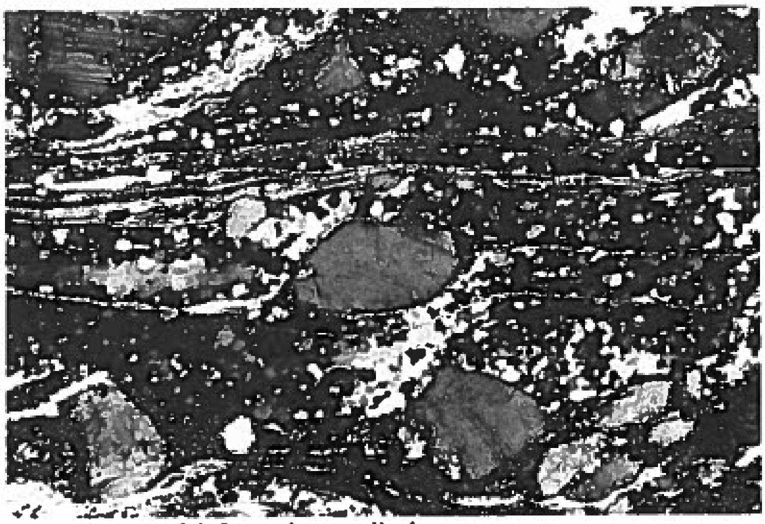


Fig. C) light microscope image of deformed granodiorite.

Fig. D) light micrograph of deformed granodiorite.

Question 5 – ctnd.

c) (5 points) What are pseudotachylites and how are they formed?

d) (5 points) How can lithosphere and asthenosphere flow be recognised in exhumed mantle periodotites? How can the shear sense of mantle shear zones be established?