Structural Analysis of Deformed rocks (GEO4-1411) - Exam 26-01-2017

Time: 09.00 – 11.30 hr. (2.5 hours)
Place: KBG Cosmos

House rules:

- You may not leave the room during the first 30 minutes of the exam.
- Latecomers will be admitted until 30 minutes after the start of the exam
- All electronic equipment needs to be switched off (including phones!!), except for equipment which the examiner has allowed.
- Put coats and bags on the floor. Bags need to be closed.
- If you need to use the toilet, you have to let the invigilator know. Leave your mobile phone behind. You cannot go to the toilet after the first student has left the exam.

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!

Also, **please reserve some time to fill in the course evaluation form.**

Question 1 – On flow in rocks

Ring *et al.* (2015) have studied the Sisters Shear Zone (SSZ) on Stewart Island, New Zealand. This is a greenschist-facies extensional shear zone active prior to and possibly during the development of the Pacific–Antarctica spreading ridge.

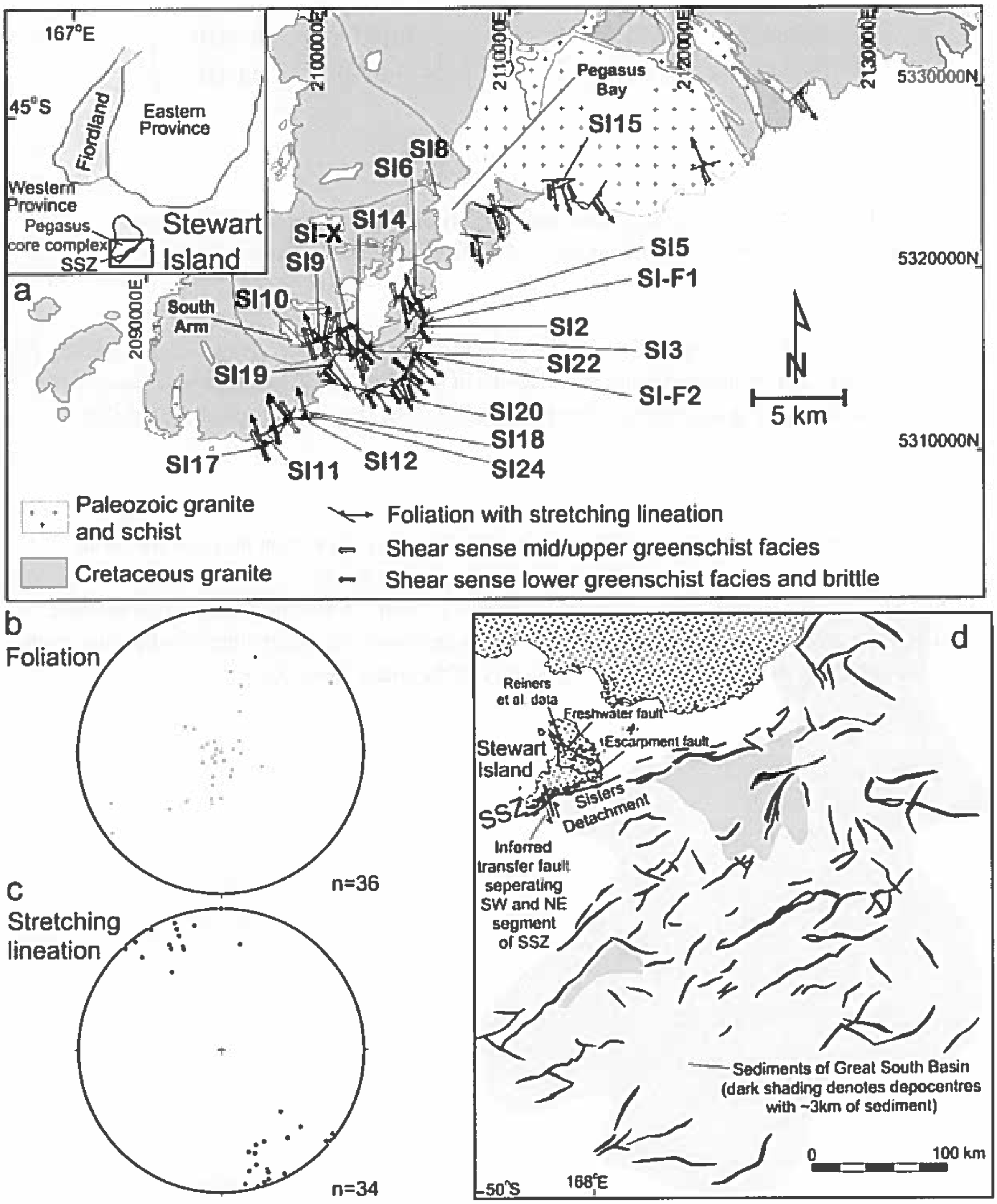

Fig.1. (a) Structural map of the SSZ, shown are strike and dip of mylonitic foliation and trend of stretching lineation (arrow heads point down plunge), also shown is sense of shear for upper/mid greenschist-facies deformation (basically defined in field by stability of biotite) and lower greenschist-facies shearing. Sample localities shown as well. Inset: location of Stewart Island, Pegasus core complex and Sisters Shear Zone. (b) Poles to foliation planes, lower hemisphere projection. (c) Stretching lineation data, lower hemisphere projection. (d) Stewart Island, trace of Sisters Detachment and Great South Basin

The following two velocity gradient tensors L have been determined for the rocks sheared under upper-mid greenschist-facies (left) en lower greenschist-facies (right)

$$\mathbf{L}_{\text{um-g}} = \begin{pmatrix} 5.0\text{x}10^{-11} & -2.0\text{x}10^{-11} \\ -6.0\text{x}10^{-11} & -3.0\text{x}10^{-11} \end{pmatrix} \quad \mathbf{L}_{\text{l-g}} = \begin{pmatrix} 4.0\text{x}10^{-11} & -0.5\text{x}10^{-11} \\ -5.0\text{x}10^{-11} & -4.0\text{x}10^{-11} \end{pmatrix} \; [s^{-1}]$$

a) (7 points)
   i) Explain what the difference is between Vorticity and Kinematic Vorticity number.
   ii) Design a flow pattern of material particles for a Kinematic Vorticity number of 0.3.

b) (9 points)
   Make a Mohr circle representation of the two tensors **L** for the Sister Shear Zone. Carefully (!) label all axes and explain what the intersections of the Mohr circle and the axes mean. Also, determine the mean instantaneous stretching rates and the stretching rates along the flow apophyses.

c) (9 points)
   i) Determine the kinematic vorticity number for the two tensors. You may use the Mohr diagram of question 1b) or calculate on the basis of the tensor.
   ii) Qualitatively interpret the tensors/Mohr circles in terms of dilatancy during deformation.
   iii) Give a meaningful interpretation of the results presented above. In other words, what do the results tell you about the structure or history of the Sister Shear Zone?

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

a) (9 points) The stereographic projections below (Fig 2) show the results of fault slip analysis of two locations in the Sister Shear Zone (SSZ) area (Fig.1), namely SI-F1 and SI-F2.
   i) Explain briefly how fault slip analysis resulting in diagrams such as Fig. 2 works.
   ii) Interpret the two diagrams: what can be said of the faulting at the two locations?
   iii) What do you think the value of the 'stress shape ratio' will be for the faulting? Explain your answer by including what is meant with this ratio.

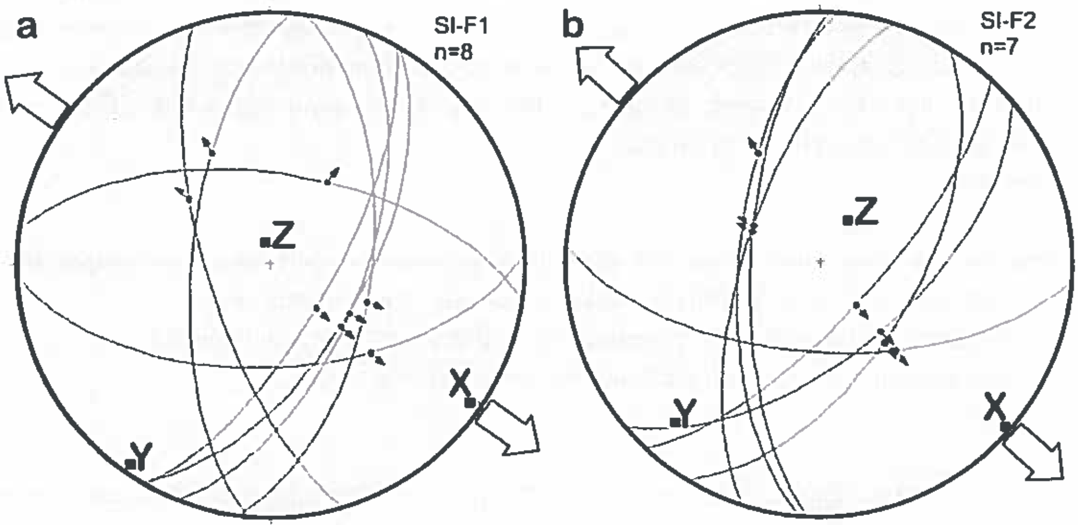

Fig.2. from Ring *et al.* (2015).

b) (8 points) On some localities, the interface between the Paleozoic granite and the Cretaceous granite (Fig. 1) is folded. Cusp and lobe structures are visible, indicating that the Paleozoic granite was the more viscous rock.
   i) What are the pitfalls ("nadelen") of using cusp and lobes for determining viscosity contrast?
   ii) What other approach might be taken to estimate the viscosity contrast of the granites?

c) (8 points) Fig.3 shows microstructures of mylonitic rocks of the SSZ, at SL11and SI12. There is plenty of evidence for dynamic recrystallization:
   i) Which of the two samples is likely to have experienced the highest stress, and why?
   ii) Point wise indicate what| you need to actually quantify the palaeostress of these samples. Be as complete as possible.

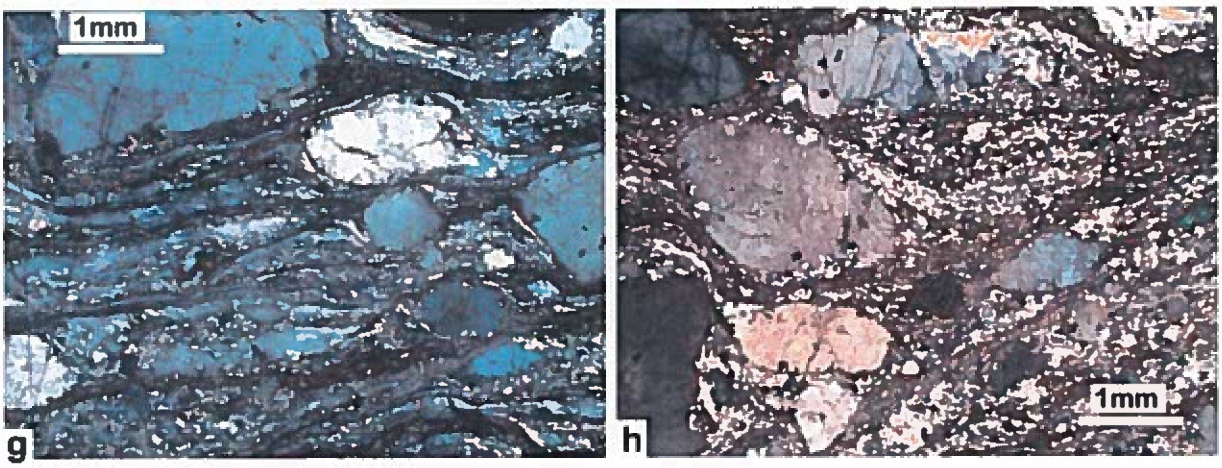

Fig. 3.

Question 3 – On mechanical instabilities and structure development

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

   (6 points)

b) Sketch stress-strain curves for plastically deforming materials showing i) strain hardening and ii) strain softening. Explain with the aid of a feedback diagram why work hardening materials do not show strain localization whereas strain softening materials often do. Explain also what kind of stress-strain behaviour will be most effective in producing localization in strain-softening materials. Assume throughout that the stress-strain behaviour of the materials considered is insensitive to strain rate.

   (6 points)

c) Describe the main characteristics of the following structures (illustrate with simple diagrams) and explain how these structures can develop and why they are periodic:
   - Ptygmatic folds (stiff folded layers embedded in a less competent matrix)
   - Crenulation cleavage with metamorphic segregation in a slate.

   (6 points)

d) Define the term "ductile shear zone" from the point of view of a structural geologist who is working in the field.
   - Go on to outline three different ways in which ductile shear 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 shear zone?

   (7 points)

Question 5 - **On Structural Analysis of Faults and Shear Zones**

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

b) (10 points) 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 fault rocks?

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

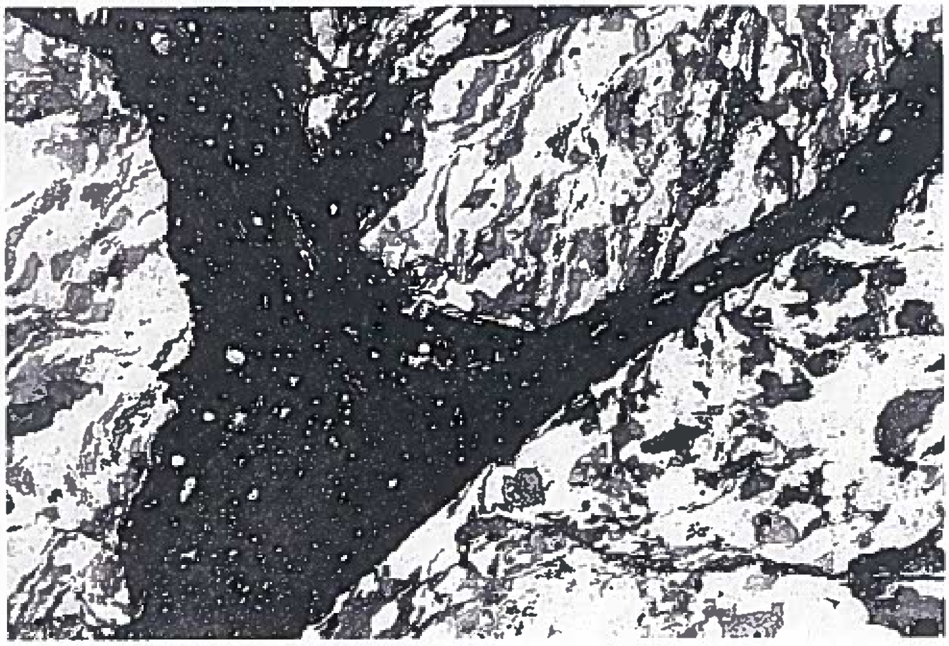

Figure 5a-2 light micrograph of fault rock microstructure. The dark material is istropic in cross polarised light.

c) (5 points) How can exhumed crustal scale fault zones be recognized in the field? Describe some examples.

d) (5 points) What is a crystallographic preferred orientation (CPO)? What information can be obtained from the CPO about the deformation in mylonite zones?