Structural Geology and Tectonics GEO3-1307

Date: Wednesday April 12th 2006
Time: 14.00-17.00 hr.
Place: C.010 and C.008

Please read the complete exam before starting. Then, answer all 4 questions (they are worth 2.5 points each). *Always explain how you got the answer.* Be creative and good luck!

Question 1: Quantification of strain

In the fieldwork area 'Camarasa', deformed limestones and conglomerates can be found that are folded into kilometer-scale asymmetric syn- and antiforms with a horizontal fold axis. See Fig. 1a (exposure perpendicular to strike). There is no evidence for a component of strain parallel to the fold axis.

Shape and orientation of quartzitic pebbles in the conglomerate have been measured applying the R_f-ϕ' method (Fig. 1b). The limestone contains deformed fossils (Fig. 1c). Small tension gashes filled with calcite crystals are present within these fossils, providing evidence for a volume change of ~5%.

a) What is the fundamental assumption you have to make with respect to the fossils in order to allow the use of the Breddin graph method (Fig. 1d) for strain analysis?

b) Determine the strain ratio R_1 of the pebbles (Fig. 1b) *and* R_2 of the deformed fossils in the limestone (Fig. 1c). What can you learn from comparing R_1 and R_2 in the given geological setting?

c) Quantify the strain of the *limestone* in 3 dimensions by giving values for the three principal stretches. Show the result in a suitable and fully labeled Flinn diagram.

d) What do the results of the strain analysis tell you about the fold mechanism of the conglomerate-limestone multilayer? (tip: determine the orientations of the principal strain axes – indicate these on Fig. 1a – hand in the figure!)

Question 2: Tensor description of strain

The 'position gradient tensors' given below describe successive steps of a complex (2-dimensional) deformation history.

$$1^{st}\text{ step: } F_{ij} = \begin{pmatrix} 1.2 & 0.2 \\ 0.3 & 0.7 \end{pmatrix} \qquad 2^{nd}\text{ step: } F_{ij} = \begin{pmatrix} 1 & 0.6 \\ 0 & 1 \end{pmatrix}$$

a) Use drawings to explain what the geometric meaning is of these two tensors (i.e., how does a square look after deformation?).

b) Is there any area change during one of the steps? If so, please quantify.

c) Determine the strain ratio and orientations of the principal strain axes after step 2. Reminder: $F_{(total)} = F_{(2nd)} * F_{(1st)}$.

d) Assume that tension gashes started developing from the very first stage of deformation step *2*, and that the tensor accurately describes the progressive deformation. What would be the final shape and orientation of the gashes?

Question 3: Structural styles

Fig. 2 shows the interpretation of a seismic section through a the northern part of the Tern basin, east of the Shetland Islands. Your task is to analyze the section:

a) The various types of structures that are visible the section can be grouped as a 'structural style'. What is the advantage of thinking in terms of structural styles rather than focusing on individual structures?

b) Make a clear and complete list of *observations*. Then, give an *interpretation* of the geological history of the structure, consistent with the observations.

When analyzing deformation that occurred at deeper levels, useful information can be obtained from porphyroblast-matrix relations.

c) Briefly explain what the essential steps and assumptions are in constructing relative timing diagrams of mineral growth and deformation. Illustrate for deformation by shear.

d) One relative timing diagram is usually not enough for reconstructing a tectono-metamorphic evolution of an area. Dream up a scenario/setting to illustrate this.

Question 4: Rock deformation behaviour

a) Explain the difference between the three main classes of rock deformation behaviour, i.e. elastic, brittle and ductile. Use appropriate stress-strain diagrams to illustrate your explanation.

b) Draw *fully* labeled diagrams for realistic brittle failure envelopes:
   - ii) for a dense rock such as a well-cemented limestone
   - iii) for a highly porous sandstone
   - iv) for a dense rock with a pre-existing shear fracture

c) You have received natural rock samples that appear deformed by ductile processes. Question now is: what deformation mechanism operated in the rock, dislocation creep or interganular pressure solution?
   - i) Write a brief but clear (!) account on what criteria you would use to come to an answer to this question. Illustrate your answer with simple sketches.
   - ii) Your final conclusion on the mechanism is of particular importance in case you want to use microstructures to estimate the differential stress during deformation in nature. Explain why.
   - iii) If you are able to estimate the differential stress that operated during natural deformation, how would you attempt to estimate the strain rate at which deformation occurred?