Naam.....Studentnummer.....

Re-exam "Deformatie en Metamorfose van de Korst"

March 7, 2017, 13:30-16:30 hrs, Unnik 201

- Do not forget to put your name and student number on each of the question and answer sheets and to return both of them.
- Answer questions 1-6 (the deformation part) and 7-10 (the metamorphism part) on separate sheets of paper.
- The maximum score per question is 10 pts.
- ***Check your answers prior to handing in the exam!***

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1. Give a short description of:

a. Effective stress
b. Pure shear
c. Blind thrust
d. Isoclinal fold
e. Pressure solution

2a. Data from a borehole are as follows: $\sigma 3$ within a granite of density (2700 kg/m^3) is 100 MPa; the differential stress is 300 MPa and the dip angle of a fault at that depth is is 52^0. Observations of fault rocks at the earth's surface suggests that the area is under extension. Adopt Andersonian fault classification and make a sketch of the described situation.

2b. Construct the Mohr circle based on the data provided above and deduce the normal and shear stresses acting on the fault plane.

2c. Use the Mohr circle construction of question 2b to infer the coefficient of friction and the cohesion of the granite. Is the deduced coefficient of friction representative for rocks in the crust? Provide arguments.

2d. At which depth has the fault been drilled? Assume that the density of the granite is representative for the entire overburden.

3a. How can you determine if sedimentation occurred **before, during** or **after** movement on a regional-scale thrust fault? Make sketches for each situation.

3b. Draw a simplified cross section across a metamorphic core complex and describe at least four features of a metamorphic core complex.

4a. Describe with the help of drawings the main characteristics of flexural slip folds.

b. Which observations in the field are diagnostic to discriminate between "neutral surface folding" and "flexural slip folding"?

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5. A sinistral ductile shear zone developed within an otherwise undeformed granite. Which shear criteria can you use to deduce the sense of shear in the shear zone? Make sketches for each criterion!

6a. Why do subductions zones potentially develop at transform faults?

b. Which pressure-temperature conditions are diagnostic for subduction zones and which rocks to you expect to find?

c. What is the consequence of slab-roll back for deformation of the overriding plate? provide examples.

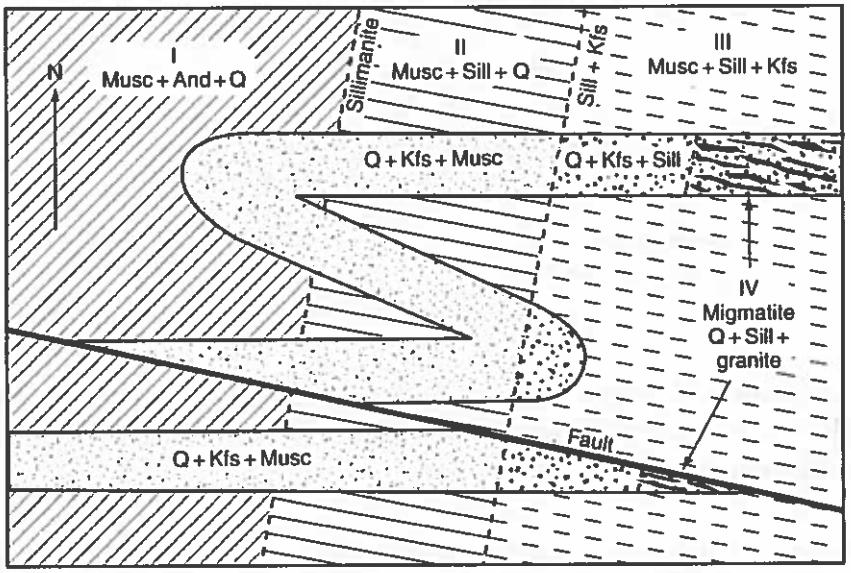
d. By which mechanisms are metamorphic rocks exhumed?

7 a. Give a short description of the following metamorphic processes: recrystallization, polymorphic transformation and chemical reaction.

b. When a porphyroblast grows in a metamorphic rock it will grow over any foliations in the rock and the foliation will be preserved as lines of mineral inclusions in the porphyroblast. The image below shows a yellow staurolite, porphyroblast which contains many quartz (colourless) and oxide (black) inclusions. What is the timing of staurolite growth with respect to the deformation history?

c. What type of foliation can be seen in the image of 7b? Is the rock shown in this image, a granofels, schist or gneiss?

8 The figure blow shows a map of a sequence of metamorphic zones in a simple metamorphic area, which contains a folded sequence of sandstone and mudstone meta-sediments.



Mineral compositions: quartz (Q) = SiO_2, Muscovite (Musc) $KAl_3Si_3O_{10}(OH)_2$, Andalusite (And) Al_2SiO_5, Silliminite (Sill) Al_2SiO_5, Alkali feldspar (Kfs) $KAlSi_3O_8$. Water H_2O.

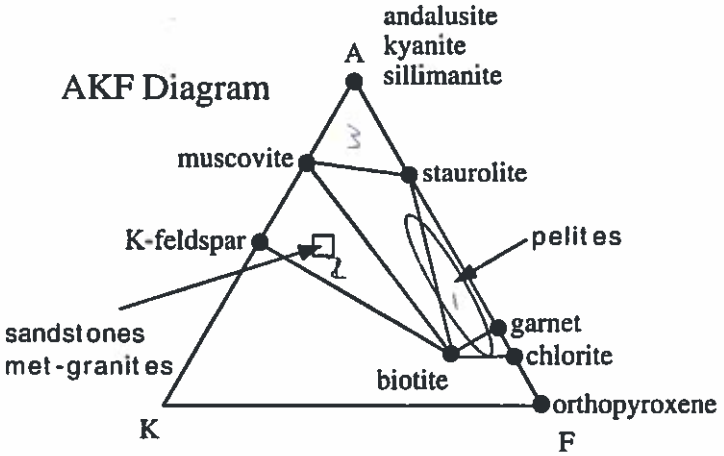
a. How many chemical components are needed to describe the mineral and fluid phases in this area?

b. Define the phase rule, and use this rule to determine the number of phases that are stable in a divariant assemblage (which is stable over a range of pressures and temperatures) and a univariant assemblage (stable along a reaction line).

c. Construct triangular compositional phase diagrams for each metamorphic zone. This can be done by considering three significant components, $KAlSi_3O_8$ SiO_2 and Al_2O_3 and projecting the mineral composition of muscovite from H_2O.

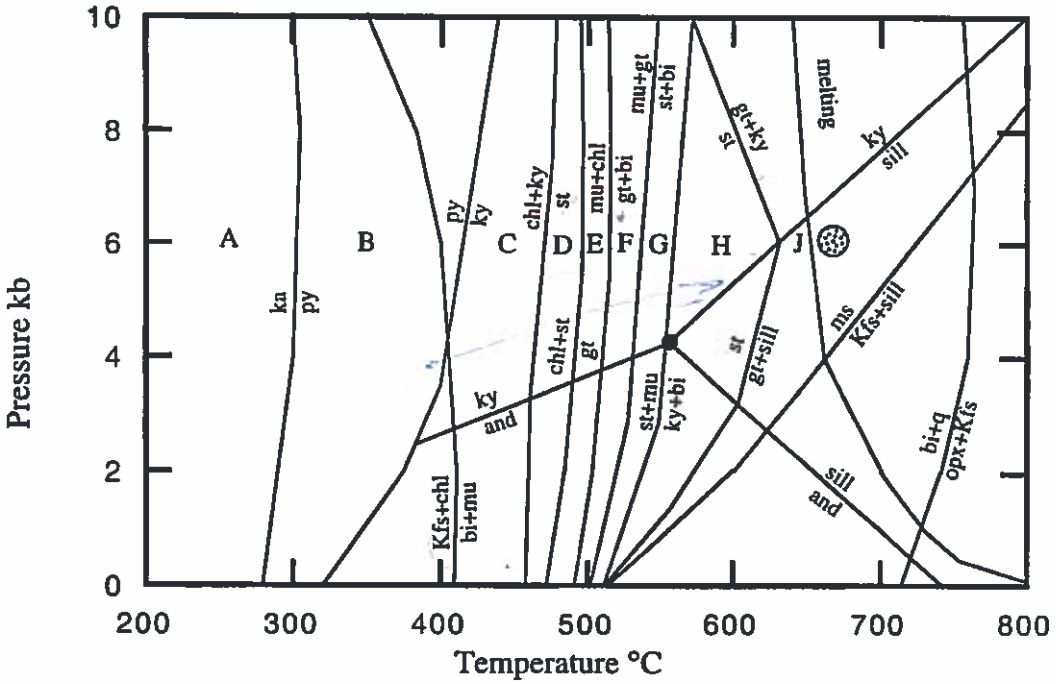
d. Zone 4 contains some migmatites. What are migmatites and what temperatures do they indicate ?

9 In NE Scotland a Barrovian sequence of metamorphic zones occurs with chlorite, biotite, garnet, staurolite, kyanite and sillimanite zones. Mineral assemblages in metamorphosed mudstones can be analysed using the AKF diagram where we consider the rock to be made up of three significant chemical components Al_2O_3, K_2O and FeO. An AKF diagram for the staurolite zone in NE Scotland is shown below.



The main mineral assemblages are 1) Staurolite, biotite, garnet in pelitic layers 2) K-feldspar, muscovite, biotite in sandstone layers and 3) kyanite, muscovite staurolite in a some Al_2O_3 rich layers.

a) Use the PT diagram (below) to work out the temperature and pressure conditions in the staurolite zone



b) Using the reactions shown on the PT diagram, draw a series of AKF diagrams for the kyanite and sillimanite zones at higher temperatures and the garnet zone at lower temperatures.

10. The figure below shows the results of a numerical model for metamorphism produced by crustal heating and erosion after a short crustal thickening event accommodated by a single large scale thrust fault. Several geotherms are shown for different times (in millions of years) after the crustal thickening.

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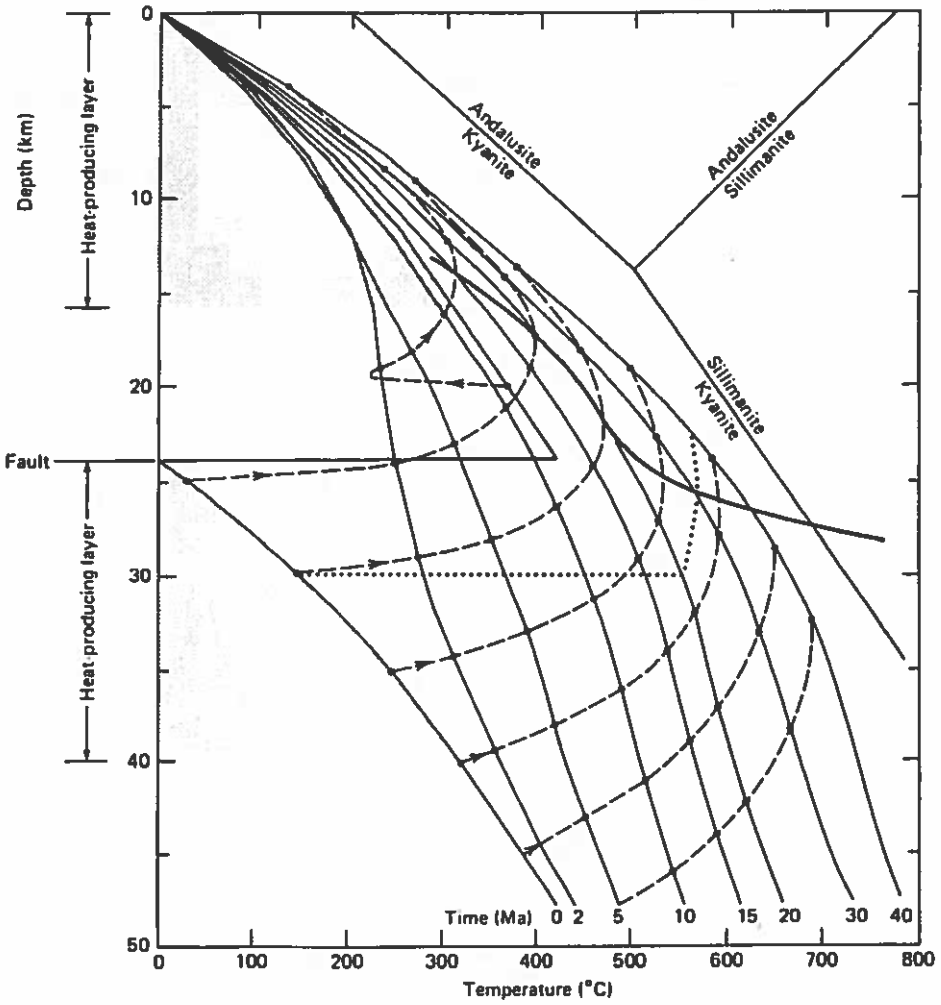

a. Draw a simplified version of this diagram showing 1) the metamorphic field gradient, 2) the PT paths for rocks buried to depths of 20, 30 and 40 km after thrusting and 3) the geotherms at times 0, 5, 20 and 40 million years after thrusting.

b. Why does the main metamorphic mineral assemblage form along part of the PT path?

c. At what temperature and at what time (since the crustal thickening) does the main metamorphic assemblage grow, in the rock buried to 30 km.

d. Why do the rocks buried to 30 and 40 km heat up after the deformation, while the rocks at 20km cool down in the first 2 million years?

e. What process results in the reduction of pressure in the crust after crustal thickening?