Open Book Exam "Deformatie en Metamorfose van de Korst"

Metamorphism exam *January 25, 2020, 11.30-13.00 hrs.*

Online in Microsoft Teams
In the teams meeting you may ask questions in the meeting chat about exam format and possible typing errors. The exam supervisor may also ask you to share your webcam to confirm that you are following the exam rule listed in the statement below.

Download of questions and submission of exam answers.
Questions can be downloaded from Blackboard from 11.20. Your exam file must be uploaded to blackboard by 13.05. Students allowed additional time exam file must be uploaded to blackboard by 13.35. To help answer the questions you can consult the course text books, course notes and files provided in the course and academic papers.

Please note that after the exam has been taken and assessed a subset of the students may be interviewed to test the reliability of the test.

By going ahead with this exam, you the student agree to the following:

I declare that, on this day, Monday 25th January 2021:
- my identity is the same as the one that logged on to Blackboard to make this test

- This test will be solely undertaken by myself, without any assistance from others and/or other sources than those allowed.

- I will not copy, screen dump, or otherwise record or distribute questions and answers.

- I will not share my answers with others

- I will only use tools and resources that are permitted **(Course notes/ slides and academic papers and textbooks)**

- I am aware that:

= Violation of the aforementioned agreement is considered fraud (see OER art 5.15)

= My answers will be checked for plagiarism

= The examiner can invite me at a later stage for an additional oral test (via MS TEAMS)

You give your agreement to these conditions by taking and submitting the exam. No further action is necessary

Instructions for exam

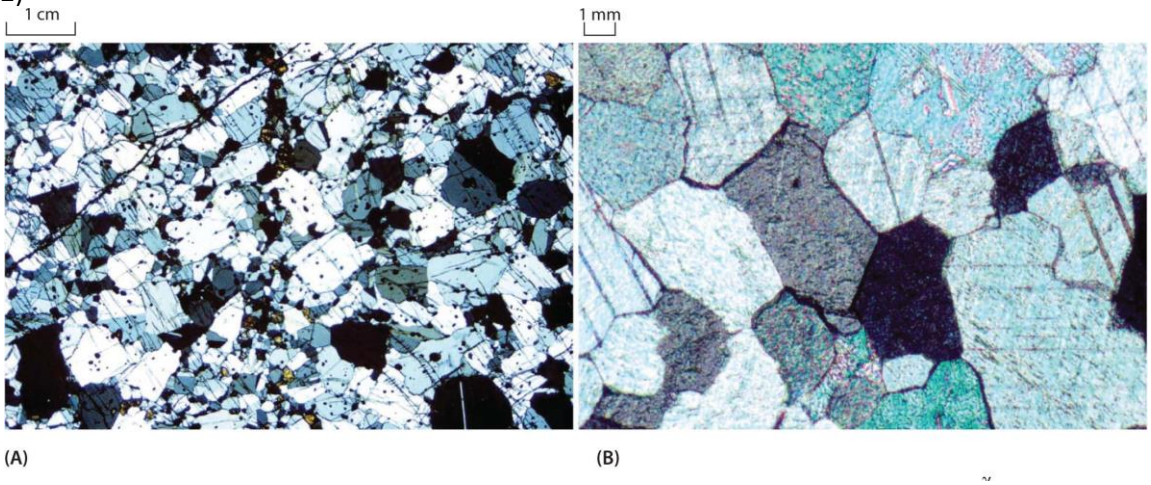
- You may answer the questions in English or Dutch.
- Put your name and student number at the start of the document and in the file name.
- Answer all questions.
- The maximum score per question is 10 pts.
- ***Check your answers prior to handing in the exam!***

Question M1.

a. What is the definition of metamorphism and what grain-scale processes are involved? Give some examples of the different processes.
b. What types of metamorphic rock are shown in the images below.

1)

2)

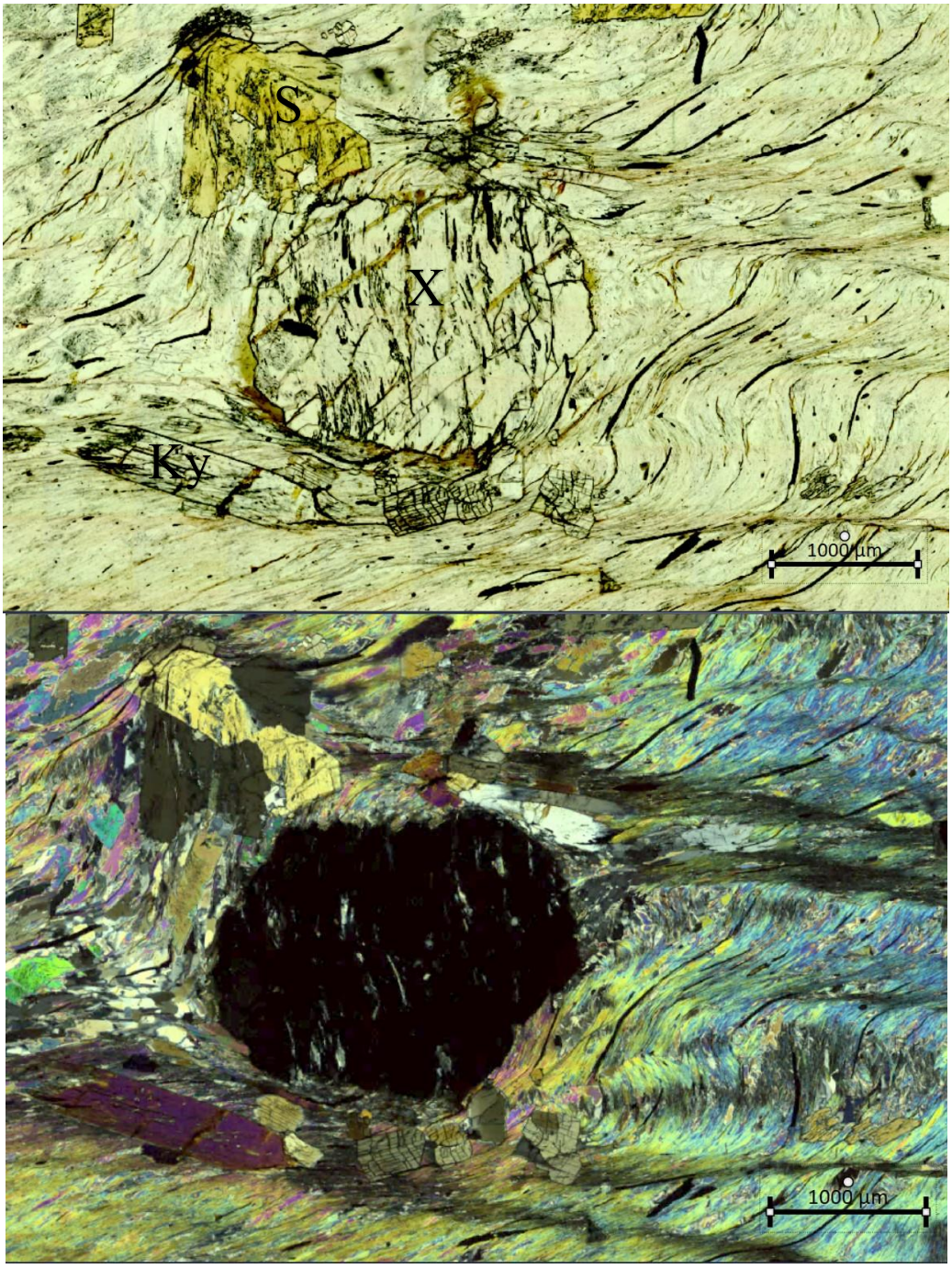


3)

4)

Question M2.

The images below show the microstructure of a rock from the Lukmanier Pass in the European Alps. The fine-grained elongated minerals along the foliations are muscovite and quartz (colourless) and black oxide grains. Three types of porphyroblasts occur: kyanite (Ky), staurolite (S) and mineral X (colourless in PPL, isotropic in XPL, with no cleavage).



Microscope images, upper plane polarized light (PPL), lower cross polarized light (XPL).

a. Give a field name for this rock, based on the grain size, structure and mineral assemblage.
b. How many deformation events have effected this rock?
c. What is the timing of the growth of type X porphyroblasts with respect to the deformation history?
d. Using the AFM diagrams in Fig. 15.22, Where does this mineral assemblage occur in the Barrovian sequence of metamorphic zones?
e. What assemblages would form in a rock with this composition, the sillimanite and biotite metamorphic zones.

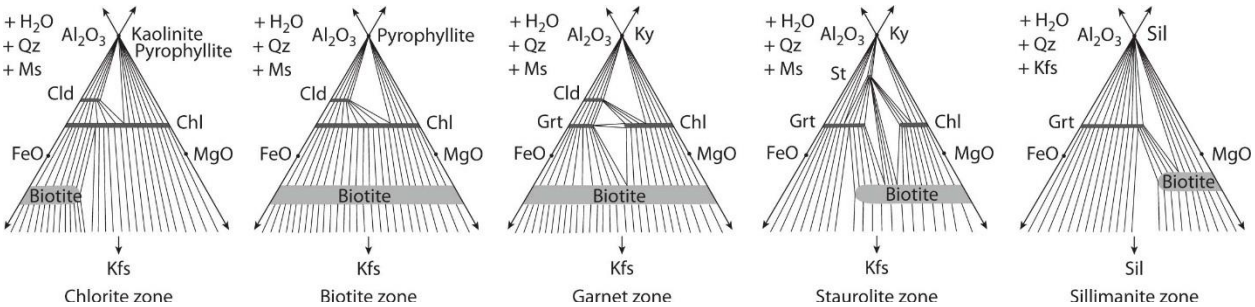
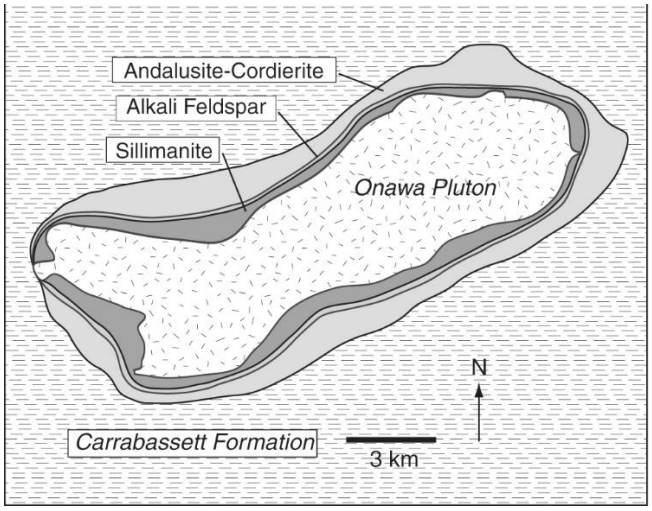
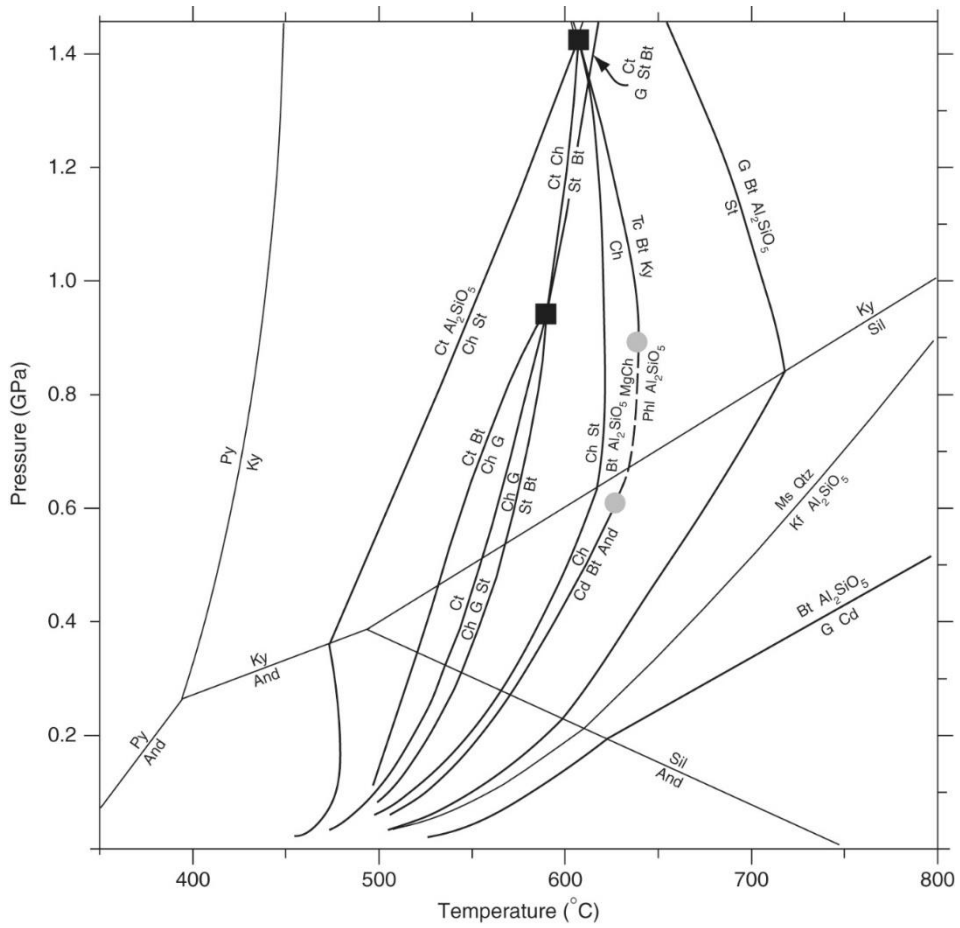


Figure 15.22 from Klein and Philpotts shows a sequence of AFM diagrams for the Barrovian metamorphic zones.

Question M3. The figure below shows a map of the metamorphic zones in the Carrabassett pelitic sediments, next to the Onawa Pluton in Maine, USA.



The next diagram shows PT conditions for reactions in the KASH and KFMASH systems.
Minerals: ms =muscovite, qtz =quartz, and =andalusite, Kf= alkali feldspar, sil= sillimanite, ky = kyanite, py = pyrophilite, ch =chlorite, cd=cordierite, St=staurolite, G= garnet, Ct =chloritoid, Bt=biotite.



a. The rocks in this area can be described by the KASH and KFMASH chemical systems. In the low-grade rocks, the following assemblages occur in the rocks with no FeO and MgO:

sandstone layers: quartz, alkali-feldspar, muscovite, water
mudstone layers: pyrophyllite, muscovite, quartz, water

Construct triangular compositional phase diagrams for the low grade, the Andalusite, the Alkali feldpar and the sillimanite zones. 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 and pyrophyllite from H_2O. You should draw one phase diagram for each metamorphic zone.

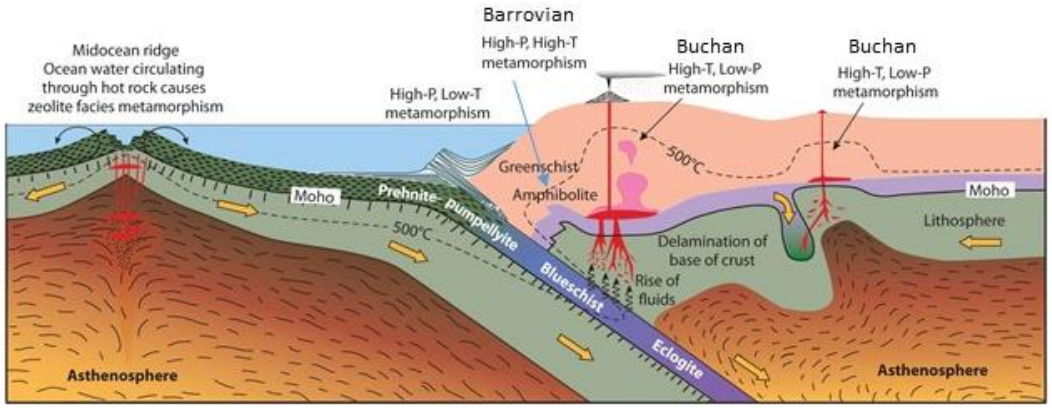
Mineral compositions: quartz (Q) = SiO_2, pyrophyllite (py) = $Al_2Si_4O_{10}(OH)_2$, muscovite (Musc) $KAl_3Si_3O_{10}(OH)_2$, Andalusite (And) Al_2SiO_5, Silliminite (Sill) Al_2SiO_5, Alkali feldspar (Kfs) $KAlSi_3O_8$.

b. From the PT diagram, what reactions occur at the Andalusite-Cordierite isograd, the alkali feldspar isograd and the sillimanite isograd?

c.. Use the PT diagram to work out the maximum depth and the gradient of temperatures in this metamorphic area. Note that crustal density is about 2800 kg/m^3, g =9.8 m/s^2, SI units of pressure are Pascal (Pa) and 1 kilobar (kb) = 100 MPa.

Question M4.

The figure below shows the plate tectonic settings of formation of metamorphic rocks.



Modified after Figure 15.36 (Klein and Philpotts). Showing ocean crust and lithosphere subducted beneath continental crust and lithosphere. In the diagram, magmas are red and crystallized igneous intrusions are pink. At the convergent margin between the two plates, the continental crust is deformed, thickened and intruded by melts.

a. Make a sketch showing the stability of the minerals glaucophane, omphacite, kyanite, andalusite and sillimanite and draw the PT path of: i) blueschist facies rocks that were transported back to the surface along the subduction zone and; ii) amphibolite facies, kyanite, staurolite, schists formed in the thickened continental crust.

b. What are the sources of heat that result in the formation of metamorphic rocks in the thickened continental crust?

c. How is it possible for an eclogite mineral assemblage, formed at high pressure, to be preserved during the retrograde PT path that brings the rock to the surface?

d. What factors determine if a Buchan (high T-low P) or Barrovian (high T-medium P) field gradient develops in the thickened crust above the subduction zone?

e. What other tectonic settings can result in the formation of metamorphic rocks with a Barrovian metamorphic field gradient?