Exam: Advanced Metamorphic Petrology and Mineralogy (GEO4-1435)
Date: Wednesday 10-11-2010
Time: 09.00-12.00

1) a) What is the difference between UHP- and eclogite-facies metamorphose?
   b) What are the major (bulk) rock types that you can expect to find in a (U)HP metamorphic terrane?.
   c) Give/describe two geodynamic models that can explain the rock association described in 1b.
   d) What would you do in the future to be able to discriminate between the two geodynamic models described in 1C?

2) Take one thin section from the collection.
   a) Write down the number of the thin section on your exam paper
   b) Describe the (dominant) mineral assemblage
   c) Describe the microstructure
   d) Give the rock a metamorphic name
   e) Give a name/rough indication of the bulk rock chemistry of your thin section

3) A vertical cross-section of the electron-optical colomn of a transmission electron microscope (TEM) is illustrated in Fig 1.
   a) Give names to the parts that are numbered 1 → 9
   b) Describe the function of the parts numbered 1 → 9
   c) Which of the numbered parts are lacking in a SEM/EMP?
   d) Which of the numbered parts are lacking in an optical microscope?
   e) What are the three main-operational modes of a TEM?

4) During the practical (practical 11) you have analysed a BSE image of a "heavy sand fraction". The same BSE image is illustrated here as Fig 2. However two of the minerals involved were changed, the other 2 are the same (compare EMP analyses of Table 1 with that in practical 11).
   a) Use the EMP analyses given in Table 1. What mineral (=solid phases 1→ 4) corresponds now to symbols A, B and C in Fig 2 (also give your calculations).
   b) In this new case can there still be a mineral hidden in the black background above B and C? If your answer will be yes, which of the solid phases (1→ 4) will it be? Explain your answer.

5) EMP analyses (and calculated structural formulae (SF)) of garnet and clinopyroxene are given in Table 2. The SF of garnet was calculated on the basis of 12 oxygen, for clinopyroxene on the basis of 6 oxygen.
   a) Calculate for garnet and pyroxene how much Fe^{3+} will be present in the structural formula
   b) Plot both EMP analyses in representative triangular diagrams and give the calculations you have used to come to these results.
   c) Are the investigated minerals chemically zoned?

d) If your answer to question 5C will be yes: does the chemical zoning that is present in garnet refers to a prograde - or retrograde pressure-temperature traject?
e) What else can you do to test if your answer, given in 5D, is correct.
f) Estimate the metamorphic conditions (in terms of P and T) under which the rock was formed using the graphical method (Kd and Jadeite isopleths graphs are given in Fig 3).
g) Plagioclase was also found in the primary mineral assemblage of the rock. What does this tell you about the calculated PT conditions described in 5f.

Table 1.

EMP analyses of the solid phases A,B,C and D, illustrated in Fig 2.
Note: The number of cations are based upon 24 Oxygen atoms (for phases 2 and 3) and based on 4.0 Oxygen atoms for phase 1 and 4.

Solid phase 1: olivine $(MgFe)_2SiO_4$

	Oxide Wt %	No. of Cations
SiO2	41.52	1.004
FeO	9.79	0.198
MgO	49.76	1.794
Total	101.07	2.996

Solid phase 2: garnet $A_3B_2Si_3O_{12}$

SiO2	37.237	5.9714
Al2O3	20.956	3.9607
CaO	7.696	1.3223
FeO	32.784	4.3967
MgO	1.661	0.3970
Total	100.333	16.0482

Solid phase 3: zircon $ZrSiO_4$

SiO2	32.640	5.9886
ZrO2	67.190	6.0114
Total	99.829	12.0000

Solid phase 4: xenotime YPO_4

P2O5	38.60	1.092
Y2O3	61.40	0.85
Total	100.00	1.94

	garnet		clinopyroxeen	
	core	rim	core	rim
SiO2	38,20	38,55	55,66	55,66
Al2O3	21,55	21,55	11,45	11,45
TiO2	0,00	0,00	0,00	0,00
FeO	27,55	26,00	4,78	4,78
MnO	1,65	0,40	0,00	0,00
MgO	2,05	5,05	7,50	7,50
CaO	9,10	8,00	12,79	12,79
Na2O	0,00	0,00	7,24	7,24
Total	100,10	99,55	99,42	99,42
Si	3,03	3,02	1,99	1,99
Al4+	0,00	0,00	0,01	0,01
Al6+	1,99	1,99	0,47	0,47
Ti	0,00	0,00	0,00	0,00
Fe	1,85	1,70	0,14	0,14
Mn	0,11	0,03	0,00	0,00
Mg	0,24	0,59	0,40	0,40
Ca	0,78	0,67	0,49	0,49
Na	0,00	0,00	0,50	0,50
Total	8,00	8,00	4,00	4,00

Table 2

Solid phase 1 (ilmenite)

	Oxide Wt %	No. of Cations
TiO_2	52.803	8.0177
MnO	2.192	0.3750
FeO	44.946	7.5896
Total	99.941	15.9823

Solid phase 2 (garnet)

SiO2	37.237	5.9714
Al2O3	20.956	3.9607
CaO	7.696	1.3223
FeO	32.784	4.3967
MgO	1.661	0.3970
Total	100.333	16.0482

Solid phase 3 (zircon)

SiO2	32.640	5.9886
ZrO2	67.190	6.0114
Total	99.829	12.0000

Solid phase 4 (Monasite)

La_2O_3	13.701	1.1098
Ce2O3	28.634	2.3022
Pr2O3	3.067	0.2454
Nd2O3	10.932	0.8574
Sm2O3	1.858	0.1405
Gd2O3	1.194	0.0869
Dy2O3	0.371	0.0263
P2O5	34.477	6.4100
UO2	0.431	0.0211
ThO2	2.631	0.1315
PbO	0.076	0.0045
SiO2	0.165	0.0363
Y2O3	1.161	0.1976
CaO	0.610	0.1435
Total	99.838	11.7130

The number of cation results are based upon 24 Oxygen atoms

Table 1. EMP analyses of the solid phases A,B,C and D present in Fig.1.

Table 2. Mineral compositions in oxide wt %

Mineral	Albite	Anorthite	Forsterite	Fayalite	Enstatite	Olivine
SiO2	68.74	43.19	42.71	29.5	59.86	41.52
TiO2	0.0	0.0	0.0	0.0	0.0	0.0
Al2O3	19.44	36.65	0.0	0.0	0.0	0.0
CaO	0.0	20.16	0.0	0.0	0.0	0.0
MgO	0.0	0.0	57.29	0.0	40.14	49.76
FeO	0.0	0.0	0.0	70.50	0.0	9.79
MnO	0.0	0.0	0.0	0.0	0.12	0.12
K2O	0.0	0.0	0.0	0.0	0.0	0.0
Na2O	11.82	0.0	0.0	0.0	0.0	0.0
Fe2O3	0.0	0.0	0.0	0.0	0.0	0.0
Cr2O3	0.0	0.0	0.0	0.0	0.0	0.01

Table 3. Data for oxides

Oxide	atomic mass	Backscattered coefficient
SiO2	60.1	0.1263
TiO2	79.9	0.1814
Al2O3	102	0.1248
CaO	56.1	0.1866
MgO	40.3	0.1224
FeO	71.8	0.2304
MnO	70.9	0.2247
K2O	94.2	0.1944
Na2O	62.0	0.1205
Fe2O3	159.7	0.2166
Cr2O3	151.97	0.2045

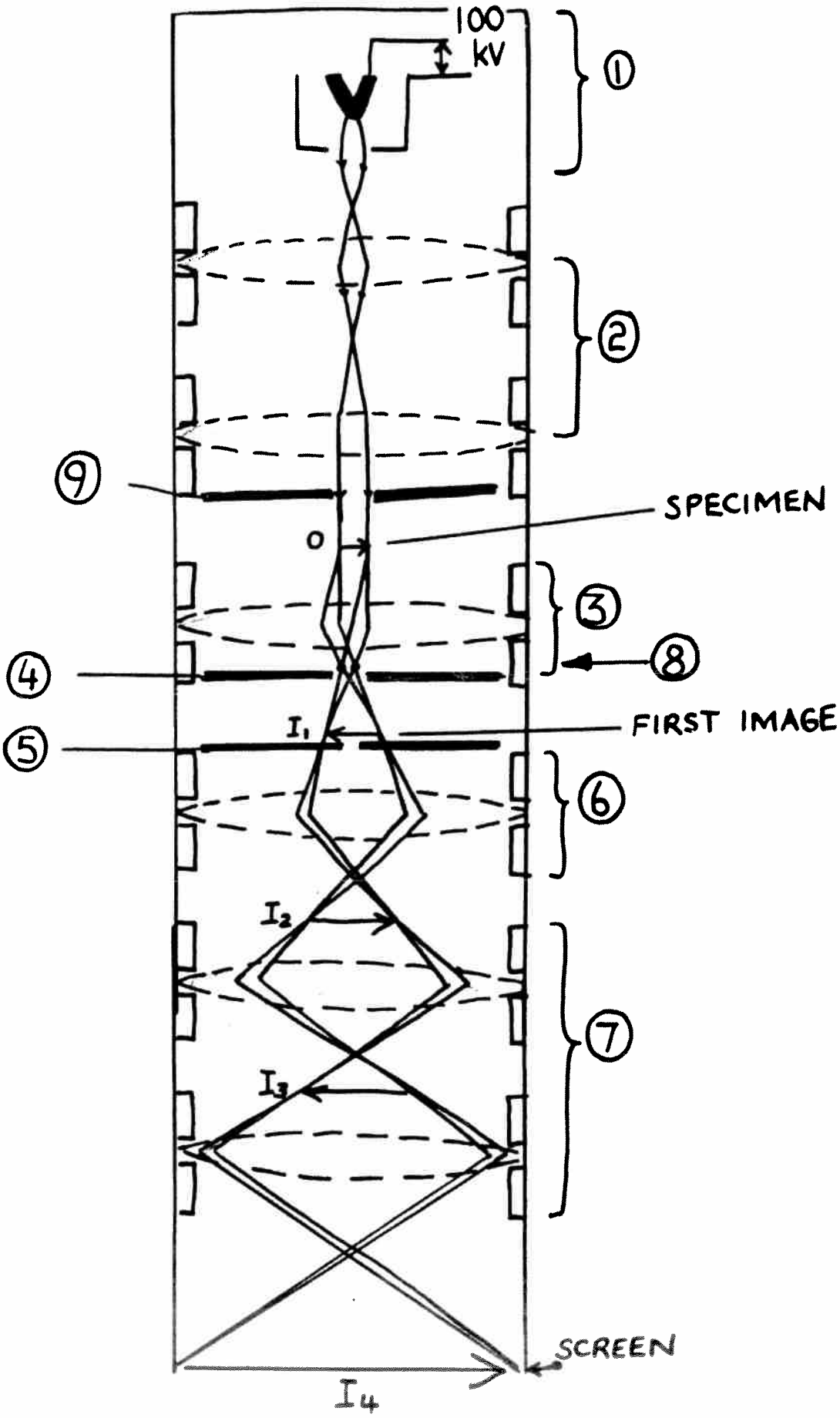

Fig 1

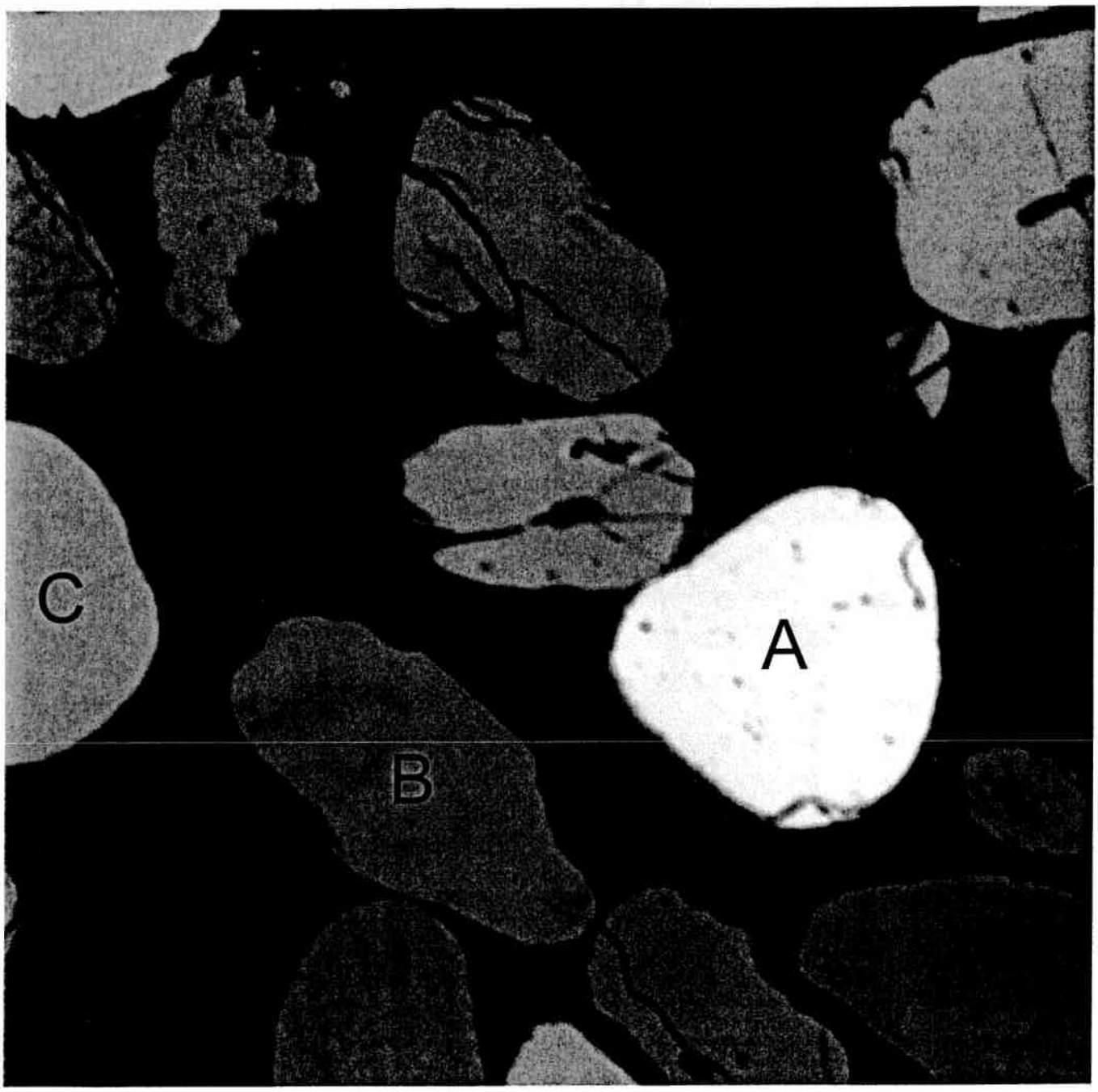

Fig 2