

INDIAN INSTITUTE OF SCIENCE EDUCATION AND RESEARCH KOLKATA
End-semester Examination, Autumn 2018

Course: ES4101 – Igneous and metamorphic petrology

Full marks: 50

Time: 3 hours

Date: 30/11/2018 FN

Instructions:

- **Section A (10 marks): Answer ALL questions.**
- **Section B (30 marks): Answer ALL questions.**
- **Section C (10 marks): Answer 1 out of 2 questions.**
- **The question paper needs to be submitted along with the answer script.**

Section A: Answer ALL questions.

Question 1. Marks: 10

- a) What is the rate of nucleation and rate of growth in plutonic conditions? (in terms of high/low) (1)
- b) What is the difference between a shield volcano and a composite volcano in terms of the shape and the composition of the magma erupted? (1)
- c) What would be the name of the rock containing 40% quartz, 30% K-feldspar, 20% plagioclase 6% biotite and 4% hornblende by weight and having a fine-grained interlocking texture? Justify your answer in a sentence. (1)
- d) Define prograde metamorphism. What is the difference between metamorphism and metasomatism? (2)
- e) What is meant by Isothermal Decompression (ITD) and Isobaric cooling (IBC) P-T paths? (1)
- f) What is the sequence of facies that commonly occur along a medium P/T series? (1)
- g) In which type of tectonic settings are tholeiitic and calc-alkaline basaltic magma normally generated? (1)
- h) Define Gibbs free energy and entropy of a system? Write the equation by which Gibbs free energy it is related to enthalpy and entropy of the system. (2)

Section B: Answer ALL questions.

Question 2. Marks: 6

- a) Define metamorphic facies. (1)
- b) What would be the formula of the resulting molecule after tremolite ($\text{Ca}_2\text{Mg}_5\text{Si}_8\text{O}_{22}(\text{OH})_2$) has undergone pargasite substitution? Show the substitution. (2)
- c) What change does plagioclase undergo from greenschist to amphibolite facies? (1)
- d) What is the typical mineral assemblage of a granulite and an eclogite-facies metamorphosed rock of mafic bulk composition? What is the characteristic difference in the mineral assemblage of the two facies? (2)

Question 3. Marks: 6

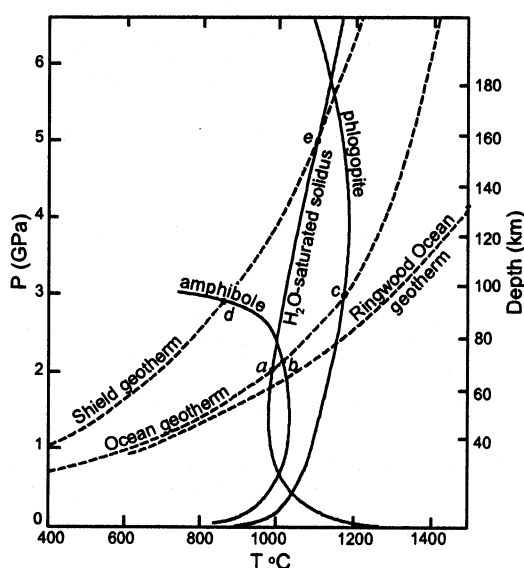
- a) What are paired metamorphic belts? Where and how do they form? (2)

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- b) Describe the tectonic-petrologic evolution of a rock along a typical clockwise P-T-t path with the help of a suitable diagram. In which tectonic setting would you expect such a P-T-t path? (3)
- c) What type of metamorphism will be experienced by the surrounding country rocks when a hot basaltic magma is emplaced at very shallow depths? Draw a schematic P-T path for the country rocks. (1)

Question 4. Marks: 6

- a) If melting of mantle is not a 'normal process', under what circumstances can it be accomplished? Give examples of regions on earth where such circumstances occur. (2)
- b) A H_2O -undersaturated rock composed of only diopside + anorthite + phlogopite is heated by burial along ocean geotherm. At which point (diagram below) will melt be generated and why? (2)
- c) The same rock as above, but H_2O -saturated, is heated along the shield geotherm. What will happen at point 'd' and 'e', and why? (2)



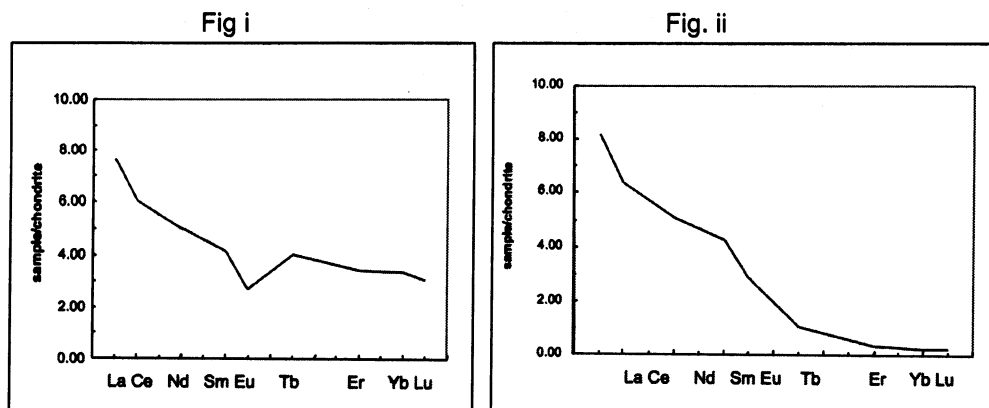
Question 5. Marks: 6

The temperature-composition (T-X) Diopside ($CaMgSi_2O_6$)-Anorthite ($CaAl_2Si_2O_8$) binary phase diagram at 1 atmosphere pressure is shown below (last page).

- a) Begin with a melt of composition $X_{Di} = 80$ at $1500^\circ C$. Plot the composition on the diagram and calculate the F at this condition. (1)
- b) If the melt is cooled isobarically, at what temperature (roughly) will F change and what occurs at this point? (1)
- c) On further cooling, at what temperature does F change again? Write the reaction involved at this point. (1)
- d) Considering ideal fractional crystallization, what would be the ratio of the solid phases (by weight) when both the solid phases crystallize together? (1)
- e) Mark on the figure the solid and the liquid evolution path for ideal fractional crystallization. (1)
- f) If the Diopside-Anorthite binary phase diagram is constructed for 1 GPa pressure, how will the eutectic point shift from that in the given diagram? (1)

Question 6. Marks: 6

- What do you mean by compatible and incompatible trace elements? Give a few examples of each. (2)
- Among gabbro and granite, which rock would be richer in incompatible trace elements and why? (1)
- Fig. (i) and (ii) represent chondrite normalized REE patterns of rocks formed by equilibrium crystallization of mantle-derived primary melts. Using the figure, what can you say about the mineralogical composition of the source rocks? Explain your answer. (3)



Section C: Answer 1 out of 2 questions.

Question 7. Marks: 10

- a) An isobaric (1 atmosphere) Diopside-Forsterite-Anorthite ternary phase diagram is provided below. Consider a melt composition of 20% anorthite and 40% forsterite by weight.
 - i. Plot the composition on the ternary phase diagram on the last page. What is the degree of freedom (F) at 1700°C? Show your work. (1)
 - ii. Which mineral begins to crystallize first as the melt is cooled? Write the reaction involved at this stage. (1)
 - iii. Among the following trace elements (Rb, Cr, Ni, La), which ones will be progressively concentrated in the remaining liquid and why? (1)
 - iv. Draw and label the solid evolution path till the entire melt has crystallized. (Consider ideal fractional crystallization). (1)
 - v. Find out geometrically the ratio of the solid phases crystallizing at 1300°C. (1)
- b) Consider a hydrated rock composed of fine-grained olivine (15%), clinopyroxene (30%), plagioclase (40%) and orthopyroxene (15%) buried at a depth of 25 km below the surface:
 - i. What would be the possible pressure at this depth? Considering a geothermal gradient of 25°C/km, what would be the likely T? (1)
 - ii. Write the likely mineral assemblage and a metamorphic name of the resulting rock. (1)

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- iii. Consider that the rock is then rapidly uplifted to a depth of about 7 km below the surface and stayed there for a much longer time. Draw and explain the likely P-T path followed by the rock from the onset of metamorphism in a calibrated P-T space. (3)

Question 8. Marks: 10

- a) Based on the mineral assemblage of the 2 different metamorphic rocks in the table below, for each rock answer the following questions:
- An appropriate metamorphic name. (1)
 - The possible parent rock (protolith). (1)
 - The corresponding metamorphic facies. (1)
 - Assuming that all the minerals in both rocks are in equilibrium, indicate the possible geobarometers and geothermometers you can use to determine the P –T conditions of equilibrium of the minerals assemblages in each rock. (2)

Rock 1

Plagioclase (25%), Hornblende (15%), Clinopyroxene (10%), Orthopyroxene (20%), Garnet (15%) with some quartz (10%) and opaque minerals (5%).

Rock 2

Garnet (10%), Biotite (25%), Kyanite (10%), Staurolite (20%), Quartz (25%) and Plagioclase (10%).

PS: Your answer must be presented under the following format.

Rock No.	Rock name	Metamorphic facies	Possible parent rock (protolith)	Thermometer	Barometer
Rock 1					
Rock 2					

- b) The temperature-composition (T-X) Forsterite-Silica binary phase diagram at 1 atmosphere pressure is shown below (last page).
- Starting with a melt of composition 90wt.% forsterite at 2000°C, briefly describe what happens with cooling till the entire melt crystallizes. Consider ideal fractional crystallization. Draw and label the solid evolution path on the figure? (4)
 - If a rock composed of enstatite and quartz starts melting, at which point will the first melt be produced? Write the melting reaction taking place at this point. (1)

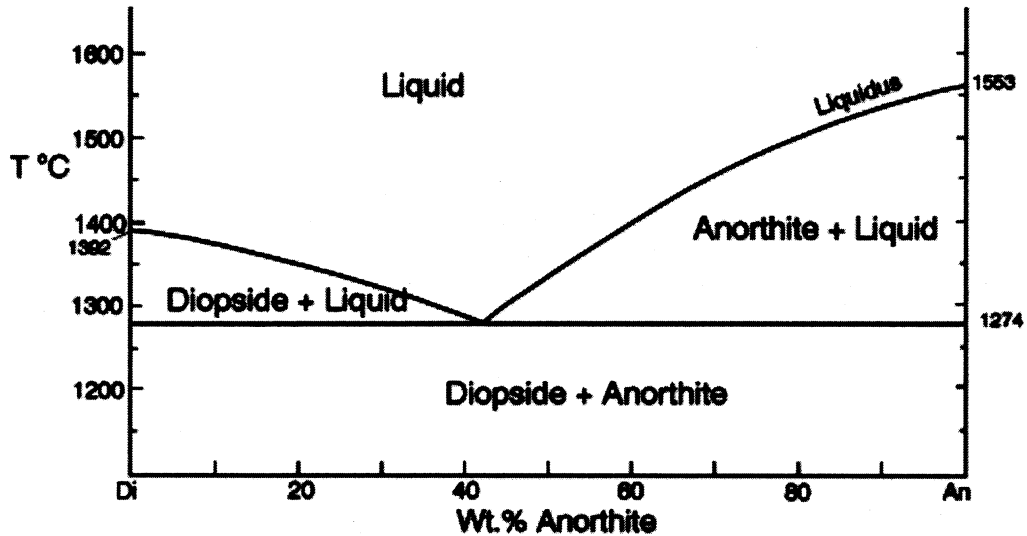
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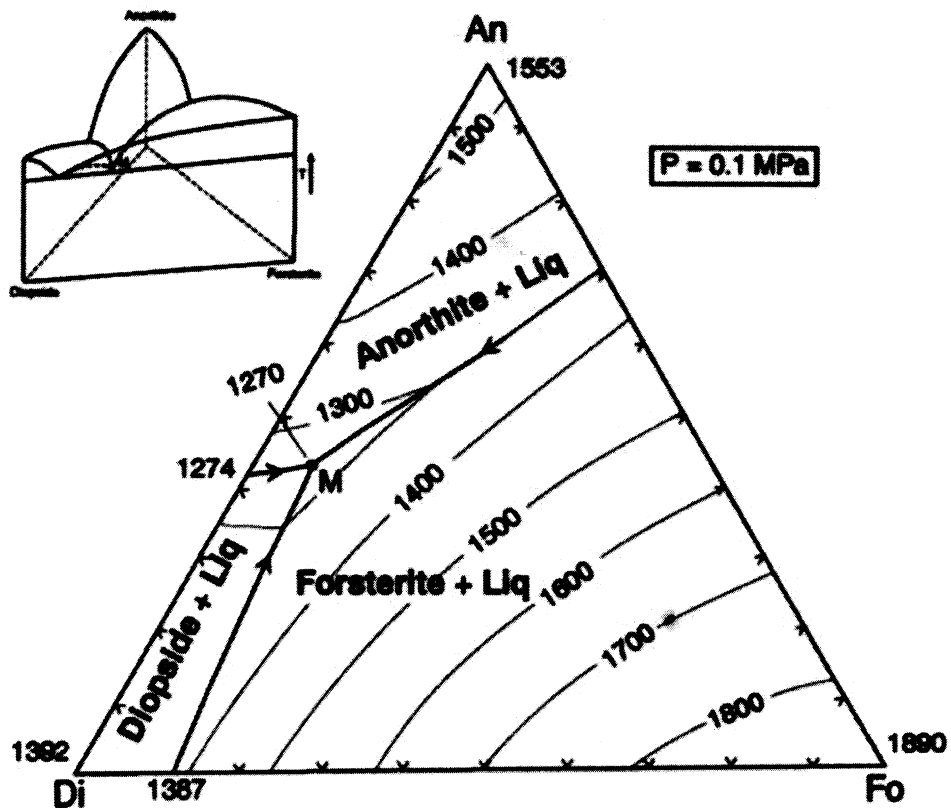
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Name: _____ Roll no. _____

Q.5



Q. 7a



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Q. 8b

