USESO 2021

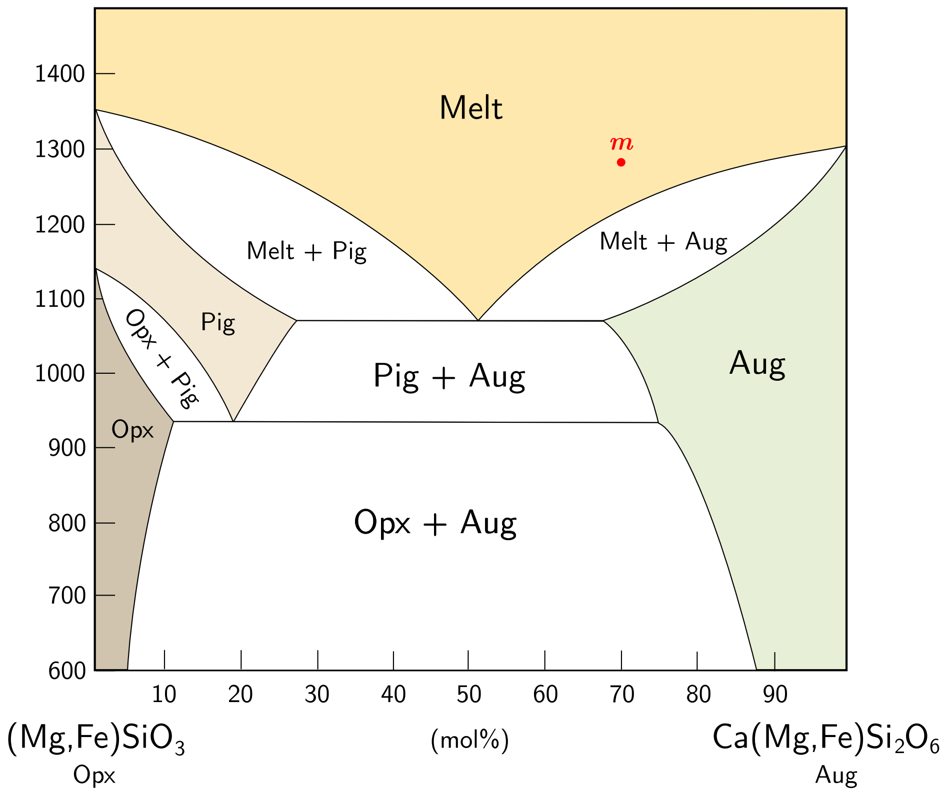
Rocks & Minerals

Instructions:

- There are free response questions and multiple choice questions. There is no penalty for guessing.
- Questions marked with (*) may have 1 or more correct answers.
- A non-graphing, non-programmable calculator is allowed; show work for calculations unless otherwise directed.

Problem 1

Below is a simplified psuedobinary phase diagram of orthopyroxene (Opx), (Mg, Fe)SiO_3, and augite (Aug), Ca(Mg, Fe)Si_2O_6. Pigeonite (denoted Pig) is a high-temperature pyroxene mineral. Here, the percentages on the x axis denote the mole percent of Ca.



1. (2 points) A pyroxene melt of a bulk composition of 70% Aug, 30% Opx (marked m) cools slowly (assume chemical equilibrium is maintained throughout crystallization) until all the melt is crystallized. At the moment immediately after the melt completely solidifies, which of the following best approximates the composition of the augite phase?

   A. 27% Aug

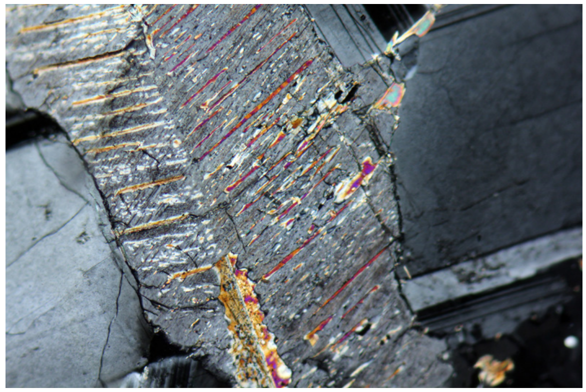
   B. 52% Aug

   C. 60% Aug

   D. 70% Aug

   E. 87% Aug

Consider the same melt. It cools until its closure temperature, T_c, at which chemical equilibrium is no longer maintained between the crystals, and diffusion effectively stops. The thin section below shows an augite crystal (grey) with pigeonite exsolution lamellae (colored).



2. (2 points) Given that the augite host crystal has a composition of 73% Aug, estimate T_c. (Assume equilibrium is perfectly maintained until the closure temperature).

The method used above is known as *solvus thermometry* (we determine the temperature using the composition of exsolved phases). Unfortunately, it is not very accurate for practical purposes.

3. (2 points) Which of the following factors presents a source of error for the estimate above?

   I) The pyroxene phase equilibria are also dependent on pressure, and crystallization is not necessarily isobaric

   II) The pyroxene phase equilibria are also dependent on the Mg-Fe solid solution

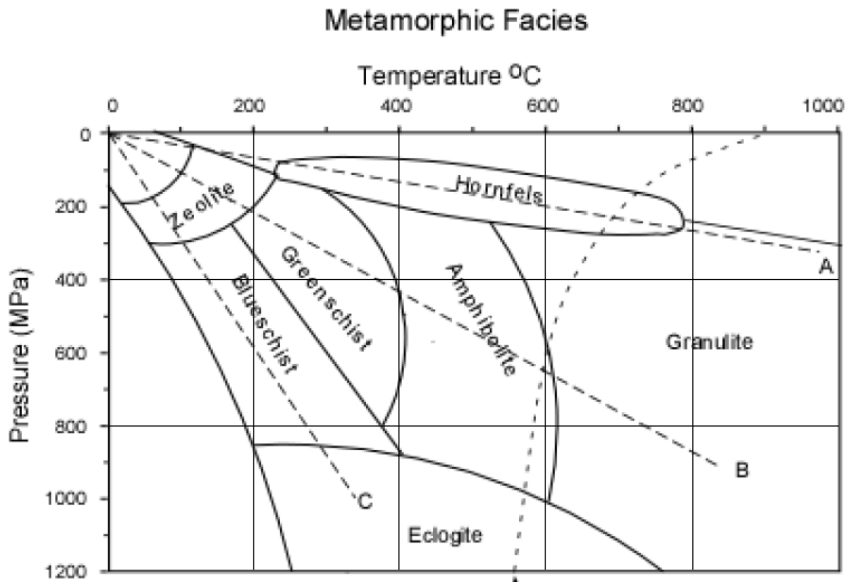
   A. I only
   B. II only
   C. I and II
   D. Neither I nor II

4. (2 points) Briefly explain how the slope of the solvus line (the line separating two exsolved solid phases) affects the accuracy of solvus thermometry.

5. (3 points) The closure temperature is also dependent on the cooling rate. Briefly explain what the presence of pigeonite indicates about the cooling rate of the crystal.

Problem 2

A metamorphic complex in Northwest China has been of particular interest since its discovery in the 1980s because of its implications for tectonics. For this problem, we'll call it the IMC (interesting metamorphic complex). By analyzing the mineral assemblage and through careful phase calculations, it was determined that the peak P-T conditions range from 650 - 800 MPa and 310 - 380 deg C.



1. Determine the possible metamorphic facies that correspond to the peak P-T conditions calculated for IMC. (*)

   A. Zeolite

   B. Blueschist

   C. Greenschist

   D. Granulite

   E. Hornfels

2. (2 points) Using a linear approximation (like the ones shown in the facies diagram), give an estimate for the geothermal gradient. Use the mean of the P and T ranges.

To constrain the age of this metamorphic complex, U-Pb analysis was conducted on two zircon populations called Gab and Det. ^{238}U decays to ^{206}Pb with a half-life of $4.468 \cdot 10^9$ years. It can be assumed that there has been no loss of parent or daughter isotopes from the zircons and that all ^{206}Pb is radiogenic. Calculations are often performed using isotopic ratios; in this case, we use the $^{206}Pb/^{238}U$ ratio.

3. (2 points) Which expression correctly gives the age t of a sample in terms of half-life (λ) and the isotopic ratio of $^{206}Pb/^{238}U$?

   A. $t = \lambda \log_2 (1 + {}^{206}\text{Pb}/{}^{238}\text{U})$

   B. $t = 2^{{}^{206}\text{Pb}/{}^{238}\text{U}} \lambda$

   C. $t = \frac{1}{\lambda} \log_2 (1 + {}^{206}\text{Pb}/{}^{238}\text{U})$

   D. $t = -\lambda \log_2 (1 + {}^{206}\text{Pb}/{}^{238}\text{U})$

   E. $t = \lambda \log_2 ({}^{206}\text{Pb}/{}^{238}\text{U})$

4. (2 points) Gab zircons were collected from a gabbro dike intruding into IMC. The dike shows little to no signs of metamorphism. Given that the average isotopic ratio $^{206}Pb/^{238}U = 0.126$, calculate the age of the Gab zircons. Showing work is not necessary.

5. (3 points) Det zircons were collected from within the metamorphic rock itself, where they were identified to be detrital zircons originating from sedimentary processes. Det zircons had a minimum age of 805 Ma. Keeping in mind the petrogenic (rock-forming) processes, justify how these two ages (the youngest Det age and the average Gab age) constrain (i.e., provide the bounds for) the age of the metamorphism.

6. (2 points) Which of the following statements is true?

   I) The geothermal gradient was greater in the past because there was greater residual internal heat from Earth's formation

   II) The geothermal gradient was greater in the past because there was greater radioactive decay in Earth's interior

   III) Precambrian-aged blueschists are rare

   A. I only

   B. III only

   C. I and II

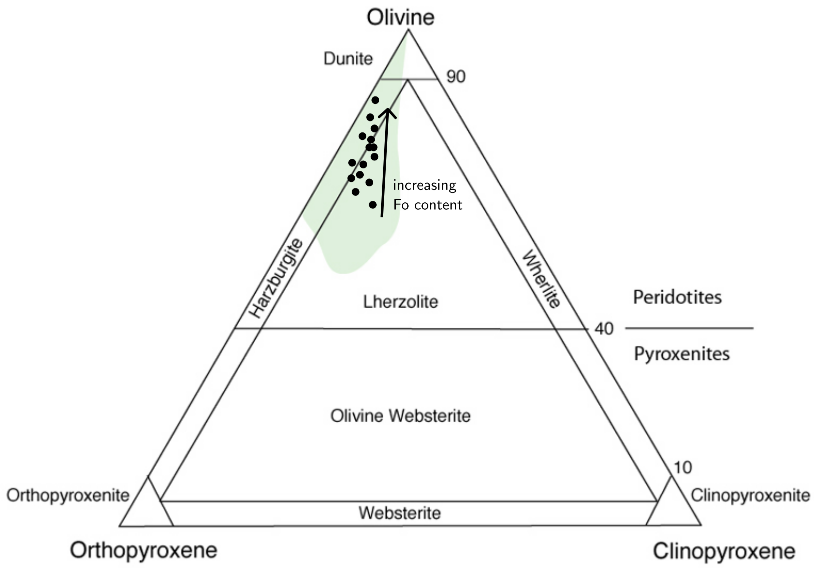
   D. I and III

   E. II and III

   F. I, II, and III

Problem 3

Mid-Ocean Ridge Basalts, or MORBs, are the most common type of igneous rock on Earth.

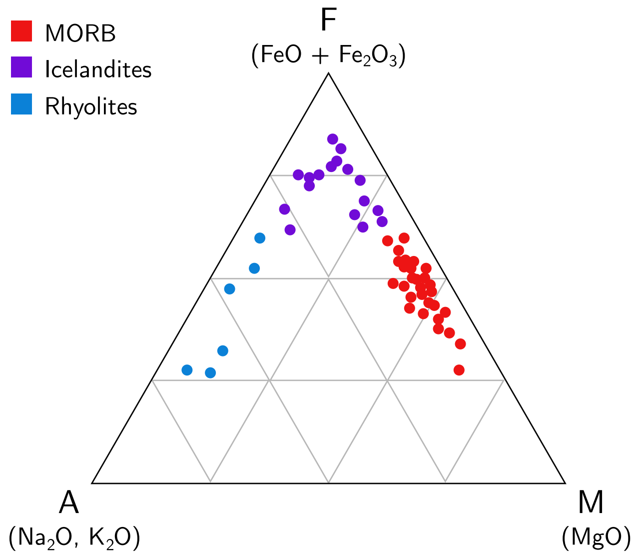


Above shows a population of peridotites, with the composition of individual samples plotted as dots. Olivine, $(Fe, Mg)_2SiO_4$, is a solid solution between forsterite (Mg_2SiO_4, melting point = 2160 K) and fayalite (Fe_2SiO_4, melting point = 1478 K). The arrow shows increasing forsterite content in olivine crystals.

Considering the implications of the diagram, answer the following true/false questions:

1. (1 point) T/F: The arrow denotes a decreasing trend in the degree of partial melting
2. (1 point) T/F: Fast spreading ridges like the East Pacific Rise are associated with harzburgite in the upper lithospheric mantle
3. (1 point) T/F: MORBs formed from very slowly spreading ridges tend to have a greater concentration of incompatible elements like K and Rb than MORBs formed at fast spreading ridges
4. (1 point) T/F: Normal MORBs have lower $^{143}Nd/^{144}Nd$ than bulk Earth

Melt formed from mantle peridotite evolves on the tholeiitic magma series; MORBs are thus known as tholeiites. Iceland is a unique location where a mantle plume has significantly enhanced mid-ocean ridge magma production. Icelandic rocks also document a complete evolution along the tholeiitic series.



Rocks from Iceland were sampled and their (relative) compositions were plotted, shown in the AFM diagram above. The AFM ternary diagram plots alkali (A), iron (F), and magnesium (M).

5. (2 points) Briefly account for the iron enrichment trend as MORBs evolve to Icelandites.

6. (2 points) As a magma evolves from MORB $\longrightarrow$ Icelandite $\longrightarrow$ rhyolite, indicate whether the given quantity increases or decreases. (0.5 points each)

   (a) Silica content

   (b) Viscosity

   (c) Gas solubility

   (d) Percentage of incompatible elements in the melt

7. (3 points) Rhyolites are rarely formed at mid-ocean ridges, so Iceland is a special case. Propose one reason for why rhyolite may be formed in Iceland.

END OF EXAM