USESO 2022

Rocks & Minerals

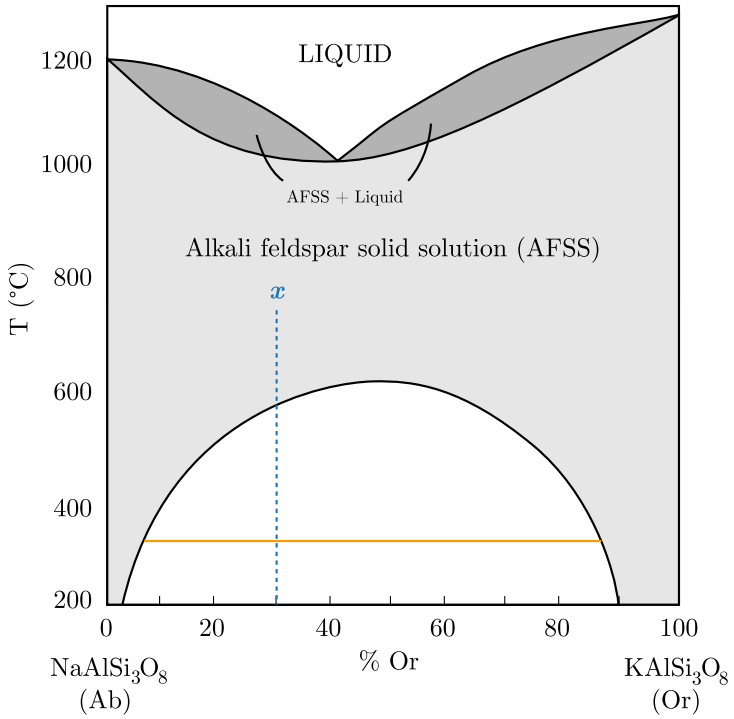
Instructions:

- There are three problems each worth 10 points; you have 30 minutes
- A calculator is allowed; show all work for calculations unless otherwise stated

Problem 1

Question	1	2	Total
Points	5	5	10 (33%)

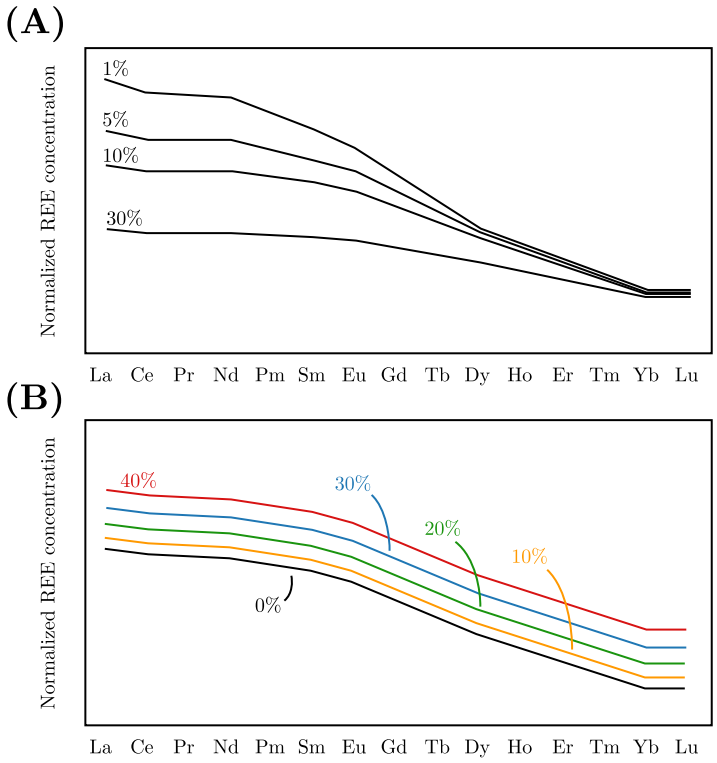
The phase diagram below shows a large feldspar crystal of composition x as it cools along the dotted blue line. Ab and Or denote albite and orthoclase, respectively.



1. (a) (2 points) Explain what happens as the crystal cools below 580 °C. Briefly describe the texture that is formed by this process.

   (b) (3 points) Assuming that the crystal remains in chemical equilibrium, determine the compositions and relative proportion of all solid phases present at 330 °C (denoted as the orange line). Show your work and give your answer as percentages.

The two diagrams below show the relative content of each rare earth element (REE) in two magmas undergoing differentiation. REEs are relatively incompatible, meaning that they do not fit well into the crystal structure of most minerals.



2. (a) (2 points) Differentiation shown in A and B have been caused either by fractional crystallization or partial melting. The percentages above each line show the degree to which either of these processes have taken place. Match A and B to either fractional crystallization or partial melting and briefly explain your choice.

   (b) (3 points) As the elements trend from lanthanum (La) to lutetium (Lu), do they become more or less incompatible? Justify your answer using the diagram(s). Then, use geochemical concepts to hypothesize why this trend exists.

Problem 2

Question	1	2	3	4	Total
Points	3	4	2	1	10 (33%)

The age of the Earth was constrained in the 1950s using a technique called lead-lead dating on meteorite samples. This method relies on measuring the ratio of radiogenic lead isotopes ^{206}Pb and ^{207}Pb to a non-radiogenic reference isotope ^{204}Pb. The two relevant decay pathways are:

$$^{238}\text{U} \longrightarrow {}^{206}\text{Pb}$$
$$^{235}\text{U} \longrightarrow {}^{207}\text{Pb}$$

1. (3 points) Write an equation relating a sample's current ratio of ^{206}Pb/^{204}Pb to its age T, the current ratio of ^{238}U/^{204}Pb, and the half-life of ^{238}U, denoted as $t_{1/2}$. You may assume that the sample is isolated, but the original ^{206}Pb concentration is **not** zero. (*Hint: the concentration of ^{204}Pb remains constant with time.*)

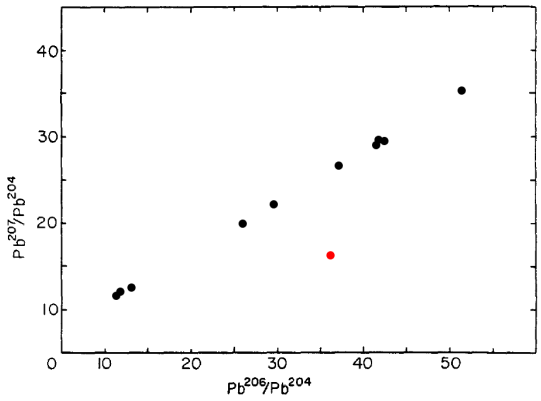
This dating method also assumes that the ratio of ^{238}U/^{235}U, denoted r, is the same as that of Earth ($r = 137.8$). For abbreviation, from here we will denote ^{206}Pb/^{204}Pb as R_{206} and ^{207}Pb/^{204}Pb as R_{207}.

2. (4 points) Show that for an isolated sample, the two lead isotope ratios can be related by:

$$R_{207} = R_{206}\left[\frac{2^{T/t_{235}} - 1}{r\left(2^{T/t_{238}} - 1\right)}\right] + k$$

   Where t_{235} and t_{238} are the half-lives of ^{235}U and ^{238}U, respectively, and k is a constant.

3. (2 points) 10 meteorite samples from various localities are analyzed and their lead compositions are plotted below **in black**. Assuming these meteorites formed concurrently with Earth, **explain** how the data from this plot can be used to estimate the age of the Earth. You **do not** need to perform any calculations or algebra.

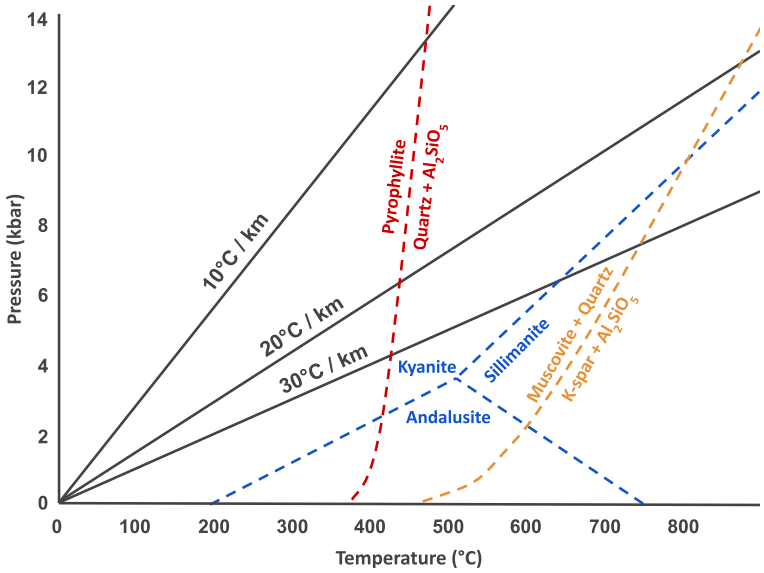


4. (1 point) The graph of ^{207}Pb/^{204}Pb and ^{206}Pb/^{204}Pb for the 10 meteorite samples is linear. However, when a sample from a Martian meteorite is analyzed and plotted in red, it falls off of the line. Propose one reason for this.

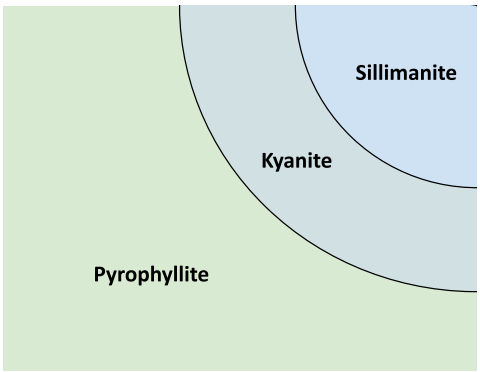
Problem 3

Question	1	2	3	4	Total
Points	1	3	2	4	10 (33.3%)

The diagram below shows stability ranges for minerals at various metamorphic grades. Andalusite, kyanite, and sillimanite are polymorphs with the same chemical formula, Al_2SiO_5.



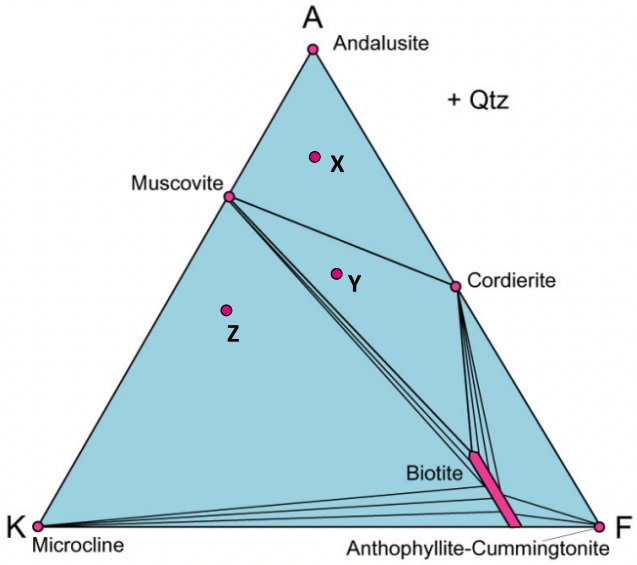
A geologist has identified the presence of pyrophyllite ($Al_2Si_4O_{10}(OH)_2$), kyanite, and sillimanite at various points in the metamorphic complex shown below. While these are not the only minerals present, they offer useful information about the complex and its formation.



1. (1 point) Which of the following most likely describes the sequence of metamorphic facies seen in this complex?
   A. Blueschist to amphibolite
   B. Prehnite-pumpellyite to eclogite
   C. Greenschist to granulite
   D. Zeolite to hornfels

2. (a) (2 points) Explain the significance of the production of H_2O in the environment where this reaction occurs.
   (b) (1 point) Minerals like kyanite and sillimanite are not stable at surface conditions, but remain in the complex anyway. What conditions would be required for them to convert back to a more stable form?

The diagram below is a triangular AKF diagram showing various common metamorphic minerals. The components A, K and F are defined as follows:



$$A = [Al_2O_3 + Fe_2O_3] - [Na_2O + K_2O + CaO]$$
$$K = [K_2O]$$
$$F = [FeO + MgO + MnO]$$

3. (2 points) Where would pyrophyllite, $Al_2Si_4O_{10}(OH)_2$, be located on this diagram?

   A. At point A

   B. At point K

   C. At point F

   D. Between points A and K

   E. Between points K and F

   F. Between points A and F

4. (a) (2 points) Which of the points labeled on the diagram would most likely produce the composition seen in the complex?

   A. X

   B. Y

   C. Z

   (b) (2 points) Using the stability chart, explain how the complex would differ if its parent rock had a composition defined by either of the other two points.