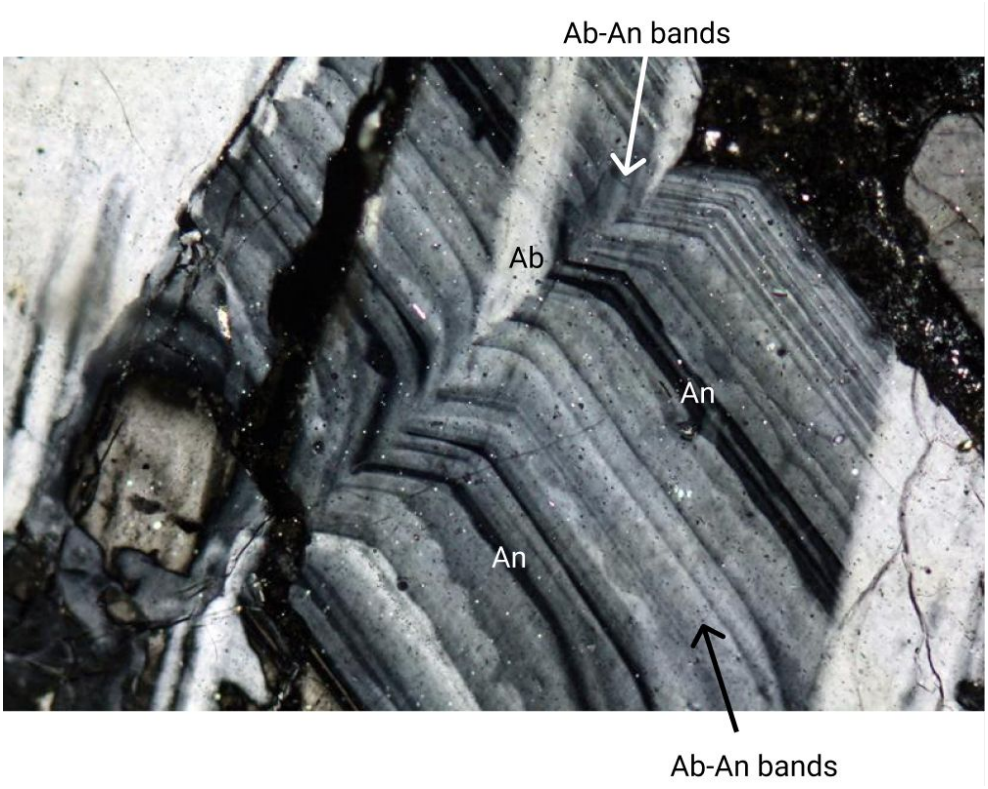
Rocks and Minerals Exam - Theoretical

Instructions:

- For multiple-select questions denoted (*), a correct answer is awarded 2 points. Selecting an answer that is not correct will result in a deduction of 2 points, while missing a correct option will not result in any point deduction.
- For questions denoted (*), there is/are anywhere between zero and all correct answers
- Point values are given for all other question types
- Follow *exactly* the format given for certain short answer questions
- Give *brief but specific* explanations for long answer questions
- **Questions begin on the next page**

Q1 - Zoning of Plagioclase



Shown in the figure is a thin section of a zoned plagioclase crystal, with anorthite-rich bands denoted with An and albite-rich bands denoted with Ab. Use the figure above for the next three questions.

1a) Identify the type of zoning exhibited by this plagioclase crystal. (1 pt)

1b) Identify all of the following statements that are **true** about the crystallization of this sample. (*)

A) Anorthite bands mark areas of relatively lower crystallization temperature
B) The transition from the crystallization of anorthite to the crystallization of albite involves a coupled substitution of Ca^{2+} for Na^{+} and Al^{3+} for Si^{4+}
C) The temperature of the local magma body in which this plagioclase crystal crystallized shifted relatively rapidly
D) The starting composition of the magma body had little effect on the zoning of the plagioclase crystal shown
E) The plagioclase crystal stayed in chemical equilibrium with its parent magma for the entirety of its crystallization

1c) Briefly **describe** any possible environment (e.g. tectonic environment, etc.) in which this zoning could have developed, and **explain** why it would develop in that environment. (4 pts)

Q2 - Magma Evolution

Consider a subducting oceanic slab that leads to partial melting of the mantle under a continental arc. The composition of the eutectic melt **M** formed is given in **Figure 1** below as the red dot. As the magma body **M** ascends and cools, rocks **A**, **B**, and **C** are formed, shown as thin sections in **Figure 2**.

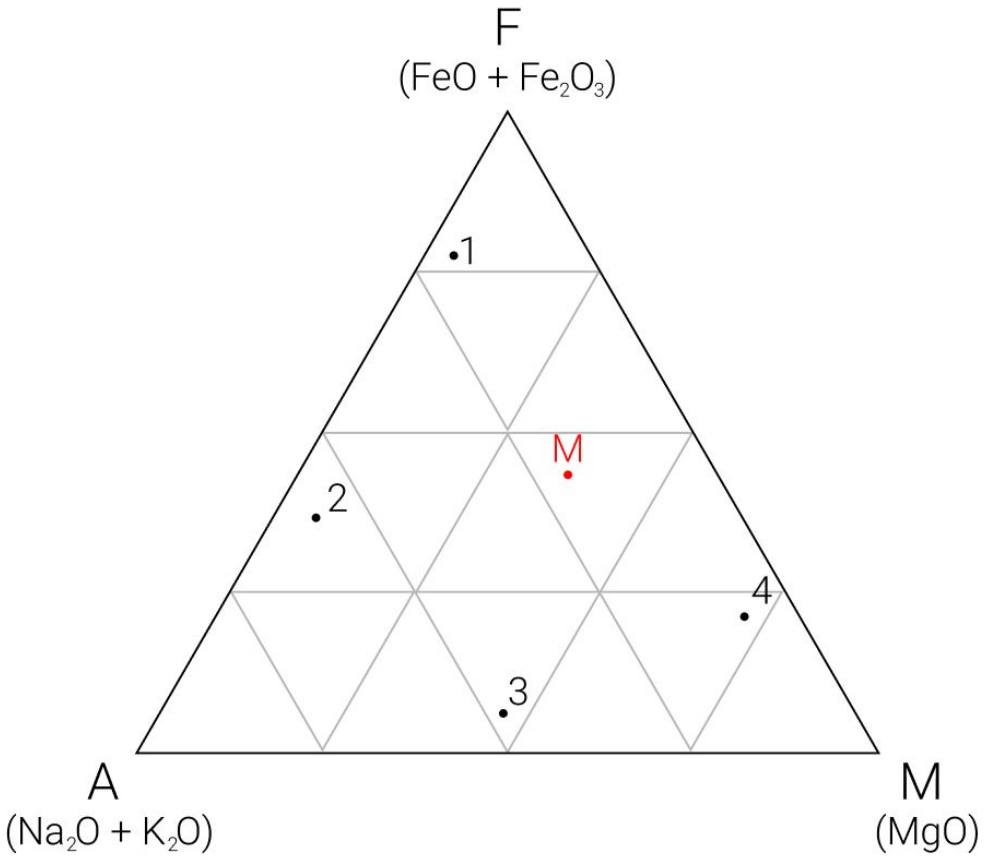
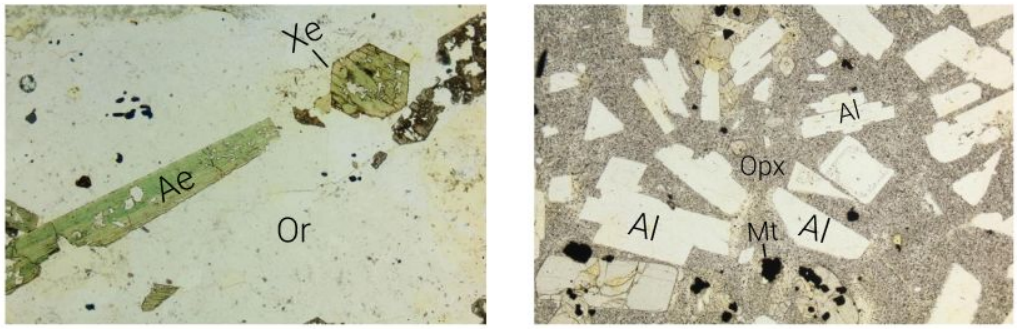
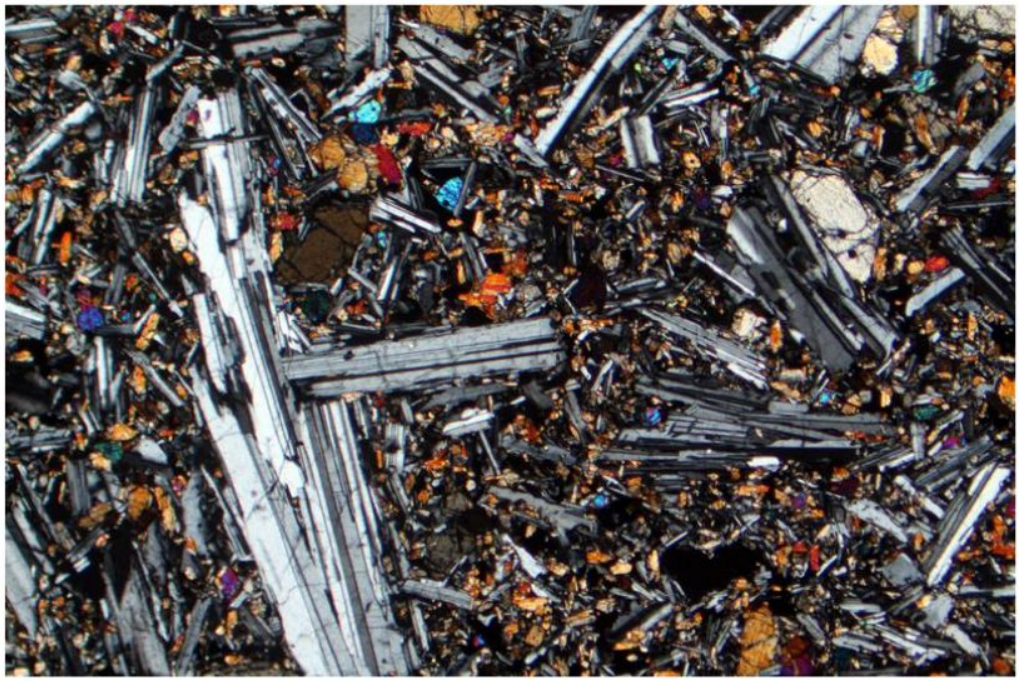


Figure 1: Shows an AFM diagram with the eutectic melt **M** and four other points, labeled 1 through 4.



Rock **A** Rock **B**



Rock **C**

Figure 2: Shows thin sections (field of view = 7 mm) of three rocks: **A**, **B**, and **C**. Rock **A** contains aegirine (a pyroxene with formula $NaFe(SiO_3)_2$ abbreviated Ae) and xenotime (a phosphate with formula YPO_4 abbreviated Xe) in a matrix of orthoclase. Rock **B** contains Al_{70} (70% albite, 30% anorthite plagioclase) and magnetite (Fe_3O_4, abbreviated Mt) crystals in a fine-grained orthopyroxene matrix. Lastly, rock **C** contains Al_{20} (20% albite, 80% anorthite plagioclase) crystals in a matrix of fine-grained olivine, clinopyroxene, and magnetite.

2a) Determine the order of crystallization (first to last) of rocks **A**, **B,** and **C** from melt **M**, giving your answer as three letters separated by no spaces (e.g. ABC). (2 pts)

2b) Given enough time for melt **M** to fully evolve, indicate the **number** on the AFM diagram where the composition of a fully-evolved melt **M** will end up. (2 pts)

2c) Identify all of the following statements regarding the evolution of **M** that are likely **true**. (*)

A) Magnesium-rich orthopyroxenes (e.g. enstatite) crystallize at higher temperatures than iron-rich orthopyroxenes (e.g. ferrosilite)
B) The presence of magnetite in rocks **B** and **C** indicates that **M** is relatively oxidized
C) **M** was more reduced during the crystallization of **B** than during the crystallization of **A**
D) Latent heat of crystallization drives the melting and assimilation of crust into **M**
E) **M** evolves along the tholeiitic magma series
F) Water catalyzes the polymerization of silica and destabilizes amphiboles in **M**
G) The relative concentrations of the CaO + MgO components of **M** remain mostly constant over time

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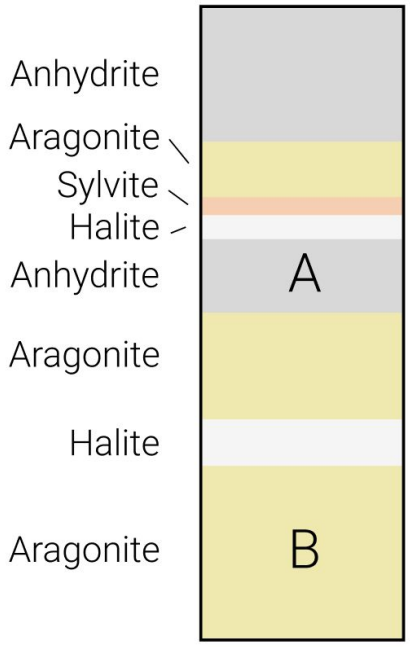
Q3 - Evaporites



Halite, sylvite, aragonite, and anhydrite are four important evaporite minerals. A deposition sequence of evaporites is shown in the figure above.

Identify all of the following statements regarding evaporite deposition that are likely **true**. (*)

A) Halite precipitates from water before the precipitation of sylvite
B) Aragonite precipitates from water after the precipitation of halite
C) The water from which **B** was precipitated was sulfate-poor
D) **A** experienced dehydration following precipitation
E) The density of the water from which **B** was precipitated is less than the density of water from which **A** was precipitated

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Q4 - Glomeroporphyritic Basalt

Shown in the figure is a sample of glomeroporphyritic basalt, which contains aggregates, called glomerocrysts, of plagioclase phenocrysts in a groundmass of fine-grained clinopyroxene. Assuming complete equilibrium crystallization (unlikely), identify all of the following statements regarding this sample that are likely **true**. (*)

A) There is distinct zoning within the plagioclase glomerocrysts
B) The bulk composition of the parent magma is more enriched in plagioclase relative to the plagioclase-clinopyroxene eutectic
C) The bulk composition of the parent magma is equal to the composition of the plagioclase-clinopyroxene eutectic
D) The bulk composition of the parent magma is more enriched in clinopyroxene relative to the plagioclase-clinopyroxene eutectic
E) The aggregation of plagioclase phenocrysts into glomerocrysts led to rapid crystal settling

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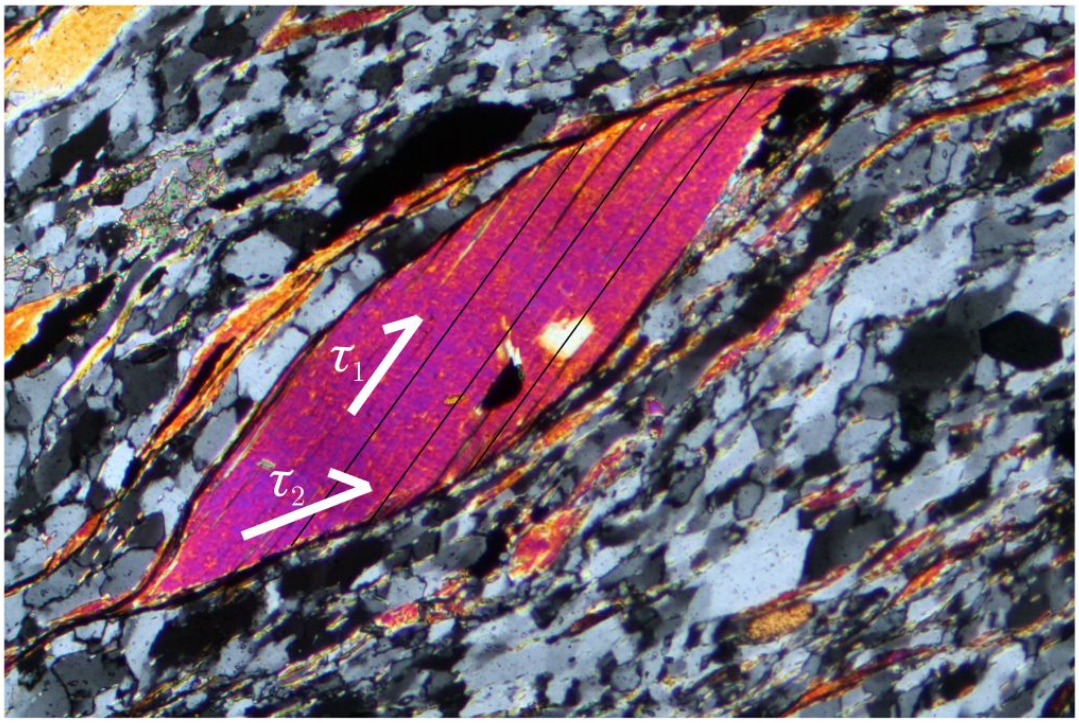
Q5 - Mica Fish



Shown in the figure is a cross-polarized light (XPL) thin section of a mica fish, which are common microscale structures present in mylonites. Two shear stress vectors are shown and are denoted τ_1 (parallel to the striations within the mica) and τ_2.

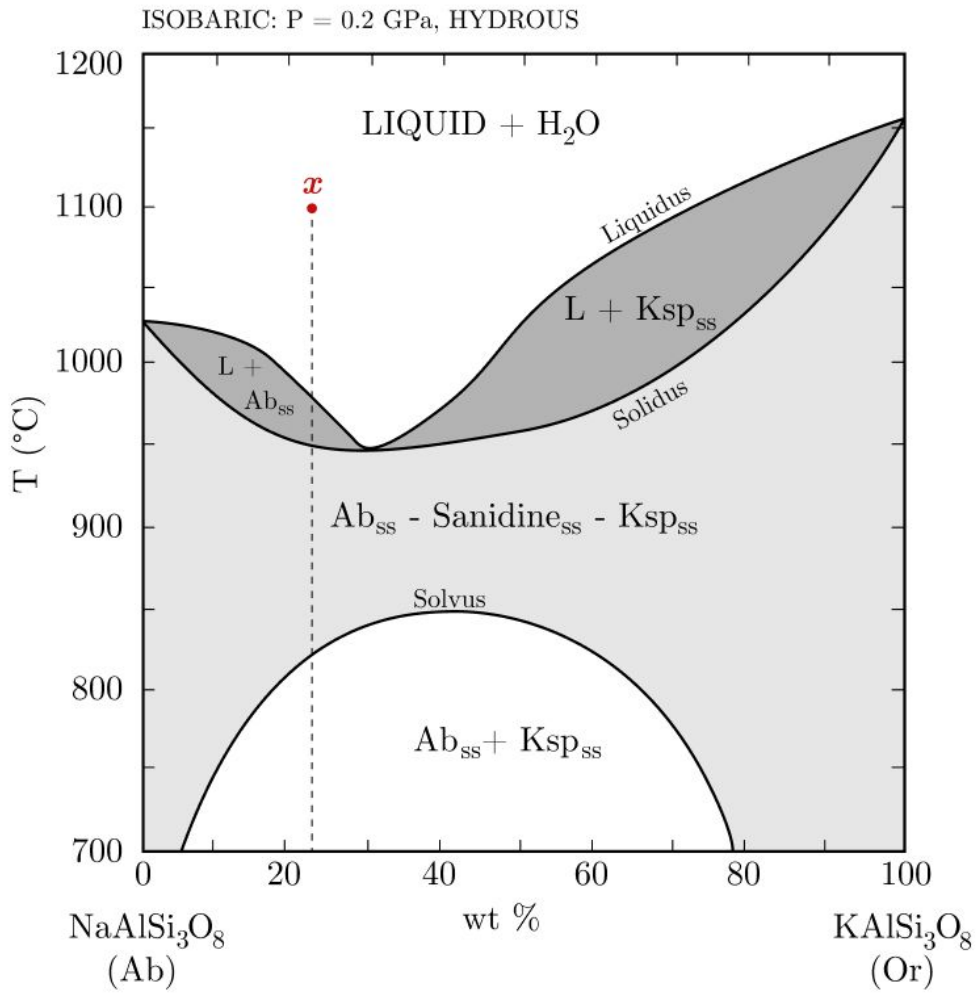
5a) Which shear vector, τ_1 or τ_2, likely dominated the formation of this mica fish? (1 pt)

A) τ_1
B) τ_2

5b) Which of the following statements regarding mica fish is **true**? (2 pts)

A) The majority of mica fish form below the brittle-ductile boundary
B) Mica fish form as a result of ultra-high temperature (UHT) metamorphism
C) Mica fish are common within most muscovite schists
D) Mica fish are common within granitic intrusions
E) The mineral grains surrounding mica fish mostly grow in size as a result of metamorphism

Q6 - Phase Diagram Fun



Consider the isobaric equilibrium crystallization of a 1100 ℃ melt, ***x***, containing an alkali feldspar composition of ~23% Or. Shown in the figure is a phase diagram of a hydrated system of albite (abbreviated Ab) and orthoclase (abbreviated Or), with the composition and temperature of the melt ***x*** plotted at the red point. Identify all of the following statements regarding the crystallization of ***x*** that are true. (*)

A) The composition of the liquid from which ***x*** crystallizes approaches a composition of 70% albite before solidifying
B) As ***x*** is cooled to below 500 ℃, the major phase is an alkali feldspar with a composition of about 23% orthoclase
C) As ***x*** is cooled from 975 ℃ to about 950 ℃, the composition of the melt generally becomes more sodic
D) As ***x*** is cooled from 800 ℃ to about 700 ℃, the bulk composition becomes more potassic

E) When ***x*** is cooled to 750 ℃, exsolution lamellae of orthoclase are present in albite, which is the dominant phase
F) The albite-orthoclase solid solution is unstable at low temperatures due to differing substituent cation charges
G) As pressure increases, the liquidus and solidus lines will fall
H) If all water is removed from the system, the liquidus and solidus lines will rise

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Q7 - Metamorphic Petrology

Consider the epitodization of calcite and chlorite, which can be represented by the equation:

Calcite + Chlorite group ⟶ Epidote group + Actinolite + H2O + CO2.
(reaction **R**)

Occasionally, if the parent metabasalt is enriched in rare earth elements (REEs) or other incompatible elements, the REE-containing allanite group may form as the dominant epidote phase. The general formula of the allanite group is $A_2M_3(Si_2O_7)(SiO_4)O(OH)$, where A sites may contain large, incompatible cations, and where M sites contain two trivalent (i.e. +3) cations and one divalent (i.e. 2+) cation, which are generally small and compatible.

THE CRYSTALLOBLASTIC SERIES

Most Euhedral

Titanite, rutile, pyrite, spinel
Garnet, sillimanite, staurolite, tourmaline
Epidote, magnetite, ilmenite
Andalusite, pyroxene, amphibole
Mica, chlorite, dolomite, kyanite
Calcite, vesuvianite, scapolite
Feldspar, quartz, cordierite

Least Euhedral

Identify all of the following statements regarding epitodization and the formation of allanite that are **true**. (*)

A) Reaction **R** is a retrograde reaction and generally occurs during the exhumation of metabasalts
B) The surface free energy of epidote is higher than that of calcite
C) The water released in the reaction is derived from chlorite-group minerals
D) The presence of internal radiation in allanite crystals signifies the incorporation of uranium and thorium in the M site
E) The solid products of reaction **R** are completely anhydrous
F) Two trivalent REEs may be incorporated into the A site of allanite

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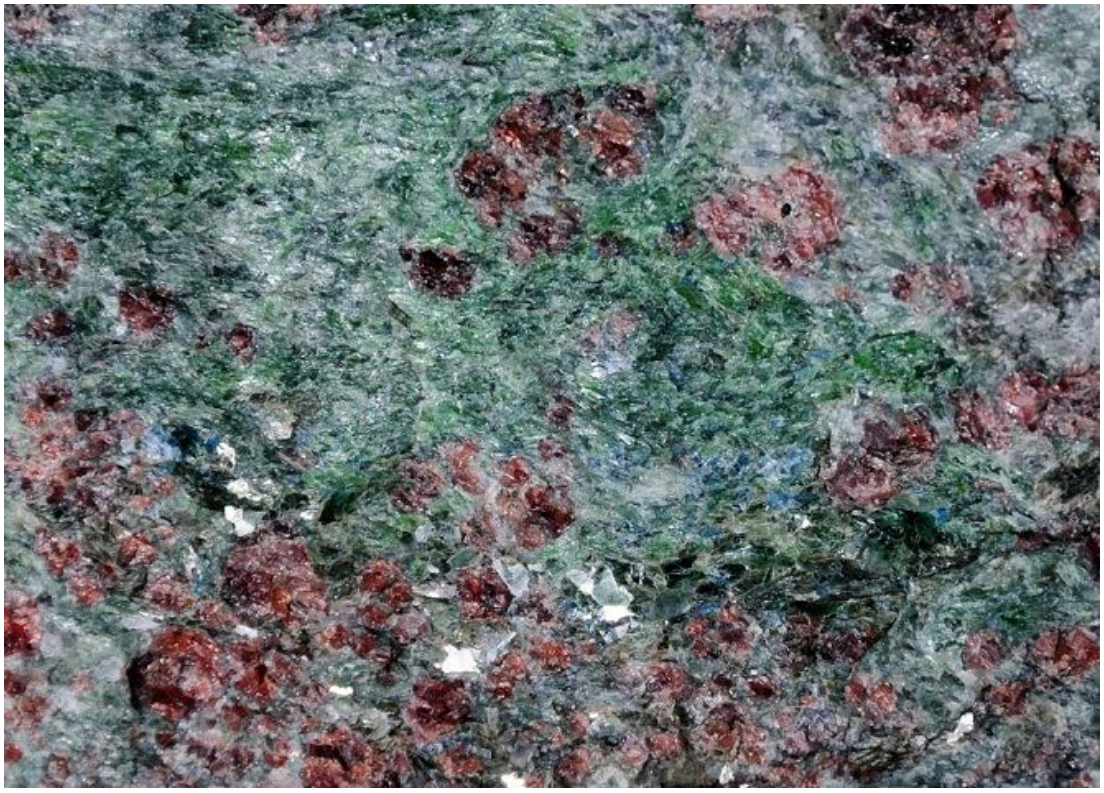
Q8 - Metakomatiites

Komatiites are geologically important rocks that provide information about ancient magmatism and primitive mantle geochemistry. Unfortunately, almost all komatiites are altered by weathering or metamorphism, which complicates their study. The metamorphism of komatiites may take two main "facies", depending on the fugacity (i.e. partial pressure) of CO_2. When CO_2 fugacity is high, carbonation occurs, which produces an assemblage of minerals that includes talc. When CO_2 fugacity is low, hydration occurs. Given this, and using the distinct geochemical characteristics of komatiites, identify all of the following that are likely **true** regarding the formation of metakomatiites. (*)

A) When CO_2 fugacity is high, the metakomatiite formed will likely contain significant serpentine minerals
B) Komatiite carbonation occurs in large scale at mid-ocean ridges from volcanic volatile release
C) Komatiite hydration occurs in large scale at mid-ocean ridges from hydrothermal circulation
D) The carbonation of komatiites produces phyllosilicates
E) The carbonation of komatiites produces significant magnesite ($MgCO_3$)
F) The carbonation of komatiites produces significant calcite ($CaCO_3$)

Q9 - A Colorful Assemblage



Refer to the figure above for following three questions:

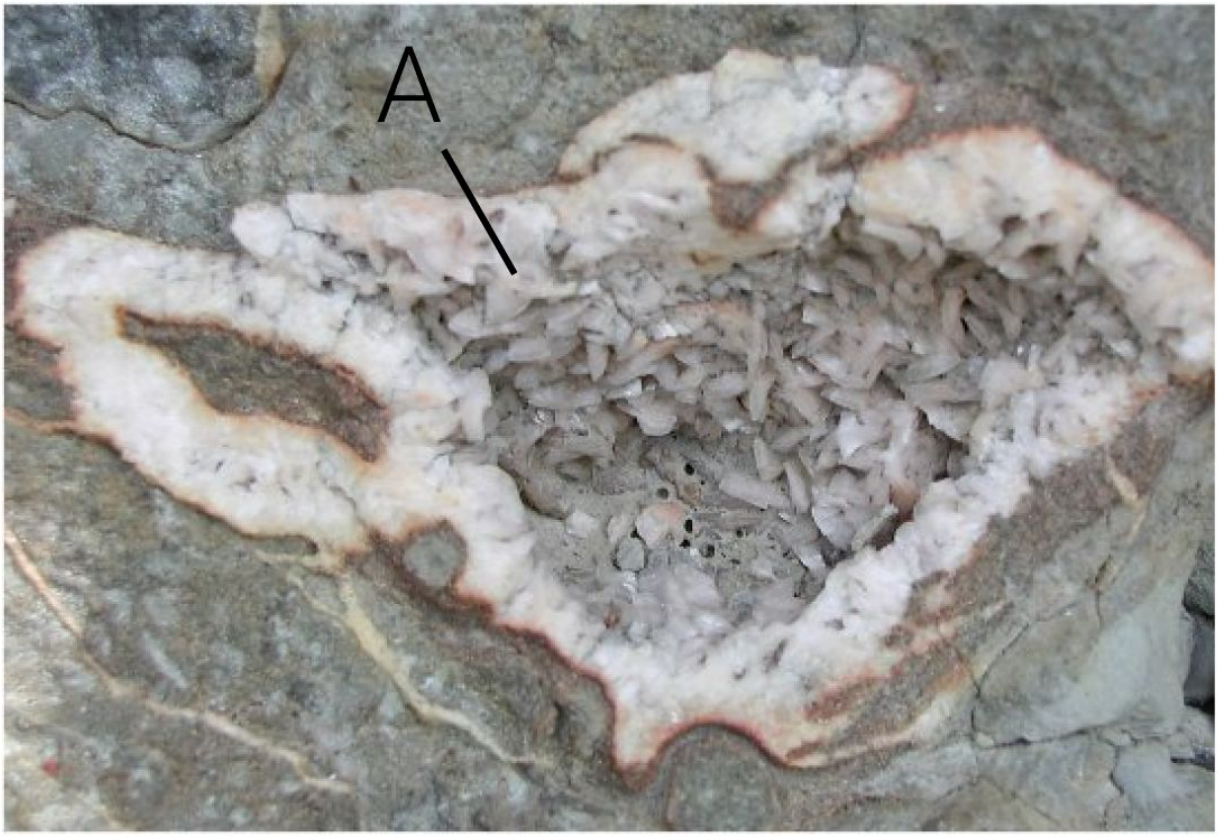
9a) Identify the red mineral shown in the sample. (1 pt)

9b) Identify the **primary constituent** (mineral) of the green matrix shown in the sample. (1 pt)

9c) Identify all of the following statements that are likely **true** regarding this sample. (*)

A) The red mineral crystallized from magma before the crystallization of the green mineral
B) The green mineral crystallized from magma before the crystallization of the red mineral
C) This rock was formed under high pressure conditions that may be found in subduction zone environments
D) Wollastonite ($CaSiO_3$) may be associated in large quantities with this rock
E) Orthoclase ($KAlSi_3O_8$) may be associated in large quantities with this rock
F) Both the red and green mineral present in the sample are silicates

Q10 - A Mysterious Vug



Refer to the figure above for the next three questions. Mineral **A** is a whitish-pink mineral that effervesces weakly upon treatment with cold dilute HCl. When **A** is powered and treated with hot dilute HCl, it effervesces strongly.

10a) Identify mineral **A** and give its mineral group. If **A** is a silicate, give the name of the structure of the silicate (e.g. phyllosilicate, inosilicate) **or** describe the structure of the silicate (e.g. sheets, chains). (2 pts)

10b) If HCl was not available in the field, what is a possible characteristic of mineral **A** that could be used to identify it and distinguish it from other minerals? (1 pt)

10c) When samples of the rock surrounding A are analyzed with XRD in the laboratory, it is determined that mineral **A** is the main constituent of the greyish matrix rock surrounding **A**. Considering this, give a **brief** description of the formation of the structure shown in the figure. (3 pts)

Woohoo, you're done with the theory portion! Now, go back to the Google form to do the ID section.