CERAMIC GLAZING as an IGNEOUS PROCESS

GLAZE COMPONENTS

A glaze is a waterproof silica glass on the surface of a ceramic pot, and was first produced by the Mesopotemians around 2000 BC. (A clay tablet dated at 1700BC from northern Iraq records a recipe for a green glaze (Cooper, 1988)). A glaze is produced by melting a mixture that consists mostly of powdered minerals, although organic materials such as wood-ash and bone-ash may also be added. Each ingredient in a glaze mix serves one or more of 4 essential purposes:

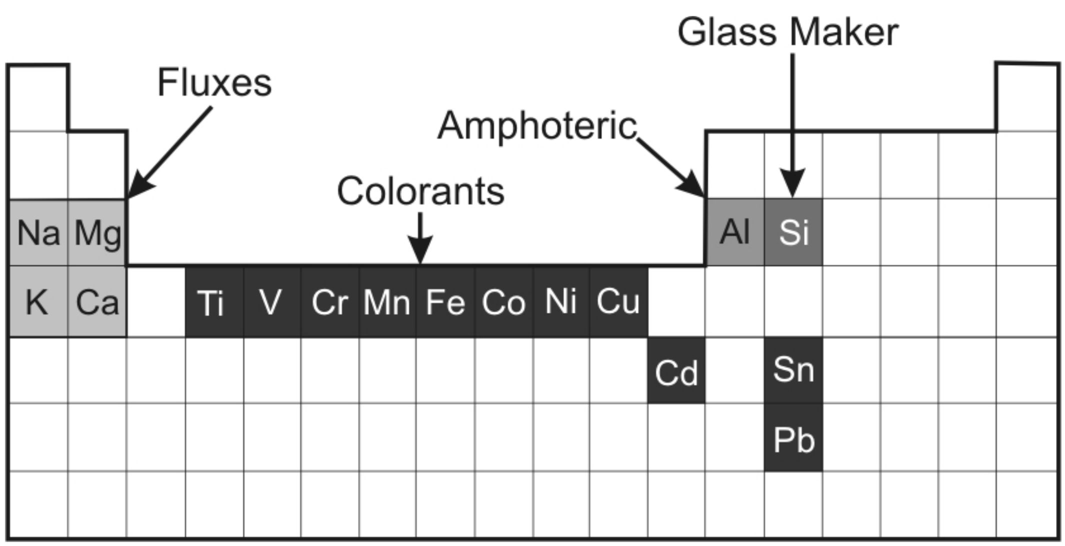
Glass Former: Mainly SiO_2

Amphoteric: Allows glaze to adhere to the pot (Mainly Al_2O_3)

Flux: Allows the glaze to melt at lower temperature (Mainly CaO, Na_2O, K_2O, MgO)

Colorant: Various metals (e.g., Fe, Co, Cu, Mn, Cr, Ti, Pb).

As might be expected, chemicals with similar behavior in glazes are related on the periodic table; most fluxes are alkali metals or alkali earth metals; most colorants are transition metals, although non-transition metals such as Sn and Pb may be used to enhance color, or produce a solid white.



GLAZE FORMULAE

To create an effective glaze, a potter must mix the components in just the right proportions; enough flux to make the silica melt but not too much to make it melt too early and become runny; enough amphoteric to make the glaze stick to the pot but not too much to make the glaze thick and “globby”; the right balance of metals to get the desired color shade. This ideal mixture must also be ideally suited for the temperature to which the kiln is fired.

With so many variables it is difficult to fully predict the results of a given recipe. Accordingly, potters adopt an experimental approach, similar to that of an experimental petrologist; a potter will systematically mix different proportions of critical components, apply them to test pieces of pottery, and fire them to the desired temperature. When a test piece has been fired the potter can select the recipe that created the most desired result. Having narrowed down the range of composition that produces desirable results, the potter may run additional experiments to hone the recipe. (What if I added 4% calcite instead of 5%? What if I added a half percent of cobalt oxide with the 2% malachite that I tried last time?)

Note that this approach is scientific experimentation and hypothesis testing. For example, in asking “What if I added 6% calcite instead of 5%?” the potter is interested in testing a hypothesis that increasing the flux by 20% will reduce the melting point further, and produce a more glassy product. In asking “What if I added a half percent of cobalt oxide with the 2% malachite that I tried last time?”, the potter is interesting in testing his hypothesis that a rich blue-green color would result by mixing the two transition metal-bearing colorants.

The following table lists minerals that are used commonly in glazes. For each of the minerals determine how it would contribute to a glaze recipe.

Mineral	**Formula**	**Glass Maker?**	**Flux?**	**Amphoteric?**	**Colorant?**
Albite	$NaAlSi_3O_8$				
Calcite	$CaCO_3$				
Cassiterite	SnO_2				
Dolomite	$CaMg[CO_3]_2$				
Flint/Quartz	SiO_2				
Hematite	Fe_2O_3				
Kaolinite	$Al_2Si_2O_5(OH)_4$				
Malachite	$Cu_2(CO_3)(OH)_2$				
Microcline	$KAlSi_3O_8$				
Pyrolusite	MnO_2				
Rutile	TiO_2				
Wollastonite	$CaSiO_3$				
Zincite	ZnO				

List four pairings of minerals that would potentially produce a workable glaze (not considering colorants)?

______________________________ ______________________________

______________________________ ______________________________

List four sets of three minerals that would potentially produce a workable glaze?

________________________________ ________________________________

________________________________ ________________________________

SILICATE GLAZES and MAGMAS

Glaze recipes are composed primarily of silicate minerals, including quartz and feldspars which are the most abundant minerals in most igneous rocks. The presence of lesser amounts of iron-bearing minerals in igneous rocks is what controls their color (Fe is the most abundant transition metal in the crust), just as the addition of small amounts of a transition-metal-bearing mineral provides colorant to a glaze recipe. Potters have experimented with glazes to prefect their recipes—glazes that have the right color and which melt at the temperatures that are reached within their kilns, and which form colored glass when they are subsequently cooled relatively quickly. Similarly, geologists have experimented with igneous rocks, but rather than simply attempting to create an eye-pleasing glass, geologists have sought to understand how rocks melt, and under what conditions, and how igneous rocks form within the Earth.

Beginning with the pioneering work of Norman L. Bowen in 1909, geoscientists have worked to understand the genesis of magmas and igneous rocks by taking small amounts of powdered minerals of known compositions, heating them to a known temperature, holding them at that temperature until the materials reach chemical equilibrium. These heated samples were then cooled rapidly to room temperature for examination under the microscope; molten rock would freeze to a glass that held any mineral crystals that existed within the magma.

Through such methods, experimental petrologists like Bowen create phase diagrams that predict how rocks of different compositions will melt, in what order minerals within these rocks will melt, and conversely, how igneous rocks form from magmas, and in what sequence minerals will form to create a rock from magma of a given composition. The ternary phase diagram SiO_2-$NaAlSi_3O_8$-$KAlSi_3O_8$ (quartz-albite-K feldspar) is used to understand how granites crystallize and melt since >90% of any granite is composed of these three minerals. This ternary diagram can also be used to understand how any two mixtures of these minerals will melt.

Examine the SiO_2-$NaAlSi_3O_8$-$KAlSi_3O_8$ (quartz-albite-K feldspar) ternary phase diagram on the following page, and answer the following questions:

At what temperature does each of the following melt?

Quartz alone: ________ *Albite alone:* _______ *K-Feldspar alone:* _______

Quartz + Albite: ________ *Quartz + K Feldspar:* ________

Quartz + Albite + K-Feldspar: ________

In general, what happens to the melting temperature of an igneous rock (or glaze) when you add an additional mineral to the mix?

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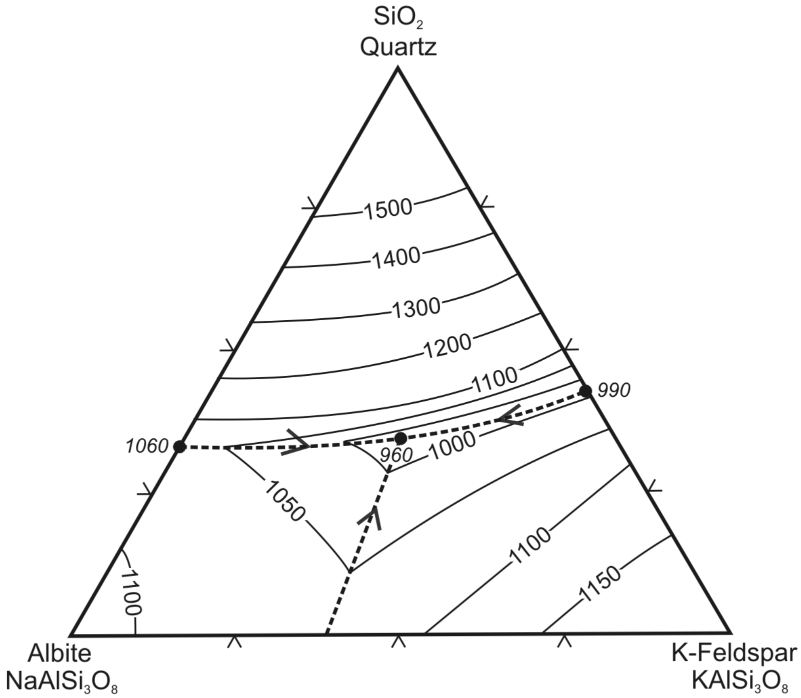
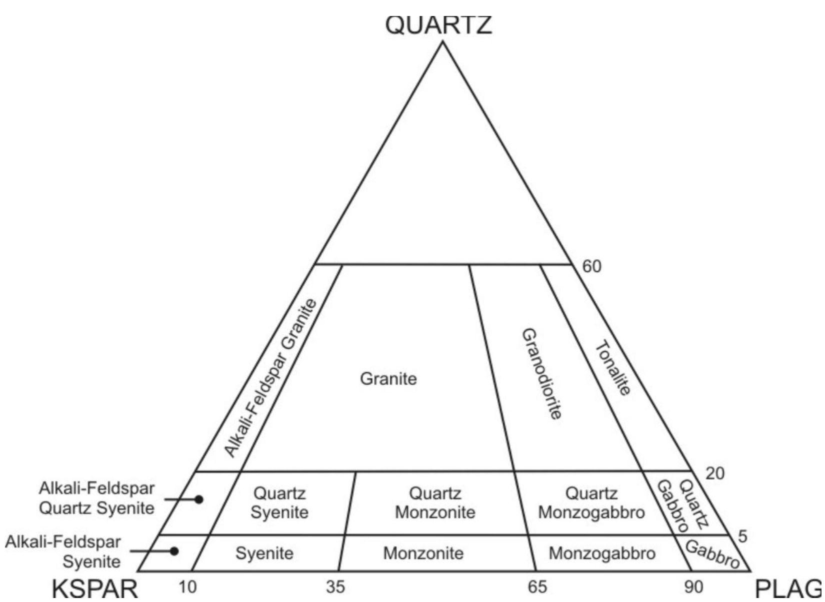


Simplified
Qtz-Ab-Kfs Ternary Phase Diagram

Modified from: DEVINEAU, PICHAVANT and VILLIERAS (2005) Melting kinetics of granitic powder aggregates at 1175°C, 1 atm. European Journal of Mineralogy, v.17, p. 387-398

Based on the Qtz-Ab-Kfs ternary phase diagram, what is the composition of rock (or recipe for glaze minerals) that will belt at the lowest temperature (eutectic)?

Quartz: _________% Albite: _________% K-Feldspar: __________%



International Union of Geological Sciences (IUGS) Classification Scheme for Intrusive Igneous Rocks

Based on the IUGS classification chart for intrusive igneous rocks, what rock forms from the lowest temperature (eutectic) melt in the Qtz-Ab-Kfs system? (Note that albite is a sodic plagioclase.)

____

Examine hand samples of the minerals that you will be using in preparing a glaze experiment, and document/review their physical properties.

Quartz: SiO_2

Hardness: ________ Cleavage/Fracture: ______________________

Color: ______________ Streak: ______________________

Quartz, var. Flint: SiO_2

Hardness: ________ Cleavage/Fracture: ______________________

Color: ______________ Streak: ______________________

Albite: $NaAlSi_3O_8$

Hardness: ________ Cleavage/Fracture: ______________________

Color: ______________ Streak: ______________________

Microcline: $KAlSi_3O_8$

Hardness: ________ Cleavage/Fracture: ______________________

Color: ______________ Streak: ______________________

Calcite: $CaCO_3$

Hardness: ________ Cleavage/Fracture: ______________________

Color: ______________ Streak: ______________________

Hematite: Fe_2O_3

Hardness: ________ Cleavage/Fracture: ______________________

Color: ______________ Streak: ______________________

Malachite: $Cu_2(CO_3)(OH)_{28}$

Hardness: ________ Cleavage/Fracture: ______________________

Color: ______________ Streak: ______________________

Pyrolusite: MnO_2

Hardness: ________ Cleavage/Fracture: ______________________

Color: ______________ Streak: ______________________

Break into groups, as assigned by your instructor and prepare two experimental test tiles to investigate the melting temperature of mineral mixtures. Each group will create two test tile (one rectangular tile with five wells; one triangular tile with 10 wells), as assigned in the table below.

- Fill each well according to the recipes on the following worksheet. For example, on the Quartz-Albite tile the 3-1 well would be filled with 3 parts quartz and 1 part albite, whereas the 1-3 well would be 1 part quartz and 3 parts albite. Use the smallest measuring spoon provided (1/8 teaspoons / smidgeon), leveling off the measurements with a popsicle stick.
- For Groups 3 through 6, choose a colorant/flux from the table on Page 2, and add 1 part of your chosen colorant/flux to each well. Add the name of the mineral that you chose to the table below by filling in the blanks.
- When all of the mineral powders have been added to each well on the test tiles, add approximately 10 drops of water to each well, and mix each with a popsicle stick to create a well mixed runny paste. The water will absorb into the bisqued tile very quickly.
- Label your tiles with your group number and minerals used by applying an iron oxide-based wash with a fine paintbrush

Group 1	Group 2	Group 3	Group 4	Group 5	Group 6
Qtz-Ab	Qtz-Ab	Qtz-Kfs	Qtz-Kfs	Qtz-Ab + Colorant (_________)	Qtz-Kfs + Flux (_________)
Qtz-Ab-Kfs	Qtz-Ab-Kfs	Qtz-Ab-Kfs + Colorant (_________)	Qtz-Ab-Kfs + Flux (_________)	Qtz-Ab-Kfs + Colorant (_________)	Qtz-Ab-Kfs + Flux (_________)

If the kiln is heated to ~1050°C (Pyrometric Cone 05), which mixtures in your test tiles do you predict would fully melt and form a glassy glaze? Mark a ✓ beside the corresponding wells on the following two worksheets.

If the kiln is heated to ~1100°C (Pyrometric Cone 03), which additional mixtures in your test tiles do you predict would fully melt and form a glassy glaze? Mark an ✘ beside the corresponding wells on the following two worksheets.

What color(s) do you predict that your glazes will be? ________________________

Which group(s) do you predict will have the test tiles with the greatest number of successful glazes?

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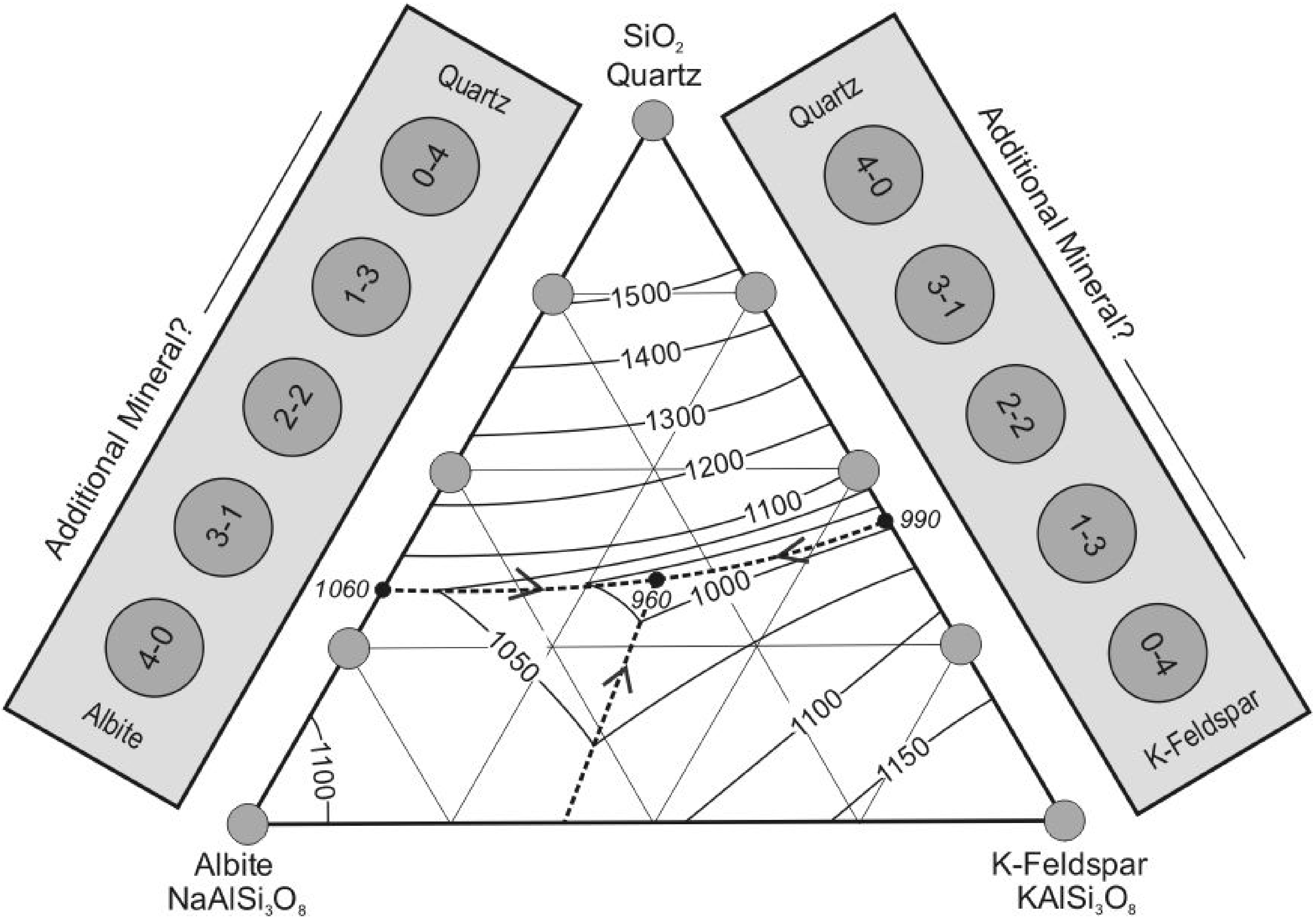
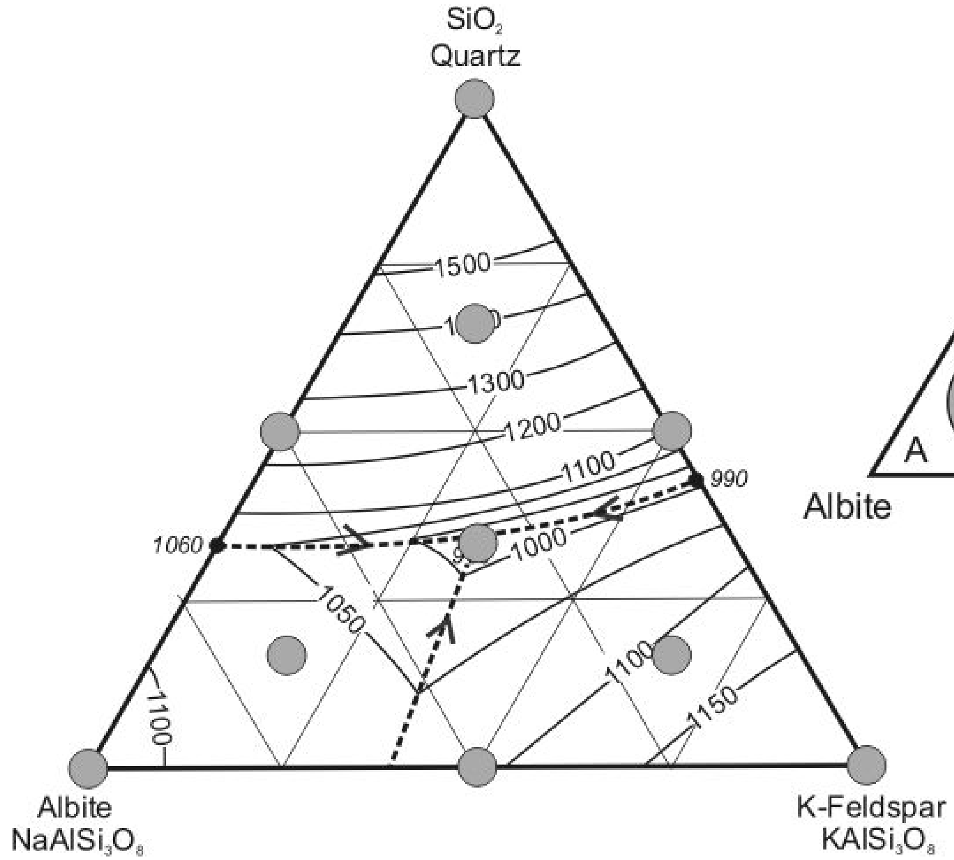
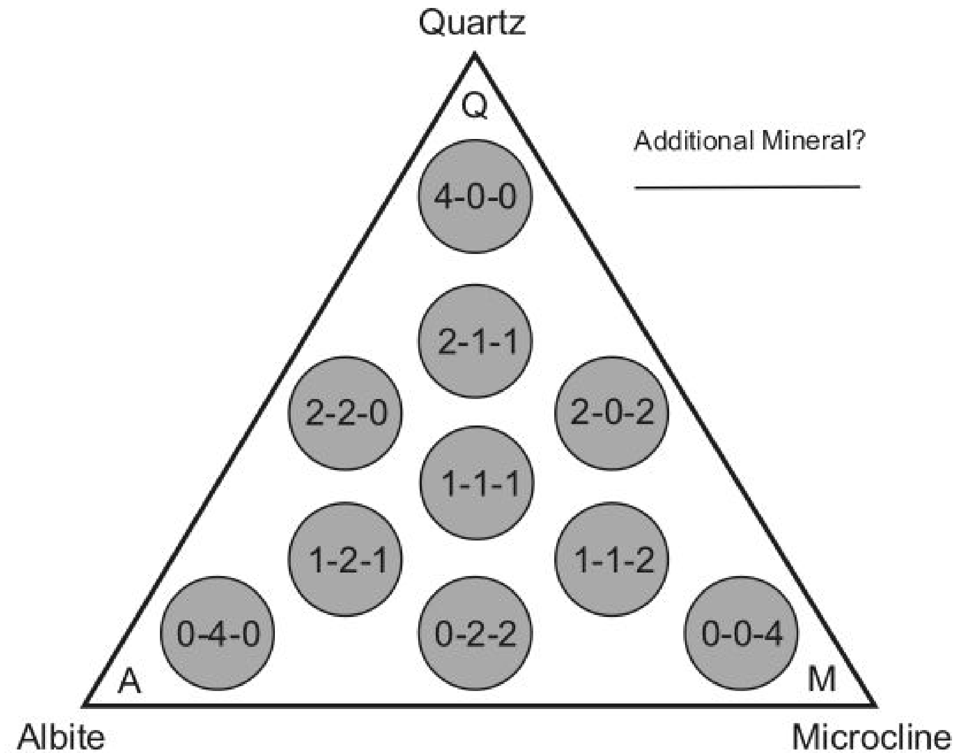

SiO$_2$
Quartz
Albite
NaAlSi$_3$O$_8$
K-Feldspar
KAlSi$_3$O$_8$
Additional Mineral?
Quartz
0-4
1-3
2-2
3-1
4-0
Albite
Additional Mineral?
Quartz
4-0
3-1
2-2
1-3
0-4
K-Feldspar
1500
1400
1300
1200
1100
990
1060
960
1000
1050
1100
1150
1100





Additional Mineral? ____________