T-X Diagrams Answers

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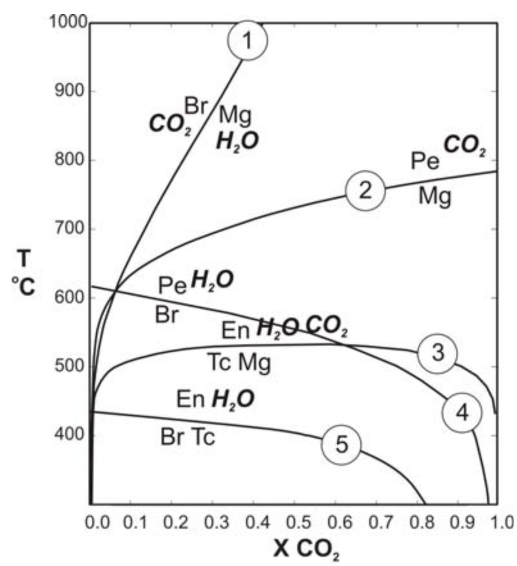
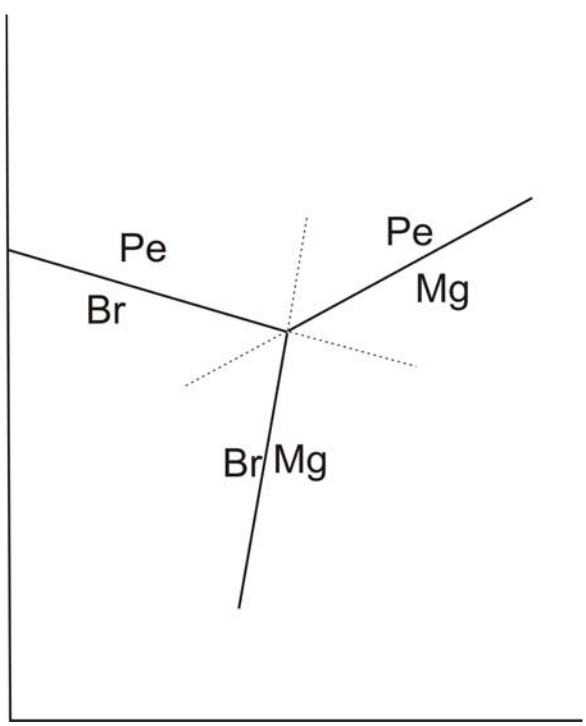
Problems

Problem 1. Look at Figure 10. One reaction (that plots as a horizontal line) is a solid-solid reaction. The others all have about the same shape, and are very dependent on fluid composition. What kinds of reactions are these? Do they involve H_2O or CO_2 and, if so, are H_2O and CO_2 on the high temperature or low-temperature side of these reactions?

The reactions have the upside down U shape. So, they involve both CO2 and H2O and these fluid species are on the high temperature side of the reactions. They are sort of combined dehydration/decarbonation reactions.

Problem 2. a. On the diagram shown below, add the H_2O and CO_2 to the reaction labels, taking care to put them on the correct side of the reaction curves. Reactions may involve both H_2O and CO_2, one or the other of them, or neither.



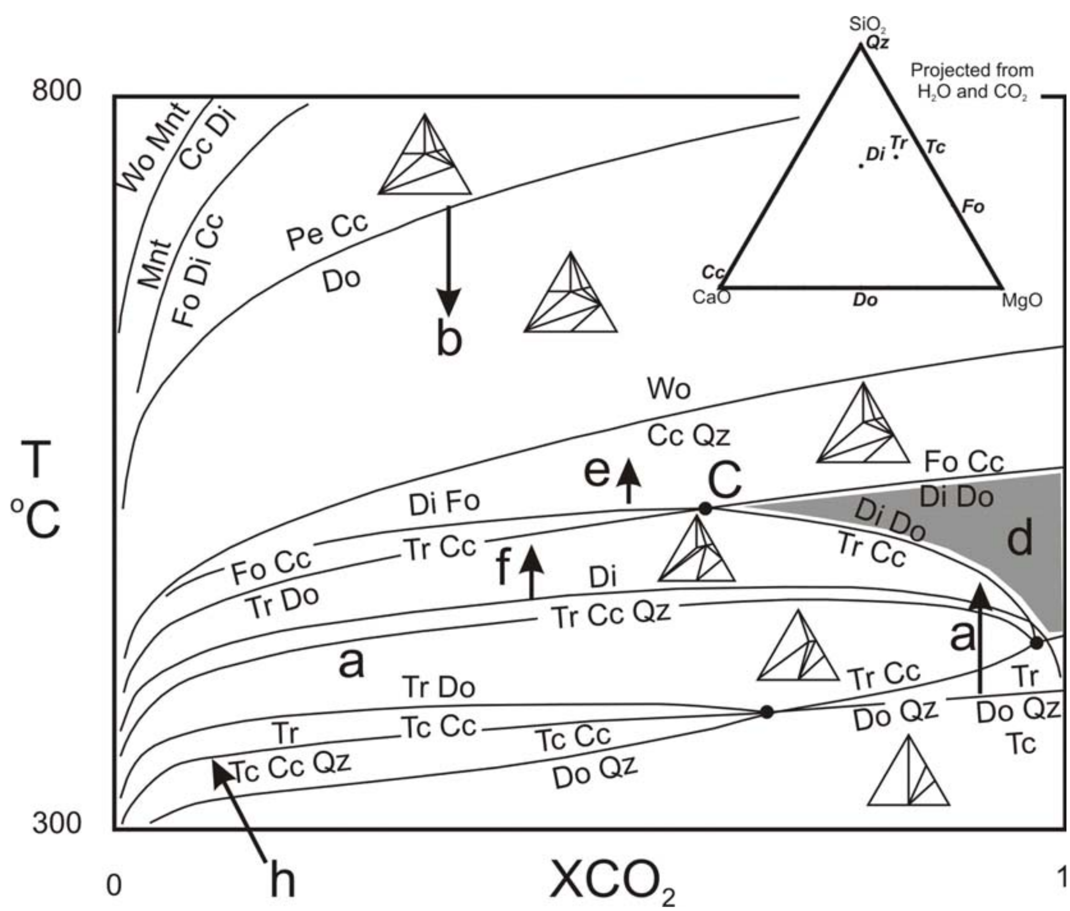


.b. There is an invariant point in Figure 12 where *Reactions 1,2* and *4* intersect, and Br-Mg-Pe coexist. Make an enlarged view of that invariant point and show the stable and metastable parts of the three reactions.

Problem 3. Consider the diagram below. Where on this diagram are the following minerals/assemblages stable?

Note, this is the same diagram that was missing a reaction before. I added the missing reaction that was already identified. Perhaps you will find another missing reaction? If so, explain.

a. talc ***everywhere***
b. dolomite **everywhere below the reaction labeled b**
c. tremolite ***everywhere above the reactions labeled c***
d. diopside + dolomite ***In the shaded area labeled d***
e. forsterite + diopside ***Above the line shown with the letter e, but there is another missing reaction at point C so it is unclear what happens right of that point***
f. diopside + tremolite + quartz ***anywhere above the line labeled f***
g. talc + quartz + dolomite ***Only at the bottom of the diagram below all reactions***
h. talc+ quartz + calcite + tremolite ***On reaction curve labeled h***
i. talc + calcite + wollastonite + dolomite ***Nowhere***



j. tremolite + calcite + forsterite + diopside + dolomite ***At invariant point C***
k. tremolite + calcite + forsterite + diopside + periclase ***Nowhere***

Use arrows or shading or whatever you wish to show your answer. But, make your answers clear.

Problem 4. Consider the phase diagram below. It shows important reactions that occur in a low-Mg carbonate rock during metamorphism.

a. Suppose the original rock is a limestone that contains only calcite. According to the phase diagram, how will the mineralogy of the rock change during metamorphism? Will the results be the same for both relatively H_2O-rich fluids and relatively CO_2-rich fluids? ***Nothing happens if there is only calcite present.***

b. Suppose the original rock is not so pure. It contains 90% calcite and 10% quartz. According to the phase diagram, how will the mineralogy of the rock change during metamorphism? Will the results be the same for both relatively H_2O-rich fluids and relatively CO_2-rich fluids***? In this case, a small amount of wollastonite will form between 600 and 700 ^oC. That's all.***

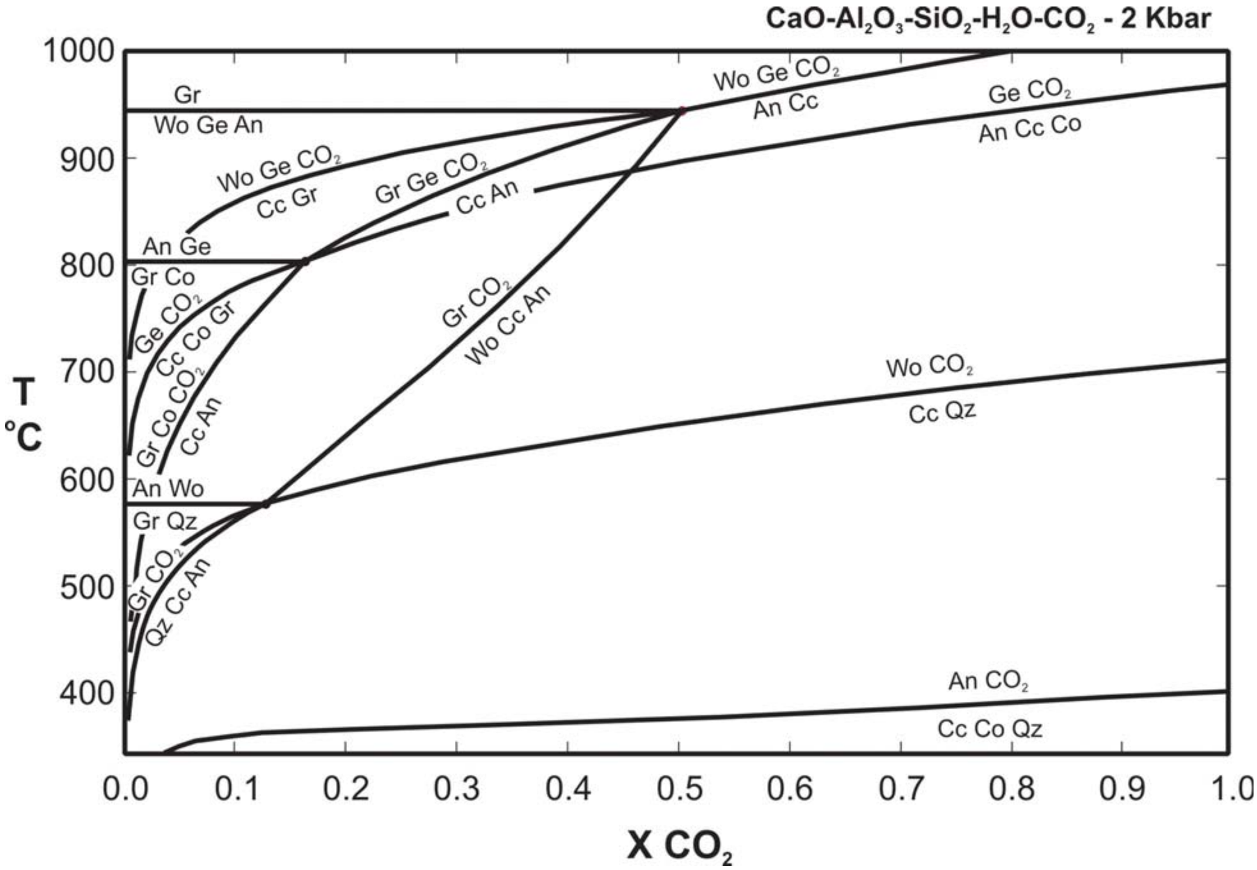
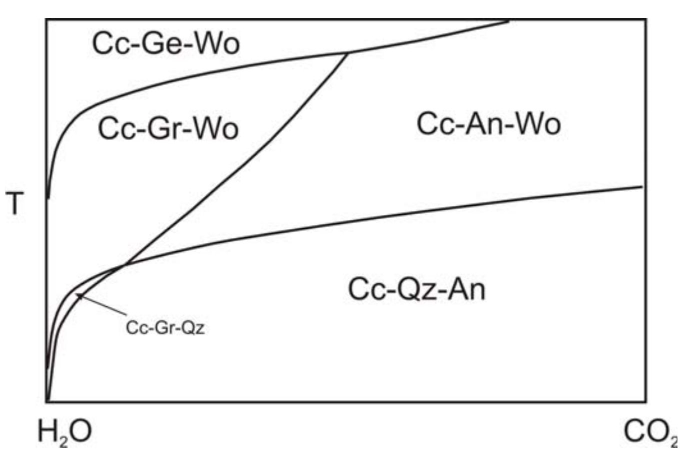


Figure 4. Phase diagram showing reactions at 2 Kbar that involve calcite and a number of silicates. Note that the reaction Cc + Qz = Wo + CO_2 is degenerate and passes through the invariant point in the lower left part of the diagram.

Parts c, d and e. Suppose that the original rock contains 80% calcite, 15% quartz, and 5% anorthite. (This is close to many natural carbonate rocks.) According to the above phase diagram, how will the mineralogy of the rock change during metamorphism? Will the results be the same for both relatively H_2O-rich fluids and relatively CO_2-rich fluids?



The drawing here shows the pseudo section. So, we see that the original assemblage is stable to quite high T unless the fluid is very water rich.

For CO2 dominate fluids, Wollastonite is the first high T mineral to form.

If it is water rich, however, then Grossular will form and be stable

until high T. AT the very highest T, whether water rich or not, Gehlenite will appear.

e. For the 80-15-5% composition being considered, is the stable metamorphic assemblage the same for fluids of all compositions? ***NO - see discussion above.***

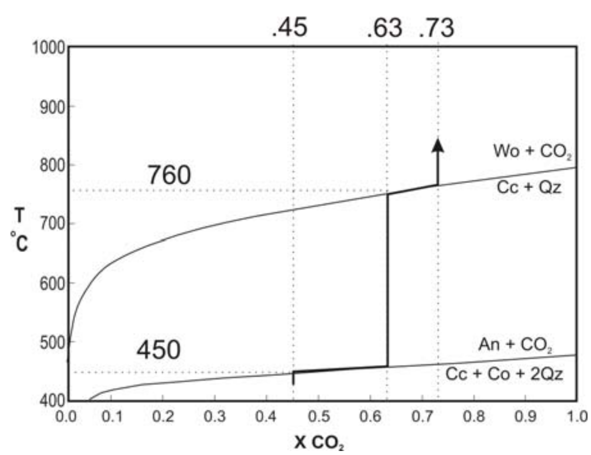
f. Under what conditions will this rock contain garnet? ***Grossular is garnet and it is only for water-rich fluids but T can be quite low.***

Problem 5. Consider the phase diagram in Figure 16, below. It includes two reactions: Cc + Co + 2 Qz = An + CO_2 and Cc + Qz = Wo + CO_2. Assume you have a rock that contains 90% minerals (70% calcite, 15% quartz, and 5% corundum) and 10% fluid. The fluid composition is XCO_2=0.45. The rock starts at room temperature and is metamorphosed. Heat is added, and the rock encounters the first reaction at about 440°C. Eventually, after more reactions, the temperature reaches 800°.

fluid%	***10***
moles % Cc	***70***
moles % Co	***5***
moles % Qz	***15***
XCo2	***0.45***

	cc	***co***	***qz***	***an***	***wo***	***CO2***	***H2O***	***tot***	***XCO2***
	70	***5***	***15***	***0***	***0***	***4.5***	***5.5***	***100***	***0.45***
rxn 1	***-1***	***-1***	***-2***	***1***		***1***		***0***	
progress (moles)	***5***								
remain	***65***	***0***	***5***	***5***	***0***	***9.5***	***5.5***		***0.63***
rxn 2	***-1***		***-1***		***1***	***1***		***0***	
progress (moles)	***5***								
remain	***60***	***0***	***0***	***5***	***5***	***14.5***	***5.5***		***0.73***

a. On the phase diagram, draw a line/curve to show how the composition of fluid changes as metamorphism occurs. You can be very specific. See Figure 11 for examples.
b. At what temperature will anorthite appear in the rock? ***450***
c. At what temperature will wollastonite appear in the rock? ***760***
d. What will be the final composition of the fluid? ***X=.73***
e. What will be the final mineral assemblage? ***Cc-An-Wo***
f. Suppose that the rock contains significantly more than 10% fluid. How will the results differ***? If the rock contained a great deal more fluid, then it would not change as much as shown on the diagram here. So, the resulting minerals would be the same but the fluid would not get to X=0.73.***



g. Suppose that the rock contains <<1% fluid. How will the results differ? ***If the rock contained very little fluid, the fluid would change more – it would end up more CO2 rich but, of course, can never get to 100% CO2. The minerals that form would be the same as before, however.***

Problem 6. Metamorphic petrologists use *index minerals* to estimate metamorphic grade. Some minerals form at low temperature, some require higher temperature.

a. Look at Figure 13 (Problem 3). In what order do minerals appear as temperature increases. You may assume that calcite, dolomite and quartz are present in the original rock. The question is, in what order do the other minerals appear? Of course, fluid composition plays a role. But, in general, which minerals are low temperature minerals, etc.? Make a list in order from low-temperature to high-temperature minerals.

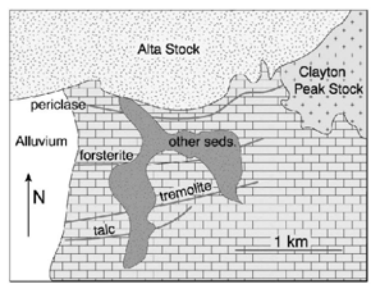


Figure 7. Isograds near Alta, Utah. This figure is modified from one on D.J. Henry's Geology 3041 web page: http://www.geol.lsu.edu/henry/Geology3041/lectures/29MetaCalcUm/Fig29-2.jpg

On the water rich side it goes Tc-Tr-Di-Fo-Wo-Pe-Mnt
On the CO2 rich side it goes Tr-Di-Fo-Wo-Pe

The figure above (Figure 17) shows geology of a *contact aureole* near Alta, Utah. Four isograds are mapped – these are lines showing the first appearance of talc, tremolite, forsterite, and periclase. The person who made this map interpreted these isograds to mean that heat from the Alta Stock was responsible for metamorphosing the original limestone.

b. Do the minerals at Alta appear in the same order that you listed in the first part of this question? Discuss differences and/or similarities. If the agreement is good, explain why. If not, why not? ***There is pretty good agreement, except that Di seems to be missing. Not sure why but a possible explanation is that there was not enough Qz in the original rock. So, there was none left to create when the Di-in curve was reached.***

c. Can you tell form the order of the isograds at Alta, whether the metamorphism occurred in the presence of an H_2O-rich fluid or a CO_2-rich fluid, or somewhere between? Explain. ***It appears to have been water rich – because talc formed. But, it could have been intermediate.***

d. Do you agree with the geological interpretation? Did heat from the Alta Stock cause the metamorphism? ***Yes, the interpretation seems fine.***

Problem 7. On the phase diagram in Problem 5, the two curves become asymptotic to the left-hand side. So, the high temperature assemblages (Wo+CO_2 or An+CO_2) are stable to very low temperature if the fluid is nearly 100% H_2O. Why is this? Explain, in layman's terms, using logic, why this makes sense. Why do the lines typically go tangential on one or both sides of a T-X diagram? (Don't just tell me it is because something is unstable there, etc. Tell me why things are the way they are.)

Lines go tangential because it is impossible to have a hydrous phase in an environment with no water present. Similarly, it is impossible to have a carbonate phases in an environment with no CO_2 present.

You can think of it this way: if there is absolutely no CO_2 present, but a mineral contains CO_2, then there is an infinite amount of energy trying to pull CO_2 out of the mineral. It is sort of like having a complete vacuum – it is impossible.

So, if a reaction involves CO_2, it can never get to the CO_2=0 side of the diagram. If a reaction involves H_2O, it can never get to the H_2O=0 side of the diagram. If a reaction involves both, it cannot reach either side of the diagram.

Problem 8. On all the T-X diagrams you have seen, the stability of carbonate phases (e.g., calcite) is decreased if the fluid contains little CO_2, compared to a fluid that is rich in CO_2. The stability of hydrous phase is decreased if the fluid contains little H_2O, compared to a fluid that is rich in H_2O. Why? Explain, in layman's terms, using logic, why this makes sense.

This is sort of the same answer as Problem 7. Consider the reaction:
calcite + quartz = wollastonite + CO_2

If there is very little CO_2 present, this reaction will tend to go to the right. The laws of equilibrium demand that the reaction take place until there is enough CO_2 present to bring the assemblage into equilibrium. It is sort of like having a vacuum sucking CO_2 from the calcite – it will continue sucking until there is enough in the fluid so that reaction stops.

Or, look at it the other way around: if there is only a small amount of CO_2 present,

then it will be very dilute and it will be less likely to react with the calcite than if the fluid was pure CO_2. So, if you have wollastonite + CO_2 it will have extended stability.

A similar argument holds for H_2O reactions.