Visualizing geochemical processes

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Students in most introductory Physical Geology courses, and in many other Earth Science courses (e.g., mineralogy, petrology, hydrogeology, geochemistry, ore deposits etc.), are expected to understand something about the chemistry of geological processes. However, understanding even simple everyday chemical processes is difficult for most people. Understanding some geochemical processes can be even more difficult, especially if they take place under temperature, pressure and chemical composition conditions that fall well outside our daily experiences, or over time periods that we cannot comprehend.

Over the past year I have experimented with a way of visualizing geochemical processes, so that students can actually "see" the elements, ions and oxides involved (in the correct proportions), and can manipulate them as the reactions take place. I have used this technique to promote understanding of the processes of magma crystallization in my first-year physical geology course, of partial melting of mantle rock in my geochemistry course, and of groundwater evolution in my hydrogeology course.

In order to be practical in a classroom setting, the modeling of various processes has to be significantly simplified. For example, many minor constituents and all trace elements are omitted, mineral stoichiometries are simplified, rock compositions are idealized and minor phases are omitted and reaction sequences are generalized. Nevertheless, I believe that the method has helped both students (and me!) to understand the processes involved. I have some evidence to support that assertion.

Magma Crystallization

To illustrate the concept of visualizing geochemical processes, we will simulate the crystallization of felsic and mafic magmas by following a series of prescribed steps that may be similar to what actually happens during the cooling process. I use this exercise in my 1st-year Physical Geology class in the section on igneous rocks.

Idealized magma starting compositions (mole per cent):

	Felsic	Mafic
SiO_2	71%	45%
Al_2O_3	10%	18%
FeO	3%	9%
CaO	5%	10%
MgO	3%	9%
Na_2O	4%	6%
K_2O	2%	1%
H_2O	2%	2%
	100%	100%

Magma and rock compositions are reported as oxides because early analytical techniques involved production and then weighing of the metal-oxides.

Using oxides actually makes some sense because under typical geological conditions these metals will almost always be complexed with oxygen in the ratios shown.

Simplified oxide compositions of the major igneous minerals:

	SiO_2	Al_2O_3	FeO	MgO	CaO	Na_2O	K_2O	H_2O
Olivine	2		(4)		← any combination adding to 4			
Pyroxene	4		(4)			← any combination adding to 4		
Amphibole	4	2	2*	1*	1*	1*	1*	1
Biotite	4	2	1	1			1	1
K-feldspar	6	2					2	
Quartz	9							
Anorthite	4	4			2			
Albite	6	2				2		

*Amphibole can have any combination of these adding to 6, but not more than 2 of any one

For example, to make a "crystal" of olivine: ($(Mg,Fe)_2SiO_4$) you use 2 SiO_2 plus some combination of MgO and FeO for a total of 4 (e.g. 2 MgO + 2 FeO). For consistency, each "crystal" is made up of roughly the same number of oxides. That is why quartz includes 9 SiO_2s, not just 1.

The crystallization process:

At a high temperature, before step 1, the magma is 100% liquid. Each step in the cooling process represents a drop in temperature. By step 12 (or earlier) all of the magma has crystallized.

Step	Process
1	connect about 1/3 of the SiO_2 into polymers
2	connect another 1/3 of the SiO_2 into polymers
3	make as much olivine as you can
4	convert about 1/2 of the olivine to pyroxene
5	make as much Ca-plagioclase as you can
6	convert any remaining olivine to pyroxene, if you can
7	make as much additional pyroxene as you can
8	convert any remaining pyroxene to amphibole, if you can
9	make as much albite as you can
10	convert any remaining amphibole to biotite, if you can
11	make as much K-feldspar as you can
12	make as much quartz as you can

Some questions to consider:

1) What are the obvious differences between felsic and mafic magmas?
2) How does the formation of silica polymers affect felsic and mafic magmas?
3) How does the crystallization of a strongly ferromagnesian mineral, such as olivine, affect the composition of the remaining magma?
4) What would the resulting rock look like if a volcanic eruption took place after step 5?
5) Why might a felsic magma produce quartz and K-feldspar, while a mafic one would not?