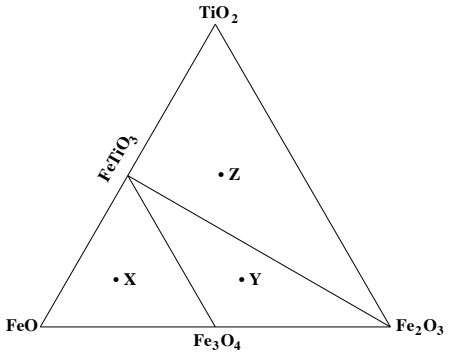
Lecture Notes - Norm Calculations

- The mineralogy and texture of an igneous rock are a complex function of its chemistry and crystallization history. Cooling rate, "humidity," nucleation and growth kinetics, diffusion, chemical zoning of minerals, and many other factors contribute to the final product viewed in a thin section. To help see through all of these trees to the forest of igneous petrology, a procedure was developed to reduce all igneous rocks to the same basis — a basis that depends on chemistry only. The result of this procedure is a mineralogic **norm**, so named to indicate a "normal mineralogy" for an igneous rock. Most geologists calculate **CIPW norms**, named after Whitman **C**ross, Joseph P. **I**ddings, Louis V. **P**irsson, and Henry S. **W**ashington who devised the procedure 90 years ago.

- In many respects the norm calculation is simply a change of the chemical components used to represent a particular bulk composition from the usual oxide components of the analyst to components that coincide in chemical composition with ideal mineralogical end members. For example, instead of the oxide components FeO, Fe_2O_3, and TiO_2, a norm might use the ideal mineral compositions of hematite (Fe_2O_3), magnetite (Fe3O4), and ilmenite ($FeTiO_3$). By using mineral compositions as components for the norm, the relative proportions of the "normal" minerals may be read directly from the "normalized" chemical analysis.

- The actual recipe for the norm calculation is more complicated than one might expect for a simple change of components. This is because not all rocks have the same minerals in their norms. To see this, examine the composition triangle for FeO, Fe_2O_3, and TiO_2. For bulk compositions that fall within the triangle containing the "Y" the normative minerals magnetite, ilmentite, and hematite work very well. However, if a rock has a composition falling within the triangle containing the "Z", the normative amount of magnetite is negative. Therefore, the norm for this rock is expressed in terms of ilmenite, hematite (Fe_2O_3), and rutile (TiO_2). Similarly, if a rock has a composition falling within the triangle containing the "X", the normative amount of hematite is negative. The norm for this rock is expressed in terms of ilmenite, magnetite, and wustite.



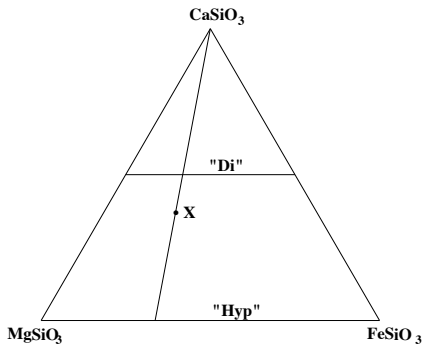
- In some instances, it is not possible to foresee that the normative amount of a mineral will be negative. Thus, for some rocks it is necessary to backtrack and modify the calculated amounts of normative minerals when negative amounts of normative minerals are encountered. This is most commonly true if the rock does not have quartz in the norm because quartz is generally the last mineral to be calculated.

- Norms are always expressed in terms of anhydrous minerals. Because the amount of water in an igneous rock may reflect the physical conditions of crystallization (*e.g.* volcanic vs. plutonic) rather than an intrinsic property of the magma, the amount of water in an analysis is ignored. The norm approximates the mineral composition of an igneous rock that crystallized to an equilibrium mineral assemblage at one atmosphere pressure and at a temperature of about 800°C. **If** we knew the Gibbs energies of all compositions of the common minerals at 800°C and 1 atmosphere pressure, it would be possible to calculate from the chemical analysis the equilibrium mineralogy for any chemical composition at these conditions. However, the results of such a calculation might not be as useful as a CIPW norm for comparing the chemistries of different igneous rocks due to the variety of mineral compositions that would be found.

- In the CIPW procedure, the final tally of normative minerals is expressed in mass units (weight percentage). Because the bulk of the norm calculation procedure is carried out in mole units, the only useful reason for converting back to mass units may be to check one's arithmetic. The sum of the mass units of normative minerals should equal the anhydrous mass sum of the original analysis. Converting to mass units is especially tedious for the pyroxenes and other ferromagnesian minerals (see below). I consider it more helpful to know the volume proportions of the normative minerals for comparison with rock modes. The simplest way to get approximate volume proportions is to express the norm in oxygen units.

- Although pyroxene compositions are commonly expressed in terms of the three components Wo ($CaSiO_3$), En ($MgSiO_3$), and Fs ($FeSiO_3$), only two pyroxenes are found together in igneous rocks: orthopyroxene (or pigeonite) and clinopyroxene. To approximate this feature of pyroxene petrology, the CIPW norm recipe calls for "diopside" and "hypersthene" rather than simply Wo, En, and Fs. This approach is not consistent with the treatment of feldspar minerals. Although only two feldspars (alkali and plagioclase) are found in most igneous rocks, the CIPW norm recipe calls for the three feldspar components.

- Most silicate minerals that contain Fe^{+2} can also contain Mg^{+2} and do not have a strong preference for one over the other. The value of $Fe^{+2}/(Fe^{+2}+ Mg^{+2})$ for these minerals depends more on the value of $Fe^{+2}/(Fe^{+2}+ Mg^{+2})$ for the rock as a whole than it does on some intrinsic property of the mineral. Therefore, it is assumed in the norm calculation that each ferromagnesian mineral contains the rock value of $Fe^{+2}/(Fe^{+2}+ Mg^{+2})$. For the pyroxenes, a rock with a bulk composition "X" (after removal of FeO for ilmenite and magnetite and removal of CaO for apatite), the minerals Di and Hyp in the norm will have compositions on a line radiating from Wo and passing through "X". Calculating the mass units of Di and Hyp from their molar proportions is complicated by the need to calculate the gram formula weight of the particular Di and Hyp obtained (— and may be best left to a computer!).



- Many real igneous rocks do contain water bound in hydrous minerals such as micas or amphiboles. These minerals are not used in the CIPW recipe, but other recipes can be devised to include micas and amphiboles. If a rock is peraluminous ($Al_2O_3 > K_2O + Na_2O + CaO$), there will be corundum and no Wo (=> no Di) in the norm. In a wet rock, muscovite would appear instead of corundum and biotite instead of hypersthene. If a rock is peralkaline ($Al_2O_3 < K_2O + Na_2O$), there will be acmite and no anorthite in the norm. In a wet rock that is peralkaline, amphibole (arfvedsonite or riebekite) may occur along with an aegirine-augite and alkali feldspar (no plagioclase!).

Readings on CIPW Norms

- Blatt and Tracy (1996) 66-68, 489-494.
- Hyndman (1985) 677-680.
- Morse (1980) Chapter 2.
- Philpotts (1989) 93-98.
- Raymond (2002) Appendix B.
- Winter (2001) 135-136, Appendix.

Norm Calculations

Analysis Title		Average Crust	
Date			
Oxide	**Wt. %**	**GFW**	
SiO2	60.00	60.085	
TiO2	1.20	79.899	
Al2O3	15.30	101.961	
Fe2O3	3.10	159.692	
FeO	3.80	71.876	
MnO	0.00	70.937	
MgO	3.50	40.311	
CaO	5.10	56.079	
Na2O	3.80	61.979	
K2O	3.10	94.203	
P2O5	0.00	141.945	
H2O+	1.10	18.015	
H2O-	0.00	18.015	

Totals	100.00		
Mole proportions of norm minerals			
Oxygen proportions of norm minerals			
Oxygen percentage of norm minerals			
GFW of norm minerals			
Mass of norm minerals			
Weight proportions of norm minerals			