

**GEOL3313 – Petrology of Igneous and Metamorphic Rocks**  
 G. Mattioli, Dept. of Geosciences, Univ. of Arkansas, Spring 2008

**Homework Assignment 3 – Calculation of CIPW Norm**  
**Due in Class February 13, 2008**

**Problem 1**

There are several different ways to calculate the normative mineralogy of an igneous rock. This type of petrologic analysis tool was first developed by W. Cross, J.P. Iddings, L.V. Pirsson, and H.S. Washington, and hence is referred to as the CIPW norm. The method outlined below ignores mineral solid solutions and is taken from Appendix B of Hyndman's *Petrology of Igneous and Metamorphic Rocks*. Other methods have been developed that include minor and trace elements not normally reported in older texts or standard XRF whole rock major element analyses. Required data for the normative minerals are shown in Table 1 and the data for this example are shown in Table 2.

Using the whole rock compositions given in the spreadsheet on the web ([http://comp.uark.edu/~mattioli/geol\\_3313/CIPW\\_norm.xls](http://comp.uark.edu/~mattioli/geol_3313/CIPW_norm.xls)), calculate the CIPW norm for the Granite, Diorite, Gabbro, and Ijolite compositions. Please show all work and be as neat as possible. Follow the step by step instructions below.

**Problem 2**

Discuss the utility of the CIPW norm. Why was it devised and how is used today? Why is it impossible for olivine and quartz to appear in the norm of the same rock?

| NAME                   | ABBREVIATION | CHEMICAL FORMULA   | FORMULA WEIGHT |
|------------------------|--------------|--|----------------|
| Quartz                 | <i>Q</i>     | SiO <sub>2</sub>   | 60.08          |
| Corundum               | <i>C</i>     | Al <sub>2</sub> O <sub>3</sub>   | 102.0          |
| Orthoclase             | <i>Or</i>    | K <sub>2</sub> O · Al <sub>2</sub> O <sub>3</sub> · 6SiO <sub>2</sub>  | 556.6          |
| Albite                 | <i>Ab</i>    | Na <sub>2</sub> O · Al <sub>2</sub> O <sub>3</sub> · 6SiO <sub>2</sub> | 524.4          |
| Anorthite              | <i>An</i>    | CaO · Al <sub>2</sub> O <sub>3</sub> · 2SiO <sub>2</sub>               | 278.2          |
| Leucite                | <i>Lc</i>    | K <sub>2</sub> O · Al <sub>2</sub> O <sub>3</sub> · 4SiO <sub>2</sub>  | 436.5          |
| Nepheline              | <i>Ne</i>    | Na <sub>2</sub> O · Al <sub>2</sub> O <sub>3</sub> · 2SiO <sub>2</sub> | 284.1          |
| Kaliophilite           | <i>Kp</i>    | K <sub>2</sub> O · Al <sub>2</sub> O <sub>3</sub> · 2SiO <sub>2</sub>  | 316.3          |
| Acmite                 | <i>Ac</i>    | Na <sub>2</sub> O · Fe <sub>2</sub> O <sub>3</sub> · 4SiO <sub>2</sub> | 462.0          |
| Sodium metasilicate    | <i>Ns</i>    | Na <sub>2</sub> O · SiO <sub>2</sub>                                   | 122.1          |
| Potassium metasilicate | <i>Ks</i>    | K <sub>2</sub> O · SiO <sub>2</sub>                                    | 154.3          |
| Wollastonite           | <i>Wo</i>    | CaO · SiO <sub>2</sub>   | 116.2          |
| Diopside               | <i>Di</i>    | CaO · FeO · 2SiO <sub>2</sub>  | 248.1          |
|                        |              | CaO · MgO · 2SiO <sub>2</sub>  | 216.5          |
| Hypersthene            | <i>Hy</i>    | FeO · SiO <sub>2</sub>   | 131.9          |
|                        |              | MgO · SiO <sub>2</sub>   | 100.4          |
| Olivine                | <i>Ol</i>    | 2FeO · SiO <sub>2</sub>  | 203.8          |
|                        |              | 2MgO · SiO <sub>2</sub>  | 140.7          |
| Dicalcium silicate     | <i>Cs</i>    | 2CaO · SiO <sub>2</sub>  | 172.2          |
| Magnetite              | <i>Mt</i>    | FeO · Fe <sub>2</sub> O <sub>3</sub>                                   | 231.5          |
| Ilmenite               | <i>Il</i>    | FeO · TiO <sub>2</sub>   | 151.7          |
| Hematite               | <i>Hm</i>    | Fe <sub>2</sub> O <sub>3</sub>   | 159.7          |
| Titanite               | <i>Tn</i>    | CaO · TiO <sub>2</sub> · SiO <sub>2</sub>                              | 196.0          |
| Perovskite             | <i>Pf</i>    | CaO · TiO <sub>2</sub>   | 135.9          |
| Rutile                 | <i>Ru</i>    | TiO <sub>2</sub>   | 79.87          |
| Apatite                | <i>Ap</i>    | 3.3 CaO · P <sub>2</sub> O <sub>5</sub>                                | 327.0          |

**Table 1 Chemical formulae for normative minerals**

## Instructions

A step-by-step calculation of the CIPW norm from a chemical analysis of a granite sample from the Idaho batholith (num. 134.15) is shown below.

| Oxide                          | Wt. % | Mol. Wt. | Mol. % (with most calculated values subtracted as an example) |
|--------------------------------|-------|----------|---|
| SiO <sub>2</sub>               | 70.66 | 60.09    | $1.1759 - 0.2262 - 0.4608 - 0.0612 = 0.4277^*$                |
| TiO <sub>2</sub>               | 0.24  | 79.90    | $0.0030 - 0.0030 = 0$   |
| Al <sub>2</sub> O <sub>3</sub> | 15.99 | 101.96   | $0.1568 - 0.0377 - 0.0768 - 0.0306 = 0.0117$                  |
| Fe <sub>2</sub> O <sub>3</sub> | 0.76  | 159.69   | $0.0048 - 0.0047 = 0$   |
| FeO                            | 0.70  | 71.85    | $0.0097 + 0.0004 - 0.0030 - 0.0047 = 0.0024$                  |
| MnO                            | 0.03  | 70.94    | $0.0004 - 0.0004 = 0$   |
| MgO                            | 0.47  | 40.30    | 0.0117  |
| CaO                            | 1.81  | 56.08    | $0.0323 - 0.0017 = 0.0306 - 0.0306 = 0$                       |
| Na <sub>2</sub> O              | 4.76  | 61.98    | $0.0768 - 0.0768 = 0$   |
| K <sub>2</sub> O               | 3.55  | 94.20    | $0.0377 - 0.0377 = 0$   |
| P <sub>2</sub> O <sub>5</sub>  | 0.07  | 141.95   | $0.0005 - 0.0005 = 0$   |
| H <sub>2</sub> O               | 0.37  |          |   |

**Table 2 Oxide weight percentages, molecular weights, and mols for example**

(\* does not include subtracted value beyond step 7; final value = 0.4137)

- 1) Divide the weight percentage (wt. %) of each oxide by its molecular weight (Table 2) to obtain the number of molecules (mols or molecular proportion) of each oxide.
- 2) Add mol. prop. of MnO to that of FeO (*e.g.* 0.0101 here).
- 3) Calculate normative apatite, which equals mol. prop. P<sub>2</sub>O<sub>5</sub> (*e.g.*, ap = 0.0005 here). Note that Ca is also in apatite, you must subtract the equivalent number of moles of CaO (3.33 times that of P<sub>2</sub>O<sub>5</sub>) from the original CaO mol. prop. ( $3.33 \times 0.0005 = 0.0017$ ).
- 4) Calculate normative ilmenite, which equals the mol. prop. of TiO<sub>2</sub> that does not exceed the available amount of FeO, as it also is required to form stoichiometric ilmenite (*e.g.*, il = 0.0030). You must also subtract the equivalent mol. prop. of FeO from the original FeO mol. prop.

If the mol. prop. of TiO<sub>2</sub> is greater than that of FeO, excess TiO<sub>2</sub> will remain. This will be used to calculate normative sphene or “titanite” (*e.g.* tn = 0 in this example). Again, since CaO (see Table 2) is also in sphene, you must subtract an amount of CaO equal to the TiO<sub>2</sub> used to make sphene. All remaining TiO<sub>2</sub> is assigned to make rutile.

- 5) Calculate normative orthoclase, which equals the mol. prop. of  $K_2O$  ( or = 0.0377 here). Subtract an equal amount of  $Al_2O_3$  and six times the mol. prop. of  $K_2O$  from the original amount of  $SiO_2$  as these are the appropriate stoichiometric proportions of these components to make orthoclase.

In rare cases of excess  $K_2O$  over the amount of  $Al_2O_3$ , assign this to normative potassium metasilicate or kalsilite ( $ks = 0$  in this example). Subtract the equivalent amount of mols from the mol. prop. of  $SiO_2$ .

- 6) Calculate normative albite, which equals the mol. prop. of  $Na_2O$  ( $ab = 0.0768$ ). Similar to step (5) above, subtract a similar amount of  $Al_2O_3$  and six times the mol. prop. of  $Na_2O$  from the original amount of  $SiO_2$  as these are the appropriate stoichiometric proportions of these components to make albite.

If there is excess of  $Na_2O$  over  $Al_2O_3$ , assign it to normative acmite, which equals the excess mol. prop. of  $Na_2O$  or  $Fe_2O_3$ , whichever is greater ( $ac = 0$  here; note that acmite is the same as aegirine,  $NaFeSi_2O_6$ ). Subtract this amount of  $Na_2O$  and mol. prop.  $Fe_2O_3$  and 4 times this amount from the mol. prop. of  $SiO_2$ .

Excess  $Na_2O$  is assigned to normative sodium metasilicate ( $ns = 0$  here). Subtract this amount from mol. prop.  $SiO_2$ . Any excess  $Fe_2O_3$  should be assigned to normative magnetite (see step 8 below).

- 7) Calculate normative anorthite, which equals the excess  $CaO$  left over after forming titanite in step 4 (here  $an = 0.0306$ ). Subtract  $CaO$  used to make anorthite from the remaining  $CaO$ ; subtract the same amount of  $Al_2O_3$  and 2 times that amount of  $SiO_2$ , corresponding to the appropriate stoichiometry for anorthite.

If there is any remaining excess  $Al_2O_3$ , assign it to normative corundum ( $c = 0.0117$  here). Any excess  $CaO$  is used to make normative diopside and wollastonite in step 10 below (both equal 0 here).

- 8) Calculate normative magnetite, which corresponds to the mo, prop. of  $Fe_2O_3$  or any excess  $Fe_2O_3$  left over after formation of acmite in step 6 above ( $mt = 0.0047$  here). Subtract an equal amount of  $FeO$  to yield the appropriate stoichiometry for magnetite.

If there any excess  $Fe_2O_3$  remains after forming magnetite and using all the  $FeO$ , then it should be assigned to form normative hematite ( $hm = 0$  here).

- 9) Calculate the mol. prop.  $MgO/(MgO + \text{remaining } FeO)$ . This is referred to as the  $Mg\#$  and for the example here is  $0.0116/(0.0116 + 0.0024)$ , which equals 0.8286.

- 10) Calculate normative diopside, which is equal to the mol. prop. of CaO remaining after making anorthite in step 7 ( $di = 0$  here). An equal amount of MgO + FeO is allocated to diopside, maintaining the appropriate Mg# as calculated in step 9. Subtract amounts of MgO and FeO from their totals. Subtract 2 times the amount of CaO from SiO<sub>2</sub>.

If CaO remains after combination with MgO + FeO, it is assigned as provisional wollastonite and an equal amount of SiO<sub>2</sub> is subtracted from its total remaining mols. ( $wo = 0$  here).

- 11) Calculate normative hypersthene, which equals any remaining MgO + FeO ( $hy = 0.0116 + 0.0024 = 0.0140$  here). Proportions should be assigned corresponding to the Mg# calculated in step 9. Equivalently, the normative hypersthene may be expressed as normative enstite and normative ferrosilite ( $en = 0.0116$ ,  $fs = 0.0024$  here). Subtract an equal amount of SiO<sub>2</sub> from its total.

If SiO<sub>2</sub> is deficient but more than half the remaining MgO + FeO, then normative hypersthene is equal to 2 times the remaining SiO<sub>2</sub> minus the mol. prop. of MgO + FeO. Assign normative olivine to the mol. prop. of MgO + FeO minus the amount of normative hypersthene ( $ol = 0$  here).

If SiO<sub>2</sub> is less than half the remaining MgO + FeO, then normative olivine is equal to the mol. prop. of MgO + FeO and half that amount is subtracted from the mol. prop. of SiO<sub>2</sub>.

If SiO<sub>2</sub> is still deficient, similar procedures should be used to make perovskite ( $pf = CaO \cdot TiO_2$ ) in place of titanite, nepheline in ( $ne = Na_2O \cdot Al_2O_3 \cdot 2SiO_2$ ) in place of albite, and leucite ( $lc = K_2O \cdot Al_2O_3 \cdot 4SiO_2$ ) in place of orthoclase.

- 12) Calculate normative silica as the mol. prop. of SiO<sub>2</sub> remaining after the first part of step 11 ( $q = 0.4137$  here) and any provisional values above are now fixed.
- 13) The norm for the rock is finally calculated from the normative oxide components determined by multiplying by the molecular weight of each normative mineral. Results for this example are shown in Table 3.

| <b>Norm. component</b> | <b>Amount</b> | <b>Mol. wt.</b> | <b>Norm. wt. %</b> |
|------------------------|---------------|-----------------|--------------------|
| Quartz (q)             | 0.4137        | 60.09           | 24.86              |
| Corundum (c)           | 0.0117        | 101.96          | 1.19               |
| Orthoclase (or)        | 0.0377        | 556.70          | 20.99              |
| Albite (ab)            | 0.0768        | 524.48          | 40.28              |
| Anorthite (an)         | 0.0306        | 278.22          | 8.51               |
| Diopside (di)          | 0.0000        | 221.92          | 0.00               |
| Hypersthene (hy)       | 0.0140        | 105.80          | 1.48               |
| Enstite (en)           | 0.0116        | 100.39          | 1.16               |
| Ferrosilite (fs)       | 0.0024        | 131.94          | 0.32               |
| Magnetite (mt)         | 0.0047        | 231.54          | 1.09               |
| Ilmenite (il)          | 0.0030        | 151.75          | 0.46               |
| Hematite (hm)          | 0.0000        | 159.70          | 0.00               |
| Apatite (ap)           | 0.0005        | 327.01          | 0.16               |
|                        |               |                 | <b>99.02</b>       |

**Table 3 Calculated Normative wt. % for Idaho Granite sample**

## **Discussion**

The calculated normative minerals have the same names as actual minerals that may be present in the mode of the rock. Several of the normative components appear as solid solutions in specific mineral phases in the rock. In general, the following observations can be made:

- “q” in the norm commonly appears as quartz in the rock.
- “or” usually appears as K-feldspar in the rock, but minor amounts of normative “or” may simply be a component in plagioclase feldspar or mica phases.
- “lc” calculation of leucite in the norm indicates excess K over that required for K-fsp, and presence of “ks” indicates an even higher degree of excess K in the rock.
- “ne” similarly, the presence of nepheline in the norm calculation indicates excess Na over that required to make the albite component in plagioclase fsp. “ns” indicates even more excess Na.
- “c” corundum in the norm indicates excess alumina above that required to make feldspars and may appear as a component in micas.
- “di” diopside in the norm appears as a clinopyroxene, and “wo” indicates excess Ca.

Certain normative minerals need not appear as separate minerals in the rock. In particular, the Ti manifested as “il” of the norm may be a solid-solution component of augite or biotite.

Complex minerals such as micas or amphiboles do not explicitly appear in the normative mineralogy of the rock but may appear as various other normative component minerals such as ab, an, or, di, hy, mt, and ol.

Some mineral combinations are precluded. For example:

**“q” cannot appear in the norm with ol, lc, ne, or pf.**

**“c” cannot appear in the norm with wo, di, ne, or ac.**

**“hy” cannot appear in the norm with ne, lc, or wo.**