

GY343 Petrology
CIPW Normative Mineralogy Calculation

Calculation of the CIPW norm

Practically all norms calculated today are produced by computer, but it is essential to understand the nature of the calculation by working through some examples. A form of the type passed out is useful for hand calculations. The following procedure is abbreviated for the purpose of calculating norms of most normal rocks. Full procedures are given in many older texts (e.g. Cross *et al.* 1903; Holmes 1930; Johannsen 1931). Note that some of the rules refer to normative minerals which are encountered rarely and are not shown on the form.

Basis for the CIPW calculation

The original intent of the CIPW calculation was to produce a consistent way to compare glassy volcanic rocks to phaneritic intrusive rocks to, for example, determine if the intrusive rock was genetically related to the volcanic rock. The result of the calculation is a calculated mineral content and abundance- i.e. the normative mineralogy. Major element oxides are used as input into the calculation. The calculation is based on the following assumptions:

- The magma from which the rock is derived is assumed to be “dry” so hydrous phases such as amphibole and mica are ignored by the calculation.
- The ferromagnesian minerals are assumed to be free of Al_2O_3 so that the amount of that component can be used to fix the abundance of feldspar and feldspathoid in the norm.
- The magnesium/iron ratio of all of the ferromagnesian minerals is assumed to be the same.
- Several mineral pairs are considered to be incompatible, such as feldspathoids and quartz, and therefore never appear together in the norm although in real rocks that may be present.

The result of the calculation often shows a close correspondence to the actual mineralogy of the rock, especially if the rock formed from a slowly cooling anhydrous magma. If an igneous rock contains significant proportions of amphibole and/or mica the calculated norm will deviate significantly from the actual modes.

Rules for calculation according to the CIPW sequence. In the following the word 'amount' should be taken to mean the molecular proportion obtained by dividing the weight per cent of an oxide by its molecular weight.

1. The molecular proportion of each constituent is determined by dividing by the

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appropriate molecular weight. These values are inserted in the horizontal column marked 'mol. prop. oxide'.

2. The amount of MnO is added to that of FeO.
- 3a. An amount of CaO equal to 3.33 that of P_2O_5 , (or 3.00 P_2O_5 and 0.33 F, if the latter is present) is allotted for apatite. To do this the P_2O_5 amount is written in the bottom right hand box of the form (intersection of the apatite and P_2O_5 columns) and 3.33 times this amount is entered in the apatite horizontal column under CaO. (At the end of the calculation all the allotments in a particular vertical column must sum to the original molecular proportion for that oxide.)
- 3b. An amount of FeO equal to that of the TiO_2 is allotted for ilmenite. If there is an excess of TiO_2 , an equal amount of CaO is to be allotted to it for provisional titanite, but only after the allotment of CaO to Al_2O_3 for anorthite (Rule 4c). If there is still an excess of TiO_2 , it is calculated as rutile. Note that there is not a row in the calculation chart for normative rutile.
- 4a. An amount of Al_2O_3 equal to that of the K_2O is allotted for provisional orthoclase.
- 4b. An excess of Al_2O_3 over the K_2O is allotted to an equal amount of remaining Na_2O for provisional albite. If there is insufficient Al_2O_3 , see Rule 4f.
- 4c. If there is an excess of Al_2O_3 over the $K_2O + Na_2O$ used in 4a and 4b, it is allotted to an equal amount of remaining CaO for anorthite.
- 4d. If there is an excess of Al_2O_3 over this CaO, it is calculated as corundum. Since all of the CaO component is used in making anorthite, rocks with normative corundum cannot have normative diopside or wollastonite.
- 4e. If there is an excess of CaO over the Al_2O_3 , of 4d, it is reserved for diopside and wollastonite (see Rules 7a and 7b).
- 4f. If in 4b there is an excess of Na_2O over Al_2O_3 , it is to be reserved for acmite and possibly for sodium metasilicate (not shown on calculation chart). There is then no anorthite in the norm.
- 5a. To an amount of Fe_2O_3 equal to that of the excess of Na_2O over Al_2O_3 (see Rule 4f) is allotted an equal amount of Na_2O for acmite.
- 5c. If, as usually happens, there is an excess of Fe_2O_3 over remaining Na_2O , it is assigned to magnetite, an equal amount of FeO being allotted to it out of what remains from the formation of ilmenite (see Rule 3b).
- 5d. If there is still an excess of Fe_2O_3 , it is calculated as haematite.
6. All the MgO and the FeO remaining from the previous allotments are added together and their relative proportions are ascertained ($MgO/[MgO+FeO]$).
- 7a. To the amount of CaO remaining after allotment in Rule 4e is allotted provisionally an equal amount of $MgO + FeO$ to form diopside, the relative proportions of these two, as they occur in the remainder, being preserved.
- 7b. If there is an excess of CaO, it is reserved for provisional wollastonite.
- 7c. If there is an excess of $MgO + FeO$ over that needed for diopside (7a), it is reserved for

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provisional hypersthene.

- 8a. Allot the necessary amount of silica to CaO to form titanite (syn. sphene; not in calculation chart) (Rule 3b, 1:1), to excess Na₂O to form acmite (Rule 5a, 4:1), to K₂O for provisional orthoclase (Rule 4a, 6:1), to Na₂O for provisional albite (Rule 4b, 6:1), to CaO for provisional anorthite (Rule 4c, 2:1), to CaO+ (Mg, Fe)O for diopside (Rule 7a, 1:1), to excess CaO for wollastonite (Rule 7b, 1:1), and to (Mg, Fe)O for hypersthene (Rule 7c, 1:1). The amounts of silica so assigned are subtracted from the total silica.
- 8b. If there is an excess of SiO₂, as there commonly is, it is calculated as quartz.
- 8c. If there is a deficiency of silica in 8a, the SiO₂ allotted to hypersthene (Rule 7c) is subtracted from the general sum of 8a and the remainder subtracted from the total SiO₂. If there is here an excess of SiO₂ more than enough to equal half the amount of (Mg, Fe)O of Rule 7c, it is allotted to the (Mg, Fe)O of 7c to form hypersthene and olivine, and is distributed according to equations (1) and (2). Let x = the number of hypersthene molecules, y = the number of olivine molecules, M = the amount of available (Mg, Fe)O, S = the amount of available SiO₂; then:

$$x = 2S - M \tag{1}$$

$$y = M - x \tag{2}$$

In this operation the relative proportions of MgO and FeO determined in Rule 6 and used in forming diopside (Rule 7a) are to be preserved. The fixed and provisional molecules of Rule 8a are calculated into their percentage weights (Rule 9).

If there is not enough silica to equal half the amount of (Mg, Fe)O of Rule 7c, all the (Mg, Fe)O of Rule 7c is calculated as olivine, SiO₂ equal to half its amount being assigned to it.

- 8d. If there is a deficiency of SiO₂ in 8c, the SiO₂ allotted to titanite (3b) is subtracted from the general sum of 8a, and the CaO and TiO₂ are calculated as perovskite (not in calculation chart; CaO • TiO₂).
- 8e. The sum of the SiO₂ needed to form the molecules of 8a is deducted from the total SiO₂, except that olivine is substituted for hypersthene and perovskite for titanite (sphene), and that albite is not included. If there is an excess of more than twice (and, of course, less than six times) that of the Na₂O for the provisional albite of 8a, this is distributed between albite and nepheline according to equations (3) and (4). If the excess is less than twice the Na₂O, it is taken care of in Rule 8f.

Let x = the number of albite molecules, y = the number of nepheline molecules, N

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= the amount of available Na_2O , S = the amount of available SiO_2 ; then:

$$x = \frac{S - 2N}{4} \quad (3)$$

$$y = N - x \quad (4)$$

- 8f. If there is still a deficiency of SiO_2 - that is, in 8e, not enough to equal twice the amount of available Na_2O - all this Na_2O is allotted to nepheline and the K_2O is distributed between orthoclase and leucite as follows:

The sum of the SiO_2 needed for the molecules in 8a is subtracted from the total SiO_2 , olivine being substituted for hypersthene, perovskite for titanite, and nepheline for albite, orthoclase being disregarded. If there is an excess of more than four times (and, of course, less than six times) that of K_2O , it is distributed between orthoclase and leucite according to equations

(5) and (6). If the excess is less than four times the K_2O , it is taken care of in Rule 8g.

Let x = the number of orthoclase molecules, y = the number of leucite molecules, K = the amount of available K_2O , S = the amount of available SiO_2 ; then:

$$x = \frac{S - 4K}{2} \quad (5)$$

$$y = K - x \quad (6)$$

- 8g. If there is still a deficiency of SiO_2 - that is, in 8f, not enough to equal four times the amount of K_2O - we have to distribute the CaO of wollastonite and diopside between these two and calcium orthosilicate, and the $(\text{Mg}, \text{Fe})\text{O}$ of diopside between diopside and olivine, according to available SiO_2 . There are two possible cases.

The most common case is that in which there is no wollastonite or its amount is insufficient to satisfy the deficiency in SiO_2 . Here, after allotting SiO_2 to form leucite (from all the K_2O), nepheline, anorthite, acmite, and olivine of Rule 8c, and possibly zircon and sodium metasilicate, the amount thus used is deducted from the total SiO_2 , the residue being the available silica.

Let x = the number of new diopside molecules, y = the number of new olivine molecules, z = the number of calcium orthosilicate molecules, S = the amount of available SiO_2 , M = the amount of $(\text{Mg}, \text{Fe})\text{O}$ (of provisional diopside), C = the amount of CaO of provisional diopside and wollastonite; then

$$x = \frac{2S - M - C}{2} \quad (7)$$

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$$y = \frac{M - x}{2} \quad (8)$$

$$z = \frac{C - x}{2} \quad (9)$$

In these three equations x = half the number of SiO_2 molecules in diopside, y = the number of SiO_2 molecules in olivine, and z = the number of SiO_2 molecules in calcium orthosilicate.

In the second case, where there is sufficient tentative wollastonite to meet the deficiency of SiO_2 , the total amount of SiO_2 in the rock is subtracted from the sum of the SiO_2 , which has been allotted to leucite, nepheline, anorthite, acmite, diopside, olivine, and to tentative wollastonite. The deficit is the number of molecules of necessary calcium orthosilicate, and also the amount of SiO_2 , to be assigned to it. This requires twice as much CaO. The rest of the CaO remains in wollastonite and takes an equal amount of SiO_2 , while the diopside remains unchanged.

9. All the allotments have now been made and the weight per cents of normative minerals are calculated by multiplying oxide amounts by the molecular weight of the minerals. To do this take the amount of any constituent which is present as a single molecule in the mineral formula and multiply this by the molecular weight to derive the weight per cent of that mineral; for example, if the figures in the orthoclase column are 0.320 SiO_2 , 0.054 Al_2O_3 and 0.054 K_2O , the weight per cent of orthoclase is $0.054 \times 556 = 30.02$ (the number of orthoclase molecules being the same as the number of Al_2O_3 , or K_2O molecules). The list of weight per cents of minerals should give the same total as the original analysis making allowance for the exclusion of H_2O , any other minor constituents that have been ignored, and rounding-off errors.

Effect of oxidation state on the norm. The oxidation state of Fe in an analyzed rock has an important effect on the norm and does influence the silica saturation significantly. Hence when highly oxidized rocks are studied, assuming the oxidation is a secondary effect, a misleading result can be obtained.

Consider two rocks which are identical except that one has suffered secondary alteration involving an increase in the ratio of $\text{Fe}^{3+}/\text{Fe}^{2+}$. The oxidized rock will contain more normative magnetite and there will thus be less $\text{MgO} + \text{FeO}$ available for diopside, hypersthene, and olivine. Since these are silicates, less SiO_2 will be required and there will thus be a relative excess of SiO_2 in the norm of the oxidized sample. Oxidation can change a rock from Ne-normative to Hy-normative or Q-normative. To overcome this problem it is common practice to adopt a standard oxidation state for analyzed samples before calculating norms. This is in any case necessary if a separate analysis for Fe^{3+} and Fe^{2+} was not made. The standard best adopted is

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debatable but as good a choice as any often consists of choosing the Fe^{3+}/Fe^{2+} ratio of the least oxidized sample of a group and adjusting the others to this value. Alternatively, Brooks (1976) has for example suggested standardizing the analyses of basaltic rocks at an Fe_2O_3/FeO ratio of 0.15.

Silica saturation in rocks. The great majority of rocks fall into one of the three major normative groups shown below:

1. *Silica-oversaturated* (Q + Hy in the norm).
2. *Silica-saturated* (Ol + Hy in the norm).
3. *Silica-undersaturated* (Ol + Ne in the norm).

The degree of silica saturation is highly dependent on the availability of SiO_2 , Na_2O and K_2O in the analysis. Hence the alkali-silica diagram can be used to make an approximate prediction of this as shown in Figure 1. Notice that the silica-saturated field (black) narrows to a negligible width in the more silic compositions. This is readily understood by thinking of the olivine + hypersthene assemblage in the norm as a 'buffer' which can take up different amounts of silica by varying the

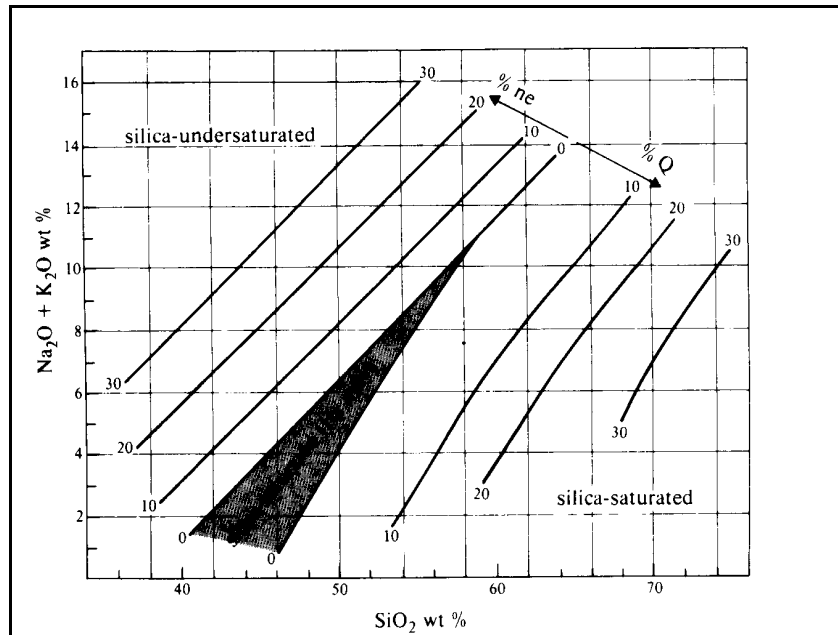


Figure 1. Alkali-silica diagram showing predicted normative character (CIPW weight %) of rocks.

When the rocks are rich in MgO and FeO a large amount of provisional hypersthene will be formed during the norm calculation. Quite large variations of silica can thus be accommodated without forming either quartz or nepheline. In silic rocks, however, there is very little provisional hypersthene and hence only a very small probability that the silica content will be just sufficient to maintain this assemblage without the production of quartz or nepheline. Hence trachytic rocks are overwhelmingly either quartz- or nepheline-normative while many basalts are olivine - hypersthene normative.

Molecular norms

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Several petrologists have argued that it is more useful to express normative mineralogy in molecular per cents rather than weight per cents, and it is certainly true that most petrological calculations are easier to perform in molecular rather than weight terms. Several systems have been devised, notable being those of Niggli (1954), Eskola (1954) and Barth (1955). The sequence of the calculation is flexible in the Niggli system and allows a greater choice of normative minerals which hence gives it applications in metamorphic and sedimentary petrology as well as in igneous petrology.

As an example, in the Eskola system the analysis is first recast into so called one-cation percentages. This is carried out by first dividing each oxide per cent by the *equivalent weight* of the oxide to produce a column of atomic proportions. The equivalent weight of the oxide is the same as the molecular weight when only one cation is present (e.g. SiO_2 , FeO) and half the molecular weight when two cations are present (e.g. Al_2O_3 , Na_2O). The atomic proportions are then totaled and recalculated as percentages (the one-cation percentages). Thus for example if the Si percentage is 49.5 this signifies that of every 100 cations in the rock 49.5 of them are Si.

The norm can then be calculated according to any preferred sequence but the proportions in which cations are allotted may differ from that in the CIPW weight norm. For example, in the weight norm orthoclase is made up of K_2O , Al_2O_3 , and SiO_2 in the proportions 1 : 1 : 6 whereas in the Eskola norm the proportions of K, Al, and Si are allotted as 1 : 1 : 3 since the formula is KAlSi_3O_8 . The difference between the 6 in the weight system and the 3 in the other is of course accounted for by the use of molecular weights as opposed to equivalent weights in the earlier stage of the calculation. Finally the normative minerals are derived in the Eskola norm by totaling the cations allotted to each mineral. For example if orthoclase is represented by allotments of 0.76K, 0.76 Al, and 2.28 Si this represents 3.80% of orthoclase in the final norm, signifying that of every 100 molecules present 3.80 of them are orthoclase.