

Calculation of the C.I.P.W. norm

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Summary. A modification of the rules for the calculation of C.I.P.W. norms when no normative quartz is present is suggested.

IN the course of writing a programme to calculate C.I.P.W. norms on EDSAC II, it became apparent that the rules, as given by Washington (1917), Johannsen (1939), and other authors, for calculating the norm in the absence of normative quartz were inconvenient. Modification of the method hitherto in common usage produces a calculation of greater simplicity.

Normative quartz is present in a great many igneous rocks and it is therefore usual to assume that quartz will occur in the norm and to form, where appropriate, the provisional normative minerals of highest silica content, orthoclase, albite, diopside, hypersthene or wollastonite, and sphene. Any excess of silica after the allocation of silica necessary to form the minerals of the norm is calculated as quartz. If, however, there is insufficient silica in the rock to combine with all other relevant oxides to give the highly silicic minerals, then these provisional minerals must be converted to alternative minerals of lower silica content.

The provisional normative minerals are listed in table I in the order in which they must be converted to alternative minerals of lower silica content. Each mineral in turn is changed to the alternative subsilicic mineral until the silica accommodated in the normative minerals is equal to the silica content of the rock. This redistribution of silica can be done quickly by considering the silica deficiency defined as the amount¹ of silica required for the formation of the normative minerals so far formed, less the amount of silica in the rock, at each stage of the redistribution. Suppose that *one* molecule of a given provisional mineral yields *U* molecules of silica and *V* molecules of the corresponding mineral of lower silica content. In this context *U* and *V* need not necessarily be

¹ The amount of a given mineral, oxide or element throughout this paper is expressed in terms of its molecular proportion, i.e. the weight percentage divided by the formula weight.

whole numbers; they can be simple fractions. If exactly one molecule of silica is formed by conversion of the provisional mineral then the number of molecules of the alternative mineral produced will be $W = V/U$. Thus, if we have an amount X of the provisional mineral, then it can yield a maximum amount XU of silica. Suppose that at a given

TABLE I

A_1	A_2	B_1	B_2	U	V	W
hypersthene	olivine	$(Mg,Fe)O.SiO_2$	$2(Mg,Fe)O.SiO_2$	$\frac{1}{2}$	$\frac{1}{2}$	1
sphene	perovskite	$CaO.TiO_2.SiO_2$	$CaO.TiO_2$	1	1	1
albite	nepheline	$Na_2O.Al_2O_3.6SiO_2$	$Na_2O.Al_2O_3.2SiO_2$	4	1	$\frac{1}{4}$
orthoclase	leucite	$K_2O.Al_2O_3.6SiO_2$	$K_2O.Al_2O_3.4SiO_2$	2	1	$\frac{1}{2}$
wollastonite	dicalcium silicate	$CaO.SiO_2$	$2CaO.SiO_2$	$\frac{1}{2}$	$\frac{1}{2}$	1
diopside	$\left\{ \begin{array}{l} \text{dicalcium} \\ \text{silicate} \\ \text{olivine} \end{array} \right\}$	$CaO.(Mg,Fe)O.2SiO_2$	$\left\{ \begin{array}{l} 2CaO.SiO_2 \\ 2(Mg,Fe)O.SiO_2 \end{array} \right\}$	1	$\left\{ \begin{array}{l} \frac{1}{2} \\ \frac{1}{2} \end{array} \right\}$	$\left\{ \begin{array}{l} \frac{1}{2} \\ \frac{1}{2} \end{array} \right\}$
leucite						

A_1 . Name of provisional mineral.

A_2 . Name of alternative subsilicic mineral.

B_1 . Formula of provisional mineral.

B_2 . Formula of alternative subsilicic mineral.

U . Number of molecules of silica formed when one molecule of the provisional mineral is converted.

V . Number of molecules of alternative subsilicic mineral formed from one molecule of provisional mineral.

W . Number of molecules of alternative mineral formed when one molecule of silica is formed from the provisional mineral.

stage of the calculation, this provisional mineral is the next to be converted to its alternative and that the silica deficiency at this stage of the calculation is D . Then if $D > XU$, all the provisional mineral must be converted to the alternative, forming an amount equal to XV of the subsilicic mineral and releasing an amount XU of silica. This reduces the deficiency to $(D - XU)$. If however $D < XU$ then it is unnecessary to change the whole amount of the provisional mineral into the alternative subsilicic mineral; the deficiency is eliminated by conversion of an amount equal to D/U . Thus an amount $(X - D/U)$ of the provisional mineral remains in the norm and an amount WD of the subsilicic mineral is formed. The values of U , V , and W for each provisional mineral are set down in table I. In redistributing silica in the absence of normative quartz the silica deficiency is calculated and the provisional minerals converted to the corresponding subsilicic minerals in the manner indicated until the deficiency has been annulled.

This method of calculating the C.I.P.W. norm is incorporated in the following rules for calculating the norm. The list of possible normative

minerals with their formulae adopted for the purposes of calculation of the norm are set down in table II. In this set of rules the abbreviation for a normative mineral is taken to mean the amount of that mineral present in the norm expressed as its molecular proportion. If the abbreviation is primed then it denotes the amount of a normative

TABLE II. Normative mineral molecules

Quartz (Q)	SiO_2
Corundum (C)	Al_2O_3
Zircon (Z)	$\text{ZrO}_2 \cdot \text{SiO}_2$
Orthoclase (or)	$\text{K}_2\text{O} \cdot \text{Al}_2\text{O}_3 \cdot 6\text{SiO}_2$
Albite (ab)	$\text{Na}_2\text{O} \cdot \text{Al}_2\text{O}_3 \cdot 6\text{SiO}_2$
Anorthite (an)	$\text{CaO} \cdot \text{Al}_2\text{O}_3 \cdot 2\text{SiO}_2$
Leucite (lc)	$\text{K}_2\text{O} \cdot \text{Al}_2\text{O}_3 \cdot 4\text{SiO}_2$
Nepheline (nc)	$\text{Na}_2\text{O} \cdot \text{Al}_2\text{O}_3 \cdot 2\text{SiO}_2$
Kaliophilite (kp)	$\text{K}_2\text{O} \cdot \text{Al}_2\text{O}_3 \cdot 2\text{SiO}_2$
Halite (hl)	NaCl
Thenardite (th)	$\text{Na}_2\text{O} \cdot \text{SO}_3$
Sodium carbonate (nc)	$\text{Na}_2\text{O} \cdot \text{CO}_2$
Acmite (ac)	$\text{Na}_2\text{O} \cdot \text{Fe}_2\text{O}_3 \cdot 4\text{SiO}_2$
Sodium metasilicate (ns)	$\text{Na}_2\text{O} \cdot \text{SiO}_2$
Potassium metasilicate (ks)	$\text{K}_2\text{O} \cdot \text{SiO}_2$
Diopside (di)	$\text{CaO} \cdot (\text{Mg}, \text{Fe})\text{O} \cdot 2\text{SiO}_2$
Wollastonite (wo)	$\text{CaO} \cdot \text{SiO}_2$
Hypersthene (hy)	$(\text{Mg}, \text{Fe})\text{O} \cdot \text{SiO}_2$
Olivine (ol)	$2(\text{Mg}, \text{Fe})\text{O} \cdot \text{SiO}_2$
Dicalcium silicate (cs)	$2\text{CaO} \cdot \text{SiO}_2$
Magnetite (mt)	$\text{FeO} \cdot \text{Fe}_2\text{O}_3$
Chromite (cm)	$\text{FeO} \cdot \text{Cr}_2\text{O}_3$
Ilmenite (il)	$\text{FeO} \cdot \text{TiO}_2$
Hematite (hm)	Fe_2O_3
Sphene (tn)	$\text{CaO} \cdot \text{TiO}_2 \cdot \text{SiO}_2$
Perovskite (pf)	$\text{CaO} \cdot \text{TiO}_2$
Rutile (ru)	TiO_2
Apatite (ap)	$3\text{CaO} \cdot \text{P}_2\text{O}_5 \cdot \frac{1}{3}\text{CaF}$
Fluorite (fr)	CaF_2
Pyrite (pr)	FeS_2
Calcite (cc)	$\text{CaO} \cdot \text{CO}_2$

mineral which has been formed provisionally. This amount may subsequently be reduced if there is no normative quartz present. The use of an oxide formula or the symbol of an element is taken to indicate the amount of that oxide or element available for the formation of normative minerals at that stage of the calculation. That is to say the total amount of oxide or element present in the rock less the amount of that oxide or element already used in the formation of normative minerals. As each normative mineral is formed the amount of silica, if any, required to

form this mineral is added to the amount of silica Y necessary for the formation of the minerals in the norm.

The revised rules proposed for the calculation of the norm are:

1. Calculate the amounts (molecular proportions) of the oxides and elements present by dividing the weight percentages by the appropriate formula weights.
2. Add (MnO+NiO) to FeO.
3. Add (BaO+SrO) to CaO.
4. Set $Z = \text{ZrO}_2$; set $Y = Z$.
5. Set $ap = \text{P}_2\text{O}_5$; subtract an amount equal to $\frac{10}{3}ap$ from CaO. If fluorine is present and if $F > \frac{2}{3}ap$ subtract an amount equal to $\frac{2}{3}ap$ from F. If $F < \frac{2}{3}ap$ all the fluorine is allocated to ap .
6. Set $fr = F/2$; subtract an amount equal to fr from CaO.
7. Set $hl = \text{Cl}$; subtract an amount equal to $hl/2$ from Na_2O .
8. If SO_3 is to be calculated as SO_3 and not as S, then set $th = \text{SO}_3$; subtract an amount equal to th from Na_2O .
9. If S is present or if SO_3 is to be calculated as S then put $pr = S/2$ or $\text{SO}_3/2$; subtract an amount equal to pr from FeO.
10. (a) If the rock contains cancrinite then put $nc = \text{CO}_2$; subtract an amount equal to nc from Na_2O .
(b) If the rock contains calcite set $cc = \text{CO}_2$; subtract an amount equal to cc from CaO. If the modal calcite is secondary or from associated limestone it is not included in the norm.
11. Set $cm = \text{Cr}_2\text{O}_3$; subtract an amount equal to cm from FeO.
12. If $\text{FeO} > \text{TiO}_2$ set $il = \text{TiO}_2$ and subtract an amount equal to il from FeO. There is no further TiO_2 available to form other normative minerals.
If $\text{FeO} < \text{TiO}_2$ set $il = \text{FeO}$ and subtract an amount equal to il from TiO_2 . There is no further FeO available to form other normative minerals.
13. If $\text{Al}_2\text{O}_3 > \text{K}_2\text{O}$ set $or' = \text{K}_2\text{O}$ and subtract an amount equal to or' from Al_2O_3 ; add an amount equal to $6or'$ to Y .
If $\text{Al}_2\text{O}_3 < \text{K}_2\text{O}$ set $or' = \text{Al}_2\text{O}_3$ and subtract an amount equal to or' from K_2O . There is no further Al_2O_3 available to form other normative minerals. Set $\text{K}_2\text{O} = ks$; add an amount equal to $(6or'+ks)$ to Y .
14. If $\text{Al}_2\text{O}_3 > \text{Na}_2\text{O}$ set $ab' = \text{Na}_2\text{O}$ and subtract an amount equal to ab' from Al_2O_3 . There is no further Na_2O available to form other normative minerals. Add an amount equal to $6ab'$ to Y .

- If $\text{Al}_2\text{O}_3 < \text{Na}_2\text{O}$ set $ab' = \text{Al}_2\text{O}_3$ and subtract an amount equal to ab' from Na_2O . There is no further Al_2O_3 available to form other normative minerals. Add an amount equal to $6ab'$ to Y .
15. If $\text{Na}_2\text{O} > \text{Fe}_2\text{O}_3$ set $ac = \text{Fe}_2\text{O}_3$ and subtract an amount equal to ac from Na_2O . There is no further Fe_2O_3 available to form other normative minerals. Set $ns = \text{Na}_2\text{O}$; add an amount equal to $(4ac + ns)$ to Y .
- If $\text{Na}_2\text{O} < \text{Fe}_2\text{O}_3$ set $ac = \text{Na}_2\text{O}$; subtract an amount equal to ac from Fe_2O_3 ; add an amount equal to $4ac$ to Y .
16. If $\text{Al}_2\text{O}_3 > \text{CaO}$ set $an = \text{CaO}$ and subtract an amount equal to an from Al_2O_3 . There is no further CaO available to form other normative minerals. Add an amount equal to $2an$ to Y ; set $C = \text{Al}_2\text{O}_3$.
- If $\text{Al}_2\text{O}_3 < \text{CaO}$ set $an = \text{Al}_2\text{O}_3$; subtract an amount equal to an from CaO ; add an amount equal to $2an$ to Y .
17. If $\text{CaO} > \text{TiO}_2$ set $tn' = \text{TiO}_2$; subtract an amount equal to tn' from CaO ; add an amount equal to tn' to Y .
- If $\text{CaO} < \text{TiO}_2$ set $tn' = \text{CaO}$ and subtract an amount equal to tn' from TiO_2 . There is no further CaO available to form other normative minerals. Set $ru = \text{TiO}_2$; add an amount equal to tn' to Y .
18. If $\text{Fe}_2\text{O}_3 > \text{FeO}$ set $mt = \text{FeO}$ and subtract an amount equal to mt from Fe_2O_3 . There is no further FeO available to form other normative minerals. Set $hm = \text{Fe}_2\text{O}_3$.
- If $\text{Fe}_2\text{O}_3 < \text{FeO}$ set $mt = \text{Fe}_2\text{O}_3$; subtract an amount equal to mt from FeO .
19. Add MgO to FeO to form $(\text{Mg},\text{Fe})\text{O}$. Calculate the ratios $\text{MgO}/(\text{MgO} + \text{FeO})$ and $\text{FeO}/(\text{MgO} + \text{FeO})$ and use these relative proportions to calculate the weight percentages of diopside, hypersthene, and olivine.
20. If $\text{CaO} > (\text{Mg},\text{Fe})\text{O}$ set $di' = (\text{Mg},\text{Fe})\text{O}$; subtract an amount equal to di' from CaO ; set $wo' = \text{CaO}$; add an amount equal to $(2di' + wo')$ to Y .
- If $\text{CaO} < (\text{Mg},\text{Fe})\text{O}$ set $di' = \text{CaO}$; subtract an amount equal to di' from $(\text{Mg},\text{Fe})\text{O}$; set $hy' = (\text{Mg},\text{Fe})\text{O}$; add an amount equal to $(2di' + hy')$ to Y .
21. Y now gives the amount of silica required for all the normative minerals so far formed.
- If $\text{SiO}_2 > Y$ set $Q = \text{SiO}_2 - Y$. The calculation of the norm is

completed by conversion of the molecular proportions to weight percentages of normative minerals.

If $\text{SiO}_2 < Y$ the deficiency $D = Y - \text{SiO}_2$ and further calculations have to be made (rules 22-27). These calculations must be continued until the deficiency has been reduced to zero. The calculation is then completed by conversion of the molecular proportions to weight percentages of the normative minerals.

TABLE III. Calculation of the C.I.P.W norm of a bostonite from Maros, Celebes

	Wt. %	Amount	Normative minerals	Y
SiO_2	61.15	1.019	<i>il</i> 0.003	
Al_2O_3	22.07	0.217, 0.143, 0.048, —	<i>or'</i> 0.074	0.444
Fe_2O_3	1.05	0.006, —	<i>ab'</i> 0.095	0.570
FeO	1.02	0.014, 0.011, 0.005, —	<i>an</i> 0.014	0.028
MgO	0.40	0.010, —	<i>C</i> 0.034	
CaO	0.75	0.014, —	<i>mt</i> 0.006	
Na_2O	5.86	0.095, —	<i>hy'</i> 0.015	0.015
K_2O	7.01	0.074, —		
H_2O^+	0.71	—		1.057
TiO_2	0.21	0.003, —		

$$\frac{\text{MgO}}{(\text{Mg,Fe})\text{O}} = \frac{2}{3}; \quad \frac{\text{FeO}}{(\text{Mg,Fe})\text{O}} = \frac{1}{3}.$$

$$D = 0.038. \quad hy'/2 = 0.008 \quad \therefore ol = 0.008; \quad hy = 0; \quad D_1 = 0.030. \\ 4ab' = 0.380 \quad \therefore ab = 0.087; \quad ne = 0.008.$$

Norm

C	3.47	ol	1.21
or	41.14	mt	1.39
ab	45.59	il	0.46
an	3.89		
ne	2.27		

22. If $D < hy'/2$ set $ol = D$ and $hy = hy' - 2D$. The silica deficiency is now zero.

If $D > hy'/2$ set $ol = hy'/2$ and $hy = 0$; put $D_1 = D - hy'/2$.

23. If $D_1 < tn'$ set $tn = tn' - D_1$ and $pf = D_1$. The silica deficiency is now zero.

If $D_1 > tn'$ set $pf = tn'$ and $tn = 0$; put $D_2 = D_1 - tn'$.

24. If $D_2 < 4ab'$ set $ne = D_2/4$ and $ab = ab' - D_2/4$. The silica deficiency is now zero.

If $D_2 > 4ab'$ set $ne = ab'$ and $ab = 0$, put $D_3 = D_2 - 4ab'$.

25. If $D_3 < 2or'$ set $lc = D_3/2$ and $or = or' - D_3/2$. The silica deficiency is now zero.

If $D_3 > 2or'$ set $lc' = or'$ and $or = 0$; put $D_4 = D_3 - 2or'$.

26. If $D_4 < wo'/2$ set $cs = D_4$ and $wo = wo' - 2D_4$. The silica deficiency is now zero.

If $D_4 > wo'/2$ set $cs = wo'/2$ and $wo = 0$; put $D_5 = D_4 - wo'/2$.

27. If $D_5 < di'$ add an amount equal to $D_5/2$ to the amounts of cs and ol already in the norm; set $di = di' - D_5$. The silica deficiency is now zero.

If $D_5 > di'$ add an amount equal to $di'/2$ to the amounts of cs and ol already in the norm; put $di = 0$ and $D_6 = D_5 - di'$.

28. Set $kp = D_6/2$ and $lc = lc' - D_6/2$. The silica deficiency is now zero.

To illustrate the use of these rules, the C.I.P.W. norm of a bostonite from Maros, Celebes (Washington, 1917, p. 274, analysis no. 37), is calculated in table III.

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References

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