The norm, its variations, their calculation and relationships

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The Norm, its Variations, their Calculation and Relationships

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With 2 tables in the text

Abstract

Systematic differences between the standard C.I.P.W. weight percent norm, the Niggli catanorm and the volume norm are presented. Complete rules are given for their calculation and conversions. Rules are given for a weight percent norm which includes biotite and hornblende and its conversion to the mesonorm and volume norm. The appropriate application of the various norms is discussed.

INTRODUCTION

The norm is a powerful petrographic tool which is especially valuable for describing and classifying volcanic rocks which are not wholly crystalline. It is customary for petrologists to recalculate rock analyses to a norm. Resulting from this practice it has been found that variation diagrams of rock suites are better constructed on a norm-dependant parameter such as the differentiation index of THORNTON and TUTTLE (1960) or the crystallization index of POLDERVAART and PARKER (1964) rather than on a weight percent parameter derived from the chemical analysis.

There are three major norm variations: the C.I.P.W. weight percent norm (JOHANNSEN, 1931), the Niggli catanorm (BARTH, 1962a) and the mesonorm (BARTH, 1962b). The C.I.P.W. norm is generally universally preferred by North American petrologists and the catanorm by European. The mesonorm is a special variation which has particular application to selected rocks. Because of tradition, very few petrologists are familiar with each of the norm variations. This article shows that the norm variations are very simply related and can be readily converted one to the other.

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THE C.I.P.W. NORM

The original norm is that of C. W. Cross, J. P. Iddings, L. V. Pirsson and H. S. Washington. The first complete compilation of the rules for its calculation was given by Johannsen (1931) but it is only when faced with writing the rules logically for computer calculation that an unambiguous set of rules became available. Kelsey (1965) gave such a set of rules. Even then, they contain a few ambiguities which have been removed by the present author. A definitive set of C.I.P.W. rules is given in the appendix to this paper in a form readily convertable to computer language and capable of being applied by any person who can reliably perform simple arithmetic. A few improvements have been made to facilitate subsequent calculation of the crystallization index.

Meaning: The C.I.P.W. norm is an expression of the total rock chemistry in terms of the selected normative minerals expressed in *weight proportions* of the minerals. If the norm is finally recalculated to 100% anhydrous, as is common practice for better comparison, then the norm gives the weight % of the normative minerals.

The basis of the C.I.P.W. norm is well illustrated by the equations used to effect desilification when, after forming diopside or hypersthene (rule 22 in the Appendix), it is found that an excessive molecular proportion of SiO_2 has been allocated.

(rule 24)	$2\,(MgO\,SiO_2)$	=	$2\,MgO\,SiO_2$	+	SiO_2
	2 EN	=	FO	+	Q
and similarly	2 FS	=	FA	+	Q

In the norm, 2MgO (molecular proportion) is both equal to 2 EN or 1 FO, whereas SiO_2 is equal to EN, FS, FO, FA or Q (in the desilification rules, Q = D).

(rule 25)	$CaO\,TiO_2\,SiO_2$	=	$CaO\,TiO_2$	+	SiO_2		
	TN	=	PF	+	Q		
(rule 26)	$Na_2O\,Al_2O_3\,6\,SiO_2$	=	$Na_2O\,Al_2O_3\,2\,SiO_2$	+	$4\,SiO_2$		
	AB	=	NE	+	4 Q		
(rule 27)	$K_2O\,Al_2O_3\,6\,SiO_2$	=	$K_2O\,Al_2O_3\,4\,SiO_2$	+	$2\,SiO_2$		
	OR	=	LC	+	2 Q		
(rule 28)	$2\,(CaO\,SiO_2)$	=	$2\,CaO\,SiO_2$	+	SiO_2		
	2 WO	=	CS	+	Q		
(rule 29)	$2\,(CaO\,MgO\,2\,SiO_2)$	=	$2\,CaO\,SiO_2$	+	$2\,MgO\,SiO_2$	+	$2\,SiO_2$
	2 Mg-DI	=	CS	+	FO	+	2 Q
similarly	2 Fe-DI	=	CS	+	FA	+	2 Q
(rule 30)	$K_2O\,Al_2O_3\,4\,SiO_2$	=	$K_2O\,Al_2O_3\,2\,SiO_2$	+	$2\,SiO_2$		
	LC	=	KP	+	2 Q		

The normative parameter differentiation index (THORNTON and TUTTLE, 1960) is defined based upon the C.I.P.W. norm and *not* on any other variation. Hence to avoid confusion it should not be calculated from any other norm. Similarly the crystallization index (POLDERVAART and PARKER, 1964) is based only on the C.I.P.W. norm. The C.I.P.W. norm may equally be referred to as the weight percent norm. It is appropriate to plot weight percent chemical parameters, such as K_2O%, total alkali % etc., against normative parameters based on the C.I.P.W. norm and not the Niggli norm.

THE NIGGLI CATANORM

Originally evolved by P. Niggli, the first set of readily available rules were compiled by BARTH (1962a). A logical set of rules, suitable for computer programming, is given by HUTCHISON (1974).

Meaning: The catanorm expresses the total rock chemistry in terms of the selected normative minerals expressed in cation proportions. For example, an oversimplified norm which gives albite 50%, anorthite 50% means that the cation proportions of $Na_{0.5}\,AlO_{1.5}\,3\,SiO_2$ and $CaO\,2\,AlO_{1.5}\,2\,SiO_2$ are equal. Both normative minerals have a total of 5 cations per molecule. Hence the cation proportions can be calculated as:

in albite Na $^1/_5$ of 50 = 10. Al $^1/_5$ of 50 = 10. Si $^3/_5$ of 50 = 30.
in anorthite Ca $^1/_5$ of 50 = 10. Al $^2/_5$ of 50 = 20. Si $^2/_5$ of 50 = 20.

Hence the total cation proportions are Na 10, Ca 10, Al 30, Si 50.

The catanorm is closer to a volume norm (= mode) than the C.I.P.W. norm. If all normative minerals had identical atomic structure so that their specific gravities depended only upon their cation contents, then the catanorm would represent a volume norm. However the specific gravity of a mineral is dependant not just on the cation content but also on detailed atomic structure, hence the catanorm is not exactly equal to the volume norm.

The basis of the catanorm can be illustrated by the equations used to effect desilification.

	$2\,(MgO\,SiO_2)$	=	$2\,MgO\,SiO_2$	+	SiO_2
	4 EN	=	3 FO	+	Q
	(2×2)		(3×1)		(1×1)
and	4 FS	=	3 FA	+	Q
	$CaO\,TiO_2\,SiO_2$	=	$CaO\,TiO_2$	+	SiO_2
	3 TN	=	2 PF	+	Q
	$NaO_{0.5}\,AlO_{1.5}\,3\,SiO_2$	=	$NaO_{0.5}\,AlO_{1.5}\,SiO_2$	+	$2\,SiO_2$
	5 AB	=	3 NE	+	2 Q
	(5 cations)		(3 cations)		(2 cations)

$$\begin{array}{lcl} KO_{0.5}\,AlO_{1.5}\,3\,SiO_2 & = & KO_{0.5}\,AlO_{1.5}\,2\,SiO_2 + SiO_2 \\ 5\,OR & = & 4\,LC + Q \\ 2\,(CaO\,SiO_2) & = & 2\,CaO\,SiO_2 + SiO_2 \\ 4\,WO & = & 3\,CS + Q \\ 2\,(CaO\,MgO\,2\,SiO_2) & = & 2\,CaO\,SiO_2 + 2\,MgO\,SiO_2 + 2\,SiO_2 \\ 8\,Mg\text{-}DI & = & 3\,CS + 3\,FO + 2\,Q \\ \text{and} \quad 8\,Fe\text{-}DI & = & 3\,CS + 3\,FA + 2\,Q \\ KO_{0.5}\,AlO_{1.5}\,2\,SiO_2 & = & KO_{0.5}\,AlO_{1.5}\,SiO_2 + SiO_2 \\ 4\,LC & = & 3\,KP + Q \end{array}$$

It is appropriate to plot cation proportions derived from the total rock analysis against normative parameters based on the Niggli and not the C.I.P.W. norm. Weight based oxides should be compared only with weight based normative parameters (C.I.P.W.), whereas molecular or cationic proportions should be compared with the cation based norm (catanorm).

THE BARTH MESONORM

The rules for the mesonorm (a variation of the catanorm) were given by Barth (1962b) and set out logically by Hutchison (1974). It is identical in meaning to the catanorm, and differs from it only in the introduction of the few minerals given in table 2. Because potassium is allocated to biotite, the normative amount of orthoclase (obtained by the catanorm) is reduced. Hornblende (actinolite + edenite + riebeckite) will also partly take the place of diopside and hypersthene. The mesonorm is suitable for granitic to dioritic rocks and for metamorphosed igneous rocks in which biotite and hornblende are more appropriate than diopside and hypersthene. The mesonorm allocates less SiO_2 to form biotite and hornblende than the catanorm or C.I.P.W. norm would do in forming diopside and hypersthene. Hence the mesonorm consistently has more Q, or for undersaturated rocks lesser amounts of undersaturated minerals than the other norms. These fundamental differences make the mesonorm more appropriate for granites, granodiorites, diorites and amphibolites.

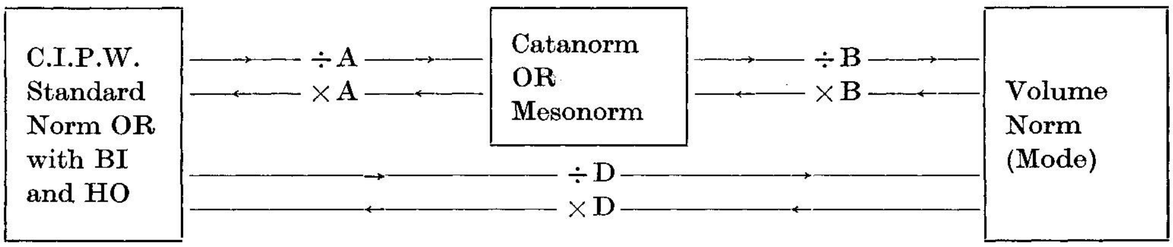
SYSTEMATIC RELATIONSHIP BETWEEN THE NORMS

Conversion from the C.I.P.W. to the catanorm is relatively simple. Hence there is no real need to compute different norms independantly. A systematic scheme is given for conversion between the norms. Since the C.I.P.W. norm is perhaps the most widely used, it will be taken as the starting point, and complete rules for its calculation are given in the appendix.

First choose whether to calculate the standard weight % C.I.P.W. norm or the modified weight % C.I.P.W. norm which includes biotite and hornblende. The choice will depend on whether an assemblage free of biotite and hornblende (e.g. basic igneous rocks) is more appropriate than one with biotite and hornblende (e.g. acid to intermediate igneous rocks and meta-igneous rocks). Having made the appropriate choice, calculate the C.I.P.W. norm according to the rules in the appendix. Normative-based parameters such as D.I. and C.I. must be based on the standard C.I.P.W. and not on the biotite-hornblende variation. It is best to end with an 100% anhydrous norm in which the total normative minerals is 100.

Table 1 gives the conversion factors required to change from the C.I.P.W. weight % norm to the catanorm (cation proportion norm) or a truly volume norm, which should be directly comparable with the mode (if the modal and normative minerals are identical). Likewise if we have already obtained a catanorm, it can be converted to a C.I.P.W. weight % or volume norm. A rock mode could be converted to a norm using the appropriate D factors. The conversion scheme is:

for each mineral in turn



Where the factors A, B, and D are given in Tables 1 and 2.
Then pro-rate to 100% by multiplying each mineral by $\frac{100 \times \text{mineral}}{\text{total of minerals}}$.

The conversion factors have been so calculated as to end with closely similar normative totals after conversion, so that the final proration to 100% results in only a very slight change in the amounts. The basis for the conversion is that a comparison of a large number of norms shows that orthoclase is closely similar in amount irrespective of which norm is calculated. Hence a conversion factor between C.I.P.W. and the catanorm for OR was taken as 1.000.

The derivation of the A, D, and B factors of table 1 is illustrated by an example. Factor A for albite $= \frac{30.99 + 50.98 + 3\,(60.08)}{5} \times$ constant. The constant for all minerals is $\frac{5}{47.10 + 50.98 + 3\,(60.08)}$, so that all conversions are relative to orthoclase. D $= \frac{\text{the mineral specific gravity}}{2.57}$ (2.57 is the specific gravity of orthoclase). B $= \frac{D}{A}$.

Table 1. *Normative minerals and conversion factors for the C.I.P.W. standard norm, the catanorm and the volume norm*

Symbol	Normative mineral	Cations	Formula	A	D	B
Salic group						
Q	quartz	1	SiO_2	1.079	1.031	0.955
C	corundum	1	$AlO_{1.5}$	0.916	1.564	1.708
Z	zircon	2	$ZrO_2\ SiO_2$	1.646	1.821	1.106
OR	orthoclase	5	$KO_{0.5}\ AlO_{1.5}\ 3\ SiO_2$	1.000	1.000	1.000
AB	albite	5	$NaO_{0.5}\ AlO_{1.5}\ 3\ SiO_2$	0.942	1.019	1.082
AN	anorthite	5	$CaO\ 2\ AlO_{1.5}\ 2\ SiO_2$	1.000	1.074	1.074
LC	leucite	4	$KO_{0.5}\ AlO_{1.5}\ 2\ SiO_2$	0.980	0.965	0.985
NE	nepheline	3	$NaO_{0.5}\ AlO_{1.5}\ SiO_2$	0.851	1.012	1.189
KP	kalsilite	3	$KO_{0.5}\ AlO_{1.5}\ SiO_2$	0.947	1.016	1.072
HL	halite	2	Na Cl	0.525	0.840	1.601
Femic group						
AC	acmite	4	$NaO_{0.5}\ FeO_{1.5}\ 2\ SiO_2$	1.037	1.381	1.331
NS	sodium metasilicate	3	$2\ NaO_{0.5}\ SiO_2$	0.731	1.019	1.395
KS	potassium metasilicate	3	$2\ KO_{0.5}\ SiO_2$	0.924	1.070	1.158
WO	wollastonite	2	$CaO\ SiO_2$	1.043	1.109	1.063
EN	enstatite	2	$MgO\ SiO_2$	0.902	1.249	1.385
FS	ferrosilite	2	$FeO\ SiO_2$	1.185	1.541	1.300
FO	forsterite	3	$2\ MgO\ SiO_2$	0.843	1.253	1.487
FA	fayalite	3	$2\ FeO\ SiO_2$	1.220	1.708	1.400
CS	larnite	3	$2\ CaO\ SiO_2$	1.031	1.288	1.249
MT	magnetite	3	$FeO\ 2\ FeO_{1.5}$	1.387	2.016	1.454
CM	chromite	3	$FeO\ 2\ CrO_{1.5}$	1.340	1.981	1.478
HM	hematite	1	$FeO_{1.5}$	1.435	2.043	1.424
IL	ilmenite	2	$FeO\ TiO_2$	1.363	1.829	1.342
TN	sphene	3	$CaO\ TiO_2\ SiO_2$	1.174	1.362	1.160
PF	perovskite	2	$CaO\ TiO_2$	1.221	1.568	1.284
RU	rutile	1	TiO_2	1.435	1.634	1.139
AP	apatite	8	$5\ CaO\ 3\ PO_{2.5}$	1.108	1.265	1.142
FR	fluorite	3	CaO 2 F	0.563	1.237	2.196
PR	pyrite	3	FeO 2 S	0.814	1.953	2.399
CC	calcite	2	$CaO\ CO_2$	0.863	1.054	1.222
CT	cassiterite	1	SnO_2	2.707	2.724	1.006
SP { Mg-SP	spinel	3	$MgO\ 2\ AlO_{1.5}$	0.852	1.381	1.621
SP { Fe-SP	hercynite	3	$FeO\ 2\ AlO_{1.5}$	1.041	1.712	1.645
DI { Mg-DI	diopside	4	$CaO\ MgO\ 2\ SiO_2$	0.973	1.253	1.288
DI { Fe-DI	hedenbergite	4	$CaO\ FeO\ 2\ SiO_2$	1.114	1.385	1.243

Table 2. *Additional normative minerals and conversion factors for the weight % norm (with biotite and hornblende), the mesonorm and the volume norm*

Symbol	Normative mineral	Cations	Formula	A	D	B
BI { Mg-BI	phlogopite	8	$KO_{0.5}\ 3\ MgO\ AlO_{1.5}\ 3\ SiO_2$	0.897	1.074	1.197
BI { Fe-BI	annite	8	$KO_{0.5}\ 3\ FeO\ AlO_{1.5}\ 3\ SiO_2$	1.109	1.167	1.052
ACT { Mg-ACT	tremolite	15	$2\ CaO\ 5\ MgO\ 8\ SiO_2$	0.951	1.175	1.236
ACT { Fe-ACT	ferro-actinolite	15	$2\ CaO\ 5\ FeO\ 8\ SiO_2$	1.140	1.339	1.175
ED { Mg-ED	edenite	16	$NaO_{0.5}\ 2\ CaO\ 5\ MgO\ AlO_{1.5}\ 7\ SiO_2$	0.916	1.187	1.296
ED { Fe-ED	ferro-edenite	16	$NaO_{0.5}\ 2\ CaO\ 5\ FeO\ AlO_{1.5}\ 7\ SiO_2$	1.094	1.362	1.245
RI	riebeckite	15	$2\ NaO_{0.5}\ 2\ FeO_{1.5}\ 3\ FeO\ 8\ SiO_2$	1.099	1.323	1.204

HO = ACT+ED+RI

Table 2 lists additional conversion factors which will be required if the norms containing biotite and hornblende are used. For these norms, the factors of table 1 apply and table 2 gives only the additional minerals needed.

The following are important fundamental differences and similarities between the norms:

1. The standard C.I.P.W. norm gives identical normative minerals to the catanorm, but the relative amounts differ. Where A of table 1 is close to 1.00, there will be little difference between the normative amounts. The greater the divergence from unity, the greater the normative difference. If A is less than unity, the amount in the catanorm will be greater than the amount in the C.I.P.W. norm and vice-versa.
2. Rock classifications based on norms, such as the basalt classification of YODER and TILLEY (1962) and GREEN and RINGWOOD (1967) should be equally valid based on either the C.I.P.W. or the catanorm, although they were defined on a C.I.P.W. basis.
3. Ratios in a mineral isomorphous series are properly calculated from the catanorm, e.g. plagioclase Ab_xAn_{100-x}, hypersthene En_xFS_{100-x} and olivine FO_xFA_{100-x}. The proportions of the end members obtained in the C.I.P.W. norm may be recalculated to cation proportions x and $100-x$ by using the factors A of table 1 without recalculation of the whole norm.
4. Relative plots of quartz, albite, orthoclase for granitic rocks are best based on mesonorm calculations because the C.I.P.W. standard norm over-allocates to the orthoclase molecule.

Appendix A: Rules for calculation of the standard C.I.P.W. weight % norm, crystallization and differentiation index

1. Calculate the amounts (molecular proportions) of the oxides and elements present in the analysis by dividing each given weight percentage by the appropriate following formula weight:

SiO_2	60.08	TiO_2	79.90	Al_2O_3	101.96	ZrO_2	123.22	Fe_2O_3	159.69		
MnO	70.94	FeO	71.85	NiO	74.71	MgO	40.31	BaO	153.34	CaO	56.08
SrO	103.62	Na_2O	61.98	Cr_2O_3	151.98	K_2O	94.20	Cl	35.45	SO_3	80.06
P_2O_5	141.94	F	19.00	CO_2	44.01	S	32.06	SnO_2	150.69		

2. Add the (MnO + NiO) amount to the FeO amount.

3. Add the (BaO + SrO) amount to the CaO amount.

   In the following rules the oxides or elements referred to are the amounts obtained for them after applying rules 1 to 3 above. All normative minerals are taken as of zero amount until formed by the following rules applied consecutively.

4. Make Z = ZrO_2. Make Y = Z.

   Throughout the norm calculation, amounts will be allocated to Y. The final total of Y is required at rule 23.

5. If $CaO \geqq 10/3\ P_2O_5$ Make $AP = P_2O_5$ Subtract 10/3 AP from CaO	If $CaO < 10/3\ P_2O_5$ Make $AP = 3/10\ CaO$ Subtract AP from P_2O_5 CaO becomes zero Excess P_2O_5 weight % in rock $= 141.94\ P_2O_5$
6. If $F \geqq 2/3\ AP$ Subtract 2/3 AP from F	If $F < 2/3\ AP$ Make F = zero
7. If $CaO \geqq 0.5\ F$ Make $FR = 0.5\ F$ Subtract FR from CaO	If $CaO < 0.5\ F$ Make FR = CaO. Subtract 2 FR from F CaO becomes zero Excess F weight % in rock = 19.00 F
8. If $Na_2O \geqq 0.5\ Cl$ Make HL = Cl Subtract 0.5 HL from Na_2O	If $Na_2O < 0.5\ Cl$ Make $HL = 2\ Na_2O$ Subtract HL from Cl Na_2O becomes zero Excess Cl weight % in rock = 35.45 Cl
9. If $FeO \geqq 0.5\ S$ (or $0.5\ SO_3$) Make $PR = 0.5\ S$ (or $0.5\ SO_3$) Subtract PR from FeO	If $FeO < 0.5\ S$ (or $0.5\ SO_3$) Make PR = FeO Subtract 2 PR from S (or SO_3) FeO becomes zero Excess S in weight % = 32.06 S (excess SO_3 in weight % = 80.06 SO_3)
10. If $CaO \geqq CO_2$ Make $CC = CO_2$ Reduce CaO by amount CC	If $CaO < CO_2$ Make CC = CaO Reduce CO_2 by amount CC CaO becomes zero Excess CO_2 weight % in rock = 44.01 CO_2
11. If $FeO \geqq Cr_2O_3$ Make $CM = Cr_2O_3$ Reduce FeO by amount CM	If $FeO < Cr_2O_3$ Make CM = FeO Reduce Cr_2O_3 by amount CM FeO becomes zero Excess Cr_2O_3 weight % in rock $= 151.98\ Cr_2O_3$
12. If $FeO \geqq TiO_2$ Make $IL = TiO_2$ Reduce FeO by amount IL TiO_2 becomes zero	If $FeO < TiO_2$ Make IL = FeO Reduce TiO_2 by amount IL FeO becomes zero
13. Make $CT = SnO_2$	
14. If $Al_2O_3 \geqq K_2O$ Make $OR = K_2O$ Reduce Al_2O_3 by amount OR Increase Y by amount 6 OR	If $Al_2O_3 < K_2O$ Make $OR = Al_2O_3$ Reduce K_2O by amount OR Al_2O_3 becomes zero Make $KS = K_2O$ Increase Y by amount (6 OR + KS)

15. If $Al_2O_3 \geqq Na_2O$
Make AB = Na_2O
Reduce Al_2O_3 by amount AB
Na_2O becomes zero
Increase Y by amount 6 AB

If $Al_2O_3 < Na_2O$
Make AB = Al_2O_3
Reduce Na_2O by amount AB
Al_2O_3 becomes zero
Increase Y by amount 6 AB

16. If $Na_2O \geqq Fe_2O_3$
Make AC = Fe_2O_3
Fe_2O_3 becomes zero
Reduce Na_2O by amount AC
Make NS = Na_2O
Increase Y by amount (4 AC + NS)

If $Na_2O < Fe_2O_3$
Make AC = Na_2O
Reduce Fe_2O_3 by amount AC
Increase Y by amount 4 AC

17. If $Al_2O_3 \geqq CaO$
Make AN = CaO
CaO becomes zero
Reduce Al_2O_3 by amount AN
Increase Y by amount 2 AN
Make C = Al_2O_3

If $Al_2O_3 < CaO$
Make AN = Al_2O_3
Reduce CaO by amount AN
Increase Y by amount 2 AN

18. If $CaO \geqq TiO_2$
Make TN = TiO_2
Reduce CaO by amount TN
Increase Y by amount TN

If $CaO < TiO_2$
Make TN = CaO
CaO becomes zero
Reduce TiO_2 by amount TN
Make RU = TiO_2
Increase Y by amount TN

19. If $Fe_2O_3 \geqq FeO$
Make MT = FeO
FeO becomes zero
Reduce Fe_2O_3 by amount MT
Make HM = Fe_2O_3

If $Fe_2O_3 < FeO$
Make MT = Fe_2O_3
Reduce FeO by amount MT

20. Make (MgFe) = (MgO + FeO). Calculate $PrMg = \frac{MgO}{MgO + FeO}$ and $PrFe = \frac{FeO}{MgO + FeO}$

21. This rule is to be applied *only* if the weight percent of SiO_2 in the rock is less than 45.00 (that is the rock is ultrabasic). If SiO_2 weight % > 45.00, omit this rule and proceed to rule 22.

If (MgFe) $\leqq$ C
Make Mg-SP = PrMg (MgFe)
Make Fe-SP = PrFe (MgFe)
Reduce C by amount (Mg-SP + Fe-SP)
(MgFe) becomes zero

If (MgFe) > C
Make Mg-SP = PrMg (C)
Make Fe-SP = PrFe (C)
C becomes zero
Reduce (MgFe) by amount (Mg-SP + Fe-SP)

22. If CaO $\geqq$ (MgFe)
Make Mg-DI = PrMg (MgFe)
Make Fe-DI = PrFe (MgFe)
Reduce CaO by amount (Mg-DI + Fe-DI)

If CaO < (MgFe)
Make Mg-DI = PrMg (CaO)
Make Fe-DI = PrFe (CaO)
Reduce (MgFe) by amount (Mg-DI + Fe-DI)

Make WO = CaO
Increase Y by amount
2 (Mg-DI + Fe-DI) + WO

Make EN = PrMg (MgFe)
Make FS = PrFe (MgFe)
Increase Y by amount
2 (Mg-DI + Fe-DI) + EN + FS

23. If $SiO_2 \geqq Y$
Make Q = $SiO_2 - Y$
Omit rules 24 to 30
Go directly to rule 31

If $SiO_2 < Y$
Make Q = zero
Make D = $Y - SiO_2$
Continue with the following rules until D becomes zero

24. If D $\leqq$ 0.5 (EN + FS)
Make FO = PrMg (D)
Make FA = PrFe (D)
Reduce EN by amount PrMg (2 D)
Reduce FS by amount PrFe (2 D)
D becomes zero. Omit rules 25–30
Go directly to rule 31

If D > 0.5 (EN + FS)
Make FO = 0.5 EN
Make FA = 0.5 FS
Reduce D by amount 0.5 (EN + FS)
EN becomes zero
FS becomes zero
Continue with rule 25

25. If D $\leqq$ TN
Make PF = D
Reduce TN by amount D
D becomes zero. Omit rules 26–30
Go directly to rule 31

If D > TN
Make PF = TN
Reduce D by amount TN
TN becomes zero
Proceed with rule 26

26. If D $\leqq$ 4 AB
Make NE = D/4
Reduce AB by amount D/4
D becomes zero. Omit rules 27–30
Go directly to rule 31

If D > 4 AB
Make NE = AB
Reduce D by amount 4 AB
AB becomes zero
Proceed with rule 27

27. If D $\leqq$ 2 OR
Make LC = 0.5 D
Reduce OR by amount 0.5 D
D becomes zero. Omit rules 28–30
Go directly to rule 31

If D > 2 OR
Make LC = OR
Reduce D by amount 2 OR
OR becomes zero
Proceed with rule 28

28. If D $\leqq$ 0.5 WO
Make CS = D
Reduce WO by amount 2 D
D becomes zero. Omit rules 29–30
Go directly to rule 31

If D > 0.5 WO
Make CS = 0.5 WO
Reduce D by amount 0.5 WO
WO becomes zero
Proceed with rule 29

29. If D $\leqq$ (Mg-DI + Fe-DI)
Increase CS by amount 0.5 D
Increase FO by amount 0.5 D (PrMg)
Increase FA by amount 0.5 D (PrFe)
Reduce Mg-DI by amount D (Pr-Mg)
Reduce Fe-DI by amount D (PrFe)
D becomes zero. Omit rule 30
Go directly to rule 31

If D > (Mg-DI + Fe-DI)
Increase CS by an amount
0.5 (Mg-DI + Fe-DI)
Increase FO by amount 0.5 (Mg-DI)
Increase FA by amount 0.5 (Fe-DI)
Reduce D by amount (Mg-DI + Fe-DI)
Mg-DI becomes zero
Fe-DI becomes zero
Proceed with rule 30

30. If D $\leqq$ 2 LC
Make KP = 0.5 D
Reduce LC by amount 0.5 D
D now becomes zero
Go to rule 31.

If D > 2 LC
Make KP = LC
Reduce D by amount 2 LC
LC becomes zero.
D is the amount of over-allocated silica. Desilification should continue until D becomes zero. This rule is so very unlikely to apply that no rules have been formulated. Go to 31.

31. Convert each normative mineral amount obtained by the foregoing rules to a normative mineral weight % by multiplying each mineral amount by the corresponding molecular weight given in the following list:

Q	60.08	C	101.96	Z	183.30	OR	556.64	AB	524.42	AN	278.20
LC	436.48	NE	284.10	KP =	316.32	HL =	58.44.				

The total of the foregoing minerals gives the weight % of the salic group (SALIC)

AC	461.99	NS	122.06	KS	154.28	Mg-DI	216.55	Fe-DI	248.09		
WO	116.16	EN	100.39	FS	131.93	FO	140.70	FA	203.78	CS	172.24
MT	231.54	CM	223.84	IL	151.75	HM	159.69	TN	196.06	PF	135.98
RU	79.90	AP	336.21	FR	78.08	PR	119.98	CC	100.09	CT	150.69
Mg-SP	142.27	Fe-SP	173.81								

The total of the foregoing minerals gives the weight % of the femic group (FEMIC).

The norm obtained will not total SALIC + FEMIC = 100 because the rock chemical analysis was used as given, and H_2O in the rock analysis was not utilized.

32. To recalculate the norm to 100% anhydrous, each of the normative minerals obtained in rule 31 should be multiplied by $\frac{100}{\text{Salic}+\text{Femic}}$. The values of Salic and Femic obtained in rule 31 can also be multiplied by the same $\frac{100}{\text{Salic}+\text{Femic}}$.

To complete the norm, HY takes the place of (EN + FS). OL the place of (FO + FA) DI the place of (Mg-DI + Fe-DI) and SP the place of (Mg-SP + Fe-SP).

33. The Differentiation Index (D.I.) of THORNTON and TUTTLE (1965) = Salic − AN (both determined in Rule 32).

34. The Crystallization Index (C.I.) of POLDERVAART and PARKER (1964) = AN + Mg-DI + FO + 0.700837 (EN) + Mg-SP (all determined in rule 32).

Appendix B: Rules for calculation of the weight % norm (with biotite and hornblende)

I. Perform rules 1 to 11 (inclusive) of the standard C.I.P.W. norm

II. Make CT = SnO_2

III. If $TiO_2 \leqq CaO$
Make TN = TiO_2
Reduce CaO by amount TN
Add TN to Y
TiO_2 becomes zero

If TiO_2 > CaO
Make TN = CaO
Reduce TiO_2 by amount TN
Add TN to Y
CaO becomes zero

IV. If $FeO \geqq TiO_2$
Make IL = TiO_2
Reduce FeO by amount IL
TiO_2 becomes zero

If $FeO < TiO_2$
Make IL = FeO
Reduce TiO_2 by amount IL
FeO becomes zero
Make RU = TiO_2

V. Perform rules 14 and 15 of the standard C.I.P.W. norm

VI. Either: If $Fe_2O_3 \leqq 1/3$ FeO

If $Na_2O \leqq Fe_2O_3$
Make RI = Na_2O
Reduce Fe_2O_3 by amount RI
Reduce FeO by amount 3 RI
Increase Y by amount 8 RI
Na_2O becomes zero

If $Na_2O > Fe_2O_3$
Make RI = Fe_2O_3
Reduce Na_2O by amount RI
Reduce FeO by amount 3 RI
Increase Y by amount 8 RI
Fe_2O_3 becomes zero

Or: If $Fe_2O_3 > 1/3$ FeO

If $Na_2O \leqq 1/3$ FeO
Make RI = Na_2O
Reduce Fe_2O_3 by amount RI
Reduce FeO by amount 3 RI
Increase Y by amount 8 RI
Na_2O becomes zero

If $Na_2O > 1/3$ FeO
Make RI = 1/3 FeO
Reduce Na_2O by amount RI
Reduce Fe_2O_3 by amount RI
Increase Y by amount 8 RI
FeO becomes zero

VII. Make NS = Na_2O. Increase Y by an amount NS

VIII. Perform rules 19, 20 and 21 of the standard C.I.P.W. norm

IX. Perform rule 17 of the standard C.I.P.W. norm

X. If (MgFe) $\leqq$ 6 OR
Make Mg-BI = 1/6 (PrMg) (MgFe)
Make Fe-BI = 1/6 (PrFe) (MgFe)
Reduce OR by amount
(Mg-BI + Fe-BI)
(MgFe) becomes zero

If (MgFe) > 6 OR
Make Mg-BI = PrMg (OR)
Make Fe-BI = PrFe (OR)
Reduce (MgFe) by amount
6 (Mg-BI + Fe-BI)
OR becomes zero

XI. If (MgFe) $\leqq$ 5/2 CaO
Make Mg-ACT = 1/5 PrMg (MgFe)
Make Fe-ACT = 1/5 PrFe (MgFe)
Reduce CaO by amount
2 (Mg-ACT + Fe-ACT)
(MgFe) becomes zero
Make WO = CaO
Increase Y by amount
8 (Mg-ACT + Fe-ACT) + WO
CaO becomes zero

If (MgFe) > 5/2 CaO
Make Mg-ACT = 0.5 PrMg (CaO)
Make Fe-ACT = 0.5 PrFe (CaO)
Reduce (MgFe) by amount
5 (Mg-ACT + Fe-ACT)
CaO becomes zero
Make EN = PrMg (MgFe)
Make FS = PrFe (MgFe)
Increase Y by amount
8 (Mg-ACT + Fe-ACT) + EN + FS

XII. If $SiO_2 \geqq Y$
Make Q = $SiO_2 - Y$
Omit rules XIII to XVI
Go directly to rule XVII

If $SiO_2 < Y$
Make Q = zero
Make D = $Y - SiO_2$
Continue with rule XIII

XIII. Either: If (Mg-ACT + Fe-ACT) $\geqq$ 2 AB

If AB $\geqq$ D/8	If AB $<$ D/8
Make Mg-ED = PrMg (D/8)	Make Mg-ED = PrMg (AB)
Make Fe-ED = PrFe (D/8)	Make Fe-ED = PrFe (AB)
Reduce Mg-ACT by amount 2 Mg-ED	Reduce Mg-ACT by amount 2 Mg-ED
Reduce Fe-ACT by amount 2 Fe-ED	Reduce Fe-ACT by amount 2 Fe-ED
Reduce AB by amount (Mg-ED + Fe-ED)	Reduce D by amount 8 (Mg-ED + Fe-ED)
D becomes zero.	AB becomes zero
Omit rules XIV to XVI	Continue with rule XIV
Go directly to rule XVII	

Or: If (Mg-ACT + Fe-ACT) $<$ 2 AB

If (Mg-ACT + Fe-ACT) $\geqq$ D/4	If (Mg-ACT + Fe-ACT) $<$ D/4
Make Mg-ED = PrMg (D/8)	Make Mg-ED = 0.5 Mg-ACT
Make Fe-ED = PrFe (D/8)	Make Fe-ED = 0.5 Fe-ACT
Reduce Mg-ACT by amount 2 Mg-ED	Reduce AB by amount (Mg-ED + Fe-ED)
Reduce Fe-ACT by amount 2 Fe-ED	Reduce D by amount 8 (Mg-ED + Fe-ED)
Reduce AB by amount (Mg-ED + Fe-ED)	Mg-ACT becomes zero
D becomes zero	Fe-ACT becomes zero
Omit rules XIV to XVI	Continue with rule XIV
Go directly to rule XVII	

XIV.

If D $\leqq$ 0.5 (EN + FS)	If D $>$ 0.5 (EN + FS)
Make FO = PrMg (D)	Make FO = 0.5 EN
Make FA = PrFe (D)	Make FA = 0.5 FS
Reduce EN by amount 2 FO	Reduce D by amount 0.5 (EN + FS)
Reduce FS by amount 2 FA	EN becomes zero. FS becomes zero
D becomes zero. Omit rules XV to XVI. Go directly to rule XVII	Continue with rule XV

XV. Either: If (FO + FA) $\leqq$ 0.5 C

If (FO + FA) $\geqq$ D	If (Fo + FA) $<$ D
Increase Mg-SP by amount 2 PrMg (D)	Increase Mg-SP by amount 2 FO
Increase Fe-SP by amount 2 PrFe (D)	Increase Fe-SP by amount 2 FA
Reduce C by amount 2 D	Reduce C by amount 2 (FO + FA)
Reduce FO by amount PrMg (D)	Reduce D by amount (FO + FA)
Reduce FA by amount PrMg (D)	FO becomes zero
D becomes zero. Omit rule XVI	FA becomes zero
Go directly to rule XVII	Continue with rule XVI

Or: If (FO + FA) $>$ 0.5 C

If C $\geqq$ 2 D	If C $>$ 2 D
Increase Mg-SP by amount 2 PrMg (D)	Increase Mg-SP by amount 2 PrMg (C)
Increase Fe-SP by amount 2 PrFe (D)	Increase Fe-SP by amount 2 PrFe (C)
Reduce C by amount 2 D	Reduce D by amount 0.5 C
Reduce FO by amount PrMg (D)	Reduce FO by amount 0.5 PrMg (C)
Reduce FA by amount PrFe (D)	Reduce FA by amount 0.5 PrFe (C)
D become zero. Omit rule XVI	C becomes zero
Go directly to rule XVII.	Continue with rule XVI.

XVI. If D $\leqq$ 4 AB Make NE = D/4 Reduce AB by amount D/4 D becomes zero. Proceed with rule XVII	If D > 4 AB Make NE = AB Reduce D by amount 4 AB AB becomes zero. There are no further rules for desilification. The D remaining is the excess SiO_2 over-allocated. This rule is very unlikely to apply. Go to rule XVII.

XVII. Convert each normative mineral amount obtained by the foregoing rules to a normative mineral weight % by multiplying each mineral amount by the corresponding molecular weight given in rule 31 of the standard C.I.P.W. norm. The following are the additional molecular weights required in the Femic group.

Mg-BI	798.50	Fe-BI	987.74	Mg-ACT	794.35	Fe-ACT	952.05
Mg-ED	1632.48	Fe-ED	1947.88	RI	917.87		

Salic is exactly as in rule 31. Femic includes the above minerals in addition to those of rule 31.

XVIII. Recalculate the norm to 100% anhydrous and make HY, OL and SP as in rule 32. In addition make BI = (Mg-BI + Fe-BI), ACT = (Mg-ACT + Fe-ACT), ED = (Mg-ED + Fe-ED), and finally hornblende (HO) = ACT + ED + RI. The D.I. and C.I. should not be calculated from this norm variation but only from the standard C.I.P.W. norm.

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