

The International Mineralogical Association amphibole nomenclature scheme: computerization and its consequences

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ABSTRACT. A FORTRAN program has been written which inputs amphibole analyses, and outputs complete IMA-approved names, along with tabulated analyses, formula units, and IMA classification parameters. Several important corrections, additions, and amendments to the IMA scheme were found to be necessary. Two newly approved names have been incorporated—*sadanagaite* (ferro-pargasitic amphibole with $\text{Si} < 5.5$), and *nyboite* (alkali amphibole with $(\text{Na} + \text{K})_{\text{A}} \geq 0.5$, $\text{Fe}^3 \leq \text{Al}^{\text{VI}}$, $\text{Si} < 7.5$). The name *anophorite* (alkali amphibole with $(\text{Na} + \text{K})_{\text{A}} \geq 0.5$, $\text{Fe}^3 > \text{Al}^{\text{VI}}$, $\text{Si} < 7.5$) has been reinstated to complement *nyboite*, with the approval of the Amphibole Subcommittee of the IMA. Results of computer processing of several hundred analyses, which together cover the range of IMA-approved names, are summarized. These indicate substantial differences between IMA and previous nomenclature. The IMA-favoured procedure for reallocating total Fe in microprobe data is quite effective, except in kaersutites. Over half the analyses processed have anomalously high cations (e.g. $\text{Ca} > 2$), or cation totals (e.g. $T + C + B > 15$), commonly reflecting low H_2O determinations. These prevent strict obedience of the IMA site occupancy calculation rules. This problem can often be overcome by recalculation free of H_2O , but other cases require modifications to the IMA rules. In particular, 'misclassification' of certain sodic-calcic amphiboles as edenite follows from transferring large excesses of C cations to the B site.

THE IMA (1978) scheme for amphibole nomenclature recommends (p. 561)* that the whole procedure is eminently suitable for computerization. During the writing of a FORTRAN program providing this facility, various additions, corrections, and amendments to the 1978 scheme were

found to be necessary. These affected not only the formal resolutions, but also the recommended site occupancy calculation rules (p. 534). This paper documents all such changes which may interest mineralogists. It was also possible to use the program to test various options not forming part of the formal scheme—such as the reallocation of total Fe in probe data between Fe^{2+} and Fe^{3+} , and the treatment of CO_2 and P_2O_5 . The paper also therefore outlines results on over 500 amphibole analyses, including the 200 quoted by Deer *et al.*, 1962. The actual FORTRAN program (and details of how to run it), will be published elsewhere, but can be obtained interim from the authors, together with complete results on all amphiboles processed to date (Rock and Leake, 1983). Results of the reclassification of these analyses are summarized in Table I.

1. Additions, corrections, and amendments to the IMA (1978) report

1.1. Additions and corrections to nomenclature

1.1.1. In the report, the division between edenites and silicic edenites is (erroneously) placed at $\text{Si} = 7.5$ in figs. 3B and 3C, but (correctly) at 7.25 in the text (e.g. p. 543). The latter is followed here (fig. 1a).

1.1.2. The recommendations are inconsistent concerning the use of the prefix 'sodium' in orthorhombic amphiboles; the correct recommendations are given on p. 538 and 540. Resolution 5.1, p. 549, should read 'The prefix sodium is to be used within the orthorhombic amphibole group for anthophyllites with $\text{Na} \geq 0.50$ and gedrites with $\text{Na} \geq 0.75$ in the standard formula'.

* Page numbers throughout refer to the IMA (1978) scheme as published in this magazine.

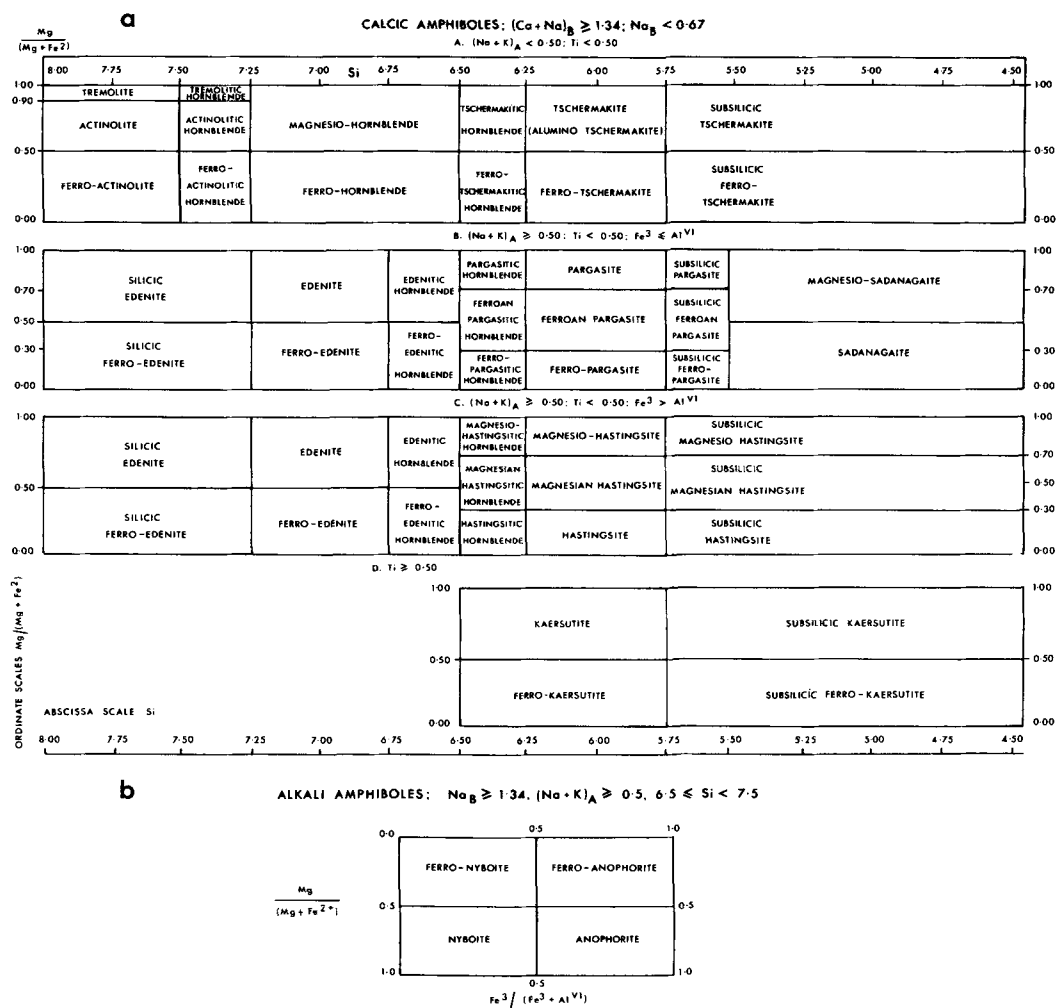


Fig. 1. Suggested fields of sadanagaite, nyboite, and anophorite.

(a) *Sadanagaite* (amendment and correction to fig. 3B of IMA scheme). 'Subsilicic kaersutite' is preferred here to 'titanian sadanagaite' for calcic amphiboles with $Ti > 0.5$, $Si < 5.5$ because (i) 'titanian sadanagaite' is not a logical extension of kaersutite to lower Si contents, since 'titanian' implies $Ti > 0.25$, not $Ti > 0.50$; (ii) kaersutite has been almost universally used for Ti-rich calcic amphiboles, richness in Ti being regarded as more important than deficiency in Si; (iii) the least disturbance to existing names results; for example, eighty-eight amphiboles almost all described as 'kaersutites' from alkaline lamprophyres (Rock, 1982) range in Si from 5.3–6.2, with five having $Si < 5.5$; as this is the archetypal petrological occurrence of 'kaersutite', it seems better to retain these five as subsilicic kaersutite, not titanian sadanagaite; (iv) two of the analysed amphiboles from the sadanagaite type-locality have $Si > 5.5$ (Table VIII, nos. 4 and 5); they are still not 'sadanagaite' even if 'titanian sadanagaite' is favoured to subsilicic kaersutite.

Low-Si analogues of hastingsites might be termed 'ferri-sadanagaite', but until such compositions have been discovered and the name approved, we refrain from using this name.

Note the correction in this figure to the boundary between edenite and silicic edenite (see section 1.1.1 for explanation).

(b) *Nyboite* and *anophorite* (addition to fig. 5 of IMA scheme). Anophorite, though formally abandoned by IMA (1978), is here reinstated with IMA approval in preference to 'ferri-nyboite', as the name has priority, the original amphibole (Freudenberg, 1910) has the correct composition [approx. $K_{0.35}Na_{0.77}Ca_{0.5}Na_{1.5}(Fe^{2+}_{1.14}Mg_{2.55}Mn_{0.05}Ti_{0.6}Fe^{3+}_{0.84}Al_{4.88}Si_{7.37}Al^{VI}_{0.34}O_{23.5}(OH)_{1.5}$], and because 'ferri-' is at present defined to mean $Fe^{3+} > 1.0$ in all amphiboles, but would signify $Fe^{3+} > Al^{VI}$ in 'ferri-nyboite'.

1.1.3. The prefix 'alumino-' is defined for anthophyllites (resolution 5.2), but not for cummingtonites. For completeness, the same limit ($Al^{VI} > 0.5$) is used here for both.

1.1.4. Under formal resolutions 7.7 and 7.8, tirolite should be $Mg/(Mg + Fe^{2+}) \geq 0.50$ and dannemorite < 0.50 , and not the reverse, in conformity with resolutions 6.5 and 6.6.

1.1.5. The calcic amphibole *Sadanagaite* $(Na,K)Ca_2(Fe \dots)_5Si_5Al_3O_{22}(OH)_2$, and the alkali amphibole *Nyboite*, $Na_3(Mg \dots)_3Al_3Si_7O_{22}(OH)_2$ have been approved since the recommendations were formulated (Shimazaki *et al.*, 1982; Ungaretti *et al.*, 1981). *Sadanagaite* has been incorporated into the present program as an extension of the edenite-pargasite amphiboles (fig. 1a). *Nyboite*, however, cannot be incorporated as an extension of the existing alkali amphibole divisions, as it alone has $Si < 8$; an additional series of divisions (fig. 1b) has therefore been incorporated here. Both these extensions of the IMA scheme are believed to take full account of the reported compositions of *sadanagaite*s and *nyboite*s (see Table VIII), and also of any uncertainties in these compositions. In formal terms the new names should be used for amphiboles chemically defined with respect to the standard formula as shown below.

1.1.6. The inclusion of *nyboite* means that fig. 5A of the IMA scheme now applies only where $Si \geq 7.5$; this additional condition must also be added to resolutions 19.6–19.9. Logically, a similar restriction of $Si \geq 7.5$ ought to apply to the use of glaucophane, crossite and riebeckite (fig. 5B; where $(Na + K)_A < 0.50$). Until one of these amphiboles with $Si \approx 7.0$ has been confirmed, however, we are reluctant to propose new names merely to ensure nomenclatural consistency. Instead we propose that the prefix *silica-poor* be used to indicate $Si < 7.5$ with glaucophanes, crossites, or riebeckites, as this will be more readily recognized (see Table VI, no. 2).

1.1.7. The inclusion of *sadanagaite* means that resolution 21.15 must now read: 'Subsilicic when $Si < 5.75$, except in *sadanagaite* (not used).' [See also caption to fig. 1a concerning use here of

'subsilicic kaersutite' in preference to 'titanian *sadanagaite*'.]

1.1.8. The existing recommendations already allow high contents of four unusual elements (Cr, Li, Pb, and Zn) to be identified with special prefixes (chromium, chromian, lithian, plumbian, zincian). They suggest (p. 562) that additional prefixes can be formulated as necessary for other minor elements. The following have been found necessary and incorporated into the program, but are not suggested as formal definitions:

Nickeloan where $0.25 < Ni < 0.99$, *Barian* where $Ba > 0.05$, *Strontian* where $Sr > 0.05$. Examples of amphiboles requiring 'strontian' are the titanian potassium richterites ('magnophorites') in some leucite-lamproites, which may carry up to 1% SrO or BaO (Table IX, nos. 1–2). The low limits for these two prefixes (cf. 0.08 for 'plumbian', which corresponds *not* to 1.1% PbO as stated on p. 535, but to 2.1%), reflect the generally low levels and high molecular weights of the two oxides.

1.1.9. The type Mn-rich alkali amphibole *Kozulite* (Nambu *et al.*, 1969) has an $Fe^{3+}/(Fe^{3+} + Al^{VI})$ ratio of 0.518, uncomfortably close to the lower limit of 0.5 incorporated in its definition (resolution 19.10). Furthermore, as the type analysis quotes only Fe_2O_3 , this should strictly be treated as total Fe and reallocated as favoured by IMA (p. 535), to bring the sum of $T + C$ cations to 13. The ratio $Fe^{3+}/(Fe^{3+} + Al^{VI})$ of the type *kozulite* then falls below 0.5, and is therefore no longer *kozulite*! In Table VIII, no. 8, total Fe has *not* been reallocated, to preserve the type amphibole as such, but we suggest 'alumino-*kozulite*' should be used where $Fe^{3+}/(Fe^{3+} + Al^{VI}) < 0.50$.

1.2. *Amendments to the recommended calculation of site occupancies* (IMA 1978, p. 534)

1.2.1. The calculation specifies only how Cr and Mn are to be treated, among the minor elements. The present program assumes that minor elements presented to it are actually held in the amphibole structure, rather than in inclusions, dislocations, etc. In the site occupancy calculation, Ni and Li are added to Mg, Ba to K, Sr to Ca, and Zn to Mn, so that $(Na + K)_A$ then represents $(Na + K + Ba)_A$ and

	$(Ca + Na)_B$	Na_B	$(Na + K)_A$	Si,	Ti	$Mg/(Mg + Fe^{2+})$	$Fe^{3+}/(Fe^{3+} + Al^{VI})$
<i>Sadanagaite</i>	≥ 1.34	< 0.67	≥ 0.50	< 5.50	< 0.50	≤ 0.50	≤ 0.50
Magnesio- <i>sadanagaite</i>	≥ 1.34	< 0.67	≥ 0.50	< 5.50	< 0.50	> 0.50	≤ 0.50
<i>Nyboite</i>	≥ 1.34	≥ 1.34	≥ 0.50	$6.5 \leq Si < 7.5$	≥ 0.50	≥ 0.50	≤ 0.50
Ferro-nyboite	≥ 1.34	≥ 1.34	≥ 0.50	$6.5 \leq Si < 7.5$	< 0.50	< 0.50	≤ 0.50
Anophorite	≥ 1.34	≥ 1.34	≥ 0.50	$6.5 \leq Si < 7.5$	≥ 0.50	≥ 0.50	> 0.50
Ferro-anophorite	≥ 1.34	≥ 1.34	≥ 0.50	$6.5 \leq Si < 7.5$	< 0.50	< 0.50	> 0.50

TABLE I. Summary of results of reclassification of 200 amphiboles in Deer *et al.* (1962) and 130 lamprophyre amphiboles in Rock (1982)

Procedure and result	Deer <i>et al.</i> amphiboles (200)	Lamprophyre amphiboles (130)
(a) Correction procedure for high cations/low water (section 2.3)		
Analyses having $S_1 > 13$ when calculated to 24 [O, OH, F, Cl]	0	0
Analyses having $S_3 > 15$ - do -	53	14
Analyses having $S_4 > 16$ - do -	34	12
Recalculation to 23 oxygens 2(OH) assumed brings $S_3 \leq 15$	30	14
Recalculation - do - brings $S_4 \leq 16$	27	12
S_3 remains < 15 after recalculation to 23 oxygens	20	0
S_4 remains < 16 after - do -	0	0
Amphibole name shows at least one change with and without recalculation	22	6
(b) Amendments to IMA site occupancy calculation (section 1.2.2) where recalculation as above impossible:		
Excess of C cations over 5 partially ignored to bring $S_4 = 16$ and $(Na+K)_A = 1$	7	21
Excess of B cations over 2 ignored to bring $S_3 = 15$	3	0
Insufficient cations to fill T site ($S_1 < 8$)	7	0
$(Ca + Na + K) > 3$; $(Ca + Na)_B$ becomes > 1	14	14
Si > 8 ; excess ignored, not transferred to C site	4	10
Ca > 2 ; excess ignored, not transferred to A site	7	15
K > 1 ; all Ca, Na assumed to be on B site, $(Na + K)_A$ becomes > 1	1	2
(c) Total Fe reallocation procedure (section 2.4)		
Number of analyses with only one Fe oxide quoted	13	92
Total Fe too low to warrant reallocation between Fe^{2+} and Fe^{3+}	8	0
S_2 successfully brought to 13 by reallocation of total Fe to Fe^{2+}/Fe^{3+}	0	41
S_2 cannot be brought to 13 ($S_2 > 13$ with Fe as Fe_2O_3 or $S_2 < 13$ with Fe as FeO)	2	50
Conversion of all quoted Fe oxide to other oxide brings S_2 nearer, but $\neq 13$	0	1
S_3 successfully brought to 15 by reallocation of total Fe (Fe-Mg-Mn amphiboles)	1	(no Fe-Mg-Mn amphiboles)
S_3 cannot be brought to 15 ($S_3 > 15$ with Fe as Fe_2O_3 or $S_3 < 15$ with Fe as FeO)	2	- do -
Name shows at least one change with and without reallocation	0	24

so on. [This was done to allow for possible borderline cases where, say, $(Ca + Na)_B < 1.34 < (Ca + Na + Sr)_B$, or $(Na + K)_A < 0.5 < (Na + K + Ba)_A$, so that inclusion of the minor elements would result in a quite different name.]

1.2.2. To obey the basic IMA site occupancy calculation rules, a recalculated amphibole analysis must have $8 < S_1 < 13$, $S_2 \geq 13$, $S_3 < 15$, $S_4 < 16$, $Si \leq 8.0$, $Ca \leq 2.0$, $K \leq 1.0$, and so on (see note 1 at end of text for explanation of S symbols). Numerous published analyses processed in the present study violate these conditions. They may have excesses of cations required to fill the $T+C$ ($S_1 > 13$), $T+C+B$ ($S_3 > 15$), or $T+C+B+A$ ($S_4 > 16$) sites, excesses of individual cations (especially Si and Ca), or deficiencies of T cations (Table I). In many cases, high cation totals can be traced directly to low H_2O determinations, and can be dealt with

optionally by recalculating to 23 oxygens (see section 2.3). In others, where H_2O is not determined, or appears unexceptionable, some adjustments to the site occupancy rules must be made. Those repeatedly found to be necessary, and therefore automatically made by the present program, are as follows:

- if $S_1 < 8$ (e.g. Table II, no. 1; Table IV, no. 1), C cations are *not* assigned to the T site to fill it;
- if $S_3 > 15$ (common), any excess is ignored and not carried over into the A site (e.g. Table IV, no. 4); this can affect the name, if $(Na + K)_A$ is close to 0.5;
- if $S_4 > 16$ (fairly common), sufficient Na_A is transferred back to Na_B to make $(Na + K)_A = 1.0$ wherever possible; $(Ca + Na)_B$ will then exceed 2.0 (e.g. Table VII, no. 4); this can affect the name, if Na_B is close to 0.67 or 1.34;

—if $Si > 8.0$ (e.g. Table VI, no. 3), any excess is ignored, not carried over into the *C* site; this rarely affects the name;

—if $Ca > 2.0$, any excess is ignored and not carried over into the *A* site, but $(Ca + Na)_B$ is left > 2.0 to highlight the excess (e.g. Table VIII, no. 4); this does not however affect the name;

—if $K > 1.0$ (e.g. Table IX, nos. 1 and 2) all *Ca*, *Na* are assumed to be on the *B* site; $(Na + K)_A$ then exceeds 1.0, and $(Ca + Na)_B$ may exceed 2.0, but again the name is unaffected;

—if $(Ca + Na + K) > 3.0$ but $Ca < 2$, $K < 1$ (e.g. Table V, Barkevikites nos. 1 and 3), $(Na + K)_A$ is set to 1.0 and $(Ca + Na)_B > 2$; again, the name is unaffected.

The above conditions $S_3 > 15$ or $S_4 > 16$ often arise where there is a *large excess* of *C* cations over 5 (i.e. $S_2 \gg 13$). Sums S_3 , and S_4 are then used merely as a device for deciding, reasonably objectively, how 'large' a 'large excess' is allowed to be before adjustments are made. This is discussed further in section 4, together with examples of the effects of the other above-mentioned procedures.

2. Options suggested to help interpret amphibole analyses

The following options lie outwith the formal IMA recommendations, but have been found useful (sometimes essential) in the interpretation of amphibole analyses. They have, therefore, been incorporated in the program, and are suggested for general adoption.

2.1. *Optional treatment of CO_2 and P_2O_5 .* These oxides can be treated as impurities in the amphibole analysis, and removed as $CaCO_3$ and $Ca_5(PO_4)_3$ (F,Cl), e.g. Table IV. When forming apatite, F is used in preference to Cl. If either or both together are insufficient to combine with the quoted P_2O_5 , they are both set to zero and hence not assigned to the amphibole formula at all. If this option is over-ridden (i.e. apatite and calcite *not* removed as impurities), P_2O_5 and CO_2 are ignored altogether (e.g. Tables II and VI).

2.2. *Optional treatment of H_2O .* Each individual analysis can be preset to calculate to $23[O]$ or $24[O,OH,F,Cl]$, or to any non-integral number of $[O]$ if desired. If not preset, the default values are as follows: calculation is to $24[O,OH,F,Cl]$ if $H_2O > 0$; to $24[F,Cl]$ if $H_2O = 0$, $(F + Cl) > 1.0$ (e.g. Table IV, no. 1); and to $23[O]$ if $H_2O = 0$, $(F + Cl) \leq 1.0$. In the final case, if $(F + Cl) > 0$ (but ≤ 1.0), the F,Cl values are output as if to $23[O]$ but not included in the formula unit (e.g. Table IX, nos. 5 and 6).

2.3. *Optional checks on water content and cation*

totals. Owing to the very wide range of possible substitutions in amphiboles, assessment of the quality of analytical data from formula unit calculations is much more difficult than with, say, feldspars or olivines. The large numbers of amphiboles processed in this study, however, suggest that high cation totals arising directly from low H_2O values are a common problem, when recalculation is to $24[O,OH,F,Cl]$. In some cases, these low water values may be accurate (the amphibole may be oxidized, or F or Cl may be present but undetermined). Nevertheless, calculation to $24[O,OH,F,Cl]$ is still unrealistic. After cation calculation (but before calculation of site occupancies), therefore, the present program gives the option of checking all analyses with $0.0 < H < 2.0$. Any of these with $S_1 > 13$, $S_3 > 15$, or $S_4 > 16$ are then recalculated to 23 oxygens, with H_2O ignored and $2(OH)$ assumed (see Table VII, no. 8). This procedure takes up the advice of Robinson *et al.* (1982) that, in doubtful cases, calculation to $23[O]$ is 'usually safer' than to $24[O,OH,F,Cl]$. It has been found to make satisfaction of the IMA site occupancy rules possible for some 75% of processed amphibole analyses with low quoted H_2O (see section 4). This recalculation procedure can be overruled if, for example, the low water (or high cation totals) are believed for any reason to be real. The trigger values for recalculation are deliberately based on *sums* of several cations rather than individual cation values, so that single 'rogue' values do not cause recalculation unnecessarily; the procedures for dealing with *individual* high cation values were given in section 1.2.2. [Amphiboles with *high H_2O* ($H > 2.0$) are not of course affected, since these tend to yield low cation totals, which do not necessarily violate the site occupancy rules.] We stress that there is good evidence for amphiboles having $(OH) > 2.0$, but variable anion totals are a factor usually ignored (Kemp and Leake, 1975; Jan and Howie, 1982).

2.4. *Optional treatment of total Fe.* If both Fe_2O_3 and FeO are quoted, the program treats these as any other oxide. Where either Fe_2O_3 or FeO is zero, the program can be set to assume automatically that the other Fe oxide represents total Fe. The procedure then adopted in reallocating total Fe between Fe^{2+} and Fe^{3+} is an adaptation of that favoured on p. 535 of IMA (1978): i.e. adjustment of S_2 to 13 cations. The program first checks that total Fe is sufficiently high to warrant an attempt at reallocation—in Mg end-members such as Table IV, no. 1, only one Fe oxide is quoted because both Fe oxides are too low to analyse separately). A lower limit of total Fe = 0.2 cations is therefore set, below which no attempt to reallocate is made. Two sets of analyses are then automatically separated, and adjusted differently as

TABLE II. Computer reclassification of published anthophyllite and gedrite analyses

DEER, HOWIE & ZUSSMAN, TABLE 33. ANTHOPHYLLITE ANALYSES						DEER, HOWIE & ZUSSMAN, TABLE 34. GEDRITE ANALYSES				
	1	2	3	4	5		1	2	3	4
SiO ₂	58.82	58.90	53.16	58.21	56.01	SiO ₂	44.22	45.50	48.49	44.89
Al ₂ O ₃	0.66	5.46	2.95	1.26	2.96	Al ₂ O ₃	23.79	17.64	13.26	17.91
Fe ₂ O ₃	0.52	0.00	4.53	1.22	0.15	Fe ₂ O ₃	0.20	2.16	1.28	0.67
FeO	0.00	3.09	3.07	6.27	7.01	FeO	9.21	9.04	14.60	13.31
MgO	30.81	26.68	30.03	30.14	27.94	MgO	20.69	20.51	20.56	18.09
CaO	3.45	0.51	0.28	0.76	1.68	CaO	0.62	0.87	0.04	0.40
Na ₂ O	0.22	0.11	0.10	0.00	0.56	Na ₂ O	0.00	1.73	0.11	1.45
K ₂ O	0.00	0.04	0.01	0.00	0.19	K ₂ O	0.00	0.00	0.00	0.05
H ₂ O+	2.64	2.64	4.83	2.89	2.12	H ₂ O+	1.42	2.12	1.48	2.02
TiO ₂	0.00	1.17	0.00	0.00	0.14	TiO ₂	0.00	0.23	0.41	0.67
P ₂ O ₅	0.00	0.23	0.01	0.00	0.00	P ₂ O ₅	0.00	0.00	0.00	0.04
MnO	2.53	0.01	0.14	0.06	0.01	MnO	0.16	0.16	0.00	0.37
F	0.00	0.00	0.01	0.00	0.00	CL	0.00	0.05	0.00	0.00
Cr ₂ O ₃	0.00	0.00	0.53	0.00	0.22	F	0.00	0.02	0.00	0.00
NiO	0.00	0.00	0.12	0.00	0.00					
TL	99.65	99.64	99.77	100.81	98.99	TL	100.31	100.01	100.23	99.87
(ANALYSIS TOTALS ARE CORRECTED FOR O=CL,F)						(ANALYSIS TOTALS ARE CORRECTED FOR O=CL,F)				
CATIONS PER FORMULA UNIT						CATIONS PER FORMULA UNIT				
O=	24	24	24	24	24	O=	24	24	24	24
SI	7.833	7.767	7.034	7.730	7.682	SI	6.070	6.311	6.827	6.328
AL	0.104	0.849	0.460	0.197	0.479	AL	3.852	2.886	2.202	2.978
FE	0.052	0.079	0.451	0.122	0.015	FE	0.021	0.225	0.136	0.071
FE	0.000	0.341	0.340	0.696	0.804	FE	1.057	1.048	1.718	1.568
MG	6.119	5.247	5.925	5.969	5.715	MG	4.235	4.242	4.317	3.803
CA	0.492	0.072	0.040	0.100	0.247	CA	0.091	0.129	0.006	0.060
NA	0.057	0.028	0.026	0.000	0.149	NA	0.000	0.465	0.030	0.396
K	0.000	0.007	0.002	0.000	0.033	K	0.000	0.000	0.000	0.009
H	2.348	2.325	4.267	2.563	1.942	H	1.302	1.964	1.391	1.901
TI	0.000	0.116	0.000	0.000	0.014	TI	0.000	0.024	0.043	0.071
MN	0.286	0.001	0.016	0.007	0.001	MN	0.019	0.019	0.000	0.044
F	0.000	0.000	0.004	0.000	0.000	CL	0.000	0.012	0.000	0.000
CR	0.000	0.000	0.055	0.000	0.024	F	0.000	0.009	0.000	0.000
NI	0.000	0.000	0.013	0.000	0.000					
CHECK ON OXYGEN(+CL,F) EQUIVALENCE OF ABOVE CATIONS						CHECK ON OXYGEN(+CL,F) EQUIVALENCE OF ABOVE CATIONS				
OXEQ=	24.00	24.00	24.00	24.00	24.00	OXEQ=	24.00	24.00	24.00	24.00
CLASSIFICATION PARAMETERS						CLASSIFICATION PARAMETERS				
CANA	0.549	0.100	0.065	0.108	0.265	CANA	0.091	0.244	0.006	0.137
NAB	0.057	0.028	0.026	0.000	0.018	NAB	0.000	0.115	0.000	0.077
NAKA	0.000	0.007	0.002	0.000	0.000	NAKA	0.000	0.350	0.030	0.329
ALVI	0.000	0.616	0.000	0.000	0.161	ALVI	1.921	1.197	1.029	1.306
MGFE	1.000	0.939	0.946	0.896	0.877	MGFE	0.800	0.802	0.715	0.708

GENERAL NOTES FOR THE ABOVE TABLES:					
P2O ₅ (WHERE QUOTED) HAS BEEN TREATED AS ZERO IN CALCULATION OF FORMULA UNIT					
RESULTS HAVE NOT BEEN CHECKED OR ADJUSTED FOR LOW WATER/HIGH CATION TOTALS					
FE HAS BEEN REDISTRIBUTED WHEREVER POSSIBLE BETWEEN FE ₃ AND FE ₂ , WHERE ONLY TOTAL FE IS QUOTED					

IMA(1978) NAMES FOR THE ABOVE TABLE					
ANALYSIS NUMBER 1					
TOTAL FE TOO LOW TO WARRANT ATTEMPTS TO DISTRIBUTE					
MANGANESE WARNING: INSUFFICIENT CATIONS TO FILL T SITE					
IF MONOCLINIC					
MAGNESIO-CUMMINGTONITE					
IF ORTHORHOMBIC					
MAGNESIO-ANTHOPHYLLITE					
ANALYSIS NUMBER 2					
IF MONOCLINIC					
MAGNESIO-CUMMINGTONITE					
IF ORTHORHOMBIC					
ALUMINO-					
MAGNESIO-ANTHOPHYLLITE					
ANALYSIS NUMBER 3					
HYDRO-					
IF MONOCLINIC					
MAGNESIO-CUMMINGTONITE					
IF ORTHORHOMBIC					
MAGNESIO-ANTHOPHYLLITE					
ANALYSIS NUMBER 4					
IF MONOCLINIC					
MAGNESIO-CUMMINGTONITE					
IF ORTHORHOMBIC					
ANTHOPHYLLITE					
ANALYSIS NUMBER 5					
IF MONOCLINIC					
MAGNESIO-CUMMINGTONITE					
IF ORTHORHOMBIC					
ANTHOPHYLLITE					

IMA(1978) NAMES FOR THE ABOVE TABLE:					
ANALYSIS NUMBER 1					
IF MONOCLINIC					
MAGNESIO-CUMMINGTONITE					
IF ORTHORHOMBIC					
GEDRITE					
ANALYSIS NUMBER 2					
IF MONOCLINIC					
SODIAN					
MAGNESIO-CUMMINGTONITE					
IF ORTHORHOMBIC					
GEDRITE					
ANALYSIS NUMBER 3					
IF MONOCLINIC					
MAGNESIO-CUMMINGTONITE					
IF ORTHORHOMBIC					
GEDRITE					
ANALYSIS NUMBER 4					
IF MONOCLINIC					
SODIAN					
MAGNESIO-CUMMINGTONITE					
IF ORTHORHOMBIC					
GEDRITE					

Note: numbering of analyses in Tables II-VII follows the cited tables in Deer, Howie & Zussman (1962)

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TABLE III. Computer reclassification of published holmquistite and cummingtonite analyses

DEER, HOWIE & ZUSSMAN, TABLE 35. HOLMQUISTITE						DEER, HOWIE & ZUSSMAN, TABLE 36. CUMMINGTONITE					
	1	2	3	4	5		1	2	3	4	
SiO ₂	59.73	59.58	58.72	55.48	59.06	SiO ₂	51.53	50.87	49.60	52.05	
Al ₂ O ₃	11.21	7.19	13.01	14.64	12.38	Al ₂ O ₃	5.02	3.46	8.65	0.77	
Fe ₂ O ₃	2.97	9.35	2.24	1.80	2.36	Fe ₂ O ₃	0.82	0.10	0.48	3.40	
FeO	8.92	4.88	8.94	10.36	10.84	FeO	16.91	22.90	18.54	22.35	
MgO	10.16	11.66	9.43	9.40	8.82	MgO	20.84	21.18	16.78	15.26	
CaO	0.56	0.06	1.00	1.32	0.21	CaO	1.34	0.68	0.97	1.89	
Na ₂ O	0.18	0.50	0.23	0.66	0.11	Na ₂ O	0.65	0.00	0.79	0.21	
K ₂ O	0.15	0.27	0.00	0.74	0.05	K ₂ O	0.00	0.00	0.00	0.00	
H ₂ O ⁺	2.08	2.23	1.87	3.16	2.09	H ₂ O ⁺	2.15	1.58	2.52	1.98	
TiO ₂	0.17	0.00	0.05	0.64	0.20	TiO ₂	0.31	0.00	0.64	0.60	
MnO	0.20	0.41	0.19	0.01	0.25	P ₂ O ₅	0.00	0.00	0.34	0.00	
CO ₂	0.00	0.00	1.54	0.00	0.00	MnO	0.22	0.00	1.08	1.41	
F	0.24	0.21	0.14	0.01	0.18						
Li ₂ O	3.56	3.54	2.43	2.40	3.33						
TL	100.03	99.79	99.73	100.62	99.80	TL	99.79	100.77	100.01	99.99	
(ANALYSIS TOTALS ARE CORRECTED FOR O=CL,F)						(ANALYSIS TOTALS ARE CORRECTED FOR O=CL,F)					
CATIONS PER FORMULA UNIT						CATIONS PER FORMULA UNIT					
O=	24	24	24	24	24	O=	24	24	24	24	
Si	7.919	7.950	7.944	7.378	7.886	Si	7.362	7.412	7.124	7.724	
Al	1.753	1.132	2.076	2.297	1.950	Al	0.846	0.595	1.466	0.135	
Fe	0.296	0.939	0.228	0.180	0.237	Fe	0.088	0.011	0.052	0.380	
Fe	0.988	0.544	1.011	1.152	1.210	Fe	2.020	2.789	2.226	2.772	
Mg	2.009	2.320	1.903	1.864	1.756	Mg	4.440	4.603	3.594	3.377	
Ca	0.080	0.009	0.145	0.188	0.030	Ca	0.205	0.106	0.149	0.300	
Na	0.046	0.129	0.060	0.170	0.028	Na	0.180	0.000	0.220	0.060	
K	0.025	0.046	0.000	0.126	0.009	K	0.000	0.000	0.000	0.013	
H	1.841	1.987	1.689	2.806	1.864	H	2.051	1.537	2.417	1.962	
Ti	0.017	0.000	0.005	0.064	0.020	Ti	0.033	0.000	0.028	0.067	
Mn	0.022	0.046	0.022	0.001	0.028	Mn	0.027	0.000	0.131	0.177	
F	0.101	0.089	0.060	0.004	0.076						
Li	1.897	1.899	1.322	1.283	1.788						
CHECK ON OXYGEN(+CL,F) EQUIVALENCE OF ABOVE CATIONS						CHECK ON OXYGEN(+CL,F) EQUIVALENCE OF ABOVE CATIONS					
OxO=	24.00	24.00	24.00	24.00	24.00	OxO=	24.00	24.00	24.00	24.00	
CLASSIFICATION PARAMETERS						CLASSIFICATION PARAMETERS					
CANA	0.098	0.138	0.205	0.358	0.059	CANA	0.205	0.106	0.369	0.361	
NAB	0.018	0.129	0.060	0.170	0.028	NAB	0.000	0.000	0.220	0.060	
NAKA	0.053	0.046	0.000	0.126	0.009	NAKA	0.180	0.000	0.000	0.013	
ALVI	1.672	1.081	2.020	1.675	1.836	ALVI	0.208	0.007	0.590	0.000	
MCFE	0.670	0.810	0.653	0.618	0.592	MGFE	0.687	0.623	0.618	0.549	

GENERAL NOTES FOR THE ABOVE TABLE.

RESULTS HAVE NOT BEEN CHECKED OR ADJUSTED FOR LOW WATER/HIGH CATION TOTALS

CO₂ (WHERE QUOTED) HAS BEEN IGNORED IN CALCULATION OF FORMULA UNIT

P₂O₅ (WHERE QUOTED) HAS BEEN REMOVED AS CA₅(PO₄)₃(F,CL) BEFORE CALCULATION OF FORMULA UNIT

IMA(1978) NAMES FOR THE ABOVE TABLE:

ANALYSIS NUMBER 1
(CLINO)-HOLMQUISTITE

ANALYSIS NUMBER 2
FERRIAN
(CLINO)-HOLMQUISTITE

ANALYSIS NUMBER 3
(CLINO)-HOLMQUISTITE

ANALYSIS NUMBER 4
(CLINO)-HOLMQUISTITE

ANALYSIS NUMBER 5
(CLINO)-HOLMQUISTITE

ANALYSIS NUMBER 6
(CLINO)-HOLMQUISTITE

IMA(1978) NAMES FOR THE ABOVE TABLE:

ANALYSIS NUMBER 1
IF MONOCLINIC
CUMMINGTONITE
IF ORTHORHOMBIC
ANTHOPHYLLITE

ANALYSIS NUMBER 2
IF MONOCLINIC
CUMMINGTONITE
IF ORTHORHOMBIC
ANTHOPHYLLITE

ANALYSIS NUMBER 3
IF MONOCLINIC
CUMMINGTONITE
IF ORTHORHOMBIC
ALUMINO-
ANTHOPHYLLITE

ANALYSIS NUMBER 4
IF MONOCLINIC
CUMMINGTONITE
IF ORTHORHOMBIC
ANTHOPHYLLITE

follows: (1) $(Ca + Na) < 1.34$; here, S_3 is adjusted to 15 [so that $Na_B = 0$ and $(Na + K)_A = (Na + K)$]. This set corresponds *approximately* to the Fe-Mg-Mn amphiboles, for which the IMA-favoured procedure of setting S_2 to 13 is clearly inapplicable; (2) $(Ca + Na) > 1.34$; here, the IMA procedure is followed (S_2 is adjusted to 13). In most amphiboles, $(Ca + Na)_B$ will then automatically = 2.0. This set corresponds approximately to the remaining three amphibole groups.

These sets follow the two options which Robinson *et al.* (1982, pp. 8-9, paragraphs (ii) and (iv)) seem to consider of most general validity. They do not exactly correspond to the defined amphibole groups since, of course, $(Ca + Na)_B$ cannot be calculated *before* Fe redistribution. $(Ca + Na)$ is, however, a close enough approximation to $(Ca + Na)_B$, given the intrinsic imprecision of *any* procedure for reallocating total Fe.

This option can again be over-ridden for a whole batch of analyses, should it be desired to leave total Fe as in all the original analyses. If it is desired to retain 'zero' FeO or Fe_2O_3 for a *single* analysis within a batch, where it is otherwise desired to reallocate total Fe, this can be easily simulated by setting the 'zero' oxide to 0.01% for this one analysis (see Table VIII, no. 8).

3. Output format

Most of the printout format in Tables II-IX is self-explanatory, but the following explanations may be helpful:

—the row labelled 'CHECK ON OXYGEN EQUIVALENCE OF CATIONS' confirms the correct operation of the program; it is the sum $[Si \times 2 + Al \times 1.5 + \dots + Pb \times 1]$, and has invariably summed to within 0.02 of the number of oxygens set under 'cations per formula unit';

—the IMA classification parameters are flagged as 'CANa' = $(Ca + Na)_B$, 'NAB' = Na_B , 'NAKA' = $(Na + K)_A$, 'ALVI' = Al^{VI} , 'MGFE' = $Mg/(Mg + Fe^{2+})$; as the parameter $Fe^{3+}/(Fe^{3+} + Al^{VI})$ is only required for alkali amphiboles, it is listed individually for any of these in particular tables (see Tables VI and VIII);

—the series of 'GENERAL NOTES' at the bottom of each analysis table indicates which of the various options (section 2) have been chosen; the number of analyses in the table with $H = 0$, $0.0 < (F, Cl) < 1.0$ is also indicated here (see Table IX);

—the individual IMA names are printed on the page following each table of analyses; series of information or warning messages are automatically printed, for example with analyses requiring recalculation to 23 oxygens, analyses with high but uncorrectable

cation totals, and analyses where total Fe cannot be allocated to Fe^{3+} plus Fe^{2+} for any reason; examples of many of these self-explanatory messages are included in Tables II-IX;

—with the Fe-Mg-Mn amphiboles, there are two possible names, for the orthorhombic and monoclinic forms; rather than requiring the crystal symmetry to be input, the program automatically outputs both possibilities for manual selection (Tables II and III); compositions within the dannemorite and tirodite definitions, however, are assumed to be monoclinic (Table VIII, nos. 9-10).

4. Results of reclassification of published amphibole analyses

Initially as a check on the operation of the program, and later as an investigation of the effects of the new IMA nomenclature on names previously applied, the 200 amphibole analyses quoted by Deer *et al.* (1962) were run through the program. Analyses will be referred to hereafter by their tables and numbers, e.g. 42/3. A further data-set (from Rock, 1982) of 130 amphiboles from the various types of lamprophyres (minettes, vogesites, spessartites, lamproites, camptonites, monchiquites, alnoites, etc.) was also processed. This includes many microprobe analyses and is also rather more homogeneous—eighty-eight of the 130 analyses are 'kaersutites' from camptonites and monchiquites. It thus complements the Deer *et al.* data-set. Many analyses of amphiboles not included in either data-set were also processed (e.g. the type sadanagaites, nyboites, tirodites and kozulites, and new analyses submitted by colleagues). The results, totalling over 500 amphiboles, are believed to confirm that the program correctly identifies all the fundamental amphibole types and prefixes (though clearly, not every possible combination of fundamental names and prefixes can, or need be, individually tested). Only representative printouts are reproduced in this paper, for reasons of space, but the complete results can be obtained from the first author. Tables II to IX were executed using various combinations of the available options (section 2).

4.1. *Differences between the IMA and Deer et al. classifications.* Several major differences here change the names used by Deer *et al.*, even before the additional features incorporated into the present program are taken into account. For example:

—no fixed meanings for prefixes ('sodian', etc.) were defined by Deer *et al.*; as a result, eighty-four of the 200 analyses require at least one prefix under the IMA scheme where Deer *et al.* assigned none; and conversely, one 'ferrian' and two 'chromian'

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TABLE IV. Computer reclassification of published tremolite and edenite analyses

DEER, HOWIE & ZUSSMAN, TABLE 38. TREMOLITE

	1	2	3	4
SiO2	58.56	59.45	55.20	54.90
AL2O3	0.00	0.49	4.60	1.20
FE2O3	0.06	0.00	0.49	0.50
FeO	0.00	0.07	1.91	2.80
MGO	25.45	25.19	21.65	25.30
CAO	13.14	11.88	13.03	12.70
NA2O	0.10	0.00	1.29	0.60
K2O	0.00	0.00	0.64	0.00
H2O+	0.00	2.27	0.86	0.93
TiO2	0.00	0.00	0.25	0.21
P2O5	0.00	0.00	0.02	0.01
MNO	0.00	0.38	0.00	0.08
F	4.65	0.00	0.25	0.00
CR2O3	0.00	0.00	0.00	0.50
TL	100.00	99.73	100.08	99.73
(ANALYSIS TOTALS ARE CORRECTED FOR O=CL,F)				
CATIONS PER FORMULA UNIT				
O=	24	24	23	23
SI	7.955	8.015	7.496	7.529
AL	0.000	0.078	0.737	0.194
FE	0.006	0.000	0.050	0.052
FE	0.000	0.008	0.217	0.321
MG	5.156	5.065	4.385	5.174
CA	1.912	1.716	1.896	1.866
NA	0.026	0.000	0.340	0.160
K	0.000	0.000	0.111	0.000
H	0.000	2.044	0.780	0.852
TI	0.000	0.000	0.026	0.022
MN	0.000	0.043	0.000	0.009
F	1.998	0.000	0.107	0.000
CR	0.000	0.000	0.000	0.054
CHECK ON OXYGEN(+CL,F) EQUIVALENCE OF ABOVE				
OxOQ=	24.00	24.00	23.00	23.00
CLASSIFICATION PARAMETERS				
CANA	1.912	1.716	2.000	1.866
NAB	0.000	0.000	0.104	0.000
NAKA	0.026	0.000	0.346	0.160
ALVI	0.000	0.078	0.233	0.000
MGFE	1.000	0.998	0.953	0.942

GENERAL NOTES FOR THE ABOVE TABLE:

P2O5 (WHERE QUOTED) HAS BEEN REMOVED AS CA5(PO4)3(F,CL) BEFORE CALCULATION OF CATIONS PER FORMULA UNIT

ANALYSES WITH HIGH CATIONS & O<H<2 RECALCULATED TO 23 OXYGENS [2(OH) ASSUMED]

FE HAS BEEN REDISTRIBUTED WHEREVER POSSIBLE BETWEEN FE3 AND FE2, WHERE ONLY TOTAL FE IS QUOTED

IMA(1978) NAMES FOR THE ABOVE TABLE:

ANALYSIS NUMBER 1

TOTAL FE TOO LOW TO WARRANT ATTEMPTS TO

DISTRIBUTE BETWEEN FE2 AND FE3

WARNING: INSUFFICIENT CATIONS TO FILL T SITE

FLUOR

TREMOLITE

ANALYSIS NUMBER 2

TOTAL FE TOO LOW TO WARRANT ATTEMPTS TO

DISTRIBUTE BETWEEN FE2 AND FE3

WARNING: SI>8; EXCESS IGNORED, NOT CARRIED

OVER INTO C SITE

TREMOLITE

ANALYSIS NUMBER 3

RECALCULATION TO 23 OXYGENS [2(OH) ASSUMED] EXECUTED TO BRING SUM OF CATIONS S3 BELOW 15; H2O VALUE SUSPECT.

NB: H (AND CL, F, IF QUOTED) VALUES ARE OUTPUT AS IF TO 23 OXYGENS, BUT ARE NOT INCLUDED IN THE FORMULA UNIT

TREMOLITIC HORNBLENDE

ANALYSIS NUMBER 4

ANALYSIS STILL HAS SUM OF CATIONS S3 ABOVE 15 WHETHER CALCULATED TO 240 WITH H2O OR 230 WITHOUT.

NB: H (AND CL, F, IF QUOTED) VALUES ARE OUTPUT AS IF TO 23 OXYGENS, BUT ARE NOT INCLUDED IN THE FORMULA UNIT

TREMOLITE

DEER, HOWIE & ZUSSMAN, TABLE 41. EDENITE & EDENITIC HORNBLENDE

	1	3	4	5	6
SiO2	51.09	50.91	48.35	48.20	47.60
AL2O3	6.47	8.68	10.00	10.00	6.49
FE2O3	0.21	1.61	0.94	3.50	6.07
FeO	0.00	3.61	10.69	10.60	11.00
MGO	23.06	19.38	14.09	10.06	11.94
CAO	12.30	10.25	10.78	10.59	9.40
NA2O	4.26	3.40	2.29	1.96	3.38
K2O	0.00	0.11	0.30	0.41	1.49
H2O+	0.00	1.74	1.93	2.22	1.80
TiO2	0.00	0.08	0.61	1.00	0.60
P2O5	0.00	0.05	0.00	0.00	0.00
MNO	0.00	0.12	0.18	0.17	0.35
F	4.89	0.00	0.00	0.00	0.20
TL	100.22	99.94	100.16	98.71	100.24
(ANALYSIS TOTALS ARE CORRECTED FOR O=CL,F)					
CATIONS PER FORMULA UNIT					
O=	24	24	24	24	24
SI	7.075	7.136	6.954	7.033	7.036
AL	1.057	1.435	1.696	1.721	1.132
FE	0.022	0.170	0.102	0.384	0.675
FE	0.000	0.423	1.285	1.293	1.359
MG	4.762	4.051	3.022	2.189	2.632
CA	1.825	1.529	1.661	1.655	1.489
NA	1.144	0.924	0.639	0.554	0.969
K	0.000	0.020	0.055	0.076	0.281
H	0.000	1.629	1.854	2.163	1.777
TI	0.000	0.008	0.066	0.110	0.067
MN	0.000	0.014	0.022	0.021	0.044
F	2.142	0.000	0.000	0.000	0.094
CHECK ON OXYGEN(+CL,F) EQUIVALENCE OF ABOVE CATIONS					
OxOQ=	24.00	24.00	24.00	24.00	24.00
CLASSIFICATION PARAMETERS					
CANA	2.000	1.762	1.853	2.000	2.000
NAB	0.175	0.233	0.192	0.345	0.511
NAKA	0.968	0.711	0.501	0.286	0.738
ALVI	0.132	0.571	0.650	0.754	0.168
MGFE	1.000	0.905	0.702	0.629	0.659

IMA(1978) NAMES FOR THE ABOVE TABLE:

ANALYSIS NUMBER 1

TOTAL FE TOO LOW TO WARRANT ATTEMPTS TO DISTRIBUTE

FLUOR

SODIAN

EDENITE

ANALYSIS NUMBER 3

EDENITE

ANALYSIS NUMBER 4

EDENITE

ANALYSIS NUMBER 5

MAGNESIO-HORNBLENDE

ANALYSIS NUMBER 6

POTASSIAN

SUBCALCIC

EDENITE

TABLE V. Computer reclassification of published 'basaltic hornblende' and 'barkevikite' analyses

DEER, HOWIE & ZUSSMAN, TABLE 48. BASALTIC HORNBLENDE				DEER, HOWIE & ZUSSMAN, TABLE 51. "BARKEVIKITE"				
	1	2	3		1	2	3	4
SiO2	39.57	45.17	39.83	SiO2	42.98	41.49	40.88	42.15
Al2O3	16.29	7.68	14.98	Al2O3	6.82	11.60	11.04	4.84
Fe2O3	7.13	14.30	7.66	Fe2O3	2.58	2.89	7.56	5.94
FeO	1.56	2.81	3.78	FeO	15.86	21.94	17.41	24.51
MgO	14.92	13.44	14.44	MgO	9.67	8.39	5.92	5.68
CaO	9.32	11.18	12.39	CaO	11.72	9.86	10.46	8.42
Na2O	3.48	1.35	2.27	Na2O	3.72	2.07	3.75	3.46
K2O	1.95	1.09	1.25	K2O	0.63	0.58	0.78	0.95
H2O+	0.84	0.19	0.58	H2O+	5.06	0.93	1.16	0.99
TiO2	4.19	2.11	2.56	TiO2	0.35	0.00	0.22	2.43
MnO	0.21	0.41	0.00	MnO	0.92	0.79	1.32	1.30
F	0.00	0.35	0.00					
TL	99.46	99.93	99.74	TL	100.31	100.54	100.50	100.67
(ANALYSIS TOTALS ARE CORRECTED FOR O=CL,F)				(ANALYSIS TOTALS ARE CORRECTED FOR O=CL,F)				
CATIONS PER FORMULA UNIT				CATIONS PER FORMULA UNIT				
O=	24	24	24	O=	24	24	24	24
Si	5.810	6.727	5.917	Si	6.314	6.452	6.376	6.763
Al	2.821	1.349	2.625	Al	1.182	2.128	2.031	0.916
Fe	0.788	1.603	0.856	Fe	0.285	0.338	0.888	0.717
Fe	0.191	0.350	0.469	Fe	1.947	2.852	2.270	3.287
Mg	3.267	2.985	3.199	Mg	2.118	1.946	1.377	1.359
Ca	1.466	1.784	1.972	Ca	1.844	1.643	1.748	1.447
Na	0.991	0.390	0.654	Na	1.059	0.624	1.134	1.076
K	0.365	0.207	0.237	K	0.118	0.115	0.155	0.195
H	0.824	0.189	0.575	H	4.963	0.966	1.208	1.061
Ti	0.463	0.236	0.286	Ti	0.039	0.000	0.026	0.293
Mn	0.026	0.052	0.000	Mn	0.115	0.104	0.175	0.177
F	0.000	0.165	0.000					
CHECK ON OXYGEN(+CL,F) EQUIVALENCE OF ABOVE CATIONS				CHECK ON OXYGEN(+CL,F) EQUIVALENCE OF ABOVE CATIONS				
Ox _{eq} =	24.00	24.00	24.00	Ox _{eq} =	24.00	24.00	24.00	24.00
CLASSIFICATION PARAMETERS				CLASSIFICATION PARAMETERS				
CANA	1.822	1.784	1.972	CANA	2.022	1.643	2.037	1.718
NAB	0.356	0.000	0.000	NAB	0.177	0.000	0.289	0.271
NAKA	1.000	0.597	0.891	NAKA	1.000	0.739	1.000	1.000
ALVI	0.631	0.076	0.541	ALVI	0.000	0.580	0.407	0.000
MGFE	0.945	0.895	0.872	MGFE	0.521	0.406	0.378	0.293

GENERAL NOTES FOR THE ABOVE TABLES:
RESULTS HAVE NOT BEEN CHECKED OR ADJUSTED FOR LOW WATER/HIGH CATION TOTALS
NO ATTEMPT HAS BEEN MADE TO DISTRIBUTE FE BETWEEN FE3 AND FE2, WHERE ONLY TOTAL FE IS QUOTED

ANALYSIS NUMBER 1 TITANIAN POTASSIAN SUBCALCIC MAGNESIO-HASTINGSITE	ANALYSIS NUMBER 1 WARNING: (CA+NA+K)>3; EXCESS LEFT IN (CA+NA)B HYDRO- SODIAN WARNING: INSUFFICIENT CATIONS TO FILL T SITE MAGNESIAN HASTINGSITIC HORNBLENDE
ANALYSIS NUMBER 2 FERRI- EDENITIC HORNBLENDE	ANALYSIS NUMBER 2 FERROAN PARGASITIC HORNBLENDE
ANALYSIS NUMBER 3 TITANIAN MAGNESIO-HASTINGSITE	ANALYSIS NUMBER 3 WARNING: (CA+NA+K)>3; EXCESS LEFT IN (CA+NA)B SODIAN MAGNESIAN HASTINGSITIC HORNBLENDE
	ANALYSIS NUMBER 4 TITANIAN SUBCALCIC SODIAN FERRO-EDENITE

prefixes assigned by Deer *et al.* (38/4, 40/4, 43/9) are not required under the IMA scheme;
—the new names reveal specimens of 'basaltic hornblende' and 'barkevikite', included in separate chapters by Deer *et al.*, to be heterogeneous mixtures of calcic amphiboles (Table V); they therefore confirm the IMA recommendations that both names should be discontinued;
—the 'alkali amphibole' group as defined by Deer *et al.* (p. 209) is divided by IMA into 'alkali' and 'sodic-calcic' amphiboles, richterite and katophor-

ite being transferred to the latter; four of the thirty-five 'alkali amphiboles' in Deer *et al.* are now sodic-calcic (53/7, 54/9, 54/13, 57/8), while the 'richterites' (Table VII) and 'katophorites' emerge as further mixtures of calcic, sodic-calcic, and alkali amphiboles;
—the additional names *anophorite* and *nyboite* introduced here (fig. 1b) cause further changes: one 'crossite' (53/7—see Table VI, no. 6) and three 'arfvedsonites' (57/4, 57/7, 57/9) are now anophorites or ferro-anophorites.

The effects of the IMA boundaries *within* each amphibole group on the Deer *et al.* names are generally much less: some apparently substantial changes are in fact only minor in compositional terms—e.g. one 'riebeckite' becomes 'sodian ferri-magnesio-cummingtonite' (54/11), and several 'kaersutites' become 'titanian potassian pargasites' (e.g. 50/3). It would, however, be futile to assess the numbers of analyses requiring 'significant' changes, especially when some of the Deer *et al.* names, such as 'hornblende', are very generalized.

4.2. *Frequency of usage of different prefixes.* As might be expected, amphiboles nearest end-member compositions in both main data-sets require fewest prefixes. By contrast, prefixes are required for most of the hastingsites (nearly all are 'potassian' or 'titanian') and kaersutites (nearly all 'potassian'). Edenites require the maximum number of prefixes (5) in both data-sets (see note 2), but three are not uncommonly necessary for other amphiboles. Some prefixes are required very frequently (e.g. potassian, sodian, titanian) whereas others (mainly those for minor elements) are not called for by either data-set. Again, however, it is unnecessary to put precise figures on the frequency of usage of each individual prefix.

4.3. *Effects of removal of P_2O_5 and CO_2 .* Levels of P_2O_5 and CO_2 are low in nearly all the analyses processed, only once (in a minette amphibole) exceeding 0.5%. Removal of neither oxide consequently affects any of the names. The potential usefulness of the options for P_2O_5 and CO_2 is however indicated by Deer *et al.* analyses 35/3 and 48/2. The latter is quoted already recalculated to 100% free of apatite impurities, but if the apatite is re-added and P_2O_5 then ignored (thus raising CaO), a different name results. The former (Table III, no. 3) has $CaO < 0$ if CO_2 is removed as calcite, suggesting another carbonate is present, or the amphibole is impure, altered, or poorly analysed. Only the rare composition prevents the name from being affected by removal of the CO_2 .

4.4. *Results of optional correction procedure for high cations and low water (section 2.3).* The importance of this option is clearly indicated by the high percentages, first, of total analyses for which it is initiated (40%); secondly, of names which are significantly different with and without recalculations (30%); and thirdly, of high cation analyses which 'improve' by recalculations (75%—see Table Ia). Not unexpectedly, the twenty analyses for which S_3 cannot be brought below 15 are confined to the Fe-Mg-Mn and calcic amphibole groups; the sodic-calcic and alkali amphiboles all have $S_3 < 15$ initially. Most of the name differences are relatively minor, but one 'magnesio-arfvedsonite' (55/8) becomes

'magnesio-katophorite' after recalculation to 23 oxygens.

The use of this option also reveals a problem with the basic IMA site occupancy rules. This concerns a range of amphiboles with $Ca \approx Na$ which, though logically sodic-calcic, are classified as calcic because they have large excesses of C cations ($S_2 \gg 13$), severely limiting the Na which can be allocated to the B site on the existing rules (p. 534). One such amphibole is included in Table IX; calculation to $24[O, OH, F, Cl]$ gives a reasonable formula unit but logically unreasonable name (no. 3), while recalculation to $23[O]$ gives a much more sensible name but rather low T cation total (no. 4). Other examples of these problematical amphiboles (e.g. Table VII, nos. 6 and 7) can only be classified as sodic-calcic if their excesses of C cations are largely ignored. This could be achieved by rephrasing rule (5) of the existing rules as follows: '(5) Sum B to 2.00 using Ca, then Na, then excess Fe^{2+} , Mn, Mg from (4).' This is equivalent to defining the Fe-Mg-Mn amphibole group in terms of total (Ca + Na) instead of $(Ca + Na)_B$. We have, however, deferred this rather major departure from the IMA rules pending further agreement, as it may affect very many amphibole calculations. The present option provides an interim measure allowing the approach recommended by Robinson *et al.* (1982) to be followed—namely, of trying several calculations and intuitively choosing the most reasonable name. It does not solve the problem (which lies within the existing IMA rules), but at least allows it to be identified in specific cases. Meanwhile we suggest that all amphiboles classified as 'edenites' with > 3 prefixes should be carefully checked to ensure they are not better named as sodic-calcic amphiboles. Manual correction outside the existing IMA rules may be necessary in such cases.

4.5. *Results of amendments to IMA site occupancy calculation (section 1.2.2).* These non-optional amendments, which mould high cation analyses to the IMA site occupancy rules where recalculations is impossible, were also triggered for a substantial proportion (19%) of analyses processed (Table Ib). Differences between the actual names with and without these amendments were not, however, investigated; the names resulting *without* them are based on invalid site occupancy calculations, and are therefore, strictly, incorrect.

4.6. *Results of the total Fe allocation procedure (section 2.4).* Most of the few analyses in the Deer *et al.* data-set which quote only one Fe oxide are near Mg end-members (where both Fe oxides were presumably too low to analyse separately). The program automatically eschews reallocation of total Fe in such cases, so this data-set provides little

TABLE VI Computer reclassification of published glaucophane and crossite analyses

DEER, HOWIE & ZUSSMAN, TABLE 53. GLAUCOPHANE AND CROSSITE ANALYSES.								
	1	2	3	4	5	6	7	8
SiO ₂	57.73	52.86	59.30	54.88	56.03	50.41	50.88	54.56
Al ₂ O ₃	12.04	11.29	8.66	9.86	8.67	7.82	8.53	8.29
Fe ₂ O ₃	1.16	5.61	5.21	4.35	7.11	8.73	4.25	7.94
FeO	5.41	7.77	8.05	12.02	9.46	10.81	13.41	10.31
MgO	13.02	9.96	9.37	7.69	8.81	7.39	8.50	8.74
CaO	1.04	2.42	1.24	1.95	1.28	3.99	5.19	0.81
Na ₂ O	6.98	6.50	6.11	5.62	6.98	7.04	4.63	6.71
K ₂ O	0.68	0.01	0.55	0.09	0.13	0.57	0.03	0.14
H ₂ O+	2.27	2.08	1.42	2.22	1.22	1.17	2.44	2.18
TiO ₂	0.00	0.24	0.25	0.87	0.36	1.66	1.86	0.23
P ₂ O ₅	0.00	0.00	0.00	0.00	0.04	0.00	0.00	0.01
MNO	0.00	1.78	0.12	0.14	0.11	0.14	0.23	0.13
TL	100.33	100.52	100.28	99.69	100.20	99.73	99.95	100.05
(ANALYSIS TOTALS ARE CORRECTED FOR O=CL,F)								
CATIONS PER FORMULA UNIT								
O=	24	24 +	24	24	24	24	24	24
Si	7.788	7.415	8.211	7.745	7.938	7.443	7.323	7.721
Al	1.916	1.868	1.414	1.641	1.449	1.362	1.448	1.384
Fe	0.118	0.592	0.543	0.462	0.758	0.970	0.460	0.846
Fe	0.610	0.911	0.932	1.418	1.120	1.334	1.613	1.220
Mg	2.619	2.084	1.935	1.618	1.861	1.627	1.825	1.844
Ca	0.150	0.364	0.184	0.295	0.194	0.631	0.800	0.123
Na	1.826	1.768	1.640	1.538	1.917	2.015	1.292	1.841
K	0.117	0.002	0.097	0.016	0.024	0.107	0.006	0.025
H	2.045	1.948	1.313	2.092	1.154	1.154	2.345	2.060
Ti	0.000	0.025	0.026	0.092	0.038	0.184	0.201	0.024
Mn	0.000	0.212	0.014	0.017	0.013	0.018	0.028	0.016
CHECK ON OXYGEN(+CL,F) EQUIVALENCE OF ABOVE CATIONS								
OXEQ=	24.00	24.00	24.00	24.00	24.00	24.00	24.00	24.00
CLASSIFICATION PARAMETERS								
CANA	1.949	1.893	1.824	1.832	1.822	2.000	2.000	1.946
NAB	1.799	1.529	1.640	1.538	1.627	1.369	1.200	1.823
NAKA	0.144	0.240	0.097	0.016	0.313	0.754	0.098	0.043
ALVI	1.704	1.283	1.414	1.386	1.387	0.805	0.772	1.104
MGE	0.811	0.696	0.675	0.533	0.624	0.549	0.531	0.602
GENERAL NOTES FOR THE ABOVE TABLE:								
NONE OF THE ABOVE ANALYSES REQUIRED RECALCULATION TO 23[O] BECAUSE OF LOW WATER/HIGH CATIONS P2O5 (WHERE QUOTED) HAS BEEN IGNORED IN CALCULATION OF FORMULA UNITS								
IMA(1978) NAMES FOR THE ABOVE TABLE:								
ANALYSIS NUMBER 1								
GLAUCOPHANE	FE ₃ /(FE ₃ +ALVI)=0.065							
ANALYSIS NUMBER 2								
SILICA-POOR CROSSITE	FE ₃ /(FE ₃ +ALVI)=0.316							
ANALYSIS NUMBER 3								
GLAUCOPHANE	FE ₃ /(FE ₃ +ALVI)=0.277							
ANALYSIS NUMBER 4	WARNING: SI>8; EXCESS IGNORED NOT CARRIED OVER INTO C SITE							
GLAUCOPHANE	FE ₃ /(FE ₃ +ALVI)=0.250							
ANALYSIS NUMBER 5								
CROSSITE	FE ₃ /(FE ₃ +ALVI)=0.353							
ANALYSIS NUMBER 6								
CALCIAN ANOPHORITE	FE ₃ /(FE ₃ +ALVI)=0.373							
ANALYSIS NUMBER 7								
BARROISITE								
ANALYSIS NUMBER 8								
CROSSITE	FE ₃ /(FE ₃ +ALVI)=0.434							

* Al₂O₃ and TiO₂ appear to have been interchanged in Deer, Howie & Zussman (1962) from the original reference

* the cation calculation quoted in Deer, Howie & Zussman (1962) appears to be slightly in error

indication of the efficiency of the procedure. With the lamprophyre data-set, the effects of the procedure are surprisingly different for amphiboles from different lamprophyres. The eighty-eight analyses of kaersutites (and closely related com-

positions) from camptonites and monchiquites are insensitive to *all* of the various adjustment of recalculation procedures (since this name is based on a single, overriding criterion, Ti > 0.5). Some 62% (40) of the sixty-four probe analyses of

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TABLE VII. Computer reclassification of published 'richterite' analyses.

DEER, HOWE & ZUSSMAN, TABLE 55. RICHTERITE ANALYSES.

	1	2	3	4	5	6	7	8
SiO2	58.88	57.74	52.67	55.02	56.74	55.14	56.01	53.73
Al2O3	0.00	0.37	1.72	4.53	0.71	1.14	0.14	2.72
Fe2O3	0.17	0.29	0.58	1.04	4.71	4.59	2.14	4.72
FeO	0.00	0.01	2.41	3.28	0.87	1.25	0.00	4.70
MgO	24.24	23.67	21.32	20.36	21.95	22.16	20.99	20.60
CaO	7.00	9.01	6.95	8.00	6.15	7.37	8.29	2.73
Na2O	7.20	3.14	3.64	6.71	5.15	2.88	3.69	7.42
K2O	0.00	0.64	5.70	1.52	1.80	1.24	0.47	1.82
H2O+	0.00	2.39	0.46	0.51	0.87	1.98	1.94	0.85
TiO2	0.00	0.01	3.53	0.00	0.28	0.50	0.00	0.41
MnO	0.00	2.40	0.06	0.00	0.07	1.38	5.81	0.00
F	4.74	0.37	1.29	0.00	1.30	0.00	0.18	0.92
Cr2O3	0.00	0.00	0.00	0.00	0.06	0.00	0.00	0.00
NiO	0.00	0.00	0.00	0.00	0.23	0.00	0.00	0.00
SrO	0.00	0.00	0.15	0.00	0.02	0.00	0.00	0.00
TL	100.23	99.88	99.94	100.97	100.36	99.63	99.58	100.23
(ANALYSIS TOTALS ARE CORRECTED FOR O=CL,F)								
CATIONS PER FORMULA UNIT								
O=	24	24	23	23	24	24	24	23
Si	0.025	7.897	7.344	7.516	7.919	7.713	7.887	7.462
Al	0.000	0.060	0.283	0.730	0.117	0.188	0.023	0.446
Fe	0.017	0.030	0.061	0.107	0.495	0.483	0.227	0.493
Fe	0.000	0.001	0.281	0.375	0.101	0.146	0.000	0.546
Mg	4.927	4.828	4.433	4.148	4.569	4.622	4.408	4.267
Ca	1.022	1.320	1.038	1.171	0.920	1.104	1.251	0.406
Na	1.902	0.833	0.984	1.777	1.394	0.781	1.007	1.998
K	0.000	0.112	1.014	0.265	0.321	0.221	0.084	0.323
H	0.000	2.183	0.428	0.465	0.811	1.849	1.824	0.788
Ti	0.000	0.001	0.370	0.000	0.029	0.053	0.000	0.043
Mn	0.000	0.278	0.007	0.000	0.008	0.164	0.694	0.000
F	2.044	0.160	0.569	0.000	0.574	0.000	0.000	0.404
Cr	0.000	0.000	0.000	0.000	0.007	0.000	0.000	0.000
Ni	0.000	0.000	0.000	0.000	0.026	0.000	0.000	0.000
Sr	0.000	0.000	0.012	0.000	0.002	0.000	0.000	0.000
CHECK ON OXYGEN(+CL,F) EQUIVALENCE OF ABOVE CATIONS								
OXEQ=	24.00	24.00	23.00	23.00	24.00	24.00	24.00	23.00
CLASSIFICATION PARAMETERS								
CANA	2.000	1.906	2.049	2.213	1.729	1.631	1.761	1.743
NAB	0.978	0.586	0.998	1.042	0.807	0.527	0.510	1.337
NAKA	0.925	0.358	1.000	1.000	0.907	0.476	0.581	0.983
ALVI	0.000	0.000	0.000	0.245	0.036	0.000	0.000	0.000
MGE	1.000	1.000	0.940	0.917	0.978	0.969	1.000	0.887

GENERAL NOTES FOR THE ABOVE TABLE:

ANALYSES WITH HIGH CATIONS & O<H<2 RECALCULATED TO 23 OXYGENS [2(OH) ASSUMED]

FE HAS BEEN REDISTRIBUTED WHEREVER POSSIBLE BETWEEN FE3 AND FE2, WHERE ONLY TOTAL FE IS QUOTED

ANALYSIS NUMBER 1

TOTAL FE TOO LOW TO WARRANT ATTEMPTS TO DISTRIBUTE BETWEEN FE2 AND FE3

FLUOR

RICHTERITE WARNING: SI>8; EXCESS IGNORED, NOT CARRIED OVER INTO C SITE

ANALYSIS NUMBER 2

MANGANOAN

SUBCALCIC

TREMOLITE

ANALYSIS NUMBER 3

(NA+K)>1(IE S4>16)EVEN WITH RECALCULATION TO 23[O];EXCESS NA REALLOCATED TO NAB:C CATIONS>>5?

NB: H(AND CL,F, IF QUOTED) VALUES ARE OUTPUT AS IF TO 23 OXYGENS, BUT ARE NOT INCLUDED IN THE FORMULA UNIT

TITANIAN

POTASSIUM WARNING:INSUFFICIENT CATIONS TO FILL T SITE

POTASSIUM

MAGNESIO-KATOPHORITE

ANALYSIS NUMBER 4

(NA+K)>1(IE S4>16)EVEN WITH RECALCULATION TO 23[O];EXCESS NA REALLOCATED TO NAB:C CATIONS>>5?

NB: H(AND CL,F, IF QUOTED) VALUES ARE OUTPUT AS IF TO 23 OXYGENS, BUT ARE NOT INCLUDED IN THE FORMULA UNIT

POTASSIAN

RICHTERITE

ANALYSIS NUMBER 5

POTASSIAN

RICHTERITE

ANALYSIS NUMBER 6

SUBCALCIC

TREMOLITE

ANALYSIS NUMBER 7

WARNING: SUM OF CATIONS S2 CANNOT BE SET TO 13.0. FE HAS BEEN LEFT AS IN ORIGINAL ANALYSIS

MANGANOAN

SUBCALCIC

SODIAN

SILICIC

EDENITE

ANALYSIS NUMBER 8

RECALCULATION TO 23 OXYGENS[2(OH) ASSUMED] EXECUTED TO BRING (NA+K)A BELOW OR EQUAL TO 1.0

NB: H(AND CL,F, IF QUOTED) VALUES ARE OUTPUT AS IF TO 23 OXYGENS, BUT ARE NOT INCLUDED IN THE FORMULA UNIT

POTASSIAN

MAGNESIO-KATOPHORITE

kaersutites have $S_2 < 13$ with total Fe as FeO, and constitute fully 80% of the fifty analyses for which the reallocation cannot be made (Table Ic). As these analyses come from many different sources, low cation totals may be an intrinsic feature of lamprophyre kaersutites. They do not, therefore, invalidate the Fe reallocation procedure, although they restrict its effectiveness to below 49% here. For other lamprophyre amphiboles, the procedure had a success rate of about 80%, and almost half (9) of nineteen amphiboles from minettes and spessartites have a different name before and after reallocation.

A curious problem occasionally arises with probe analyses of alkali amphiboles, where total Fe is quoted as FeO, but the Fe reallocation procedure fails. If Al^{VI} also happens to be zero, the parameter $Fe^{3+}/(Fe^{3+} + Al^{VI})$ is then undefined, and the amphibole cannot be assigned more precisely than to figs. 5A or 5B of the IMA (1978) scheme. The possibility must be recognized in computer programming, to avoid exponent overflow.

5. Summary of conclusions and recommendations

Results of the computer processing of over 500 amphibole analyses, including 200 from Deer *et al.* (1962) and 130 from lamprophyres, suggest the following conclusions and recommendations:

- Names resulting from the IMA (1978) scheme often differ from those in previous literature, especially for previously described 'alkali amphiboles', because of the newly introduced sodic-calcic amphibole group.

- Amphiboles previously termed 'barkevikite' and 'basaltic hornblende' emerge as heretogeneous mixtures of different IMA amphibole groups, supporting the recommendation to abandon these names.

- The IMA-favoured procedure for reallocation of total Fe in probe data between Fe^{2+} and Fe^{3+} —namely, adjustment of the sum $[Si + Ti + Cr + Al + Fe + Mg + Mn]$ to 13—was effective for some 80% of calcic, sodic-calcic, and alkali amphiboles processed, except kaersutites. For kaersutites, it was under 40% effective, due to persistent $T + C$ cation totals below 13, with total Fe quoted as FeO. For Fe-Mg-Mn amphiboles, the IMA-favoured procedure is entirely inapplicable, and the sum $[Si + Ti + Cr + Al + Fe + Mn + Mg + Ca]$ is recommended to be brought instead to 15. Names were significantly different with and without reallocation of total Fe, for some 25% of probe analyses processed.

- With a few probe analyses of alkali amphiboles the parameter $Fe^{3+}/(Fe^{3+} + Al^{VI})$ is un-

defined, because Al^{VI} is zero and Fe^{3+} cannot be estimated from total Fe.

- A lower limit of total Fe content should be placed on attempts to reallocate Fe, since most procedures fail for amphiboles near Mg end-members.

- Low cation totals were rare in amphiboles processed, but seven analyses had insufficient cations to fill the T site.

- By contrast with 6, over half the analyses had at least one anomalously high individual cation value (e.g. $Si > 8$, $Ca > 2$, $K > 1$), or high cation total (e.g. $[Ca + Na + K] > 3$; sum of $[T + C + B]$ cations > 15 ; A cations > 1). These high cations commonly resulted from low H_2O determinations, and could be overcome in about 75% of such cases by recalculation to 23 oxygens, with $2(OH)$ assumed. Some 30% of recalculated analyses had significantly different names before and after this recalculation.

- In the remaining 25% of high-cation analyses (13% of all analyses), high cations could not be overcome, and compensation procedures were essential to allow better satisfaction of the IMA site occupancy calculation rules. For example, excesses of $T + C + B$ cations over 15 had to be ignored, and excesses of A cations over 1 transferred back to Na_B .

- The IMA rules may need reappraisal in the case of sodic-calcic amphiboles which have $Ca \approx Na$ but also large excesses of C cations over 5. If such excesses are transferred to the B site, these amphiboles are commonly classified as edenites, with multiple prefixes. There is a strong case here for ignoring most or all excesses of C cations over 5. The recalculation procedure (see 7) often allows the problem to be identified in individual cases.

- Amphibole names are rarely affected by the difference between ignoring CO_2 and P_2O_5 , and removing them as calcite and apatite. Nevertheless, both options should be tried for borderline cases and impure analyses.

- Microprobe analyses with minor F or Cl but no H_2O should be calculated initially to 23 oxygens. Where $(F + Cl)$ then approaches 2, recalculation to $24[O, OH, F, Cl]$ is probably justified.

- Readers' attention is drawn to the various additions, corrections, and amendments to the IMA (1978) report, which are fully detailed in section 1 of this paper. These are the correction of fig. 3 of the IMA report (1.1.1); the use of 'sodium' in orthorhombic amphiboles (1.1.2); the use of 'aluminio-' for cummingtonites (1.1.3); the definitions of tirodite and dannemorite (1.1.4); the incorporation of the new amphiboles *sadanagaite* and *nyboite* (newly approved since 1978); the reinstatement of

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	SADANAGAITE (Shimazaki et al.1982)					NYBOITES (Ungaretti et al.1981)		KOZULITE (Nambu et al.1969)		TIRODITES (Dein 1964)	
	1	2	3	4	5	6	7	8	9	10	
SiO ₂	30.20	29.50	33.50	38.80	37.00	53.84	52.63	51.38	55.27	55.74	
Al ₂ O ₃	24.80	23.20	19.70	16.90	15.30	12.92	13.87	1.69	0.34	0.23	
Fe ₂ O ₃	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.85	0.00	0.00	
FeO	15.20	16.40	17.80	9.50	19.10	5.83	5.75	0.01	4.52	7.09	
MgO	6.60	7.70	6.40	13.50	7.20	14.21	13.12	2.71	19.18	18.55	
CaO	12.30	11.90	11.90	13.80	11.00	2.33	2.75	1.12	1.19	1.04	
Na ₂ O	1.00	0.70	1.20	1.20	1.20	9.26	8.55	8.41	0.26	0.08	
K ₂ O	3.70	3.50	3.10	2.50	2.60	0.14	0.11	1.36	0.00	0.02	
H ₂ O ⁺	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.10	2.16	2.26	
TiO ₂	4.00	4.00	2.10	1.10	1.40	0.16	0.15	0.00	0.00	0.00	
P ₂ O ₅	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.09	0.00	
MnO	0.10	0.30	0.50	0.10	0.50	0.02	0.08	27.96	16.62	14.73	
TL	97.90	97.20	96.20	97.40	96.10	97.91	97.01	99.59	99.63	99.74	
CATIONS PER FORMULA UNIT											
O=	23	23	23	23	23	23	23	24	24	24	
Si	4.614	4.495	5.237	5.750	5.779	7.382	7.302	8.010	7.974	8.024	
Al	4.469	4.170	3.632	2.954	2.819	2.090	2.270	0.311	0.058	0.039	
Fe	0.341	1.152	0.433	0.101	0.463	0.000	0.000	0.334	0.000	0.000	
Fe	1.600	0.937	1.893	1.076	2.031	0.576	0.667	0.001	0.545	0.853	
Mg	1.504	1.750	1.492	2.984	1.677	2.905	2.715	0.630	4.127	3.982	
Ca	2.013	1.942	1.993	2.191	1.975	0.342	0.409	0.187	0.184	0.160	
Na	0.296	0.207	0.364	0.345	0.363	2.461	2.300	2.542	0.073	0.022	
K	0.721	0.680	0.618	0.473	0.518	0.024	0.019	0.271	0.004	0.004	
H	0.000	0.000	0.000	0.000	0.000	0.000	0.000	2.186	2.081	2.173	
Ti	0.460	0.458	0.247	0.123	0.164	0.017	0.016	0.000	0.000	0.000	
Mn	0.013	0.039	0.066	0.013	0.066	0.002	0.009	3.695	2.033	1.798	
CHECK ON OXYGEN(+CL,F) EQUIVALENCE OF ABOVE CATIONS											
OxO=	23.00	23.00	23.00	23.00	23.00	23.00	23.00	24.00	24.00	24.00	
CLASSIFICATION PARAMETERS											
CANA	2.030	2.000	2.000	2.191	2.000	2.000	2.000	2.000	0.257	0.183	
NAB	0.017	0.058	0.007	0.000	0.025	1.658	1.591	1.813	0.073	0.022	
NAKA	1.000	0.830	0.975	0.818	0.856	0.828	0.728	0.999	0.000	0.004	
ALVI	1.083	0.665	0.869	0.704	0.598	1.471	1.572	0.311	0.032	0.039	
MGFE	0.484	0.651	0.441	0.735	0.452	0.834	0.803	0.998	0.883	0.824	
GENERAL NOTES FOR THE											

anophorite to complement *nyboite*, and the introduction of *ferro-nyboite* and *ferro-anophorite* (1.1.5); the adjustment of fig. 5 of the scheme, and the definition of 'subsiliic', to accommodate these new species (1.1.6-7); the recognition of unusual amounts of Ni, Ba, and Sr through adjectival prefixes (1.1.8); and the treatment of minor elements such as Li, Ni, Zn, Sr, and Ba in the calculation of site occupancies (1.2.1).

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NOTES

1. Throughout this paper, sums of cations are symbolized as follows:

$$S_1 = \Sigma \text{Si} + \text{Al} + \text{Cr} + \text{Fe}^3 + \text{Ti}$$

$$S_2 = \Sigma \text{Si} + \text{Al} + \text{Cr} + \text{Fe}^3 + \text{Ti} + \text{Mg} + \text{Fe}^2 + \text{Mn} + [\text{Zn} + \text{Ni} + \text{Li}]$$

$$S_3 = \Sigma \text{Si} + \text{Al} + \text{Cr} + \text{Fe}^3 + \text{Ti} + \text{Mg} + \text{Fe}^2 + \text{Mn} + [\text{Zn} + \text{Ni} + \text{Li}] + \text{Ca} + [\text{Sr}]$$

$$S_4 = \Sigma \text{Si} + \text{Al} + \text{Cr} + \text{Fe}^3 + \text{Ti} + \text{Mg} + \text{Fe}^2 + \text{Mn} + [\text{Zn} + \text{Ni} + \text{Li}] + \text{Ca} + [\text{Sr}] + \text{Na} + \text{K} + [\text{Ba}] \text{—i.e. sum of all cations.}$$

2. The consistently high number of prefixes required for many edenite analyses partly reflects the peculiar status of this amphibole composition. Although natural edenite-rich amphiboles do exist, the pure end-member has nowhere yet been recognized—even the original 'edenite' analysed by Rammelsberg is nothing but a common calciferous hornblende (Leake, 1962). Many amphiboles near the theoretical end-member edenite may in fact not be true amphiboles, but mixed pyroxene-amphibole (pyribole) minerals. Clearly, then, attempts to treat them as amphiboles would result in 'poor fits' to the IMA classification. Names would deviate widely from

end-members, and would be directly reflected in large numbers of prefixes. Other 'edenites' with 4 or 5 prefixes are probably really sodic-calcic amphiboles (section 4.4).

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