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A BASIC COMPUTER PROGRAM TO DETERMINE THE NAME OF AN AMPHIBOLE FROM AN ELECTRON MICROPROBE ANALYSIS

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Abstract

A BASIC computer program for naming an amphibole is presented, which employs STOUT's (1972) suggested modes of Fe^{3+}-recalculation and the I.M.A.-nomenclature (International Mineralogical Association, LEAKE, 1978, compiler). Considering the two stoichiometric constraints of STOUT, the program calculates formulas and site occupancies for a given microprobe analysis of an amphibole; it classifies the amphibole into one of the four major groups on the basis of (Ca + Na)- and Na-values in the M4-site and determines the specific name on the basis of $Mg/(Mg + Fe^{2+})$-, $Fe^{3+}/(Fe^{3+} + Al^{VI})$-, $Fe^{2+}/(Fe^{2+} + Mg)$-, $Mn/(Mn + Fe^{2+} + Mg)$- and Si-ratios, as defined by the I.M.A.-nomenclature.

Zusammenfassung

Ein BASIC-Computerprogramm zur Benennung von Amphibolen wird vorgestellt. Dabei werden die von STOUT (1972) vorgeschlagene Fe^{3+}-Berechnung und die I.M.A.-Nomenklatur (International Mineralogical Association, LEAKE, 1978, compiler) verwendet. Das Programm berechnet Formeln und Gitterbesetzungen für eine Mikrosondenanalyse eines Amphibols unter Berücksichtigung der zwei stöchiometrischen Beschränkungen von STOUT; das Amphibol wird aufgrund der (Ca + Na)- und Na-Werte in der M4-Stelle in eine der vier Hauptgruppen eingeordnet. Der jeweilige spezifische Name wird, wie von der I.M.A.-Nomenklatur definiert, aufgrund der $Mg/(Mg + Fe^{2+})$-, $Fe^{3+}/(Fe^{3+} + Al^{VI})$-, $Fe^{2+}/(Fe^{2+} + Mg)$-, $Mn/(Mn + Fe^{2+} + Mg)$- und Si-Werte bestimmt.

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Introduction

Since the amphibole structure admits great flexibility of ionic replacement, the minerals of the group exhibit an extremely wide range of chemical composition (DEER et al., 1963; ERNST, 1968; COLVILLE et al., 1966). As a result the nomenclature of amphiboles has been difficult and confusing. LEAKE (1968, pp. 5) states that "attempts to classify amphiboles according to their optical properties are inevitably unsuccessful, because very different compositions can give very nearly identical optical properties." He suggested three important variables to define the main name to be given to an amphibole, namely the amounts of Si, (Ca + Na + K) and $Mg/(Fe^{3+} + Fe^{2+} + Mn + Mg)$ in the half unit cell. Following this attempt in a compilation of I.M.A.-nomenclature (LEAKE, 1978), a procedure for naming an amphibole on the basis of chemical analysis is agreed upon. However the problem of using this procedure is that the ratio $Mg/(Mg + Fe^{2+})$ cannot be accurately obtained from electron microprobe analysis. Therefore one must critically examine the procedure to be used, in order to calculate the Fe^{2+} and Fe^{3+}, when only the total Fe has been determined, as different procedures could give different names to the same chemical analyses.

Most papers written on amphiboles based on electron microprobe analysis state the problem involved in amphibole nomenclature, since Fe^{3+} cannot be determined and several assumptions have to be made for calculating Fe^{3+} from the total Fe obtained as FeO. Several authors have used different methods to solve specific problems, such as HEITANEN (1974), who calculated 20% of the total Fe as Fe_2O_3 to agree with the approximate $Fe_2O_3/(FeO + Fe_2O_3)$-ratio in the host rocks,after an allowance to form epidote and accessories was made; GRAPES (1975) and GRAPES et al. (1977) took gravimetric analyses of a number of green hornblendes from the Hidaka metagabbro-amphibolite rocks and got a straight line plot when the total Fe as FeO was plotted against Fe_2O_3; thus it was possible to read the amount of unknown Fe_2O_3 directly from the graph and the total Fe as FeO (EMPA) adjusted accordingly.

As stated above these procedures may hold true for the specific problem at hand.

KLEIN (1968, pp. 286) states that the anthophyllite-gedrite analyses may be recalculated on the basis of 15 cations or on the basis of 23 oxygens, but neither approach is perfect. KLEIN (1969) also considered the problem of nomenclature and named all the sodium-amphiboles in his study with Al_2O_3-content ranging from about 6 to 12 weightpercent as glaucophane and stated that some wouldturn out to be crossite or ferroglaucophane if the Fe^{2+}/Fe^{3+}-ratios were known. STOUT (1972) proposed several modes of recalculation and showed that it is possible to bracket the amount of Fe^{3+}, present in the total Fe determined as FeO (EMPA), by calculating the minimum Fe^{3+} (normalizing all the cations in the formula to 15, except Na = ΣCa) and the maximum Fe^{3+} (normalizing all the cations in the formula that are assumed to occupy the tetrahedral and octahedral sites to 13 = ΣFm) on the basis of stoichiometric constraints. (The notations ΣNa, ΣCa and ΣFm are adopted from STOUT, 1972).

Since then many authors have adopted a similar approach (BRADY, 1974; DOOLAN et al., 1978; BROWN, 1977, among others). Several other procedures are also used (CZAMANSKE et al., 1973; ROBINSON et al., 1971; SPEAR, 1981; LAIRD & ALBEE, 1981, among others).

The objective of this paper is to outline a computer program written to determine the name of an amphibole from an electron microprobe analysis on the basis of STOUT's limiting recalculations of Fe^{3+} (1972) and I.M.A.-nomenclature compiled by LEAKE (1978).

Discussion

According to the I.M.A.-nomenclature the amphiboles are classified into four major groups, on the basis of the (Ca + Na)- and Na-values in the M4- or B-site (Fig. 1). However the detailed amphibole nomenclature employs the values $Mg/(Mg + Fe^{2+})$, $Fe^{3+}/(Fe^{3+} + Al^{VI})$, $Fe^{2+}/(Fe^{2+} + Mg)$ and $Mn/(Mn + Fe^{2+} + Mg)$.

STOUT's (1972) Fe^{3+}-limiting recalculations are employed in order to determine the Fe^{3+} and Fe^{2+} from the total Fe determined as FeO, thereby enabling one to calculate the ratios given above.

The two stoichiometric constraints suggested by STOUT (1972) i.e. restriction of Ca to the M4-site ($\Sigma Ca = 15$, implying minimum Fe^{3+}) and only Ca and Na in the M4-site ($\Sigma Fm = 13$, implying maximum Fe^{3+}) are considered. The calculation for minimum Fe_2O_3 maximizes the number of cations in the formula, minimizes Na in the M4-site and maximizes Na in the A-site, whereas the calculation for maximum Fe_2O_3 yields the minimum number of cations in the formula, minimum Na in the A-site and maximum Na in the M4-site.

In order to evaluate the difference in the actual values of the cations in the recalculated formulas due to the different normalizations, one representative analysis from each major amphibole group is taken and subjected to several modes of recalculations (i.e. assuming all the Fe to be in the ferrous state, alle the Fe in the ferric state and then normalizing all the cations to 15 = Na, all cations except Na to 15 = ΣCa, all cations except (Na + Ca) to 13 = ΣFm; see also STOUT, 1972, table 2).

This is helpful as one can clearly see the similarity or difference between the formula calculated on the basis of 23 oxygens, where Fe is assumed to be in the ferrous state (a method generally adopted by most authors), and those calculated on the assumptions stated above.

In table 1 the results of the Fe^{3+}-limiting recalculations of representative analyses of the four major amphibole groups are given. Comparison of the total sum of cations in the different modes of recalculation (indicated as ΣNa in table 1) shows that the cation sums, calculated on the basis of the ferrous assumption, are almost the same as those calculated on $\Sigma Ca = 15$ for the Fe-Mg-Mn-amphiboles and the calcic amphiboles (table 1a and 1b), and on the basis of $\Sigma Fm = 13$ for the calcic-sodic amphiboles and the alkali-amphiboles (table 1c and 1d). Therefore it is possible that for the Fe-Mg-Mn-amphiboles and the calcic amphiboles the formula calculated on $\Sigma Ca = 15$, and for the calcic-sodic amphiboles and alkali-amphiboles the formula based on $\Sigma Fm = 13$, can be used for detailed nomenclature.

Table 2 gives a summary of the criteria given by the I.M.A.-nomenclature (LEAKE, 1978) for determining the specific name of an amphibole. The values obtained in $\Sigma Ca = 15$ and $\Sigma Fm = 13$ for the same examples are given in table 1. A careful glance at the table shows that the values of (Ca + Na) and

Table 1 a: Limiting recalculation of a representative Fe-Mn-Mg-amphibole (GEDRITE)
Reference: STOUT, 1972: Table 5 A, analysis GIL 2

			all ferrous	all ferric	ΣNa = 15	ΣCa = 15	ΣFm = 13
SiO_2	41.20	Si	6.1954	5.7876	6.0063	6.1810	5.3683
TiO_2	0.00	Ti	0.0000	0.0000	0.0000	0.0000	0.0000
Al_2O_3	17.50	Al	3.1015	2.8973	3.0068	3.0943	2.6875
Cr_2O_3	0.00	Cr	0.0000	0.0000	0.0000	0.0000	0.0000
Fe_2O_3	0.00	Fe^{3+}	0.0000	3.0300	1.4047	0.1075	2.8113
FeO	25.80	Fe^{2+}	3.2444	0.0000	1.7407	3.1294	0.0000
MnO	0.50	Mn	0.0637	0.0595	0.0617	0.0635	0.0552
MgO	10.70	Mg	2.3978	2.2400	2.3246	2.3922	2.0777
CaO	0.20	Ca	0.0322	0.0301	0.0312	0.0321	0.0279
K_2O	0.00	K	0.0000	0.0000	0.0000	0.0000	0.0000
Na_2O	1.50	Na	0.4373	0.4085	0.4240	0.4363	0.3790
Total	97.40	ΣSi	6.1954	5.7876	6.0063	6.1810	5.3683
		ΣAl	9.2969	8.6849	9.0131	9.2753	8.0558
		ΣFm	15.0028	14.0144	14.5448	14.9679	13.0000
		ΣCa	15.0350	14.0445	14.5760	15.0000	13.0279
		ΣNa	15.4723	14.4530	15.0000	15.4363	13.4069

Table 1 b: Limiting recalculation of a representative calcic amphibole (TSCHERMAKITIC HORNBLENDE)
Reference: KLEIN, 1968: Analysis 3-4 H

			all ferrous	all ferric	ΣNa = 15	ΣCa = 15	ΣFm = 13
SiO_2	45.70	Si	6.4818	6.2984	6.2465	6.4399	6.2338
TiO_2	0.00	Ti	0.0000	0.0000	0.0000	0.0000	0.0000
Al_2O_3	14.20	Al	2.3737	2.3066	2.2875	2.3584	2.2829
Cr_2O_3	0.00	Cr	0.0000	0.0000	0.0000	0.0000	0.0000
Fe_2O_3	0.00	Fe^{3+}	0.0000	1.3020	1.6700	0.2974	1.2890
FeO	11.30	Fe^{2+}	1.3403	0.0000	-0.3784	1.0343	0.0000
MnO	0.20	Mn	0.0240	0.0233	0.0232	0.0239	0.0231
MgO	15.60	Mg	3.2973	3.2040	3.1776	3.2760	3.1712
CaO	10.40	Ca	1.5804	1.5357	1.5231	1.5702	1.5200
K_2O	0.00	K	0.0000	0.0000	0.0000	0.0000	0.0000
Na_2O	1.70	Na	0.4675	0.4543	0.4505	0.4645	0.4496
Total	99.10	ΣSi	6.4818	6.2984	6.2465	6.4399	6.2338
		ΣAl	8.8555	8.5960	8.5340	8.7983	8.5228
		ΣFm	13.5171	13.1253	13.0264	13.4299	13.0000
		ΣCa	15.0975	14.6610	14.5495	15.0000	14.5261
		ΣNa	15.5650	15.1153	15.0000	15.4646	14.9757

Table 1 c: Limiting recalculation of a representative calcic-sodic amphibole (BARROISITE)
Reference: MILLER, 1977: Analysis T 258 / E 1

			all ferrous	all ferric	ΣNa = 15	ΣCa = 15	ΣFm = 13
SiO_2	47.40	Si	6.9307	6.6704	6.6402	7.2556	6.8255
TiO_2	0.31	Ti	0.0344	0.0331	0.0330	0.0361	0.0339
Al_2O_3	12.10	Al	2.0852	2.0069	1.9978	2.1829	2.0535
Cr_2O_3	0.00	Cr	0.0000	0.0000	0.0000	0.0000	0.0000
Fe_2O_3	0.00	Fe^{3+}	0.0000	1.7283	1.9282	0.0000	0.6982
FeO	14.69	Fe^{2+}	1.7962	0.0000	-0.2073	1.8804	1.0708
MnO	0.18	Mn	0.0223	0.0215	0.0214	0.0233	0.0220
MgO	10.70	Mg	2.3315	2.2440	2.2338	2.4408	2.2961
CaO	7.20	Ca	1.1280	1.0856	1.0807	1.1808	1.1108
K_2O	0.28	K	0.0522	0.0503	0.0500	0.0547	0.0514
Na_2O	4.50	Na	1.2757	1.2278	1.2223	1.3355	1.2564
Total	97.36	ΣSi	6.9307	6.6704	6.6402	7.2556	6.8255
		ΣAl	9.0159	8.6773	8.6380	9.4385	8.8790
		ΣFm	13.1961	12.7042	12.6471	13.8191	13.0000
		ΣCa	14.3241	13.7898	13.7278	15.0000	14.1180
		ΣNa	15.6520	15.0679	15.0000	16.3901	15.4186

Table 1 d: Limiting recalculation of a representative alkali-amphibole (FERRO-GLAUCOPHANE)
Reference: KATAGAS, 1980: Table 1, analysis 1

			all ferrous	all ferric	ΣNa = 15	ΣCa = 15	ΣFm = 13
SiO_2	57.36	Si	8.0310	7.7315	8.0340	9.2260	8.0281
TiO_2	0.00	Ti	0.0000	0.0000	0.0000	0.0000	0.0000
Al_2O_3	11.44	Al	1.8850	1.8164	1.8875	2.1675	1.8861
Cr_2O_3	0.00	Cr	0.0000	0.0000	0.0000	0.0000	0.0000
Fe_2O_3	0.00	Fe^{3+}	0.0000	0.0000	0.0176	0.0000	0.0161
FeO	15.24	Fe^{2+}	1.7841	1.7165	1.8017	2.0488	1.7667
MnO	0.00	Mn	0.0000	0.0000	0.0000	0.0000	0.0000
MgO	6.25	Mg	1.3039	1.2548	1.3039	1.4973	1.3029
CaO	0.35	Ca	0.0525	0.0505	0.0525	0.0603	0.0525
K_2O	0.00	K	0.0000	0.0000	0.0000	0.0000	0.0000
Na_2O	7.14	Na	1.9380	1.8650	1.9380	2.2255	1.9366
Total	97.78	ΣSi	8.0310	7.7315	8.0340	9.2260	8.0281
		ΣAl	9.9160	9.7479	9.9215	11.3935	9.9142
		ΣFm	13.0040	12.5192	13.0095	14.9396	13.0000
		ΣCa	13.0565	12.5697	13.0620	15.0000	13.0524
		ΣNa	14.9945	14.4346	15.0000	17.2255	14.9890

Na in the M4-site, obtained on the basis of ΣFm = 13 for the amphiboles in each of the four major groups, are within the limits given by LEAKE (1978).

On the basis of ΣCa = 15 these values are in accordance with those of Leake (1978) for the Fe-Mg-Mn-amphiboles and calcic amphiboles, but not for the calcic-sodic amphiboles and alkali-amphiboles.

The $Mg/(Mg + Fe^{2+})$-, $Fe^{2+}/(Fe^{2+} + Mg)$-, $Fe^{3+}/(Fe^{3+} + Al^{VI})$-, $Mn/(Mn + Fe^{2+} + Mg)$- and Si-values differ in the different modes of recalculation!

This can be observed in table 2 and is also indicated by asterisk. The values obtained for the above variables on the basis of ΣCa = 15 for the Fe-Mg-Mn-amphiboles and the calcic amphiboles and those obtained on the basis of ΣFm = 13 for the calcic-sodic amphiboles and alkali-amphiboles are within the limits of the values given by the I.M.A.-nomenclature (LEAKE, 1978).

In line with the observations stated above, the computer program is written to determine the name of an amphibole (out of 60 names, see fig. 1) from a microprobe analysis.

Having taken a microprobe analysis of an amphibole in terms of weight-percentages of oxides, the program works as follows:

1) Calculating the formula of the amphibole
   a) assuming of all the Fe to be in the ferrous state
   b) assuming of all the Fe to be in the ferric state

   In both cases the number of oxygens in the formula is normalized to 23.

2) Recalculating the Fe^{3+}- and Fe^{2+}-values on the basis of:
   a) ΣNa = 15 (normalizing all cations to 15)
   b) ΣCa = 15 (normalizing all cations except Na to 15)
   c) ΣFm = 13 (normalizing all cations except Na and Ca to 13)

   In the above three calculations the total amount of oxygen present in the formula is calculated by multiplying the normalized cation values by the respective number of oxygens in the different oxides and summing up the product.

   In most cases the calculated oxygen-value is less than 23. Thus, 23 minus this amount of Fe^{3+} which combines with this oxygen is calculated. Fe^{2+} is then determined by subtracting the amount of calculated Fe^{3+} from the total Fe (table 3).

   Where the total amount of oxygen in the formula exceeds 23, the total Fe is assumed to be equal to Fe^{2+}; Fe^{3+} is taken as zero, since a negative Fe^{3+} implies that the value of Fe^{2+} is higher than the actual amount of total Fe.

3) Calculating the site occupancies for the cations on the basis of ΣCa = 15 and ΣFm = 13 according to LEAKE (1978), taking the general amphibole formula:

$$A_{0-1}B_2C_5{}^{VI}T_8{}^{IV}O_{22}(OH,F,Cl)_2$$

   where A is the A-site, B the M4-site, C the octahedral site and T the tetrahedral site.

Table 2: Parameters used in determining the name of an amphibole

	Fe-Mn-Mg-amphibole GEDRITE			calcic amphibole TSCHERMAKITIC HBL			calcic-sodic amphibole BARROISITE			alkali-amphibole FERRO-GLAUCOPHANE		
	ΣCa	ΣFm	LK	ΣCa	ΣFm	LK	ΣCa	ΣFm	LK	ΣCa	ΣFm	LK
Na_B	0.0000	0.3790	-	0.0000	0.4496	<0.67	* 0.0000	0.8892	0.67-1.34	* 0.0000	1.9366	≧1.34
$(Ca + Na)_B$	0.0321	0.4069	<1.34	1.5702	1.9696	≧1.34	* 1.1808	2.0000	≧1.34	0.0603	1.9890	-
$(Na + K)_A$	0.4364	0.0000	-	0.4645	0.0000	<0.50	* 1.3902	0.4187	<0.50	* 2.2255	0.0000	<0.50
$\frac{Mg}{Mg + Fe^{2+}}$	0.4332	* 1.0000	0.1-0.9	0.7600	1.0000	0.5-1.0	0.5648	0.6820	0.5-1.0	0.4222	0.4245	0-1
$\frac{Fe^{3+}}{Fe^{3+} + Al^{vi}}$	-	-	-	-	-	-	-	-	-	-	0.0085	0.0-0.3
Si	6.1810	* 5.3683	6-7	6.4390	* 6.2340	6.25-6.5	7.2560	6.8260	6.5-7.5	9.2260	8.0281	-

* Values not within the range as defined by I.M.A.-amphibole-nomenclature (LEAKE, 1978)

ΣCa = 15 indicates all cations except Na normalized to 15

ΣFm = 13 indicates cations normally thought to occupy tetrahedral and octahedral (M 1, M 2, M 3) sites normalized to 13

LK = LEAKE, 1978 (specific values in the standard formula of an amphibole)

a) Sum T to 8.00 using Si, then Al, then Cr^{3+}, then Fe^{3+}, then Ti^{4+}
b) Sum C to 5.00 using excess Al, Cr^{3+}, Ti^{4+} and Fe^{3+} from (a), then Mg, then Fe^{2+}, then Mn
c) Sum B to 2.00 using excess Fe^{2+}, Mg and Mn from (b), then Ca, then Na
d) Excess Na from (c) is assigned to A, then all K. Total A should be between 0 and 1.00 inclusive.

4) The second phase of the program considers the detailed I.M.A.-amphibole nomenclature (LEAKE, 1978, refer fig. 1).
a) On the basis of the (Ca + Na)- and Na-values in the M4- or B-site (calculated on the basis of $\Sigma Fm = 13$) the unknown amphibole is classified into one of the four major groups, according to the following criteria:
I) Fe-Mg-Mn-amphibole group
$(Ca + Na)_B < 1.34$
II) Calcic amphibole group
$(Ca + Na)_B \geqq 1.34$ and $Na_B < 0.67$
III) Calcic-sodic amphibole group
$(Ca + Na)_B \geqq 1.34$ and $0.67 \leqq Na_B < 1.34$
IV) Alkali-amphibole group
$Na_B \geqq 1.34$

b) After the major group, to which the amphibole analysis belongs, is known, the program considers the detailed nomenclature on the basis of $Mg/(Mg + Fe^{2+})$-ratio:
I) On the basis of $\Sigma Ca = 15$ for the Fe-Mg-Mn-amphiboles and calcic amphiboles
II) On the basis of $\Sigma Fm = 13$ for the calcic-sodic amphiboles and alkali-amphiboles
In the alkali-amphibole group the ratios $Fe^{3+}/(Fe^{3+} + Al^{VI})$, $Fe^{2+}/(Fe^{2+} + Mg)$ and $Mn/(Mn + Mg + Fe^{2+})$ are also considered, as the nomenclature of some amphiboles is dependent on these ratios (see table 3).

The program has been evaluated using series of analyses from the literature and works very well. In table 3 analyses are given from the literature; the names are determined using the present computer program. Original names or comments given by the respective authors are also included for comparative purposes. These names are found to be compatible with the names obtained using the program.

Of course one should realize the problem involved in naming the anthophyllite-cummingtonite groups only on the basis of chemical composition, as the basic difference is a structural one, which is more reflected in the optical properties than in chemistry. Thus for the anthophyllite-cummingtonite groups the program gives two names and for the specific name one has to study the mineral optically and determine whether the chemical analysis represents the orthorhombic or the monoclinic variety.

The lithium-amphiboles (holmquistites) are not included in the program as it is impossible to determine Li with an electron microprobe.

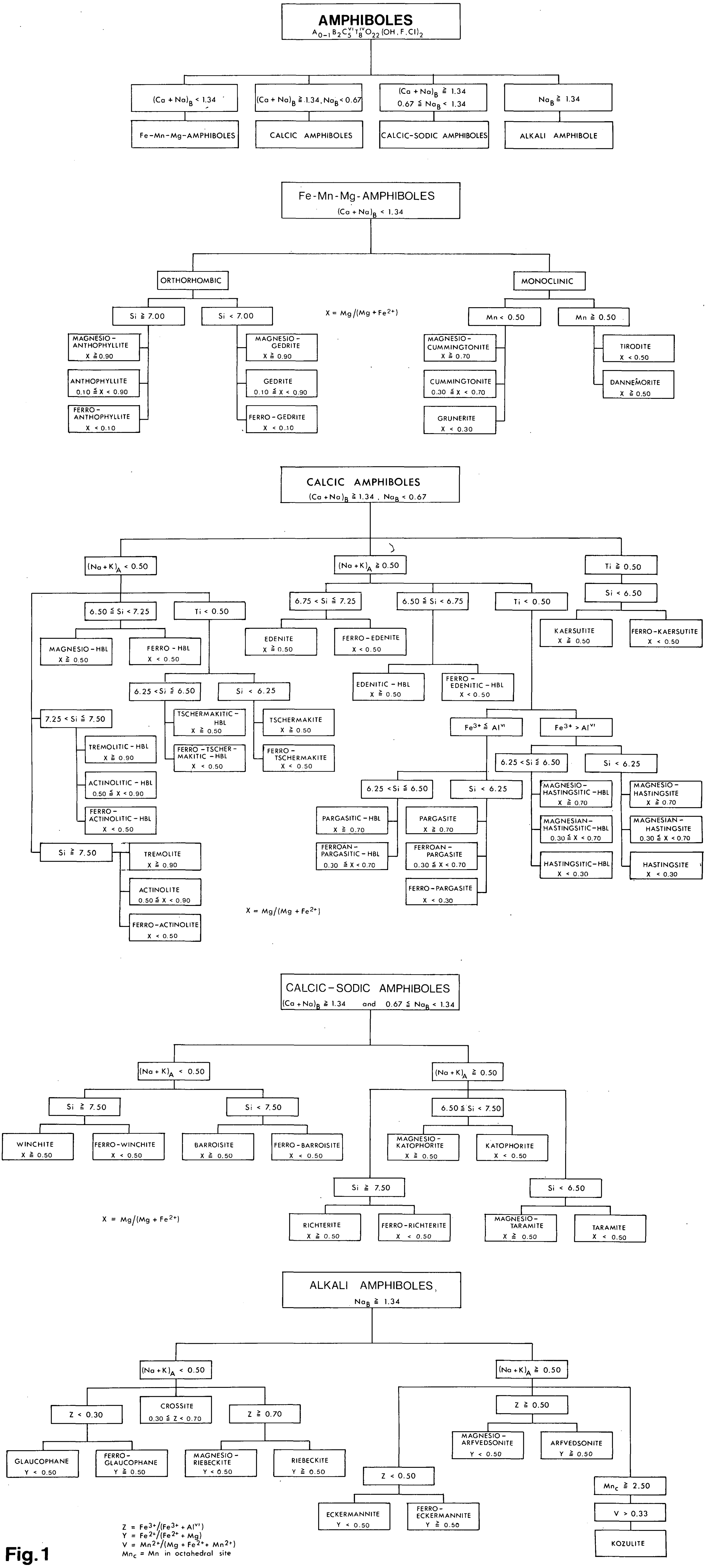
AMPHIBOLES
$A_{0-1}B_2C_5^{VI}T_8^{IV}O_{22}(OH,F,Cl)_2$
$(Ca+Na)_B < 1.34$
Fe-Mn-Mg-AMPHIBOLES
$(Ca+Na)_B \geqq 1.34, Na_B < 0.67$
CALCIC AMPHIBOLES
$(Ca+Na)_B \geqq 1.34$ $0.67 \leqq Na_B < 1.34$
CALCIC-SODIC AMPHIBOLES
$Na_B \geqq 1.34$
ALKALI AMPHIBOLE
Fe-Mn-Mg-AMPHIBOLES
$(Ca+Na)_B < 1.34$
ORTHORHOMBIC
MONOCLINIC
$Si \geqq 7.00$
$Si < 7.00$
$X = Mg/(Mg+Fe^{2+})$
$Mn < 0.50$
$Mn \geqq 0.50$
MAGNESIO-ANTHOPHYLLITE $X \geqq 0.90$
ANTHOPHYLLITE $0.10 \leqq X < 0.90$
FERRO-ANTHOPHYLLITE $X < 0.10$
MAGNESIO-GEDRITE $X \geqq 0.90$
GEDRITE $0.10 \leqq X < 0.90$
FERRO-GEDRITE $X < 0.10$
MAGNESIO-CUMMINGTONITE $X \geqq 0.70$
CUMMINGTONITE $0.30 \leqq X < 0.70$
GRUNERITE $X < 0.30$
TIRODITE $X < 0.50$
DANNEMORITE $X \geqq 0.50$
CALCIC AMPHIBOLES
$(Ca+Na)_B \geqq 1.34$, $Na_B < 0.67$
$(Na+K)_A < 0.50$
$(Na+K)_A \geqq 0.50$
$Ti \geqq 0.50$
$Si < 6.50$
KAERSUTITE $X \geqq 0.50$
FERRO-KAERSUTITE $X < 0.50$
$6.50 \leqq Si < 7.25$
$Ti < 0.50$
MAGNESIO-HBL $X \geqq 0.50$
FERRO-HBL $X < 0.50$
$6.25 < Si \leqq 6.50$
$Si < 6.25$
TSCHERMAKITIC-HBL $X \geqq 0.50$
FERRO-TSCHERMAKITIC-HBL $X < 0.50$
TSCHERMAKITE $X \geqq 0.50$
FERRO-TSCHERMAKITE $X < 0.50$
$7.25 < Si \leqq 7.50$
TREMOLITIC-HBL $X \geqq 0.90$
ACTINOLITIC-HBL $0.50 \leqq X < 0.90$
FERRO-ACTINOLITIC-HBL $X < 0.50$
$Si \geqq 7.50$
TREMOLITE $X \geqq 0.90$
ACTINOLITE $0.50 \leqq X < 0.90$
FERRO-ACTINOLITE $X < 0.50$
$6.75 < Si \leqq 7.25$
$6.50 \leqq Si < 6.75$
$Ti < 0.50$
EDENITE $X \geqq 0.50$
FERRO-EDENITE $X < 0.50$
EDENITIC-HBL $X \geqq 0.50$
FERRO-EDENITIC-HBL $X < 0.50$
$Fe^{3+} \leqq Al^{VI}$
$Fe^{3+} > Al^{VI}$
$6.25 < Si \leqq 6.50$
$Si < 6.25$
PARGASITIC-HBL $X \geqq 0.70$
FERROAN-PARGASITIC-HBL $0.30 \leqq X < 0.70$
PARGASITE $X \geqq 0.70$
FERROAN-PARGASITE $0.30 \leqq X < 0.70$
FERRO-PARGASITE $X < 0.30$
$6.25 < Si \leqq 6.50$
$Si < 6.25$
MAGNESIO-HASTINGSITIC-HBL $X \geqq 0.70$
MAGNESIAN-HASTINGSITIC-HBL $0.30 \leqq X < 0.70$
HASTINGSITIC-HBL $X < 0.30$
MAGNESIO-HASTINGSITE $X \geqq 0.70$
MAGNESIAN-HASTINGSITE $0.30 \leqq X < 0.70$
HASTINGSITE $X < 0.30$
$X = Mg/(Mg+Fe^{2+})$
CALCIC-SODIC AMPHIBOLES
$(Ca+Na)_B \geqq 1.34$ and $0.67 \leqq Na_B < 1.34$
$(Na+K)_A < 0.50$
$(Na+K)_A \geqq 0.50$
$Si \geqq 7.50$
$Si < 7.50$
WINCHITE $X \geqq 0.50$
FERRO-WINCHITE $X < 0.50$
BARROISITE $X \geqq 0.50$
FERRO-BARROISITE $X < 0.50$
$6.50 \leqq Si < 7.50$
MAGNESIO-KATOPHORITE $X \geqq 0.50$
KATOPHORITE $X < 0.50$
$Si \geqq 7.50$
$Si < 6.50$
RICHTERITE $X \geqq 0.50$
FERRO-RICHTERITE $X < 0.50$
MAGNESIO-TARAMITE $X \geqq 0.50$
TARAMITE $X < 0.50$
$X = Mg/(Mg+Fe^{2+})$
ALKALI AMPHIBOLES
$Na_B \geqq 1.34$
$(Na+K)_A < 0.50$
$(Na+K)_A \geqq 0.50$
$Z < 0.30$
CROSSITE $0.30 \leqq Z < 0.70$
$Z \geqq 0.70$
GLAUCOPHANE $Y < 0.50$
FERRO-GLAUCOPHANE $Y \geqq 0.50$
MAGNESIO-RIEBECKITE $Y < 0.50$
RIEBECKITE $Y \geqq 0.50$
$Z \geqq 0.50$
MAGNESIO-ARFVEDSONITE $Y < 0.50$
ARFVEDSONITE $Y \geqq 0.50$
$Z < 0.50$
ECKERMANNITE $Y < 0.50$
FERRO-ECKERMANNITE $Y \geqq 0.50$
$Mn_C \geqq 2.50$
$V > 0.33$
KOZULITE
$Z = Fe^{3+}/(Fe^{3+}+Al^{VI})$
$Y = Fe^{2+}/(Fe^{2+}+Mg)$
$V = Mn^{2+}/(Mg+Fe^{2+}+Mn^{2+})$
Mn_C = Mn in octahedral site

Fig. 1

Out of the 60 names, considered in the present program, the authors were unable to find representative analyses for the following amphiboles: ferro-anthophyllite, ferro-winchite and magnesio-taramite. For the following amphiboles representative microprobe analyses were not found, eben though and extensive survey of the amphibole literature was made: ferro-gedrite, ferro-barroisite, kataphorite, taramite, eckermannite and kozulite. Thus the available wet chemical analyses of these minerals in the literature were taken. The Fe^{3+} was recalculated back to Fe^{2+} and added to the already determined FeO, to obtain the total Fe, similar to the total Fe usually obtained with the microprobe as FeO.

The total sum, excluding H_2O, Cl and F, is taken to represent a microprobe analysis. It is important to note, that the names obtained, using these analyses, are the same as those given by the authors (see table 3)!

A few analyses are not within the total sum-range given by LEAKE, 1968, but as these were the only available ones for the specific names they were taken as an example.

Conclusion

An attempt has been made to determine a name for an amphibole, whose chemical composition is obtained with an electron microprobe, using a computer program, which employs STOUT's (1972) methods of Fe^{3+}-limiting recalculations and the I.M.A.-amphibole nomenclature (LEAKE, 1978, compiler).

(Ca + Na)- and Na-values in the M4-site calculated on the assumption of maximum Fe^{3+} ($\Sigma Fm = 13$) are used for classifying the amphiboles into the four major groups. The Mg/(Mg + Fe^{2+})-ratio calculation determined, assuming minimum Fe^{3+} ($\Sigma Ca = 15$) and maximum Fe^{3+} ($\Sigma Fm = 13$) in the formula, is used for the detailed nomenclature of the first two groups (Fe-Mg-Mn-amphiboles and calcic amphiboles) and the last two major groups (calcic-sodic amphiboles and alkali-amphiboles) respectively. Justification for using these values is given in table 2.

Evaluation of the program, using a series of analyses in the literature, gave consistent and compatible names. For the 56 amphiboles out of the 60 given in fig. 1, representative analyses and the determined corresponding names along with the original references are given in table 3.

Table 3 a: Representative chemical analyses of Fe-Mg-Mn-amphiboles

	1	2	3	4
SiO_2	60.00	52.50	49.01	40.80
TiO_2	0.00	0.00	0.20	0.00
Al_2O_3	0.40	4.40	14.91	18.30
Cr_2O_3	0.00	0.00	0.00	0.00
FeO	0.40	20.40	0.55	25.00
MnO	0.60	0.30	0.00	0.40
MgO	33.40	18.00	28.62	11.40
CaO	0.20	0.50	0.23	0.20
K_2O	0.00	0.00	0.00	0.00
Na_2O	0.20	0.10	1.46	1.60
Total	95.20	96.20	94.98	97.70
Si	8.0861	7.6935	6.6776	6.0704
Ti	0.0000	0.0000	0.0207	0.0000
Al^{IV}	0.0000	0.3665	1.3224	1.9296
Al^{VI}	0.0635	0.4534	1.0719	1.2794
Cr	0.0000	0.0000	0.0000	0.0000
Fe	0.0451	2.5000	0.0627	3.1106
Mn	0.0685	0.0372	0.0000	0.0504
Mg	6.7079	3.9309	5.8112	2.5277
Ca	0.0289	0.0785	0.0336	0.0319
K	0.0000	0.0000	0.0000	0.0000
Na	0.0523	0.0284	0.3857	0.4616
Total	15.0523	15.0284	15.3857	15.4616
oxygen$_{tot.}$	23.1440	23.0876	23.0883	22.9057
Fe^{2+}	0.0451	2.5000	0.0627	2.9220
Fe^{3+}	0.0000	0.0000	0.0000	0.1886
$Mg/(Mg + Fe^{2+})$	0.9933	0.6113	0.9893	0.4638
Na_B	0.0000	0.0000	0.0000	0.0000
$(Ca + Na)_B$	0.0289	0.0785	0.0336	0.0319
$(Na + K)_A$	0.0523	0.0284	0.3857	0.4616

1: MAGNESIO-ANTHOPHYLLITE (KLEIN, 1968: Table 3, analysis 1, "anthophyllite")
2: ANTHOPHYLLITE (STOUT, 1972: Table 4 A, analysis GAB 1, "anthophyllite")
3: MAGNESIO-GEDRITE (SCHREYER, 1976: Table 4, analysis GE 1, "magnesio-gedrite")
4: GEDRITE (STOUT, 1972: Table 5 A, analysis GK, "gedrite")

Table 3 b: Representative chemical analyses of Fe-Mg-Mn-amphiboles

	5	6	7
SiO_2	38.41	56.78	52.50
TiO_2	0.48	0.00	0.00
Al_2O_3	19.72	0.96	1.60
Cr_2O_3	0.00	0.00	0.00
FeO	35.53	13.31	27.30
MnO	2.30	0.33	0.80
MgO	0.03	24.71	14.70
CaO	0.03	0.83	0.60
K_2O	0.04	0.00	0.00
Na_2O	1.16	0.12	0.10
Total	97.67	97.04	97.60
Si	6.1453	7.9572	7.8403
Ti	0.0583	0.0000	0.0000
Al^{IV}	1.8547	0.0428	0.1597
Al^{VI}	1.8639	0.1158	0.1219
Cr	0.0000	0.0000	0.0000
Fe	4.7538	1.5599	3.4094
Mn	0.3117	0.0392	0.1012
Mg	0.0072	5.1605	3.2715
Ca	0.0051	0.1246	0.0960
K	0.0082	0.0000	0.0000
Na	0.3598	0.0326	0.0290
Total	15.3680	15.0326	15.0290
$oxygen_{tot.}$	23.2470	23.0528	22.9956
Fe^{2+}	4.7538	1.5599	3.4005
Fe^{3+}	0.0000	0.0000	0.0089
$Mg/(Mg + Fe^{2+})$	0.0015	0.7679	0.4903
Na_B	0.0000	0.0000	0.0000
$(Ca + Na)_B$	0.0051	0.1246	0.0960
$(Na + K)_A$	0.3680	0.0326	0.0290

5: FERRO-GEDRITE (YAMASAKI, 1957: Table 5, "aluminian ferroanthophyllite")
6: MAGNESIO-CUMMINGTONITE (WILKINSON, 1975: Table 4, analysis 1, "magnesio-cummingtonite")
7: CUMMINGTONITE (STOUT, 1972: Table 3 A, analysis 249 L 3, "cummingtonite")

Table 3 c: Representative chemical analyses of Fe-Mg-Mn-amphiboles

	8	9	10
SiO_2	49.55	50.60	55.27
TiO_2	0.00	0.00	0.00
Al_2O_3	0.12	0.04	0.34
Cr_2O_3	0.00	0.00	0.00
FeO	40.14	36.10	4.52
MnO	1.84	5.80	16.62
MgO	4.89	6.40	19.18
CaO	0.70	0.40	1.19
K_2O	0.00	0.00	0.00
Na_2O	0.00	0.05	0.26
Total	97.24	99.39	97.38
Si	8.0040	7.9298	8.0190
Ti	0.0000	0.0000	0.0000
Al^{IV}	0.0000	0.0074	0.0000
Al^{VI}	0.0228	0.0000	0.0581
Cr	0.0000	0.0000	0.0000
Fe	5.4226	4.7311	0.5484
Mn	0.2518	0.7699	2.0424
Mg	1.1772	1.4947	4.1470
Ca	0.1212	0.0672	0.1850
K	0.0000	0.0000	0.0000
Na	0.0000	0.0152	0.0731
Total	15.0000	15.0152	15.0731
$oxygen_{tot.}$	23.0158	22.9411	23.0847
Fe^{2+}	5.4226	4.6133	0.5484
Fe^{3+}	0.0000	0.1179	0.0000
$Mg/(Mg + Fe^{2+})$	0.1784	0.2447	0.8832
Na_B	0.0000	0.0000	0.0000
$(Ca + Na)_B$	0.1212	0.0672	0.1850
$(Na + K)_A$	0.0000	0.0152	0.0731

8 : GRUNERITE (SCHREYER, 1978: Table 1, "cummingtonite")
9 : TIRODITE (BLACK, 1973: Table 1, "manganiferous grunerite")
10: DANNEMORITE (KLEIN, 1964: Analysis # 2, "Mn-cummingtonite")

Table 3 d: Representative chemical analyses of calcic amphiboles

	11	12	13	14
SiO_2	46.73	44.07	52.93	53.00
TiO_2	0.33	1.05	0.05	0.07
Al_2O_3	10.10	12.86	6.01	2.97
Cr_2O_3	0.00	0.00	0.00	0.01
FeO	14.77	17.29	4.17	10.90
MnO	0.00	0.00	0.00	0.25
MgO	12.85	8.30	21.07	17.30
CaO	11.70	11.38	12.86	13.70
K_2O	0.20	0.08	0.48	0.06
Na_2O	0.83	1.21	1.13	0.30
Total	97.51	96.22	98.70	98.56
Si	6.8105	6.6747	7.3029	7.4754
Ti	0.0365	0.1208	0.0052	0.0075
Al^{IV}	1.1895	1.3253	0.6971	0.4937
Al^{VI}	0.5454	0.9696	0.2802	0.0000
Cr	0.0000	0.0000	0.0000	0.0011
Fe	1.8002	2.1902	0.4811	1.2857
Mn	0.0000	0.0000	0.0000	0.0299
Mg	2.7909	1.8724	4.3323	3.6363
Ca	1.8270	1.8469	1.9011	2.0704
K	0.0372	0.0145	0.0845	0.0108
Na	0.2345	0.3539	0.3023	0.0820
Total	15.2717	15.3684	15.3868	15.0928
$oxygen_{tot.}$	22.8504	23.1272	22.9902	22.7768
Fe^{2+}	1.5009	2.1902	0.4616	0.8392
Fe^{3+}	0.2993	0.0000	0.0196	0.4465
$Mg/(Mg + Fe^{2+})$	0.6503	0.4609	0.9037	0.8125
Na_B	0.0000	0.0000	0.0000	0.0000
$(Ca + Na)_B$	1.8270	1.8469	1.9011	2.0704
$(Na + K)_A$	0.2717	0.3684	0.3868	0.0928

11: MAGNESIO-HORNBLENDE (LIOU et al., 1981: Analysis TPY 6617, "green hornblende")

12: FERRO-HORNBLENDE (LIOU et al., 1981: Analysis T-342, "hornblende")

13: TREMOLITIC HORNBLENDE (ADIB, 1982: Analysis A 2, "end member formula $Ed_{17}Ho_{33}Tr_{50}$")

14: ACTINOLITIC HORNBLENDE (PURTSCHELLER & RAMMLMAIR, 1982: Analysis IV-23, "hornblende")

Table 3 e: Representative chemical analyses of calcic amphiboles

	15	16	17	18
SiO_2	48.72	59.40	52.80	50.60
TiO_2	0.29	0.00	1.41	0.14
Al_2O_3	4.59	0.57	2.87	1.63
Cr_2O_3	0.00	0.00	0.06	0.00
FeO	20.15	0.43	10.60	25.77
MnO	0.39	0.00	0.18	1.34
MgO	10.64	23.75	16.30	5.88
CaO	11.29	13.25	11.10	11.56
K_2O	0.40	0.00	0.08	0.00
Na_2O	0.79	0.14	0.30	0.23
Total	97.26	97.54	95.70	97.15
Si	7.3459	8.0984	7.7267	7.8684
Ti	0.0332	0.0000	0.1568	0.0165
Al^{IV}	0.6541	0.0000	0.2733	0.1316
Al^{VI}	0.1616	0.0916	0.2217	0.1672
Cr	0.0000	0.0000	0.0069	0.0000
Fe	2.5407	0.0490	1.2972	3.3512
Mn	0.0498	0.0000	0.0223	0.1765
Mg	2.3908	4.8254	3.5547	1.3626
Ca	1.8239	1.9355	1.7404	1.9260
K	0.0769	0.0000	0.0149	0.0000
Na	0.2309	0.0370	0.0851	0.0693
Total	15.3079	15.0370	15.1001	15.0693
$oxygen_{tot.}$	22.9409	23.1627	23.1844	23.0690
Fe^{2+}	2.4226	0.0490	1.2972	3.3512
Fe^{3+}	0.1182	0.0000	0.0000	0.0000
$Mg/(Mg + Fe^{2+})$	0.4967	0.9899	0.7326	0.2891
Na_B	0.0000	0.0000	0.0000	0.0000
$(Ca + Na)_B$	1.8239	1.9355	1.7404	1.9260
$(Na + K)_A$	0.3079	0.0370	0.1001	0.0693

15: FERRO-ACTINOLITIC HORNBLENDE (SMULIKOWSKI, 1974: Table 1, analysis 4, "post-actinolite, blue hornblende")

16: TREMOLITE (HOINKES, 1976: Table 1, analysis # 1, "tremolite")

17: ACTINOLITE (PURTSCHELLER & RAMMLMAIR, 1982: Analysis IV-RV3, "hornblende")

18: FERRO-ACTINOLITE (DICKIN, 1981: Table 1, analysis CC 24, "ferro-actinolite")

Table 3 f: Representative chemical analyses of calcic amphiboles

	19	20	21	22
SiO_2	42.10	43.30	40.98	41.30
TiO_2	0.30	0.30	0.36	0.33
Al_2O_3	10.80	13.10	17.38	19.10
Cr_2O_3	0.00	0.00	0.00	0.00
FeO	17.40	19.60	19.38	17.73
MnO	0.00	0.00	0.10	0.34
MgO	11.30	8.70	9.43	6.29
CaO	12.30	12.30	8.85	11.35
K_2O	0.30	0.50	0.43	0.59
Na_2O	0.90	1.30	0.99	0.95
Total	95.40	99.10	97.90	97.98
Si	6.3387	6.3989	6.0523	6.1513
Ti	0.0343	0.0337	0.0404	0.0373
Al^{IV}	1.6613	1.6011	1.9477	1.8487
Al^{VI}	0.2552	0.6805	1.0776	1.5041
Cr	0.0000	0.0000	0.0000	0.0000
Fe	2.1909	2.4222	2.3936	2.2083
Mn	0.0000	0.0000	0.0125	0.0429
Mg	2.5354	1.9160	2.0755	1.3961
Ca	1.9842	1.9475	1.4004	1.8112
K	0.0576	0.0943	0.0810	0.1121
Na	0.2627	0.3725	0.2835	0.2743
Total	15.3204	15.4667	15.3645	15.3864
$oxygen_{tot.}$	22.4914	22.8068	22.7876	23.0582
Fe^{2+}	1.1737	2.0358	1.9688	2.2083
Fe^{3+}	1.0171	0.3865	0.4248	0.0000
$Mg/(Mg + Fe^{2+})$	0.6836	0.4848	0.5132	0.3873
Na_B	0.0000	0.0000	0.0000	0.0000
$(Ca + Na)_B$	1.9842	1.9475	1.4004	1.8112
$(Na + K)_A$	0.3204	0.4667	0.3645	0.3864

19: TSCHERMAKITIC HORNBLENDE (TAGIRI, 1977: Table 1, analysis 1 H, "hornblende")

20: FERRO-TSCHERMAKITIC HORNBLENDE (TAGIRI, 1977: Table 1, analysis HT593/2 H, "hornblende")

21: TSCHERMAKITE (MOGESSIE, 1982: Unpublished analysis, sample F-89, Festkogel, Ötztal, Eastern Alps, Austria)

22: FERRO-TSCHERMAKITE (DOOLAN et al., 1978: Table 2, analysis 1-5, "aluminous amphibole")

Table 3 g: Representative chemical analyses of calcic amphiboles

	23	24	25	26
SiO_2	47.20	44.58	44.42	42.56
TiO_2	0.00	1.78	0.40	0.89
Al_2O_3	11.60	7.09	15.25	12.99
Cr_2O_3	0.00	0.00	0.01	0.00
FeO	3.30	21.10	15.30	18.23
MnO	0.00	0.31	0.06	0.00
MgO	17.60	9.28	10.28	7.45
CaO	12.10	10.76	9.41	11.44
K_2O	0.00	0.94	0.41	1.23
Na_2O	3.50	1.33	1.54	1.21
Total	95.30	97.17	97.08	96.00
Si	6.8856	6.8546	6.6001	6.5720
Ti	0.0000	0.2079	0.0452	0.1038
Al^{IV}	1.1144	1.1454	1.3999	1.4280
Al^{VI}	0.8800	0.1395	1.2707	0.9361
Cr	0.0000	0.0000	0.0012	0.0000
Fe	0.3992	2.7131	1.9011	2.3541
Mn	0.0000	0.0404	0.0076	0.0000
Mg	3.8262	2.1264	2.2763	1.7132
Ca	1.8912	1.7726	1.4981	1.8927
K	0.0000	0.1844	0.0777	0.2413
Na	0.9900	0.3965	0.4437	0.3608
Total	15.9866	15.5809	15.5214	15.6021
$oxygen_{tot.}$	23.3777	22.9954	23.2418	23.1589
Fe^{2+}	0.4026	2.7040	1.9011	2.3541
Fe^{3+}	0.0000	0.0091	0.0000	0.0000
$Mg/(Mg + Fe^{2+})$	0.9048	0.4402	0.5449	0.4212
Na_B	0.0000	0.0000	0.0000	0.0000
$(Ca + Na)_B$	1.8912	1.7726	1.4981	1.8927
$(Na + K)_A$	0.9900	0.5809	0.5214	0.6021

23: EDENITE (FEININGER, 1980: Table 6, analysis 7, "green magnesian amphibole intermediate between barroisite and hornblende")

24: FERRO-EDENITE (SMULIKOWSKI, 1974: Table 1, analysis 5, "brown hornblende")

25: EDENITIC HORNBLENDE (HOINKES, 1978: Table 3, analysis S 66, "hornblende")

26: FERRO-EDENITIC HORNBLENDE (LIOU et al., 1981: Analysis T-12A, "brown hornblende")

Table 3 h: Representative chemical analyses of calcic amphiboles

	27	28	29	30
SiO_2	40.90	39.40	43.70	49.10
TiO_2	5.61	4.37	0.00	1.44
Al_2O_3	10.70	10.90	14.40	5.50
Cr_2O_3	0.00	0.00	0.00	0.00
FeO	11.20	17.40	13.80	17.70
MnO	0.14	0.35	0.20	0.30
MgO	13.20	9.36	14.10	12.10
CaO	12.10	11.70	10.50	10.50
K_2O	1.37	0.83	0.00	0.54
Na_2O	2.33	3.17	2.00	1.65
Total	97.55	97.48	98.70	98.83
Si	6.1415	6.0992	6.2641	7.2910
Ti	0.6400	0.5140	0.0000	0.1625
Al^{IV}	1.8585	1.9008	1.7359	0.7090
Al^{VI}	0.0352	0.0878	0.6969	0.2536
Cr	0.0000	0.0000	0.0000	0.0000
Fe	1.4064	2.2525	1.6543	2.1980
Mn	0.0178	0.0459	0.0243	0.0377
Mg	2.9538	2.1593	3.0120	2.6776
Ca	1.9467	1.9406	1.6126	1.6706
K	0.2624	0.1639	0.0000	0.1023
Na	0.6784	0.9514	0.5559	0.4751
Total	15.9408	16.1153	15.5559	15.5773
$oxygen_{tot.}$	23.1988	23.1651	22.7584	23.2235
Fe^{2+}	1.4064	2.2525	1.1711	2.1980
Fe^{3+}	0.0000	0.0000	0.4832	0.0000
$Mg/(Mg + Fe^{2+})$	0.6774	0.4894	0.7200	0.5492
Na_B	0.0000	0.0000	0.0000	0.0000
$(Ca + Na)_B$	1.9467	1.9406	1.6126	1.6706
$(Na + K)_A$	0.9408	1.1153	0.5559	0.5773

27: KAERSUTITE (SHEPPARD, 1977: Analysis 134/LH7, "titaniferous hornblende")

28: FERRO-KAERSUTITE (SHEPPARD, 1977: Analysis L 148, "titaniferous hornblende")

29: PARGASITIC HORNBLENDE (KLEIN, 1968: Table 5, analysis 4 H, "hornblende")

30: FERROAN PARGASITIC HORNBLENDE (PURTSCHELLER & RAMMLMAIR, 1982: Analysis III-RP4, "hornblende")

Table 3 i: Representative chemical analyses of calcic amphiboles

	31	32	33
SiO_2	42.20	41.10	39.90
TiO_2	2.20	0.43	0.00
Al_2O_3	12.80	17.40	16.30
Cr_2O_3	0.08	0.00	0.00
FeO	11.40	16.60	24.30
MnO	0.10	0.20	0.20
MgO	14.30	11.00	4.80
CaO	11.90	8.60	10.80
K_2O	0.46	1.54	0.00
Na_2O	2.23	0.84	1.70
Total	97.67	97.71	98.00
Si	6.1636	6.0684	6.0869
Ti	0.2441	0.0482	0.0000
Al^{IV}	1.8364	1.9316	1.9131
Al^{VI}	0.3670	1.0963	1.0176
Cr	0.0092	0.0000	0.0000
Fe	1.3924	2.0497	3.1001
Mn	0.0124	0.0250	0.0258
Mg	3.1125	2.4204	1.0912
Ca	1.8622	1.3605	1.7653
K	0.0857	0.2901	0.0000
Na	0.6315	0.2405	0.5028
Total	15.7172	15.5307	15.5028
$oxygen_{tot.}$	22.8727	22.8958	22.8036
Fe^{2+}	1.1378	1.8413	2.7074
Fe^{3+}	0.2546	0.2084	0.3927
$Mg/(Mg + Fe^{2+})$	0.7323	0.5679	0.2873
Na_B	0.0000	0.0000	0.0000
$(Ca + Na)_B$	1.8622	1.3605	1.7653
$(Na + K)_A$	0.7172	0.5305	0.5028

31: PARGASITE (EMBEY et al., 1981: Table 2, analysis 1, "pargasite")
32: FERROAN PARGASITE (TESSADRI, 1981: Unpublished analysis, sample T 24, Sterzing, Eastern Alps, "pargasitic hornblende")
33: FERRO-PARGASITE (KLEIN, 1968: Table 5, analysis 24 H, "hornblende")

Table 3 j: Representative chemical analyses of calcic amphiboles

	34	35	36
SiO_2	43.20	41.07	40.20
TiO_2	0.00	0.79	0.42
Al_2O_3	12.80	10.96	10.00
Cr_2O_3	0.00	0.00	0.00
FeO	14.20	21.84	27.80
MnO	0.00	0.22	1.51
MgO	13.80	7.98	3.60
CaO	11.30	11.81	10.60
K_2O	0.00	0.32	1.27
Na_2O	2.30	1.92	1.56
Total	97.60	96.91	96.96
Si	6.3015	6.3078	6.4455
Ti	0.0000	0.0922	0.0513
Al^{IV}	1.6985	1.6922	1.5545
Al^{VI}	0.5020	0.2917	0.3351
Cr	0.0000	0.0000	0.0000
Fe	1.7322	2.8051	3.7275
Mn	0.0000	0.0286	0.2051
Mg	2.9998	1.8265	0.8602
Ca	1.7660	1.9434	1.8210
K	0.0000	0.0627	0.2598
Na	0.6505	0.5717	0.4850
Total	15.6505	15.6219	15.7447
$\text{oxygen}_{\text{tot.}}$	22.7270	22.7092	22.8138
Fe^{2+}	1.8161	2.2234	3.3551
Fe^{3+}	0.5461	0.5817	0.3724
$Mg/(Mg + Fe^{2+})$	0.7166	0.4510	0.2041
Na_B	0.0000	0.0000	0.0000
$(Ca + Na)_B$	1.7660	1.9434	1.8210
$(Na + K)_A$	0.6505	0.6344	0.7447

34: MAGNESIO-HASTINGSITIC HORNBLENDE (KLEIN, 1968: Table 5, analysis 14 H, "hornblende")
35: MAGNESIAN HASTINGSITIC HORNBLENDE (MOGESSIE, 1982: Unpublished analysis, Sölden/Ötztal, Eastern Alps, Austria, "green hornblende")
36: HASTINGSITIC HORNBLENDE (FRISCH, 1976: Analysis 49, 074, "hastingsitic hornblende")

Table 3 k: Representative chemical analyses of calcic amphiboles

	37	38	39
SiO_2	42.90	39.38	39.40
TiO_2	0.21	0.54	0.08
Al_2O_3	13.70	11.32	14.20
Cr_2O_3	0.00	0.00	0.00
FeO	10.52	15.41	30.40
MnO	0.11	0.52	0.46
MgO	16.10	11.05	2.70
CaO	11.30	12.07	11.80
K_2O	0.79	1.21	0.26
Na_2O	1.66	2.85	2.60
Total	97.29	94.37	101.90
Si	6.1758	6.1622	5.9893
Ti	0.0230	0.0642	0.0092
Al^{IV}	1.8242	1.8378	2.0107
Al^{VI}	0.5002	0.2499	0.5334
Cr	0.0000	0.0000	0.0000
Fe	1.2665	2.0165	3.8646
Mn	0.0134	0.0689	0.0592
Mg	3.4540	2.5768	0.6116
Ca	1.7429	2.0236	1.9219
K	0.1451	0.2415	0.0504
Na	0.4633	0.8647	0.7663
Total	15.6084	16.1062	15.8167
$oxygen_{tot.}$	22.6652	22.8234	22.6790
Fe^{2+}	0.5969	1.6633	3.2225
Fe^{3+}	0.6696	0.3533	0.6420
$Mg/(Mg + Fe^{2+})$	0.8527	0.6077	0.1595
Na_B	0.0000	0.0000	0.0000
$(Ca + Na)_B$	1.7429	2.0236	1.9219
$(Na + K)_A$	0.6084	1.1062	0.8167

37: MAGNESIO-HASTINGSITE (CRAWFORD, 1980: Table 6, analysis B, "pargasitic amphibole")

38: MAGNESIAN HASTINGSITE (BROWN, 1978: Analysis 7, "hastingsite - magnesio-hastingsite")

39: HASTINGSITE (HONNOREZ et al., 1975: Table 3, analysis P 6707-33 M, "chlor amphibole")

Table 3 I: Representative chemical analyses of calcic-sodic amphiboles

	40	41	42	43
SiO_2	56.10	47.40	45.99	58.23
TiO_2	0.04	0.31	1.00	0.21
Al_2O_3	1.70	12.10	5.77	0.15
Cr_2O_3	0.05	0.00	0.00	0.07
FeO	3.07	14.69	34.27	0.01
MnO	0.07	0.18	1.08	0.02
MgO	23.10	10.70	0.49	24.20
CaO	9.03	7.20	4.93	6.69
K_2O	0.73	0.28	1.10	0.48
Na_2O	3.68	4.50	3.26	7.22
Total	97.57	97.36	97.69	97.28
Si	7.6587	6.8255	7.1500	7.9926
Ti	0.0041	0.0339	0.1181	0.0219
Al^{IV}	0.2735	1.1745	0.8500	0.0074
Al^{VI}	0.0000	0.8790	0.1706	0.0169
Cr	0.0054	0.0000	0.0000	0.0076
Fe	0.3505	1.7690	4.4555	0.0011
Mn	0.0081	0.0220	0.1422	0.0023
Mg	4.6996	2.2961	0.1135	4.9501
Ca	1.3208	1.1108	0.8212	0.9839
K	0.1271	0.0514	0.2182	0.0840
Na	0.9741	1.2564	0.9827	1.9215
Total	15.4220	15.4187	15.0220	15.9894
$oxygen_{tot.}$	22.6738	22.6509	22.2000	23.0171
Fe^{2+}	0.0000	1.0708	2.8556	0.0011
Fe^{3+}	0.3505	0.6982	1.5999	0.0000
$Mg/(Mg + Fe^{2+})$	1.0000	0.6820	0.0382	0.9998
$Fe^{3+}/(Fe^{3+} + Al^{VI})$	1.0000	0.4427	0.9036	0.0000
$Fe^{2+}/(Fe^{2+} + Mg)$	0.0000	0.3180	0.9618	0.0002
$Mn/(Mn + Fe^{2+} + Mg)$	0.0017	0.0065	0.0457	0.0001
Na_B	0.6792	0.8892	0.9827	1.0161
$(Ca + Na)_B$	2.0000	2.0000	1.8039	2.0000
$(Na + K)_A$	0.4220	0.4187	0.2182	0.9894

40: WINCHITE (SMITH, 1977: Table 1, analysis 3, "tremolite - richterite")
41: BARROISITE (MILLER, 1977: Table 10 a, sample T 258/E 1,"barroisite")
42: FERRO-BARROISITE (HYTÖNEN & HEIKKINEN, 1966: Table 4, analysis #1, "iron-rich alkali amphibole")
43: RICHTERITE (BEVAN, 1977: Table II, analysis 1, "richterite")

Table 3 m: Representative chemical analyses of calcic-sodic amphiboles

	44	45	46	47
SiO_2	47.20	47.87	48.87	37.20
TiO_2	1.66	2.26	1.72	1.36
Al_2O_3	1.71	4.48	3.86	12.13
Cr_2O_3	0.00	0.00	0.00	0.00
FeO	34.40	14.27	23.40	29.95
MnO	0.78	0.17	1.52	1.14
MgO	0.15	13.94	6.13	1.42
CaO	5.07	6.41	5.02	7.36
K_2O	1.20	1.07	1.03	2.43
Na_2O	4.73	6.20	6.52	4.22
Total	96.90	96.67	98.07	97.21
Si	7.6557	7.0944	7.4992	5.9957
Ti	0.2046	0.2545	0.2005	0.1665
Al^{IV}	0.3270	0.7825	0.5008	2.0043
Al^{VI}	0.0000	0.0000	0.1973	0.2999
Cr	0.0000	0.0000	0.0000	0.0000
Fe	4.6672	1.7686	3.0028	4.0368
Mn	0.1072	0.0213	0.1976	0.1556
Mg	0.0363	3.0787	1.4018	0.3411
Ca	0.8813	1.0178	0.8254	1.2710
K	0.2484	0.2023	0.2016	0.4996
Na	1.4879	1.7815	1.9399	1.3188
Total	15.6176	16.0017	15.9668	16.0894
$oxygen_{tot.}$	22.7752	22.7499	22.9448	22.4945
Fe^{2+}	4.2177	1.2683	2.8925	3.0259
Fe^{3+}	0.4495	0.5003	0.1103	1.0109
$Mg/(Mg + Fe^{2+})$	0.0085	0.7082	0.3264	0.1013
$Fe^{3+}/(Fe^{3+} + Al^{VI})$	1.0000	1.0000	0.3587	0.7712
$Fe^{2+}/(Fe^{2+} + Mg)$	0.9915	0.2918	0.6736	0.8987
$Mn/(Mn + Fe^{2+} + Mg)$	0.0246	0.0049	0.0440	0.0442
Na_B	1.1187	0.9822	1.1746	0.7290
$(Ca + Na)_B$	2.0000	2.0000	2.0000	2.0000
$(Na + K)_A$	0.6176	1.0017	0.9662	1.0894

44: FERRO-RICHTERITE (THOMPSON, 1976: Analysis # 1, "ferro-richterite")
45: MAGNESIO-KATOPHORITE (NIELSON, 1979: Table 3, analysis 10, "magnesio-katophorite")
46: KATOPHORITE (DEER et al., 1963: p. 360, analysis # 3, "katophorite")
47: TARAMITE (LEAKE, 1968: Analysis 926, "subcalcic-sodic-potassic hastingsite")

Table 3 n: Representative chemical analyses of alkali-amphiboles

	48	49	50
SiO_2	54.40	57.39	54.40
TiO_2	0.00	0.00	0.00
Al_2O_3	8.20	11.44	9.00
Cr_2O_3	0.00	0.00	0.00
FeO	16.00	15.24	10.30
MnO	0.00	0.00	0.00
MgO	8.40	6.25	12.20
CaO	1.20	0.35	1.60
K_2O	0.00	0.00	0.00
Na_2O	7.20	7.14	6.60
Total	95.40	97.81	94.10
Si	7.8610	8.0281	7.7036
Ti	0.0000	0.0000	0.0000
Al^{IV}	0.1390	0.0000	0.2964
Al^{VI}	1.2576	1.8861	1.2056
Cr	0.0000	0.0000	0.0000
Fe	1.9335	1.7828	1.2198
Mn	0.0000	0.0000	0.0000
Mg	1.8089	1.3029	2.5746
Ca	0.1858	0.0525	0.2428
K	0.0000	0.0000	0.0000
Na	2.0173	1.9366	1.8121
Total	15.2031	14.9890	15.0549
$oxygen_{tot.}$	22.7537	22.9918	22.6034
Fe^{2+}	1.4410	1.7667	0.4266
Fe^{3+}	0.4925	0.0161	0.7932
$Mg/(Mg + Fe^{2+})$	0.5566	0.4245	0.8579
$Fe^{3+}/(Fe^{3+} + Al^{VI})$	0.2814	0.0085	0.3968
$Fe^{2+}/(Fe^{2+} + Mg)$	0.4434	0.5755	0.1421
$Mn/(Mn + Fe^{2+} + Mg)$	0.0000	0.0000	0.0000
Na_B	1.8142	1.9366	1.7572
$(Ca + Na)_B$	2.0000	1.9890	2.0000
$(Na + K)_A$	0.2031	0.0000	0.0549

48: GLAUCOPHANE (PAPIKE et al., 1969: Table 1, analysis 201, "sodic amphibole")

49: FERRO-GLAUCOPHANE (KATAGAS, 1980: Table 1, analysis 1, "ferro-glaucophane")

50: CROSSITE (FEININGER, 1978: Table 6, analysis 5, "glaucophane")

Table 3 o: Representative chemical analyses of alkali-amphiboles

	51	52	53	54
SiO_2	54.00	53.00	52.59	57.20
TiO_2	0.03	0.03	0.91	2.20
Al_2O_3	2.56	4.11	1.64	0.38
Cr_2O_3	0.00	0.00	0.00	3.50
FeO	24.00	27.10	18.72	0.44
MnO	0.12	0.31	0.60	0.05
MgO	7.53	6.02	9.32	20.90
CaO	1.26	2.59	3.41	3.70
K_2O	0.07	0.04	2.06	1.20
Na_2O	6.37	5.50	6.79	8.30
Total	95.94	98.70	96.04	97.87
Si	7.9382	7.6757	8.0180	7.9409
Ti	0.0034	0.0033	0.1054	0.2320
Al^{IV}	0.0618	0.3243	0.0000	0.0591
Al^{VI}	0.3817	0.3773	0.2947	0.0030
Cr	0.0000	0.0000	0.0000	0.3841
Fe	2.9504	3.2821	2.3868	0.0511
Mn	0.0149	0.0380	0.0775	0.0059
Mg	1.6496	1.2993	2.1176	4.3239
Ca	0.1985	0.4019	0.5570	0.5503
K	0.0131	0.0074	0.4006	0.2125
Na	1.8156	1.5444	2.0072	2.2341
Total	15.0272	14.9537	15.9649	15.9970
$oxygen_{tot.}$	22.2761	22.2076	23.0318	23.1697
Fe^{2+}	1.5026	1.6973	2.3868	0.0511
Fe^{3+}	1.4478	1.5848	0.0000	0.0000
$Mg/(Mg + Fe^{2+})$	0.5233	0.4336	0.4701	0.9883
$Fe^{3+}/(Fe^{3+} + Al^{VI})$	0.7914	0.8077	0.0000	0.0000
$Fe^{2+}/(Fe^{2+} + Mg)$	0.4767	0.5664	0.5299	0.0117
$Mn/(Mn + Fe^{2+} + Mg)$	0.0047	0.0125	0.0169	0.0013
Na_B	1.8015	1.5444	1.4430	1.4497
$(Ca + Na)_B$	2.0000	1.9463	2.0000	2.0000
$(Na + K)_A$	0.0272	0.0074	0.9649	0.9970

51: MAGNESIO-RIEBECKITE (KOLLER, 1978: Table 1, analysis 9, "riebeckite - magnesio-riebeckite")

52: RIEBECKITE (KOLLER, 1978: Table 1, analysis 8, "riebeckite - magnesio-riebeckite")

53: ECKERMANNITE (ESKOLA & SAHLSTEIN, 1930: Analysis # 2, "fluor-taramite")

54: FERRO-ECKERMANNITE (BEVAN, 1977: Table II, analysis III, "richterite")

Table 3 p: Representative chemical analyses of alkali-amphiboles

	55	56	57
SiO_2	49.74	49.30	51.38
TiO_2	3.09	1.28	0.00
Al_2O_3	3.13	0.99	1.69
Cr_2O_3	0.00	0.00	0.00
FeO	17.61	33.80	2.57
MnO	0.48	0.98	27.96
MgO	11.19	0.25	2.71
CaO	2.40	3.06	1.12
K_2O	1.26	1.33	1.36
Na_2O	8.55	5.89	8.41
Total	97.45	96.88	97.20
Si	7.3827	7.9214	8.0241
Ti	0.3485	0.1563	0.0000
Al^{IV}	0.5475	0.0786	0.0000
Al^{VI}	0.0000	0.1088	0.3110
Cr	0.0000	0.0000	0.0000
Fe	2.1858	4.5417	0.3356
Mn	0.0603	0.1334	3.6985
Mg	2.4751	0.0599	0.6307
Ca	0.3817	0.5268	0.1874
K	0.2386	0.2726	0.2709
Na	2.4605	1.8349	2.5465
Total	16.0808	15.6343	16.0049
$oxygen_{tot.}$	22.7362	22.7519	22.7758
Fe^{2+}	1.6581	4.0455	0.0000
Fe^{3+}	0.5277	0.4962	0.3356
$Mg/(Mg + Fe^{2+})$	0.5988	0.0146	1.0000
$Fe^{3+}/(Fe^{3+} + Al^{VI})$	1.0000	0.8201	0.5190
$Fe^{2+}/(Fe^{2+} + Mg)$	0.4012	0.9854	0.0000
$Mn/(Mn + Fe^{2+} + Mg)$	0.0144	0.0315	0.8543
Na_B	1.6183	1.4732	1.8126
$(Ca + Na)_B$	2.0000	2.0000	2.0000
$(Na + K)_A$	1.0808	0.6343	1.0049

55: MAGNESIO-ARFVEDSONITE (NIELSEN, 1979: Table 3, analysis II, "magnesio-arfvedsonite")

56: ARFVEDSONITE (THOMPSON, 1976: Table 1, analysis SK 887, "ferro-richterite - arfvedsonite")

57: KOZULITE (NAMBU et al., 1969, "kozulite")

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Appendix

The program is written on a Commodore BASIC computer (2001 series). The program itself is written in a very simple way; only few BASIC-commands have been used, in order to enable everyone to go through the program step by step.
An outprint of the program is available from the authors.

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