Classification and Nomenclature

The information contained in this section is taken from the report of the I.M.A. Subcommittee on Amphiboles (Leake 1978), the addendum to this report (Leake & Hey 1979) and Leake (pers. comm.). A standard amphibole formula may be written as:

$A_{0-1}B_2C_5T_8O_{22}(OH,F,Cl)_2$ where

A = Na,K;
B = Na,Li,Ca,Mn,Fe^{2+}, Mg;
C = Mg,Fe^{2+}, Mn,Al,Fe^{3+},Ti,Li, and
T = Si,Al.

The assignment of cations given above is by no means comprehensive, and a more detailed examination of group and site occupancies will be given in a later section. The classification of the amphiboles is based largely on crystal chemistry, having as its basis the chemical contents of the formula unit calculated to 24(O,OH,F,Cl), where possible. A large number of amphiboles are now routinely analyzed by electron microprobe, and the Fe^{2+}/Fe^{3+} ratio is not derived experimentally. There are general techniques whereby this ratio may be calculated; these are examined more closely in the next section. Leake & Hey (1979) suggested calculating the formula on the basis of thirteen cations excluding Ca, Na and K, and then adjusting the Fe^{2+}/Fe^{3+} ratio to bring O + OH to 24 or O to 23.

In this classification, principal stoichiometries are identified by generally well-established names, with prefixes and adjectival modifiers to indicate the presence of substantial substitutions by ions that are not essential constituents of the end members. Prefixes are an inseparable part of the name and should be attached by a hyphen; consequently, an amphibole should be indexed under (the initial letter of) the prefix, with perhaps a cross-reference under the species name. Adjectival modifiers are not an essential part of the amphibole name, but are simple adjectives ending in -ian or -oan according to the valency of the substituting ion. They denote minor substitutions and are not an essential part of the amphibole name; consequently, they are not used in the first stage of indexing, and the amphibole should be indexed under its species name. Prefixes and adjectival modifiers of general application are listed in Table 1, together with the limits and restrictions on their use. Additional adjectives may be approved as needed (*e.g.*, nickeloan, cuprian). A few prefixes must be defined differently in the different amphibole groups; these will be given later. The prefixes magnesio-, ferro-, alumino- and ferri- are often used with names that refer to part of a series. Alternate names are often so widely used for ends of some series that they are preferable to the ideal names (*e.g.*, tremolite instead of magnesio-actinolite, tschermakite instead of alumino-tschermakite). The prefix "pure" *may* be used to indicate a theoretical end-member formula.

TABLE 1. PREFIXES AND ADJECTIVAL MODIFIERS FOR THE AMPHIBOLES

	Prefixes
alumino-	see Tables 2, 3 and 4, also text
chlor-	when Cl≥1·00* (∿4% Cl)
chromium-	when Cr≥1·00 (∿9% Cr_2O_3)
ferri-	when Fe^3≥1·00 (∿9% Fe_2O_3) except in alkali amphiboles and hastingsite
ferro-	see Tables 2, 3 and 4, also text
fluor-	when F≥1·00 (∿2% F)
hydro-	when OH≥3·00 (∿3% H_2O)
manganese-	when Mn≥1·00 (∿10% MnO) except in end-members containing Mn
magnesio-	see Tables 2, 3 and 4, also text
oxy-	when (OH+F+Cl) is confirmed as <1·00
potassium-	when K≥0·50 (∿2.7% K_2O)
sodium-	see Table 2
titanium-	when Ti≥1·00 (∿10% TiO_2) except in kaersutite
zinc-	when Zn≥1·00 (∿5% ZnO)
	Adjectival modifiers
calcian	see Tables 2 and 5
chromian	when Cr = 0·25-0·99 (∿2·3-9% Cr_2O_3)
ferrian	when Fe^3 = 0·75-0·99 (∿6·8-9% Fe_2O_3) except in alkali amphiboles and hastingsite
ferroan	see Figure 2 (only with pargasite and pargasitic hornblende)
lithian	when Li≥0·25 (∿0·4% Li_2O) except in alkali amphiboles when lithian is used for Li≥0·50 (∿0·8% Li_2O). Not used with holmquistite and clinoholmquistite
magnesian	see Figure 2 (only with hastingsite and hastingsitic hornblende)
manganoan	when Mn = 0·25-0·99 (∿2·5-10% MnO) except in end-members containing Mn
plumbian	when Pb≥0·08 (∿1·1% PbO)
potassian	when K = 0·25-0·49 (∿1·3-2·7% K_2O)
silicic	see Figure 2 and Table 3
subcalcic	see Table 3
subsilicic	see Table 3
titanian	when Ti = 0·25-0·99 (∿2·5-10% TiO_2)
zincian	when Zn = 0·25-0·99 (∿1·2-5% ZnO)

*cation and anion numbers are in atoms per formula unit

The amphiboles are divided into four principal groups on the basis of the B-group cation occupancy:

$(Ca+Na)_B$<1.34	Iron–magnesium–manganese amphibole group
$(Ca+Na)_B$≥1.34 and Na_B <0.67	Calcic amphibole group
$(Ca+Na)_B$≥1.34 and 0.67<Na_B<1.34	Sodic–calcic amphibole group
Na_B≥1.34	Alkali amphibole group

TABLE 2. THE IRON-MAGNESIUM-MANGANESE AMPHIBOLES: GENERAL FORMULAE, END-MEMBER NAMES AND END-MEMBER FORMULAE

Orthorhombic forms

Anthophyllite $Na_x(Mg,Mn,Fe^{2})_{7-y}Al_y(Al_{x+y}Si_{8-x-y})O_{22}(OH,F,Cl)_2$ $x+y < 1{\cdot}00$

End member	Formula
Magnesio-anthophyllite	$Mg_7Si_8O_{22}(OH)_2$
Ferro-anthophyllite	$Fe^{2}_7Si_8O_{22}(OH)_2$
Sodium-anthophyllite	$NaMg_6Fe^{2}Al_1Si_7O_{22}(OH)_2$

Gedrite $Na_x(Mg,Mn,Fe^{2})_{7-y}Al_y(Al_{x+y}Si_{8-x-y})O_{22}(Oh,F,Cl)_2$ $x+y \geq 1{\cdot}00$

End member	Formula
Magnesio-gedrite	$Mg_5Al_2Si_6Al_2O_{22}(OH)_2$
Ferro-gedrite	$Fe^{2}_5Al_2Si_6Al_2O_{22}(OH)_2$
Sodium-gedrite	$NaMg_5Fe^{2}Al_1Si_6Al_2O_{22}(OH)_2$

Holmquistite $Li_2(Mg,Fe^{2})_3(Fe^{3},Al)_2Si_8O_{22}(OH,F,Cl)_2$

End member	Formula
Magnesio-holmquistite	$Li_2Mg_3Al_2Si_8O_{22}(OH)_2$
Ferro-holmquistite	$Li_2Fe^{2}_3Al_2Si_8O_{22}(OH)_2$

Monoclinic forms

Cummingtonite series $(Mg,Fe^{2},Mn)_7Si_8O_{22}(OH)_2$

End member	Formula
Magnesio-cummingtonite	$Mg_7Si_8O_{22}(OH)_2$
Grunerite	$Fe^{2}_7Si_8O_{22}(OH)_2$
Tirodite	$Mn_2Mg_5Si_8O_{22}(OH)_2$
Dannemorite	$Mn_2Fe^{2}_5Si_8O_{22}(OH)_2$

Clinoholmquistite $Li_2(Mg,Fe^{2},Mn)_3(Fe^{3},Al)_2Si_8O_{22}(OH,F,Cl)_2$

End member	Formula
Magnesio-clinoholmquistite	$Li_2Mg_3Al_2Si_8O_{22}(OH)_2$
Ferro-clinoholmquistite	$Li_2Fe^{2}_3Al_2Si_8O_{22}(OH)_2$

Prefixes and adjectival modifiers specific to Fe-Mg-Mn amphiboles

Anthophyllite	Alumino-	$^{vi}Al \geq 0{\cdot}50$
Gedrite	Sodium-	$Na \geq 0{\cdot}75$
Cummingtonite series	Sodian	$Na \geq 0{\cdot}25$
Fe-Mg-Mn group	Calcian	$Ca \geq 0{\cdot}50$

TABLE 3. THE CALCIC AMPHIBOLES: END-MEMBER NAMES AND END-MEMBER FORMULAE

End member	Formula
Tremolite	$Ca_2Mg_5Si_8O_{22}(OH)_2$
Ferro-actinolite	$Ca_2Fe^{2}_5Si_8O_{22}(OH)_2$
Edenite	$NaCa_2Mg_5Si_7AlO_{22}(OH)_2$
Ferro-edenite	$NaCa_2Fe^{2}_5Si_7AlO_{22}(OH)_2$
Pargasite	$NaCa_2Mg_4AlSi_6Al_2O_{22}(OH)_2$
Ferro-pargasite	$NaCa_2Fe^{2}_4AlSi_6Al_2O_{22}(OH)_2$
Hastingsite	$NaCa_2Fe^{2}_4Fe^{3}Si_6Al_2O_{22}(OH)_2$
Magnesio-hastingsite	$NaCa_2Mg_4Fe^{3}Si_6Al_2O_{22}(OH)_2$
Alumino-tschermakite	$Ca_2Mg_3Al_2Si_6Al_2O_{22}(OH)_2$
Ferro-alumino-tschermakite	$Ca_2Fe^{2}_3Al_2Si_6Al_2O_{22}(OH)_2$
Ferri-tschermakite	$Ca_2Mg_3Fe^{3}_2Si_6Al_2O_{22}(OH)_2$
Ferri-ferro-tschermakite	$Ca_2Fe^{2}_3Fe^{3}_2Si_6Al_2O_{22}(OH)_2$
Alumino-magnesio-hornblende	$Ca_2Mg_4AlSi_7AlO_{22}(OH)_2$
Alumino-ferro-hornblende	$Ca_2Fe^{2}_4AlSi_7AlO_{22}(OH)_2$
Kaersutite	$NaCa_2Mg_4TiSi_6Al_2(O+OH)_{24}$
Ferro-kaersutite	$NaCa_2Fe^{2}_4TiSi_6Al_2(O+OH)_{24}$

Prefixes specific to calcic amphiboles

Alumino-	^{vi}Al	$\geq$	1.00
Sodian	Na	$\geq$	1.00 (~3.5% Na O)
Subcalcic	Ca	$<$	1.50 (~9.5% CaO)
Silicic	Si	$>$	7.25 $(Na+K)^{A} \geq 0.50$

General formulae, end-member formulae and limits on the use of end-member names for each of these groups are given in Tables 2–5 and Figures 1–4.

Fe–Mg–Mn amphiboles: this group naturally divides into two subgroups, the orthorhombic and the monoclinic groups. Where it is necessary to distinguish different space-group varieties, the space-group symbol may be added as a suffix (*e.g.*, cummingtonite $P2_1/m$. For holmquistite and clinoholmquistite, it is important that Li be greater or equal to 1.0 apfu (atoms per formula unit) (~1.7% Li_2O).

Calcic amphiboles: with tschermakite, tschermakitic hornblende, ferro-tschermakite and ferro-tschermakitic hornblende, the prefixes alumino- and ferri- immediately precede the word tschermakite; otherwise, the order in which prefixes are used is not fixed. Neither ferri- nor ferrian should be used with hastingsite, a name that implies high Fe^{3+}.

Sodic-calcic amphiboles: as with the calcic amphiboles, the prefixes alumino- and ferri- immediately precede the fundamental amphibole name; otherwise, the order in which the prefixes are used is not fixed.

Alkali amphiboles: the optical orientation may be indicated by prefixing the symbol *G*, *C*, *O* or *R* for the four possible orientations (Borg 1967b).

General considerations

For amphiboles that are not precisely characterized (*e.g.*, identified from optical properties without chemical anaysis), it is not possible to allocate a precise name. In this case, the assigned amphibole name should be made into an adjective followed by the word amphibole, thus: tremolitic amphibole, pargasitic amphibole. Similarly, hornblende is to be used for a calcic amphibole identified by physical or

TABLE 4. THE SODIC-CALCIC AMPHIBOLES: END-MEMBER NAMES AND END-MEMBER FORMULAE

End member	Formula
Richterite	$NaCaNaMg_5Si_8O_{22}(OH)_2$
Ferro-richterite	$NaCaNaFe^2_5Si_8O_{22}(OH)_2$
Ferri-winchite	$CaNaMg_4Fe^3Si_8O_{22}(OH)_2$
Alumino-winchite	$CaNaMg_4AlSi_8O_{22}(OH)_2$
Ferro-alumino-winchite	$CaNaFe^2_4AlSi_8O_{22}(OH)_2$
Ferro-ferri-winchite	$CaNaFe^2_4Fe^3Si_8O_{22}(OH)_2$
Alumino-barroisite	$CaNaMg_3Al_2Si_7AlO_{22}(OH)_2$
Ferro-alumino-barroisite	$CaNaFe^2_3Al_2Si_7AlO_{22}(OH)_4$
Ferri-barroisite	$CaNaMg_3Fe^3_2Si_7AlO_{22}(OH)_2$
Ferro-ferri-barroisite	$CaNaFe^2_3Fe^3_2Si_7AlO_{22}(OH)_2$
Magnesio-ferri-katophorite	$NaCaNaMg_4Fe^3Si_7AlO_{22}(OH)_2$
Magnesio-alumino-katophorite	$NaCaNaMg_4AlSi_7AlO_{22}(OH)_2$
Ferri-katophorite	$NaCaNaFe^2_4Fe^3Si_7AlO_{22}(OH)_2$
Alumino-katophorite	$NaCaNaFe^2_4AlSi_7AlO_{22}(OH)_2$
Ferri-taramite	$NaCaNaFe^2_3Fe^3_2Si_6Al_2O_{22}(OH)_2$
Magnesio-ferri-taramite	$NaCaNaMg_3Fe^3_2Si_6Al_2O_{22}(OH)_2$
Alumino-taramite	$NaCaNaFe^2_3Al_2Si_6Al_2O_{22}(OH)_2$
Magnesio-alumino-taramite	$NaCaNaMg_3Al_2Si_6Al_2O_{22}(OH)_2$
Prefixes specific to sodic-calcic amphiboles	
Alumino-	$^{vi}Al \geq 1.00$

TABLE 5. THE ALKALI AMPHIBOLES: END-MEMBER NAMES AND END-MEMBER FORMULAE

End member	Formula
Glaucophane	$Na_2Mg_3Al_2Si_8O_{22}(OH)_2$
Ferro-glaucophane	$Na_2Fe^2_3Al_2Si_8O_{22}(OH)_2$
Magnesio-riebeckite	$Na_2Mg_3Fe^3_2Si_8O_{22}(OH)_2$
Riebeckite	$Na_2Fe^2_3Fe^3_2Si_8O_{22}(OH)_2$
Eckermannite	$NaNa_2Mg_4AlSi_8O_{22}(OH)_2$
Ferro-eckermannite	$NaNa_2Fe^2_4AlSi_8O_{22}(OH)_2$
Magnesio-arfvedsonite	$NaNa_2Mg_4Fe^3Si_8O_{22}(OH)_2$
Arfvedsonite	$NaNa_2Fe^2_4Fe^3Si_8O_{22}(OH)_2$
Nyboite	$NaNa_2Mg_3Al_2Si_7AlO_{22}(OH)_2$
Kozulite	$NaNa_2Mn_4(Fe^3,Al)Si_8O_{22}(OH)_2$
Prefixes specific to alkali amphiboles	
Calcian	$Ca \geq 0.50$ (~3% CaO)
Lithian	$Li \geq 0.50$ (~1% Li_2O)

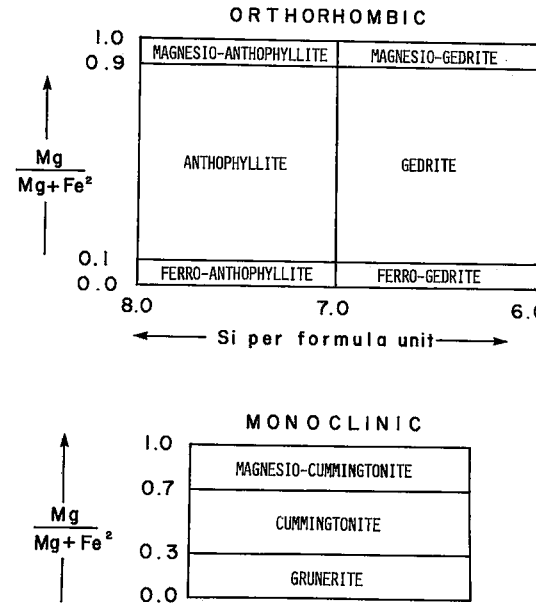

FIG. 1. The nomenclature of the iron–magnesium–manganese amphiboles for which $Li < 1.0$ atoms p.f.u. [after Leake (1978)].

optical properties (or both) and not confidently identifiable as near to an end-member.

For the various asbestiform amphiboles, mineralogical usage should involve the precise mineral name followed by -asbestos, thus: anthophyllite-asbestos, actinolite-asbestos. Where the nature of the mineral is not known, asbestos alone may be appropriate. Where the approximate nature of the mineral is known but not its precise composition, the assigned amphibole name should be made into an adjective followed by the word asbestos; thus anthophyllitic asbestos. For this purpose, crocidolite is used to cover alkali amphibole asbestos in general, whereas the above recommendations are to be followed if the precise composition is known.

A large number of amphibole names have been formally abandoned (Leake 1978) and should not be used; this includes barkevikite, basaltic hornblende, ferrohastingsite and carinthine. This nomenclature is fairly simple considering the complexity of the amphibole group and should result in rapid and unambiguous naming of amphiboles.

Formula-Unit Calculation

The results of a chemical analysis of an amphibole are normally presented as the weight