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NOMENCLATURE OF PYROXENES

SUBCOMMITTEE ON PYROXENES*
COMMISSION ON NEW MINERALS AND MINERAL NAMES
INTERNATIONAL MINERALOGICAL ASSOCIATION

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ABSTRACT

This is the final report on the nomenclature of pyroxenes by the Subcommittee on Pyroxenes established by the Commission on New Minerals and Mineral Names of the International Mineralogical Association. The recommendations of the Subcommittee as put forward in this report have been formally accepted by the Commission. Accepted and widely used names have been chemically defined, by combining new and conventional methods, to agree as far as possible with the consensus of present use. Twenty names are formally accepted, among which thirteen are used to represent the end members of definite chemical compositions. In common binary solid-solution series, species names are given to the two end members by the "50% rule". Adjectival modifiers for pyroxene mineral names are defined to indicate unusual amounts of chemical constituents. This report includes a list of 105 previously used pyroxene names that have been formally discarded by the Commission.

Keywords: pyroxenes, nomenclature, International Mineralogical Association, final report.

SOMMAIRE

Nous présentons le rapport final sur le sujet de la nomenclature de la famille des pyroxènes, résultat des délibérations d'un sous-comité de la Commission des nouveaux minéraux et des noms de minéraux de l'Association Internationale de Minéralogie. Les recommandations du sous-comité, publiées ici, ont été formellement acceptées par la Commission. Nous avons défini les noms utilisés couramment qui ont été retenus en termes compositionnels précis, en utilisant les méthodes conventionnelles et nouvelles, afin d'atteindre un consensus avec l'utilisation courante. Vingt noms d'espèces ont formellement été acceptés, dont treize servent comme pôles ayant une composition chimique définie. Dans les solutions solides binaires courantes, nous acceptons la règle du 50% pour attribuer le nom de l'espèce. Des adjectifs viennent modifier le nom d'un pyroxène pour indiquer un enrichissement anomale d'un ou de plusieurs éléments. Cent-cinq noms utilisés antérieurement sont abandonnés formellement.

(Traduit par la Rédaction)

Mots-clés: pyroxène, nomenclature, Association Internationale de Minéralogie, rapport final.

INTRODUCTION

The subcommittee on pyroxenes has, after a thorough evaluation of the group of pyroxene minerals, presented its recommendations for a new classification and nomenclature to the Commission on New Minerals and Mineral Names (hereafter abbreviated as CNMMN). These recommendations have been approved by the Commission by a formal vote (May 20th, 1987).

The classification and nomenclature of the pyroxenes have been largely based on their crystal chemistry. In practice, the chemical content of the pyroxene formula unit calculated to six oxygen atoms, or to four cations (Vieten & Hamm 1978), is essential for the classification. This formula unit corresponds to one quarter of the unit cell for the monoclinic pyroxenes and to one eighth of the unit cell for the orthorhombic pyroxenes. The basic principle adopted for amphibole nomenclature (Leake 1978) is to denote the principal stoichiometries by generally well-established names, with adjectival modifiers to indicate the presence of substantial substitutions that are not essential constituents of the end members; this has been followed as far as possible in the pyroxene nomenclature.

No new names have been introduced in the proposed nomenclature. Accepted and widely used names have been chemically defined by combining new and conventional methods to agree as far as possible with the consensus of present use. Two kinds of adjectival modifiers are used, one to specify a part of the compositional range shown by a mineral that forms a wide solid-solution (*e.g.*, magnesium-rich augite, iron-rich augite), and the other to specify elemental substitutions that are not essential consti-

*Subcommittee members: J. Fabries (France), A.K. Ferguson (Australia), I.V. Ginzburg (USSR), M. Ross (USA), F.A. Seifert (Germany) and J. Zussman (UK). Non-voting members: K. Aoki (Japan) and G. Gottardi (Italy, deceased).

tuents (*e.g.*, titanian augite). One hundred and five previously used pyroxene names, mostly synonyms, and obsolete or almost unused names, have been formally discredited by the CNMMN. General publications dealing with the pyroxene group, *e.g.*, *Rock-Forming Minerals* (Deer *et al.* 1978, denoted DHZ in the Tables), Special Paper **2** (Papike 1969) and *Reviews in Mineralogy* **7** (Prewitt 1980), both published by the Mineralogical Society of America, provide references to the voluminous literature.

Crystal Chemistry of the Pyroxenes

Pyroxenes are silicates that, in their simplest form, contain single SiO_3 chains of linked SiO_4 tetrahedra. Generally, small amounts of Si are replaced by Al and other small cations. The repeat distance *c* along the chain (*Z* axis) comprises two tetrahedra and is approximately 0.52 nm in length. The general chemical formula (formula unit) for all pyroxenes*[1] is $M2M1T_2O_6$, where *M*2 refers to cations in a generally distorted octahedral coordination, *M*1 to cations in a regular octahedral coordination, and *T* to tetrahedrally coordinated cations.

Any pyroxene belongs to either the orthorhombic or the monoclinic crystal system. There are two types of orthorhombic pyroxene: orthopyroxene (*Pbca*) and orthopyroxene (*Pbcn*)*[2]. Only the former has been found in nature. Monoclinic pyroxenes are called clinopyroxenes. Their space groups are $C2/c$, $P2_1/c$ and $P2/n$, depending on their chemical composition and genetic history.

Throughout this report, the standard pyroxene formula is used with superscript arabic numerals (*e.g.*, Fe^{2+}) referring to charges, and subscript numerals (*e.g.*, Mg_2), to numbers of atoms. To derive a pyroxene formula from a chemical analysis, the calculation should be based on six oxygen atoms when both Fe^{2+} and Fe^{3+} have been determined. In microprobe analyses only total Fe is determined, and the option of calculating to four cations should at least be permitted if not actually preferred. Vieten & Hamm (1978) showed that calculation to four cations will be more reliable for the majority of pyroxenes characterized by electron-microprobe analysis. Therefore, for electron-microprobe data, it is recommended that the components be totalled to six oxygen atoms and four cations by adjusting the ratios Fe^{2+}/Fe^{3+}, Ti^{4+}/Ti^{3+}, *etc.*

The standard pyroxene formula $M2M1T_2O_6$ contains two tetrahedral sites. In the allocation of the cations to obtain a pyroxene formula, the following procedure is recommended:

1) Sum *T* to 2.000 using Si^{4+}, then Al^{3+}, then Fe^{3+}.

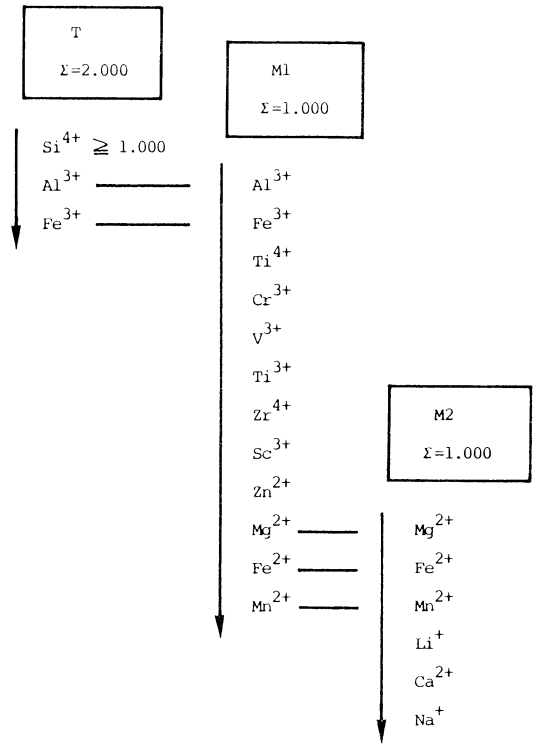

FIG. 1. Flow chart for ideal site-occupancy of cations among the *T*, *M*1 and *M*2 sites of pyroxenes. Only representative cations are included. Arrows indicate order of filling of sites. Real site-occupancy usually differs slightly from the ideal site-occupancy.

TABLE 1. FOUR COUPLED SUBSTITUTIONS OF PYROXENES IN THE STANDARD FORMULA $R^{2+}R^{2+}R_2^{4+}O_6$

Substitution site	M2	M1	T	examples
standard	R^{2+}	R^{2+}	$2R^{4+}$	
substitution(1)	(R^{+})	(R^{3+})	$2R^{4+}$	Na-Al Na-Fe^{3+} Na-Cr^{3+} Na-Sc^{3+}
substitution(2)	(R^{+})	$R^{2+}_{0.5}(R^{4+}_{0.5})$	$2R^{4+}$	Na-(Ti^{4+}/2)
substitution(3)	R^{2+}	(R^{3+})	(R^{3+})R^{4+}	Al-Al Fe^{3+}-Al Cr^{3+}-Al
Substitution(4)	R^{2+}	$R^{2+}_{0.5}(R^{4+}_{0.5})$	(R^{3+})R^{4+}	(Ti^{4+}/2)-Al

2) Sum *M*1 to 1.000 using all Al^{3+} and Fe^{3+} in excess of that used to fill the *T* sites. If there is insufficient Al^{3+} and Fe^{3+} to sum to 1.000, then add Ti^{4+}, Cr^{3+}, V^{3+}, Ti^{3+}, Zr^{4+}, Sc^{3+}, Zn^{2+}, Mg^{2+}, Fe^{2+} and, finally, Mn^{2+}, until the sum is 1.000.

*See comments at end of text.

3) Sum $M2$ using all Mg^{2+}, Fe^{2+} and Mn^{2+} in excess of that used to fill the $M1$ sites. Then add Li^{+}, Ca^{2+} and Na^{+} so that the sum becomes 1.000 or close to it. If the sum is far from 1.000, one must be suspicious about the results of the analysis.

A flow chart (Fig. 1) gives a diagrammatic representation of the site allocation of the principal cations in pyroxenes. However, because the distribution of cations among the $M1$, $M2$ and T sites in a given pyroxene is partly a function of temperature, the accurate site-occupancy must be determined by structure determination. The site-occupancy given in Figure 1 is called ideal site-occupancy to distinguish it from real occupancy. A method for classifying pyroxenes by their ideal site-occupancies has been proposed by Bokii & Ginzburg (1985). In the present classification of pyroxenes, the $M1$ and $M2$ sites are considered together as a single M site in order to avoid the possible difference between the real and ideal site-occupancies.

Starting from the most common pyroxene formula, $M2(R^{2+})M1(R^{2+})T_2(2R^{4+})O_6$, four coupled substitutions are possible if one assumes more than one R^{4+} in the T site. They are listed in Table 1, where the elements in parentheses are coupled substitutions.

Substitution (1) encompasses the end members jadeite ($NaAlSi_2O_6$), aegirine*3 ($NaFe^{3+}Si_2O_6$), kosmochlor*4 ($NaCr^{3+}Si_2O_6$), and jervisite ($NaScSi_2O_6$). Substitution (2) results in components such as $NaFe^{2+}_{0.5}Ti^{4+}_{0.5}Si_2O_6$, and is less important than the other substitutions.

In substitution (3) the Al–Al couple is often referred to as "Tschermak's component"; $CaAlAlSiO_6$, in particular, is called "calcium Tschermak's component". Substitution in esseneite*5 ($CaFe^{3+}AlSiO_6$) is obtained by this type of substitution. This substitution is also important in "fassaite"*6. Substitution resulting in $CaTi^{3+}AlSiO_6$ was reported by Dowty & Clark (1973) and Mason (1974) in pyroxene from the Allende meteorite (Table 3, No. 4). In substitution (4), the component $CaMg_{0.5}Ti^{4+}_{0.5}AlSiO_6$ is found in some pyroxenes. There are a few instances of the component of substitution (2) or (4) amounting to nearly 50%, as described later (Table 3). However, no particular names are given for the end-member components of substitutions (2) and (4).

Mineral Names of the Pyroxenes

Twenty mineral names and their grouping

The pyroxenes form extensive solid-solutions by various types of ionic substitutions, some of which are described above. To cope with the problem of pyroxene nomenclature, it is necessary to subdivide the solid-solution series into ranges with specified compositions and names. Wherever there is a complete solid-solution series between two end members, it is customary in mineral nomenclature to use only two names, and the division between them should

TABLE 2. ACCEPTED PYROXENE MINERAL NAMES AND THEIR CHEMICAL SUBDIVISIONS*

mineral names	composition as end-member	main composition space as solid solution	group
I. Mg-Fe pyroxenes			
1. enstatite (En)(1)	$Mg_2Si_2O_6$	$(Mg,Fe)_2Si_2O_6$	Pbca
2. ferrosilite(Fs)(2)	$Fe^{2+}_2Si_2O_6$		
3. clinoenstatite		$(Mg,Fe)_2Si_2O_6$	$P2_1/c$
4. clinoferrosilite			
5. pigeonite		$(Mg,Fe,Ca)_2Si_2O_6$	$P2_1/c$
II. Mn-Mg pyroxenes			
6. donpeacorite		$(Mn,Mg)MgSi_2O_6$	Pbca
7. kanoite (Ka)(3)	$MnMgSi_2O_6$	$(Mn,Mg)MgSi_2O_6$	$P2_1/c$
III. Ca pyroxenes			
8. diopside (Di)(4)	$CaMgSi_2O_6$	$Ca(Mg,Fe)Si_2O_6$	C2/c
9. hedenbergite(Hd)(5)	$CaFe^{2+}Si_2O_6$		
10. augite		$(Ca,Mg,Fe)_2Si_2O_6$	C2/c
11. johannsenite(Jo)(6)	$CaMnSi_2O_6$		C2/c
12. petedunnite(Pe)(7)*1	$CaZnSi_2O_6$		C2/c
13. esseneite(Es)(8)*2	$CaFe^{3+}AlSiO_6$		C2/c
IV. Ca-Na pyroxenes			
14. omphacite		$(Ca,Na)(R^{2+},Al)Si_2O_6$	C2/c, P2/n
15. aegirine-augite		$(Ca,Na)(R^{2+},Fe^{3+})Si_2O_6$	C2/c
V. Na pyroxenes			
16. jadeite (Jd)(9)	$NaAlSi_2O_6$	$Na(Al,Fe^{3+})Si_2O_6$	C2/c
17. aegirine (Ae)(10)	$NaFe^{3+}Si_2O_6$		
18. kosmochlor(Ko)(11)	$NaCr^{3+}Si_2O_6$		C2/c
19. jervisite (Je)(12)*3	$NaSc^{3+}Si_2O_6$		C2/c
VI. Li pyroxene			
20. spodumene (Sp)(13)	$LiAlSi_2O_6$		C2/c

*Name, abbreviation and composition are given for any pyroxene that is used as an end member of a pyroxene solid solution; such end members are numbered between parentheses from 1 to 13. Main compositions are given for solid solutions.

*1 Petedunnite has been determined by electron microprobe (Essene & Peacor 1987) to have the composition $(Ca_{0.92}Na_{0.06}Mn_{0.02})(Zn_{0.37}Mn_{0.19}Fe^{2+}_{0.19}Fe^{3+}_{0.12}Mg_{0.14})(Si_{1.94}Al_{0.06})O_6$. This mineral was approved as a valid species by the CNMMN, IMA, in 1983.

*2 Esseneite has been determined by electron microprobe (Cosca & Peacor 1987) to have the composition $(Ca_{1.01}Na_{0.01})(Fe^{3+}_{0.72}Mg_{0.16}Al_{0.04}Ti_{0.03}Fe^{2+}_{0.02})(Si_{1.19}Al_{0.81})O_{6.00}$. This mineral was approved as a valid species in 1985.

*3 Jervisite has been determined by electron microprobe (Mellini et al. 1982) to have the composition $(Na_{0.43}Ca_{0.31}Fe^{2+}_{0.14}\square_{0.12})(Sc_{0.66}Fe^{2+}_{0.15}Mg_{0.19})Si_2O_6$. This mineral was approved as a valid species in 1982.

be at $A_{50}B_{50}$ (the "50% rule"). However, this "50% rule" cannot be applied rigorously to the large groups of pyroxenes that show wide ranges of coupled substitutions. This is particularly so when the minerals concerned are abundant and widespread, and have a historically established nomenclature in mineralogical and petrological circles. Taking this situation into consideration, 20 accepted and widely used names have been adopted as species names of the pyroxenes (Table 2).

The definition of the pyroxene species has been based on 13 end members, or chemical components, listed in Table 2, and the component $Ca_2Si_2O_6$ (Wo)*[7]. These end members are given the name of the mineral whose composition they most closely approximate. The 20 pyroxene species are grouped into 6 chemical subdivisions on the basis of the cation occupancy of the *M*2 sites and crystal-chemical similarity. This classification is a slight modification of the widely used scheme proposed by Deer *et al.* (1978).

For the precise classification of the pyroxenes into 20 mineral species, however, the following characteristics of the pyroxenes must be considered. Firstly, the Mg–Fe pyroxenes and some of the Ca pyroxenes are the most common rock-forming pyroxenes and form wide solid-solutions that cover the pyroxene quadrilateral of the ternary system $Ca_2Si_2O_6$(Wo) – $Mg_2Si_2O_6$(En) – $Fe_2Si_2O_6$(Fs). Therefore, these pyroxenes are better treated together as the Ca–Mg–Fe or "quadrilateral" pyroxenes. Secondly, Na pyroxenes form continuous solid-solution series with the Ca–Mg–Fe pyroxenes, forming the Na–Ca pyroxenes. Thirdly, donpeacorite and kanoite (Mn–Mg pyroxenes), johannsenite, petedunnite and esseneite (Ca pyroxenes), and spodumene are rare in occurrence and unique in chemistry. For simplicity they are treated together as 'other' pyroxenes*[8].

All the pyroxenes are thus divided into four chemical groups for the purpose of broad classification: Ca–Mg–Fe pyroxenes (**Quad,** 8), Ca–Na pyroxenes (**Ca–Na,** 2), Na pyroxenes (**Na,** 2) and 'other' pyroxenes (**Others,** 8). The abbreviation of the group and the number of accepted species are given between parentheses. **Quad** represents "quadrilateral" for the Ca–Mg–Fe pyroxenes. The four chemical groups are further divided into 20 mineral species by using 12 components (using the Wo component for Di and Hd components). The composition ranges for the accepted names will be given later.

The pyroxene names may be qualified by one or more adjectival modifiers according to definite rules described later to specify important (though relatively minor) departures from the composition ranges. Where the composition range of the mineral species is large, as in augite, one or more adjectival modifiers are used to specify the composition more clearly (*e.g.,* subcalcic augite, Fe-rich augite).

Application of 50% rule

The 50% rule has been applied to complete solid-solution series between two end members as far as possible. They are the Mg–Fe pyroxene series (enstatite–ferrosilite and clinoenstatite–clinoferrosilite series), Ca pyroxene series (diopside–hedenbergite series) and Na pyroxene series (jadeite–aegirine series). Subdivision names applied to the intermediate solid-solution ranges, such as bronzite, hypersthene, and eulite of the enstatite–ferrosilite series, and salite and ferrosalite of the diopside–hedenbergite series, have been discarded. However, the 50% rule was not applied rigorously to the Ca–Mg–Fe pyroxenes and Na–Ca pyroxenes. The widely accepted terms such as augite, pigeonite, omphacite and aegirine–augite*[9] have been retained.

Gem names of spodumene

Two names, *hiddenite* and *kunzite,* often are used respectively for (pale) emerald-green and lilac-colored spodumene of gem quality. They are not accepted as formal pyroxene names, but can be used as varietal gem names.

Relationships with the pyroxenoids

Pyroxenoids are closely related to pyroxenes in that they have a similar type of chemical composition and a structure that also consists of SiO_3 single chains. However, the repeat of the chains, which is two SiO_4 tetrahedra in the pyroxenes, is three or more SiO_4 tetrahedra in the pyroxenoids. Though the tetrahedral sites are mostly occupied by Si ions, the large cations are mostly Ca, Mn and Fe^{2+} in the pyroxenoids. The classification and nomenclature of the pyroxenoids are beyond the scope of this report. However, the following two points may be noted. Firstly, there is a polymorphic relationship with some pyroxenes such as ferrosilite, hedenbergite and johannsenite. These show pyroxenoid structures at high temperatures or pressures. Secondly, the wollastonite chemical component ($Ca_2Si_2O_6$) is used to express the composition of the Ca–Mg–Fe pyroxenes, though wollastonite belongs to the pyroxenoid structural group.

Classification and Nomenclature of the Pyroxenes

Preliminary classifications; construction of the Q–J diagram and application of pyroxene data

Before classifying the pyroxenes into the 20 mineral species listed in Table 2, the following procedure is recommended to divide them into four chemical groups: Ca–Mg–Fe pyroxenes (**Quad**), Na–Ca pyroxenes (**Na–Ca**), Na pyroxenes (**Na**), and other pyroxenes (**Others**) (Morimoto & Kitamura 1983).

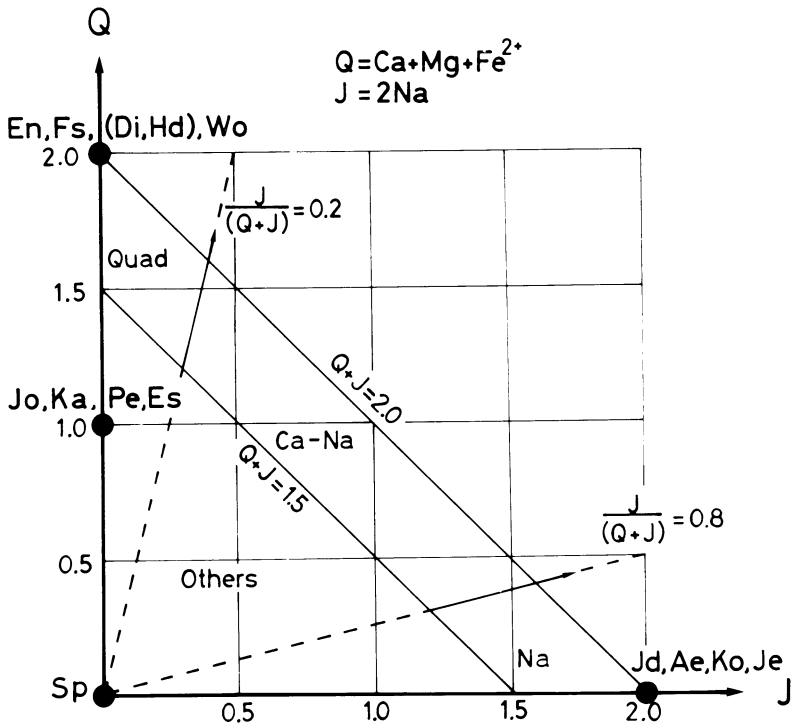

FIG. 2. Q–J diagram for the pyroxenes, on which the positions of the 13 accepted end-members have been indicated. Abbreviations and compositions of the end members are listed in Table 2.

In this procedure, the pyroxenes are classified by using the total number of specified cations at the M ($M1$ and $M2$) sites on the basis of six oxygen atoms. The $M1$ and $M2$ sites are considered together as M sites, without considering the site preference of atoms between the two sites.

The numbers of Ca, Mg, Fe^{2+} and Na cations in the M sites are plotted in the Q–J diagram (Fig. 2) as $Q = Ca + Mg + Fe^{2+}$ and $J = 2Na$. The lines representing the following equations are used to subdivide the Q–J diagram:

(1) $Q + J = 2.0$
(2) $Q + J = 1.5$
(3) $J/(Q + J) = 0.2$
(4) $J/(Q + J) = 0.8$

The areas corresponding to the Ca–Mg–Fe pyroxenes, Ca–Na pyroxenes, Na pyroxenes and other pyroxenes are labeled (Fig. 2) **Quad**, **Ca–Na**, **Na**, and **Others**, respectively.

In this diagram, J is meant to include the total number of Na and R^{3+}, usually Al, Fe^{3+}, Cr^{3+} and Sc^{3+}, that couple with Na in substitution (1) mentioned in Table 1. Where the coupling substitution in the pyroxene is not of type (1), but of type (2) or (3), the J value apparently does not represent the real numbers of Na and R^{3+} at the M sites. However, substitution (3) (*e.g.*, Al–Al) works to move the J and Q values closer to the origin of the Q–J diagram, and substitution (2) (*e.g.*, Na–Ti^{4+}) to move the J value farther away from the Q axis of ordinates. Therefore, the effects of substitutions (2) and (3) tend to cancel each other out in and near the area of Na pyroxenes. Thus the J (= 2Na) values in the Na-rich pyroxenes represent, to a good approximation, the total number of Na and R^{3+} (Al, Fe^{3+}, Cr^{3+} and Sc^{3+}) at the M sites.

The boundary $Q + J = 2.0$ represents the upper limit of $Q + J$ at the M sites. The boundary $Q + J = 1.5$ represents the limit below which more than half of the $M1$ or $M2$ sites may be occupied by ions other than Q and J ions. In this case, the pyroxenes are considered as belonging to **'Others'**, which include the Mn–Mg and Li pyroxenes, johannsenite, petedunnite and esseneite. The third and fourth equations represent the lines dividing the area limited by the two above-mentioned $Q + J$ lines into Ca + Mg + Fe (**Quad**), **Ca–Na** and **Na** pyroxenes. The

boundaries defined by $J/(Q+J) = 0.2$ and 0.8 are used by Deer *et al.* (1978) and Cameron & Papike (1981).

Because the Mn–Mg pyroxenes and johannsenite (Table 2) have Mn ions occupying more than half of the $M2$ and $M1$ sites, respectively, they appear along the Q axis between 1.0 and 1.5 of the Q values in the Q–J diagram. Similarly, petedunnite and esseneite appear along the Q axis with a Q value between 1.0 and 1.5. Spodumene compositions cluster at the origin of the Q–J diagram because both Q and J are zero. The 13 end members (Table 2) and Wo thus are located in the Q–J diagram (Fig. 2).

Application of this classification procedure to 406 pyroxene compositions presented by Deer *et al.* (1978) has shown that most of them, except those of johannsenite and spodumene, are included in the area between the lines $Q+J = 2.0$ and 1.5. Of the 406, the 103 pyroxene compositions selected by Cameron & Papike (1981), for which the Q values are less than 1.90 and Mn is less than 0.08 atoms per formula unit, are plotted in the Q–J diagram of Figure 3. The 'CaMgTAL' pyroxene (Cameron & Papike 1981) is included in the **Quad** area as described later (Table 3, No. 1). Only 20 compositions among 406 plot slightly over the line $Q+J = 2.0$, and most of these show unusual total numbers of cations. The results of the classification of the pyroxenes into the four chemical groups by this procedure are in almost complete agreement with the results obtained by Deer *et al.* (1978) and by Cameron & Papike (1981). A few unusual pyroxenes with Mn less than 0.08 atoms in the chemical formula unit have been found to lie outside the area between $Q+J = 2.0$ and $Q+J = 1.5$ lines in the Q–J diagram. The classification of these unusual pyroxenes will be discussed later.

The pyroxenes that plot in the area between $Q+J = 2.0$ and 1.5 have components other than Q and J ions at less than 25% of the M sites. Therefore, we can classify such pyroxenes on the basis of the normalized Q and J components, thereby neglecting the effects of the other components. The following procedures are adopted for further classification:

1) The pyroxenes in the **Quad** area are classified on the pyroxene quadrilateral (Wo–En–Fs diagram) with normalized Ca, Mg and Fe ($= Fe^{2+} + Fe^{3+} + Mn$) atomic proportions.

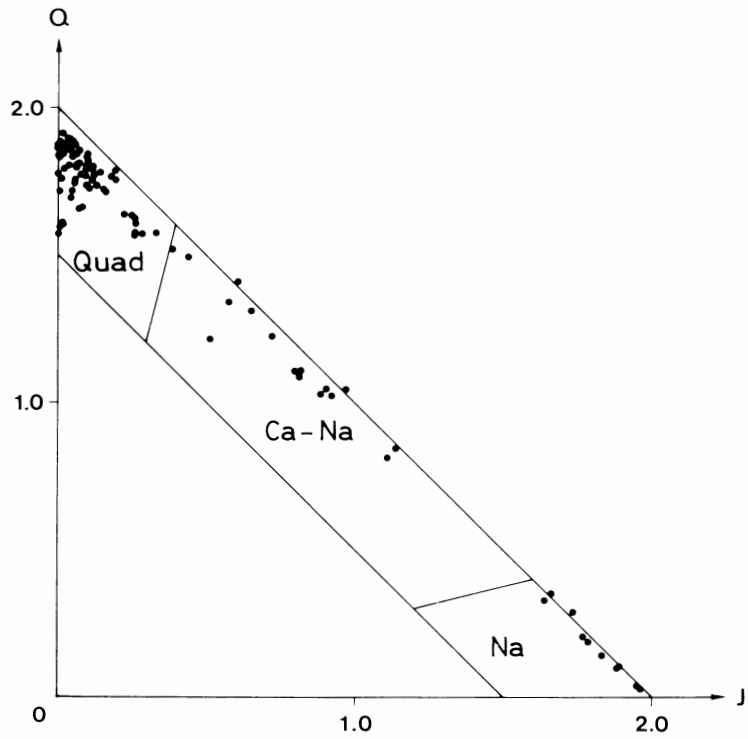

FIG. 3. The 103 pyroxene compositions selected by Cameron & Papike (1981) from the compilation of Deer *et al.* (1978), plotted on the Q–J diagram. For these pyroxenes the Q values are less than 1.90, and Mn is less than 0.08 atoms per formula unit.

TABLE 3. CHEMICAL COMPOSITION AND CLASSIFICATION OF EIGHT UNUSUAL PYROXENES*

a) Ca-rich group related to S3 and S4

No.	1. 320-8 (406-16)		2. 403-3		3. D and S*1		4. T and R*2	
Si	1.443	2.00	1.506	2.00	1.434	2.00	1.196	2.00
Al	.557		.494		.566		.804	
Al	.091		.171		.306		.186	
Ti^{4+}	.165		.065		.022	Ti^{4+}	.111	
Fe^{3+}	.128		.159		.218	Ti^{3+}	.394	
Mg	.385		.570		.408		.289	
Fe^{2+}	.229	2.00	.063	2.02	.060	2.00		2.00
Mn	.005		.007		.005			
Ca	.992		.975		.979		1.021	
Na	.006		.007		.002			
K	.000		.001		-			
Q	1.61		1.61		1.45		1.31	
J	0.01		0.01		0.00		0.00	
Mineral names	subsilicic titanian ferrian diopside		subsilicic aluminian ferrian diopside		subsilicic aluminian ferrian diopside		subsilicic titanoan aluminian pyroxene	
Names in literature	titanaugite (320-8) titanium-fassaite (406-16) CaMgTAL (C and P)*3		fassaite		fassaite		titanaugite	

b) Na-rich group related to S2

No.	5. 488-9		6. 491-14		7. 492-19 (C and G*4)		8. C and G*4	
Si	1.994	2.00	2.024	2.02	2.026	2.03	2.009	2.01
Al	.032		.000		.000		.000	
Al	.000		.021		.098		.348	
Ti^{4+}	.265		.023		.227		.104	
Fe^{3+}	.458		.728		.192		.031	
Mg	.150		.070		.070		.168	
Fe^{2+}	.107	2.00	.113	2.00	.420	1.98	.356	2.00
Mn	.003		.006		.021		.011	
Na	.933		.872		.794		.610	
Ca	.083		.155		.152		.361	
K	-		.009		-		.006	
Q	0.34		0.34		0.64		0.89	
J	1.87		1.74		1.59		1.22	
Mineral names	titanian magnesian ferroan aegirine		calcian ferroan aegirine		titanian aegirine-augite		titanian ferroan omphacite	
Names in literature	titanian aegirine		aegirine-augite		titanian aegirine-augite (492-19) titanian aegirine (C and G*4)		titanian ferro-omphacite	

*Numbers such as 320-8, etc. represent pages and analysis number in DHZ (1978). Other references are in text. With the exception of 320-8 (=406-16), all the DHZ analyses in this table were not included in the 103 selected analyses of Cameron & Papike (1981). All pyroxenes in the table are shown with their numbers in the Q-J diagram (Fig. 7). S2, S3 and S4 represent the following components of substitutions (2), (3) and (4), respectively:

$S2=NaR^{2+}_{0.5}Ti^{4+}_{0.5}Si_2O_6$, $S3=CaR^{3+}AlSiO_6$, and $S4=CaR^{2+}_{0.5}Ti^{4+}_{0.5}AlSiO_6$. To indicate R ions explicitly in these components, the notation S(R), such as S2(Mg) and S3(Al), is used. S3(Fe) is a new pyroxene, esseneite (Es).

Component ratios;

1. $(Wo_{22}En_{12}Fs_{10})_{44}S4(Mg)_{18}S4(Fe)_{16}Es_{13}S3(Al)_9$
2. $(Wo_{26}En_{25}Fs_2)_{53}S3(Al)_{17}Es_{16}S4(Mg)_{12}S4(Fe)_2$
3. $(Wo_{22}En_{20}Fs_2)_{44}S3(Al)_{31}Es_{21}S4(Mg)_4$
4. $S3(Ti)_{39}S4(Mg)_{22}(Wo_{11}Fs_9)_{20}S3(Al)_{19}$
5. $Ae_{46}S2(Mg)_{28}S2(Fe)_{20}\Delta_6$*5
6. $(Ae_{73}Jd_2Wo_8Fs_6En_3)_{92}S2_4\Delta_4$
7. $(Ae_{19}Jd_{10}Fs_{12}Wo_8En_2)_{51}S2(Fe)_{42}S2(Mg)_4\Delta_3$
8. $(Jd_{35}Ae_3Wo_{18}Fs_{15}En_7)_{78}S2(Fe)_{14}S2(Mg)_6\Delta_2$

*1 Devine & Sigurdsson (1980), Table 1 for fassaite.
*2 Tracy & Robinson (1977), Table 3, Analysis 1 for pyroxene for the Allende meteorite (Mason 1974).
*3 Cameron & Papike (1981), Table A3, Analysis 320-8 and 406-16.
*4 Curtis & Gittins (1979), Table 2, Analysis 5 for No. 7 and Table 5, Analysis 5 for No. 8.
*5 Δ represents minor components, some of which have unusual metal ratios for the pyroxene structure.

2) The pyroxenes in the **Na** area are jadeite, aegirine, kosmochlor and jervisite. Because kosmochlor and jervisite show little or no solid solution toward other end members, they play no role in the classification. Jadeite and aegirine are classified on the **Quad**-Jd-Ae diagram together with the Ca-Na pyroxenes, aegirine-augite and omphacite.

The classification of the Ca–Mg–Fe "quadrilateral" pyroxenes

The common rock-forming pyroxenes form wide ranges of solid solutions of the Ca–Mg–Fe pyroxenes and can be expressed in the pyroxene quadrilateral in the system $Mg_2Si_2O_6$(En) – $Fe^{2+}_2Si_2O_6$(Fs) – $CaMgSi_2O_6$(Di) – $CaFe^{2+}Si_2O_6$(Hd). The Ca–Mg–Fe pyroxenes include varieties that have orthorhombic symmetry. They consist of a simple chemical series $(Mg, Fe)_2Si_2O_6$, thus contrasting with the clinopyroxenes, which have wide ranges of chemical composition in the Ca–Mg–Fe pyroxenes. Therefore, the Ca–Mg–Fe pyroxenes are defined on the basis of symmetry and relative amounts of $Ca_2Si_2O_6$(Wo), $Mg_2Si_2O_6$(En) and $Fe^{2+}_2Si_2O_6$(Fs). The composition ranges of the clinopyroxenes and orthopyroxenes are indicated in Figures 4 and 5, respectively, where the composition is normalized to $Ca + Mg + \Sigma Fe = 100$ with $\Sigma Fe = Fe^{2+} + Fe^{3+} + Mn^{2+}$ (*10).

The distinction between augite and pigeonite in the Ca–Mg–Fe pyroxenes is primarily structural, their space groups being $C2/c$ and $P2_1/c$, respectively. There is a miscibility gap between augite and pigeonite, and many pyroxenes with 15–25% Wo have proved to be mixtures of the two. Augite with less than about 25% Wo is often called subcalcic augite. On heating, pigeonite undergoes a rapid displacive transformation to a $C2/c$ structure that cannot be quenched. Augite does not show this type of transformation.

The most calcium-rich orthopyroxene contains approximately 5% Wo. The high-temperature form of enstatite has the space group *Pbcn* and can be expressed as "enstatite–*Pbcn*". This form is not quenchable and has not been found in nature. "Protoenstatite" has been used conventionally to describe this form, but this name is not adopted as a mineral name. The Wo value of "enstatite–*Pbcn*" does not exceed 2% and the En value commonly exceeds 90%.

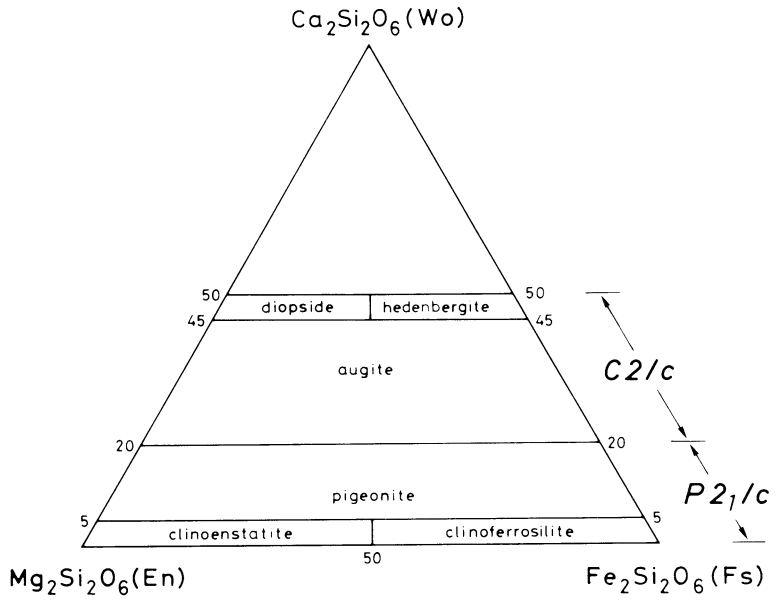

FIG. 4. Composition range of the Ca–Mg–Fe clinopyroxenes, with accepted names.

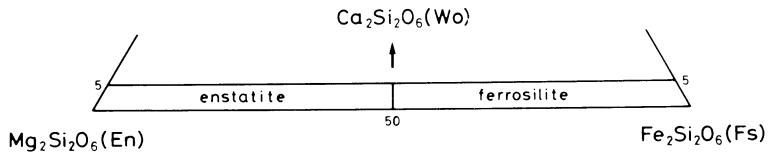

FIG. 5. Composition ranges of orthopyroxenes, with accepted names.

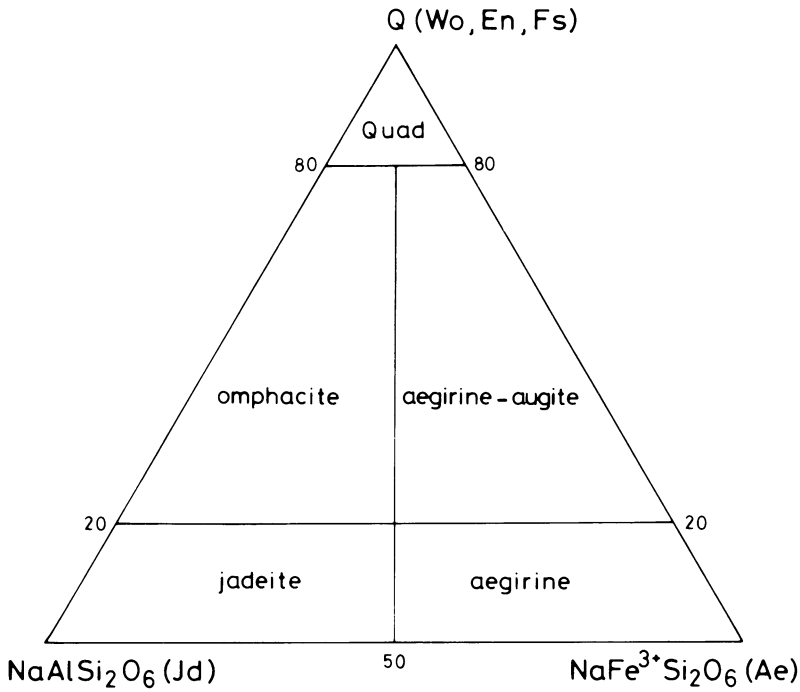

FIG. 6. Ca–Mg–Fe and Na pyroxenes, with accepted names. **Quad** represents the Ca–Mg–Fe pyroxene area (see Fig. 4).

Thus the composition field of "enstatite-*Pbcn*" is different from that of enstatite-*Pbca*.

The classification of the Na and Ca–Na pyroxenes

The Na pyroxenes, jadeite and aegirine, commonly contain more than 90% of the $NaAlSi_2O_6$ or $NaFe^{3+}Si_2O_6$ component, respectively, but contain neither the Ko nor the Je component. Because kosmochlor is a rare accessory constituent of some iron meteorites, and only one terrestrial locality is known for each of kosmochlor and jervisite, these two species are separately treated in the classification of the Na pyroxenes. Both jadeite and aegirine, however, show extensive solid-solution with the Ca–Mg–Fe pyroxenes, expecially with the diopside–hedenbergite series and augite, leading to the Ca–Na pyroxenes. The Na and Ca–Na pyroxenes are classified on the **Quad**–Jd–Ae diagram (Fig. 6), with normalized Q (Wo + En + Fs), Jd and Ae components[*11]. The arbitrary divisions between the Ca–Mg–Fe pyroxenes, Na–Ca pyroxenes, and Na pyroxenes are defined at 20 and 80% of Q = (Wo + En + Fs). Omphacite displays a $C2/c \rightleftharpoons P2/n$ polymorphic transition, and both high-temperature $C2/c$ and low-temperature $P2/n$ polymorphs appear in nature. Omphacite can thus be divided into two subspecies: omphacite-$C2/c$ and omphacite-$P2/n$. Because omphacite-$P2/n$ shows a unique crystal-structure different from that of jadeite and augite, it is accepted as an independent pyroxene species. Aegirine–augite is also accepted as an independent species to keep balance with omphacite, though it is not known to occur with the $P2/n$ structure. The classification of the Ca–Na pyroxenes by Essene & Fyfe (1967) is not followed in this report.

The classification of other pyroxenes

Most naturally occurring pyroxenes in the **'Others'** area are johannsenite ($CaMnSi_2O_6$), petedunnite ($CaZnSi_2O_6$) and spodumene ($LiAlSi_2O_6$) (Fig. 2). Recent investigations of natural manganese-bearing pyroxenes have yielded two new minerals, kanoite and its dimorph donpeacorite, $(Mn,Mg)MgSi_2O_6$, which seem to form a solid solution with En (Petersen *et al.* 1984). They too occur in the **'Others'** area. These results suggest a possible Mn–Mg–Fe pyroxene quadrilateral. Esseneite ($CaFe^{3+}AlSiO_6$) is the first pyroxene with the substitution (3) as described in Table 1.

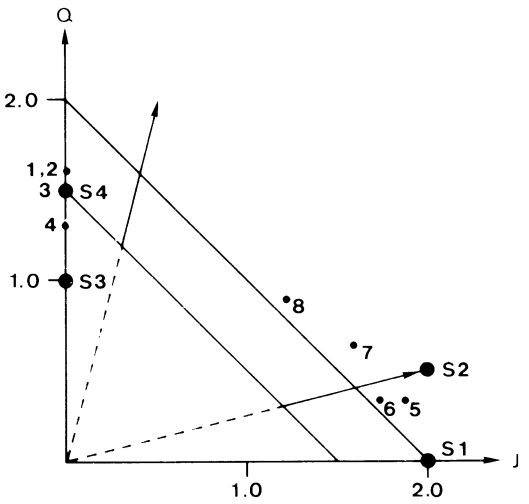

FIG. 7. Q–J diagram for eight unusual pyroxenes with Q value less than 1.62 and Mn less than 0.08 atoms per formula unit (Table 3). The components formed by the substitutions (1) to (4), as indicated in Table 1, are plotted in the diagram. They represent the following compositions: $S1 = NaR^{3+}Si_2O_6$, $S2 = NaR^{2+}_{0.5}Ti^{4+}_{0.5}Si_2O_6$, $S3 = CaR^{3+}AlSiO_6$ and $S4 = CaR^{2+}_{0.5}Ti^{4+}_{0.5}AlSiO_6$.

The classification of unusual pyroxenes

Several pyroxenes with unusual chemical compositions (Table 3) appear outside the area between the $Q+J = 2.0$ and $Q+J = 1.5$ lines in the Q–J diagram, though they do not belong to the 'other' pyroxenes mentioned above (Fig. 7). They contain large amounts of chemical constituents of substitutions (2), (3) and (4) mentioned in Table 1 in the standard chemical formulae.

These pyroxenes can be divided into two groups: firstly Ca-rich pyroxenes with the $S3$ ($CaR^{3+}AlSiO_6$) and $S4$ ($CaR^{2+}_{0.5}Ti^{4+}_{0.5}AlSiO_6$) components representing substitutions (3) and (4), respectively, and secondly Na-rich pyroxenes with the $S2$ component ($NaR^{2+}_{0.5}Ti^{4+}_{0.5}Si_2O_6$) representing substitution (2). The former shows a significant deficiency of Si atoms (such as Si < 1.60) in the standard formula, resulting in the Q value close to or less than 1.5 (point S4 in Fig. 7). The latter appears outside the line $Q+J = 2.0$, approaching point S2 in Figure 7. All these unusual pyroxenes are classified by using the accepted pyroxene names and the adjectival modifiers mentioned below, except for the Allende pyroxene (Table 3, No. 4), which is called subsilicic titanoan aluminian pyroxene.

The Allende pyroxene (No. 4) contains 39% of the $S3$ (Ti) component and can be considered as a new mineral. However, we have decided only to use accepted names in this report; if a species has not yet been approved, we use *pyroxene,* as for No. 4 in Table 3. The names used in the literature for the unusual pyroxenes are listed in Table 3 in comparison with those in this report. The "CaMgTAL" pyroxene (No. 1) is diopside in this classification.

Adjectival Modifiers

Adjectival modifiers for mineral names are used to indicate unusual amounts of chemical constituents. In order to define the unusual amounts for the pyroxene mineral group quantitatively, extreme compositions of pyroxenes have been listed in Table 4, where the values for the main cations are shown as well as those for the accessory cations. Tables provided by Deer *et al.* (1978) and Robinson (1980) mainly were used in constructing the table.

An element specified as a modifier should be present as a general rule in a quantity larger than 0.1 or 0.01 atoms in the standard chemical formula of 6 O or 4 metal atoms (Table 5), depending on the maximum content in Table 4.

TABLE 4. EXTREME CHEMICAL COMPOSITIONS OF PYROXENES IN DHZ (1978)*

	Mg-Fe pyroxenes	Ca pyroxenes	Na pyroxenes
Si	**1.76** (42-9)	**1.44** (320-8)*1	**1.94** (488-9)
Al^{3+}	0.24 (42-9)	0.56 (320-8)	0.07 (488-8)
Fe^{3+}	0.04 (49-8)	0.09 (320-11)	0.02 (488-9)
Al^{3+}	0.15 (49-6)	0.35 (320-11)	**0.98** (464-1)
Ti^{4+}	0.04 (40-30)	0.17 (320-8)*2	0.27 (488-9)*
Fe^{3+}	0.12 (170-8)	0.37 (321-5)*4	**0.97** (487-1)
Mg^{2+}	**1.99** (41-1)	**1.27** (208-4)	0.15 (488-9)
Fe^{2+}	**1.72** (47-33)*5	**1.09** (220-13)	0.11 (488-9)
Mn^{2+}	0.27 (45-21)*6	0.36 (217-5)*7	0.03 (487-4)
Cr^{2+}	0.02 (36-9)	0.06 (207-11)	- *8
Ni^{2+}	-	0.003 (317-1)	-
Zn^{2+}	-	0.21 (216-11)*9	-
Ca^{2+}	0.26 (169-2)	**1.03** (202-4)	0.16 (466-14)
Na^{+}	0.10 (169-2)	0.31 (323-7)	**0.98** (464-1)

* Number of cations per formula unit, minimum values for Si and maximum values for other cations. Bold numbers are for the main consituent elements. Numbers in the parentheses such as 42-9, etc. indicate pages and analysis numbers in DHZ (1978). Other references are in the text.

*1 Table 3, No. 1. Table 3, No. 4: pyroxene from the Allende meteorite 1.20 (Mason 1974, Tracy & Robinson 1977).

*2 Probe analysis 0.252 & 0.282, half of $CaR^{2+}_{0.5}Ti^{4+}_{0.5}AlSiO_6$ (S4) (Tracy & Robinson 1977, Robinson 1980).

*3 Table 3, No. 5. Half of $NaR^{2+}_{0.5}Ti^{4+}_{0.5}Si_2O_6$ (S2).

*4 406-15 0.67, omitted because of possible errors in chemical analysis.

*5 Probe analysis 1.880 (Jaffe et al. 1978).

*6 Probe analysis 0.301 (Robinson 1980), kanoite 1.04 (Kobayashi 1977).

*7 Johannsenite 0.963 (417-2).

*8 Kosmochlor 0.90 (522-1).

*9 Petedunnite 0.37 (Table 2, remark *1).

The suffixes are those proposed by Schaller (1930) and adapted by CNMMN (Nickel & Mandarino 1987). The suffix -ian is used for the higher valence state (*e.g.*, ferrian) or for an element with a nonvariable state (*e.g.*, lithian). The suffix -oan implies the lower valence state (*e.g.*, ferroan). It is recommended that such modifiers never be used for main cations normally contained in the named mineral, for example, in terms like calcian augite, aluminian omphacite, and sodian aegirine-augite, in which the modifiers obviously are superfluous.

If there is less than the amount necessary for the assignment of the modifiers such as 'aluminian' in Table 5, or 0.1 Al, but if the increased content of the element must be stressed, the modifier 'aluminum-bearing' may be used. This second type of modifier should be used also (1) if only incomplete analytical data are available, preventing the calculation of a full chemical formula, or (2) for pyroxenes where the valence state of a cation is unknown. With regard to the Si content in pyroxenes, it is suggested that $Si < 1.75$ is a suitable limit for use of the term 'subsilicic', though one should bear in mind that the $Si < 5.75$ limit for 'subsilicic' in amphiboles corresponds to $Si < 1.5$ for pyroxenes.

In certain cases, particularly for the augite series, it is convenient to use the following adjectival modifiers: iron-rich, magnesium-rich, and subcalcic. A prefix actually attached or hyphenated to a mineral name, however, is incorrect and should be avoided (Nickel & Mandarino 1987), because it would cause the mineral to be indexed alphabetically under the prefix rather than the proper mineral name. This is why such terms as "ferropigeonite", "ferro-augite", *etc.*, should not be used as mineral names.

It is often useful to give the space group of the mineral, particularly if it can occur in two or more forms. For example, we could distinguish between the two forms of omphacite by adding the space-group symbol, *i.e.*, omphacite-*C*2/*c*, omphacite-*P*2/*n*, or by adding the lattice-type symbol, *i.e.*, omphacite-*C*, omphacite-*P* (Bailey 1978).

TABLE 5. LIST OF ADJECTIVAL MODIFIERS TO BE USED FOR PYROXENE MINERAL NAMES*

cation	content*1	name
Al^{3+}	>0.10	aluminian
Ca^{2+}	>0.10	calcian
Cr^{3+}	>0.01	chromian
Fe^{2+}	>0.10	ferroan
Fe^{3+}	>0.10	ferrian
Li^{+}	>0.01	lithian
Mg^{2+}	>0.10	magnesian
Mn^{2+}	>0.10	manganoan
Mn^{3+}	>0.01	manganian
Na^{+}	>0.10	sodian
Ni^{2+}	>0.01	nickeloan
Si^{4+}	<1.75	subsilicic
Ti^{3+}	>0.01	titanoan
Ti^{4+}	>0.10	titanian
Zn^{2+}	>0.01	zincian

* The limit of the content is determined based on the values listed in Table 4.

*1 Number of cations per formula unit $M2M1T_2O_6$. If the mineral name itself implies the presence of certain cations, adjectival modifiers for these cations should not be used ('subsilicic' is an exception).

Obsolete Names Of Pyroxenes

The names of 105 pyroxenes or altered pyroxenes listed in Table 6 have formally been discarded by the CNMMN and are therefore obsolete. The recommended name is written in bold-face type in the same table.

TABLE 6. OBSOLETE NAMES OF PYROXENES.

The following pyroxene mineral names, or names which refer to altered pyroxenes, have been formally discarded by CNMMN. The correct names are written in bold-face type. The original form of this table was compiled by Malcolm Ross using the following references: Dana (1892), Tschermak (1897), Chester (1886), Ford (1932), Winchell & Winchell (1951), Deer *et al.*, (1963, 1978), Strunz (1970), and the unpublished Thesaurus of Mineralogical Terms of the International Mineralogical Association, which has been available since August 1974.

acmite = **aegirine**
aegirine-hedenbergite = **augite**
aegirite (aegyrite) = **aegirine**
agalite = probably **enstatite** partly altered to talc
aglaite = altered **spodumene**
alalite = **diopside**
alkali augite = **aegirine-augite**
amblystegite = **enstatite**
anthochroite = **augite**
asteroite = iron-rich **augite**
baikalite = **diopside**
bastite = **enstatite** which has altered to serpentine, talc, or perhaps anthophyllite
blanfordite = manganoan **aegirine-augite**
bronzite = **enstatite**
calc-clinobronzite = **pigeonite**

calc-clinoenstatite = **pigeonite**
calc-clinohypersthene = **pigeonite**
calc-pigeonite = subcalcic **augite**
canaanite = **diopside**
chladnite = **enstatite**
chloromelanite = **omphacite** or **aegirine-augite**
chrome-acmite = chromian **aegirine**
chromejadeite = chromian **jadeite**
clinohypersthene = **clinoenstatite** or **clinoferrosilite**
coccolite (kokkolith) = iron-rich **augite**
cymatolite = altered **spodumene**
diaclasite = altered **enstatite**
diallage = **diopside** that has altered or that has good (100) parting; also used for alteration products of other pyroxenes
diopsidjadeite = **omphacite**
endiopside = magnesium-rich **augite**
enstatite-diopside = magnesium-rich **augite**
eulite = **ferrosilite**
eulysite = **ferrosilite**
fassaite = ferrian aluminian **diopside** or **augite**
fedorovite = **diopside**
ferroaugite = **augite**
ferrohedenbergite = **augite**
ferrohypersthene = **ferrosilite**
ferro-johannsenite = iron-rich **johannsenite**
ferropigeonite = iron-rich **pigeonite**
ferrosalite = **hedenbergite**
ficinite = **enstatite**
funkite = **hedenbergite**
germarite = altered **enstatite**
hiddenite = **spodumene**
hudsonite = **hedenbergite**
hypersthene = **enstatite** or **ferrosilite**
jadeite-aegirine (jadeite-aegirite) = **jadeite** or **aegirine**
jeffersonite = zincian manganoan **diopside** or **augite**
killinite = altered **spodumene**
korea-augite = **augite**
kunzite = **spodumene**
lavroffite = **diopside**
lavrovite = **diopside**
lawrowite = **diopside**
leucaugite = **diopside**
lime-bronzite = probably **pigeonite** or **enstatite** + **augite,** ("inverted" **pigeonite**)
loganite = **diopside** + actinolite + talc
lotalite = **hedenbergite**
malacolite = **diopside** with good (001) parting, also **diopside** from Sala, Sweden
mansjoite = **augite** or **diopside** or **hedenbergite**
mayaite = **omphacite**
mellcrite = **orthopyroxene**
mondradite = probably an altered **pyroxene**
mussite = **diopside**
orthobronzite = **enstatite**
orthoenstatite = **enstatite**
orthoeulite = **ferrosilite**
orthoferrosilite = **ferrosilite**
orthohypersthene = **enstatite** or **ferrosilite**
paulite = **enstatite**
peckhamite = **enstatite**
phastine = altered **enstatite**
picrophyll = altered **pyroxene**?
pigeonite-augite = probably subcalcic **augite**
pitkarantite = **pyroxene**?
potash-aegirine = synthetic product, probably not properly characterized
protheite = **augite**
protobastite = **enstatite**
pyrallolite = altered **pyroxene**?, talc?
pyrgom = **pyroxene**
sahlite = **diopside**
salite = **diopside**
schefferite = manganoan **diopside**
schillerspar (schillerspat) = **enstatite** that is altered to serpentine, talc, or anthophyllite
shepardite = **enstatite**
soda-spodumene = sodian **spodumene**
strakonitzite = altered **pyroxene,** steatite?
szaboite = partly altered **enstatite**
titanaugite = titanian **augite**
titandiopside = titanian **diopside**
titanpigeonite = titanian **pigeonite**
trachyaugite = **augite**
traversellite = **diopside**
triphane = **spodumene**
tuxtlite = **omphacite**
uralite = pseudomorph of amphibole after pyroxenes
urbanite = iron-rich **augite** or **aegirine-augite**
ureyite = **kosmochlor**
vanadinaugite = vanadium-bearing **augite**
vanadinbronzite = vanadium-bearing **enstatite**
vargasite = altered **pyroxene**?
victorite = **enstatite**
violaite = **augite**
violan = magnesium-rich **augite** or **diopside**

Comments

*[1]In omphacite-$P2/n$, the $M1$ and $M2$ sites are further divided into $M1a$ and $M1b$ (for $M1$) and $M2a$ and $M2b$ (for $M2$).

*[2]Orthopyroxene (*Pbcn*) is stable only at elevated temperatures for a limited composition near $MgSiO_3$.

*[3]Aegirine is used in preference to "acmite" in this report. It is in common usage in the literature, and is consistent with the almost universal use of aegirine-augite for minerals of intermediate compositions, though "acmite" has priority by 14 years (Dana 1892). Common practice in experimental petrology has been to use the abbreviation Ac for $NaFe^{3+}Si_2O_6$; Ae should be used instead.

*[4]The CNMMN, IMA, has recently voted in favor of the name kosmochlor instead of "ureyite" for the pyroxene of generalized composition $NaCrSi_2O_6$.

*5Esseneite is a new pyroxene with the composition $CaFe^{3+}AlSiO_6$ (Table 2, No. 13).

*6"Fassaite" has the general formula $Ca(Mg,Fe^{3+},Al)(Si,Al)_2O_6$. This name has been rejected as a formal name in this report.

*7$Ca_2Si_2O_6$ exists as wollastonite in nature; it belongs not to the pyroxenes but to the pyroxenoids. To represent the compositions of the Ca–Mg–Fe pyroxenes, the ternary system $Ca_2Si_2O_6$(Wo) – $Mg_2Si_2O_6$(En) – $Fe_2Si_2O_6$(Fs) has been used, *e.g.*, $En_{20}Fs_{38}Wo_{42}$.

*8Definition of the **'Other'** pyroxenes is different from that given by Cameron & Papike (1981).

*9The name aegirine–augite appears to be in more common usage than "aegirineaugite", and "acmite–augite".

*10For the nomenclature of the Ca–Mg–Fe pyroxenes, normalization must be made to $Ca+Mg+\Sigma Fe = 100$, where $\Sigma Fe = Fe^{2+} + Fe^{3+} + Mn$. Hereafter the mol percent of the end-member components is always used without remark and is represented simply by %. If the mole % values of the quadrilateral components are calculated by the atomic % of Ca to the total cations at the *M* sites, no pyroxenes should contain more than 50% $Ca_2Si_2O_6$. However, if Ca, Mg and Fe are normalized, or, calculated as $100\,Ca/(Ca+Mg+\Sigma Fe)$, $100\,Mg/(Ca+Mg+\Sigma Fe)$ and $100\,\Sigma Fe/(Ca+Mg+\Sigma Fe)$, respectively, then in some cases, augite will plot on a Wo–En–Fs triangular diagram above the 50% $Ca_2Si_2O_6$ line. In particular, where the plot in the Q–J diagram is very close to or outside the boundary $Q+J = 1.5$, the effect of johannsenite and petedunnite components must be considered. If the effect is negligible, the pyroxene must be considered to have an unusual composition and must be referred to the section of unusual pyroxenes.

*11To normalize *Q*, Jd and Ae components, $Ca+Mg+Fe^{2+}+2Na$ at the *M* sites must be made to total 100%. Then the normalized 2Na% must be divided according to the ratio Al/Fe^{3+} to give the ratio Jd/Ae. Thus $Q+Jd+Ae$ must always give 100%. Where the plot in the Q–J diagram is significantly outside the boundary $Q+J = 2.0$, the effect of substitution (2) must be considered, as in the section of unusual pyroxenes.

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