

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.

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 20, 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 oxygens, or to four cations (Vieten and 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 and Winchell, 1978) is to denote 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 principle 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 (or Mg-rich) augite and iron-rich (or Fe-rich) augite]; the other to specify elemental substitutions that are not essential constituents (e.g., titanian augite). The CNMMN has formally discredited 105 previously used pyroxene names—mostly synonyms, obsolete or almost unused, or recommended for rejection.

General publications dealing with the pyroxene group include *Rock-Forming Minerals* (Deer et al., 1978), *Mineralogical Society of America Special Paper 2* (Papike, 1969) and *MSA Reviews in Mineralogy*, volume 7 (Prewitt, 1980), which provide references to the voluminous literature.

CRYSTAL CHEMISTRY OF THE PYROXENES

Pyroxenes are silicates that, in their simplest form, contain single SiO₃ chains of linked SiO₄ tetrahedra. Generally, small amounts of Si are replaced by Al and other small cations. The repeat along the chain (*c* axis) comprises two tetrahedra and is approximately 0.52 nm in length. The general chemical formula (formula unit) for all pyroxenes¹ is M₂M₁T₂O₆, where M₂ refers to cations

¹ In omphacite-*P2/n*, the M₁ and M₂ sites are further divided into M_{1a} and M_{1b} (for M₁) and M_{2a} and M_{2b} (for M₂).

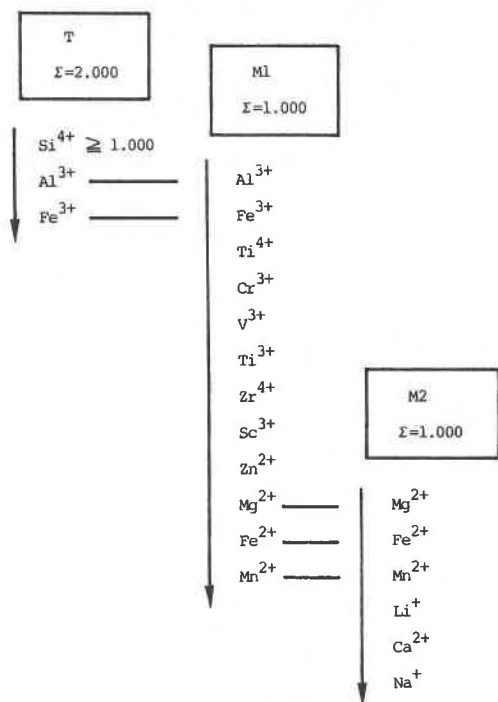


Fig. 1. Flow chart for ideal site occupancy of cations between the T, M1, and M2 sites of pyroxenes. Only representative cations are included. Arrows indicate order of filling of sites. Real site occupancy is usually slightly different from the ideal site occupancy.

in a generally distorted octahedral coordination, M1 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 orthorhombic pyroxene types: 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*, *P2₁/c*, and *P2₁/n*, depending on their chemical composition and petrogenetic history.

Throughout this report, the standard pyroxene formula is used with superscripted arabic numerals (e.g., Fe²⁺) referring to charges and subscripted numerals (e.g., Mg₂) referring to numbers of atoms.

In order to derive a pyroxene formula from a chemical analysis, the calculation should be based on six oxygen atoms when Fe²⁺ and Fe³⁺ are both 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 and Hamm (1978) have shown that calculation to four cations will be more reliable for microprobe analyses of the majority of pyroxenes. Therefore, for microprobe analyses, it is recommended that the components be totaled to six oxy-

gens and four cations by adjusting the ratios Fe²⁺/Fe³⁺, Ti⁴⁺/Ti³⁺, etc.

The standard pyroxene formula M₂M₁T₂O₆ 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 Si⁴⁺, then Al³⁺, and then Fe³⁺.
2. Sum M1 to 1.000 using all Al³⁺ and Fe³⁺ in excess of that used to fill the T sites. If there is insufficient Al³⁺ and Fe³⁺ to sum to 1.000, then add Ti⁴⁺, Cr³⁺, V³⁺, Ti³⁺, Zr⁴⁺, Sc³⁺, Zn²⁺, Mg²⁺, Fe²⁺, and finally Mn²⁺ until the sum is 1.000.
3. Sum M2 using all Mg²⁺, Fe²⁺, and Mn²⁺ in excess of that used to fill the M1 sites. Then add Li⁺, Ca²⁺, 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 Bokij and 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 difference between the real and ideal site occupancies.

Starting from the most common pyroxene formula, M₂(R²⁺)M₁(R²⁺)T₂(2R⁴⁺)O₆, four coupled substitutions are possible if one assumes more than one R⁴⁺ 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 (NaAlSi₂O₆), aegirine³ (NaFe³⁺Si₂O₆), kosmochlor⁴ (NaCr³⁺Si₂O₆, Ko), and jervisite (NaScSi₂O₆, Je). Substitution 2 results in components such as NaFe_{0.5}Ti_{0.5}Si₂O₆, but is less important than the other substitutions.

In substitution 3, the Al-Al couple is often referred to as "Tschermak's component"; CaAlAlSiO₆, in particular, is called "calcium Tschermak's component." Substitution in esseneite,⁵ CaFe³⁺AlSiO₆, is obtained by this type of substitution. This substitution is also important in

³ "Aegirine" is used in preference to "acmite" in this report. "Aegirine" 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 NaFe³⁺Si₂O₆; Ae should now 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 NaCrSi₂O₆.

⁵ Esseneite is a new pyroxene with the composition CaFe³⁺AlSiO₆ (Table 2, no. 13).

² Orthopyroxene (*Pbcn*) is stable only at elevated temperatures for a limited composition near MgSiO₃.

TABLE 1. Four coupled substitutions* of pyroxenes in the standard chemical formula $R^{2+}R^{2+}R_2^{4+}O_6$

	Substitution site			Examples
	M2	M1	T	
Standard occupancy	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^+)	$R_{0.5}^{2+}(R_{0.5}^{4+})$	$2R^{4+}$	Na-(Ti ⁴⁺ /2)
Substitution 3	R^{2+}	(R^{3+})	$(R^{3+})R^{4+}$	Al-Al Fe ³⁺ -Al Cr ³⁺ -Al (Ti ⁴⁺ /2)-Al
Substitution 4	R^{2+}	$R_{0.5}^{2+}(R_{0.5}^{4+})$	$(R^{3+})R^{4+}$	

* Shown by parentheses.

“fassaite.”⁶ Substitution resulting in $CaTi^{3+}AlSiO_6$ was reported by Dowty and Clark (1973) and Mason (1974) in pyroxenes from the Allende meteorite (Table 3, no. 4). In substitution 4, the component $CaMg_{0.5}Ti_{0.5}^{4+}AlSiO_6$ 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

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.

names are given for the end-member components of substitutions 2 and 4.

MINERAL NAMES OF THE PYROXENES

Twenty (20) 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. Whenever 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 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 mineral species names of the pyroxenes (Table 2).

The definition of the pyroxene species has been based on 13 end members, or chemical components (given in

TABLE 2. Accepted pyroxene mineral names and their chemical subdivisions

Mineral names	Composition as end member	Main composition as solid solution	Space group
A. Mg-Fe pyroxenes			
1. enstatite (En)	$Mg_2Si_2O_6$	} $(Mg,Fe)_2Si_2O_6$	<i>Pbca</i>
2. ferrosilite (Fs)	$Fe_2^{2+}Si_2O_6$		
3. clinoenstatite			
4. clinoferrosilite			
5. pigeonite			
B. Mn-Mg pyroxenes			
6. donpeacorite		$(Mn,Mg)MgSi_2O_6$	<i>Pbca</i>
7. kanoite (Ka)	$MnMgSi_2O_6$	$(Mn,Mg)MgSi_2O_6$	
C. Ca pyroxenes			
8. diopside (Di)	$CaMgSi_2O_6$	} $Ca(Mg,Fe)Si_2O_6$	<i>C2/c</i>
9. hedenbergite (Hd)	$CaFe^{2+}Si_2O_6$		
10. augite			
11. johannsenite (Jo)	$CaMnSi_2O_6$	} $(Ca,Mg,Fe)_2Si_2O_6$	<i>C2/c</i>
12. petedunnite (Pe)*	$CaZnSi_2O_6$		
13. esseneite (Es)**	$CaFe^{3+}AlSiO_6$		
D. Ca-Na pyroxenes			
14. omphacite		$(Ca,Na)(R^{2+},Al)Si_2O_6$	<i>C2/c, P2_1/n</i>
15. aegirine-augite		$(Ca,Na)(R^{2+},Fe^{3+})Si_2O_6$	
E. Na pyroxenes			
16. jadeite (Jd)	$NaAlSi_2O_6$	} $Na(Al,Fe^{3+})Si_2O_6$	<i>C2/c</i>
17. aegirine (Ae)	$NaFe^{3+}Si_2O_6$		
18. kosmochlor (Ko)	$NaCr^{3+}Si_2O_6$		
19. jervisite (Je)†	$NaSc^{3+}Si_2O_6$		
F. Li pyroxene			
20. spodumene (Sp)	$LiAlSi_2O_6$		<i>C2/c</i>

Note: 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 printed in boldface type. Main compositions are given for solid solutions. Space groups are also given.

* Petedunnite has been determined by Essene and Peacor (1987) to have the composition $(Ca_{0.92}Na_{0.08}Mn_{0.02})(Zn_{0.37}Mn_{0.19}Fe_{0.19}^{2+}Fe_{0.12}^{3+}Mg_{0.14})(Si_{1.94}Al_{0.06})O_6$ by means of an electron microprobe. This mineral was approved as a valid species by the CNMMN, IMA, in 1983.

** Esseneite has been determined by Cosca and Peacor (1987) to have the composition $(Ca_{1.01}Na_{0.01})(Fe_{0.72}^{2+}Mg_{0.19}Al_{0.04}Ti_{0.03}Fe_{0.02}^{3+})(Si_{1.19}Al_{0.81})O_{6.00}$ by means of an electron microprobe. This mineral was approved as a valid species by the CNMMN, IMA, in 1985.

† Jervisite has been determined by M. Mellini et al. (1982) to have the composition $(Na_{0.43}Ca_{0.31}Fe_{0.14}^{2+}□_{0.12})(Sc_{0.66}Fe_{0.15}^{3+}Mg_{0.19})Si_2O_6$ by means of an electron microprobe. This mineral was approved as a valid species by the CNMMN, IMA, in 1982.

bold face in Table 2) and the component $\text{Ca}_2\text{Si}_2\text{O}_6$ (Wo).⁷ These end members are given the names of the minerals whose compositions they most closely approximate. The 20 pyroxene species are grouped into six chemical subdivisions on the basis of the cation occupancy of the M2 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. First of all, 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 $\text{Ca}_2\text{Si}_2\text{O}_6$ (Wo)– $\text{Mg}_2\text{Si}_2\text{O}_6$ (En)– $\text{Fe}_2\text{Si}_2\text{O}_6$ (Fs) system. Therefore, these pyroxenes are better treated together as the Ca-Mg-Fe or “quadrilateral” pyroxenes. Second, Na pyroxenes form continuous solid-solution series with the Ca-Mg-Fe pyroxenes, forming the Na-Ca pyroxenes. Third, donpeacorite and kanoite in the Mn-Mg pyroxenes, johannsenite, petedunnite, and esseneite in the 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**, 4) and other pyroxenes (**Others**, 6). The abbreviations of the groups and the numbers of the accepted species are given in 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 (the Wo component is used for the Di and Hd components). The composition ranges for the accepted names will be given later in this report.

The pyroxene names may be qualified by one or more adjectival modifiers according to definite rules described later in this report to specify important (though relatively minor) departures from the composition ranges. When 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-clinofersilite series), Ca pyroxene series (diopside-hedenbergite series) and Na pyroxene se-

ries (jadeite-aegirine series). Subdivision names of 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-augite⁹ have been retained.

Gem names of spodumene

Two names, “hiddenite” and “kunzite,” are often used for (pale) emerald-green- and lilac-colored spodumene of gem quality, respectively. 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. Although the tetrahedral sites in both the pyroxenes and the pyroxenoids are mostly occupied by Si ions, the large cations in the pyroxenoids are mostly Ca, Mn, and Fe^{2+} ions. The classification and nomenclature of the pyroxenoids are beyond the scope of this report. However, the following two points may be noted. First, there is a polymorphic relationship with some pyroxenes such as ferrosilite, hedenbergite, and johannsenite. These show pyroxenoid structures at high temperatures or pressures. Second, the wollastonite chemical component ($\text{Ca}_2\text{Si}_2\text{O}_6$) 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 and Kitamura, 1983).

In this procedure the pyroxenes are classified by using the total numbers of specified cations at the M (M1 and M2) sites on the basis of six oxygens. 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 $Q = \text{Ca} + \text{Mg} + \text{Fe}^{2+}$ and $J = 2\text{Na}$. The lines representing the

⁷ $\text{Ca}_2\text{Si}_2\text{O}_6$ exists as wollastonite in nature, which belongs not to the pyroxenes but to the pyroxenoids. To represent the compositions of the Ca-Mg-Fe pyroxenes, the ternary $\text{Ca}_2\text{Si}_2\text{O}_6$ (Wo)– $\text{Mg}_2\text{Si}_2\text{O}_6$ (En)– $\text{Fe}_2\text{Si}_2\text{O}_6$ (Fs) system has been used, e.g., $\text{En}_{20}\text{Fs}_{38}\text{Wo}_{42}$.

⁸ Definition of the “Other pyroxenes” is different from that given by Cameron and Papke (1981).

⁹ The name “aegirine-augite” appears to be in more common usage than “aegirineaugite,” and “acmite-augite.”

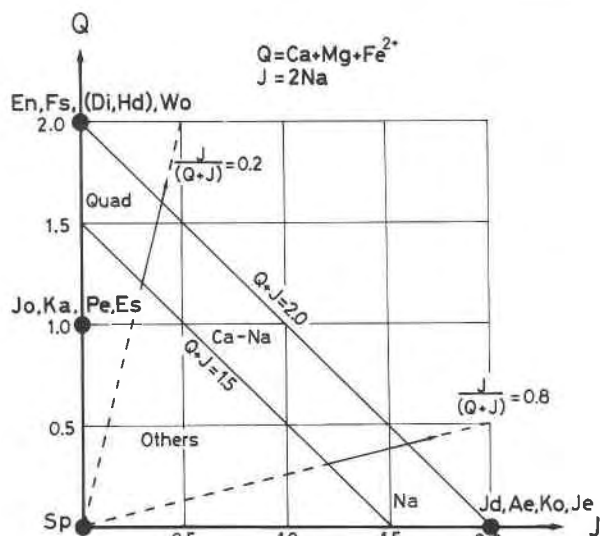


Fig. 2. Q - J diagram for the pyroxenes, on which the positions of the 13 accepted end members have been indicated. Abbreviations and compositions of the end members are listed in Table 2.

following equations are used to subdivide the Q - J diagram:

$$Q + J = 2.0 \quad (1)$$

$$Q + J = 1.5 \quad (2)$$

$$J/(Q + J) = 0.2 \quad (3)$$

$$J/(Q + J) = 0.8. \quad (4)$$

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. When the coupled 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-Ti⁴⁺) 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 the 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. Equations 3 and 4 represent the lines dividing the area limited by the two above-mentioned $Q + J$ lines into Ca

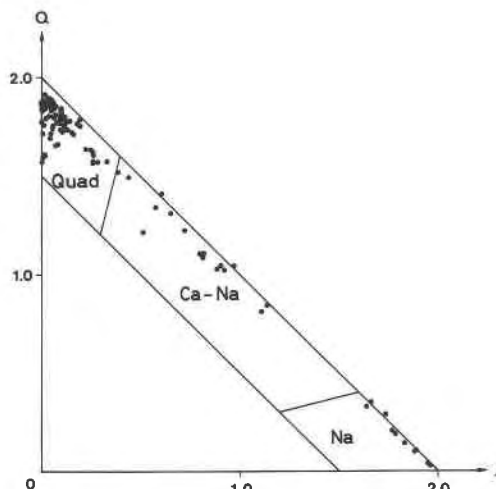


Fig. 3. The 103 pyroxenes from Deer et al. (1978) selected by Cameron and Papike (1981) plotted on the Q - J diagram. For these pyroxenes, the Q values are less than 1.90, and Mn is less than 0.08 atoms per formula unit.

+ 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 and 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 have Q values between 1.0 and 1.5 in the Q - J diagram. Similarly, petedunnite and esseneite plot along the Q axis with Q values between 1.0 and 1.5. Spodumene plots at the origin of the Q - J diagram because both Q and J are zero. Thus, the thirteen end members (Table 2) and Wo are located in the Q - J diagram (Fig. 2).

Application of this classification procedure to 406 pyroxene analyses presented in Deer et al. (1978) has shown that most of the analyses, except those of johannsenite and spodumene, are included in the area between the lines $Q + J = 2.0$ and $Q + J = 1.5$. The 103 Deer et al. (1978) pyroxenes selected by Cameron and Papike (1981), for which the Q values are less than 1.90 and Mn is less than 0.08 atoms per formula units, are plotted in the Q - J diagram of Figure 3. The "CaMgTAL" pyroxene (Cameron and Papike, 1981) is included in the Quad area as described later in this report (Table 3, no. 1). Only 20 analyses 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 and Papike (1981). A few unusual pyroxenes with Mn less than 0.08 atoms for the chemical formula unit have been found to lie outside the area between the lines $Q + J = 2.0$ and $Q + J = 1.5$ in the Q - J diagram. The classification of these unusual pyroxenes will be discussed later in this report.

The pyroxenes that plot in the area between $Q + J = 2.0$ and $Q + J = 1.5$ have components than Q and J ions at less than 25% of the M sites. Therefore, we can classify

TABLE 3. Chemical composition and classification of eight unusual pyroxenes

	A. Ca-rich group related to S3 and S4				B. Na-rich group related to S2			
	1: 320-8 (406-16)	2: 403-3	3: D and S*	4: T and R**	5: 488-9	6: 491-14	7: 492-19 C and G‡	8: C and G‡
Si	1.443	1.506	1.434	1.196	1.994	2.024	2.026	2.009
Al	0.577	0.494	0.566	0.804	0.032	0.000	0.000	0.000
Al	0.091	0.171	0.306	0.186	0.000	0.021	0.098	0.348
Ti ⁴⁺	0.165	0.065	0.022	0.111	0.265	0.023	0.227	0.104
Ti ³⁺				0.394				
Fe ³⁺	0.128	0.159	0.218		0.458	0.728	0.192	0.031
Mg	0.385	0.570	0.408	0.289	0.150	0.070	0.070	0.168
Fe ²⁺	0.229	0.063	0.060	2.00	0.107	0.113	0.420	0.356
Mn	0.005	0.007	0.005		0.003	0.006	0.021	0.011
Ca	0.992	0.975	0.979	1.021	0.083	0.155	0.152	0.361
Na	0.006	0.007	0.002		0.933	0.872	0.794	0.610
K	0.000	0.001	—		—	0.009	—	0.006
Q	1.61	1.61	1.45	1.31	0.34	0.34	0.64	0.89
J	0.01	0.01	0.00	0.00	1.87	1.74	1.59	1.22
Mineral names	subsilicic titanian ferrrian diopside	subsilicic aluminian ferrrian diopside	subsilicic aluminian ferrrian diopside	subsilicic titanian aluminian pyroxene	titanian magnesian ferroan aegirine	calcian ferroan aegirine	titanian aegirine-augite	titanian ferroan omphacite
Names in literature	titanaugite (320-8) titanium fassaite (406-16) CaMgTAL (C and P)†	fassaite	fassaite	titanaugite	titanian aegirine	aegirine-augite	titanian aegirine-augite (492-19) titanian aegirine (C and G)‡	titanian ferro-omphacite

Note: Numbers such as 320-8, etc. represent pages and analysis number in Deer et al. (1978). Other references are in text. With the exception of 320-8 (= 406-16), all the Deer et al. (1978) analyses in this table were not included in the 103 selected analyses of Cameron and 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_{0.5}Ti_{0.5}Si₂O₆, S3 = CaR³⁺AlSiO₆, and S4 = CaR_{0.5}Ti_{0.5}AlSiO₆. 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, essenseite (Es). Component ratios for the eight samples are as follows: (1) (Wo₂₂En₁₂Fs₁₀)₄₄S4(Mg)₁₆S4(Fe)₁₆Es₁₆S3(Al)₈, (2) (Wo₂₈En₂₅Fs₂₅)₅₃S3(Al)₁₇Es₁₆S4(Mg)₁₂S4(Fe)₂, (3) (Wo₂₂En₂₀Fs₂₄)₄₄S4(Al)₅Es₂S4(Mg)₄, (4) S3(Ti)₃₆S4(Mg)₂₂(Wo₁₁Fs₉)₂₀S3(Al)₁₉, (5) Ae₄₈S2(Mg)₂₈S2(Fe)₂₀Δ₈, (6) (Ae₇₃Jd₂Wo₆Fs₆En_{3/2})₂S2₄Δ₄, (7) (Ae₁₉Jd₁₀Fs₁₂Wo₆En_{2/5})₅S2(Fe)₄₂S2(Mg)₄Δ₃, (8) (Jd₃₅Ae₃Wo₁₈Fs₁₅En_{7/7})₇S2(Fe)₁₄S2(Mg)₈Δ₂. The symbol Δ represents minor components, some of which have unusual metal ratios for the pyroxene structure.

* Devine and Sigurdsson (1980), Table 1 for fassaite.

** Tracy and Robinson (1977), Table 3, analysis I for pyroxene from the Allende meteorite (Mason, 1974).

† Cameron and Papike (1981), Table A3, analysis 320-8 and 406-16.

‡ Curtis and Gittins (1979), Table 2, analysis 5 for no. 7 and Table 5, analysis 5 for no. 8.

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 ΣFe (= Fe²⁺ + Fe³⁺ + Mn) atoms. (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.

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 by the pyroxene quadrilateral of the Mg₂Si₂O₆ (En)-Fe₂³⁺Si₂O₆ (Fs)-CaMgSi₂O₆ (Di)-CaFe²⁺Si₂O₆ (Hd) system. The Ca-Mg-Fe pyroxenes include varieties that have orthorhombic symmetry. These orthopyroxenes consist essentially of a simple chemical series (Mg,Fe)₂Si₂O₆ and thus contrast with the Ca-Mg-Fe cli-

nopyroxenes, which have wide ranges of chemical composition. Therefore, the Ca-Mg-Fe pyroxenes are defined on the basis of symmetry and relative amounts of Ca₂Si₂O₆ (Wo), Mg₂Si₂O₆ (En), and Fe₂³⁺Si₂O₆ (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 + ΣFe = 100 with ΣFe = Fe²⁺ + Fe³⁺ + Mn²⁺.¹⁰

¹⁰ For the nomenclature of the Ca-Mg-Fe pyroxenes, normalization must be made to Ca + Mg + ΣFe = 100, where ΣFe = Fe²⁺ + Fe³⁺ + Mn. Hereafter the mole percent of the end member components is always used without remark and is represented simply by %. If the mole percents of quadrilateral components are calculated by the atomic percent of Ca to the total cations at the M sites, no pyroxenes should contain more than 50% Ca₂Si₂O₆. However, if Ca, Mg, and Fe are normalized, or calculated as 100Ca/(Ca + Mg + ΣFe), 100 Mg/(Ca + Mg + ΣFe), and 100 ΣFe/(Ca + Mg + ΣFe), respectively, then some augites will plot on a Wo-En-Fs triangular diagram above the 50% Ca₂Si₂O₆ line. Especially when the plot in the *Q-J* diagram is very close to or outside of 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.

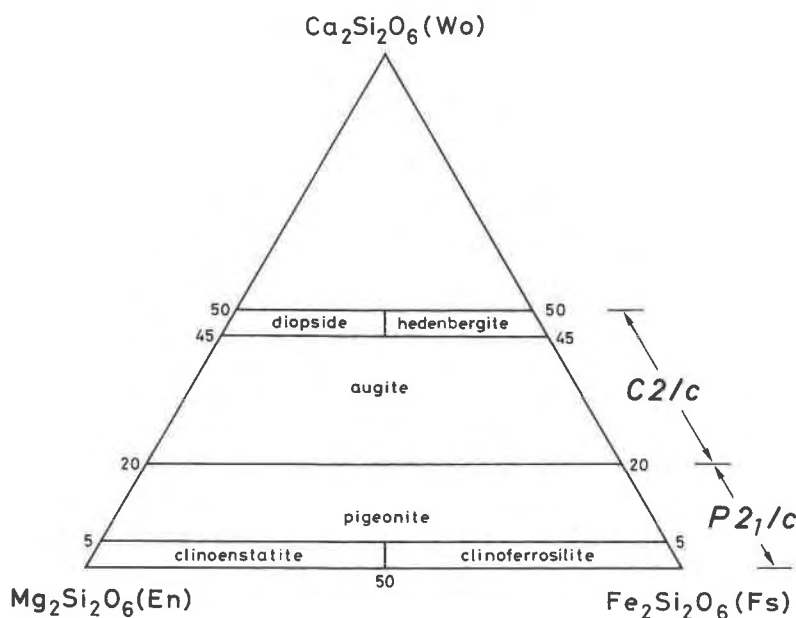


Fig. 4. Composition ranges of the Ca-Mg-Fe clinopyroxenes with accepted names.

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, which cannot be quenched. Augite does not show this type of transformation.

The most Ca-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%. Thus the composition field of “enstatite- $Pbcn$ ” is different from that of enstatite- $Pbca$.

Classification of the Na and Ca-Na pyroxenes

The Na pyroxenes, jadeite and aegirine, commonly contain more than 90% of the $\text{NaAlSi}_2\text{O}_6$ or $\text{NaFe}^{3+}\text{Si}_2\text{O}_6$ 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, especially 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 divi-

¹¹ To normalize Q , Jd, and Ae components, the sum of $\text{Ca} + \text{Mg} + \text{Fe}^{2+} + 2\text{Na}$ at the M sites must be made to total 100%. Then the normalized percentage of 2Na must be divided into the ratio of Al/Fe^{3+} to give the ratio of Jd/Ae. Thus $Q + \text{Jd} + \text{Ae}$ must always give 100%. When 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.

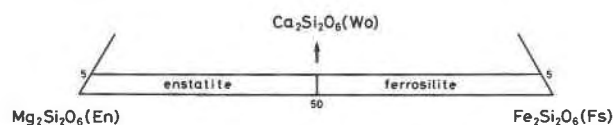


Fig. 5. Composition ranges of orthopyroxenes with accepted names.

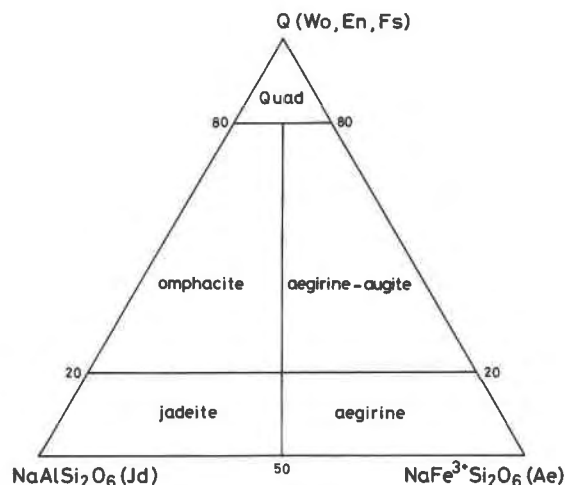


Fig. 6. Ca-Mg-Fe and Na pyroxenes with accepted names. Quad represents the Ca-Mg-Fe pyroxene area (see Fig. 4).

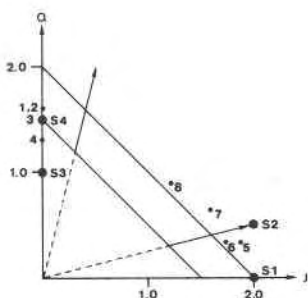


Fig. 7. Q - J diagram for eight unusual pyroxenes with Q value less than 1.62 and Mn less than 0.08 atoms per formula unit (Table 3). The components formed by the substitutions 1 to 4, as indicated in Table 1, are plotted in the diagram. They represent the following compositions: S1 = $\text{NaR}^{3+}\text{Si}_2\text{O}_6$, S2 = $\text{NaR}_{0.5}^{2+}\text{Ti}_{0.5}^{4+}\text{Si}_2\text{O}_6$, S3 = $\text{CaR}^{3+}\text{AlSiO}_6$, and S4 = $\text{CaR}_{0.5}^{2+}\text{Ti}_{0.5}^{4+}\text{AlSiO}_6$.

sions between the Ca-Mg-Fe pyroxenes, Na-Ca pyroxenes, and Na pyroxenes are defined at 20% and 80% of Q . Omphacite displays a $C2/c = P2/n$ 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

TABLE 4. Extreme chemical compositions of pyroxenes in Deer et al. (1978)

	Mg-Fe pyroxenes	Ca pyroxenes	Na pyroxenes
Si	1.76 (42-9)	1.44 (320-8) ^a	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) ^b	0.27 (488-9) ^c
Fe ³⁺	0.12 (170-8)	0.37 (321-5) ^d	0.97 (487-1)
Mg ²⁺	1.99 (41-1)	1.27 (208-4)	0.15 (488-9)
Fe ²⁺	1.72 (47-33) ^e	1.09 (220-13)	0.11 (488-9)
Mn ²⁺	0.27 (45-21) ^f	0.36 (217-5) ^g	0.03 (487-4)
Cr ²⁺	0.02 (36-9)	0.06 (207-11)	— ^h
Ni ²⁺	—	0.003 (317-1)	—
Zn ²⁺	—	0.21 (216-11) ⁱ	—
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)

Note: Given are the number of cations per formula unit, minimum values for Si, and maximum values for other cations. Bold numbers are for the main constituent elements. Numbers in the parentheses such as 42-9, etc., indicate pages and analysis numbers in Deer et al. (1978). Other references are in text.

^a Table 3, no. 1; Table 3, no. 4: Pyroxene from the Allende meteorite 1.20 (Mason, 1974; Tracy and Robinson, 1977).

^b Probe analyses 0.252 and 0.282, half of $\text{CaR}_{0.5}^{2+}\text{Ti}_{0.5}^{4+}\text{AlSiO}_6$ (S4) (Tracy and Robinson, 1977; Robinson, 1980).

^c Table 3, no. 5. Half of $\text{NaR}_{0.5}^{2+}\text{Ti}_{0.5}^{4+}\text{Si}_2\text{O}_6$ (S2).

^d 406-15 0.67, omitted because of possible errors in chemical analysis.

^e Probe analysis 1.880 (Jaffe et al., 1978).

^f Probe analysis 0.301 (Robinson, 1980), kanoite 1.04 (Kobayashi, 1977).

^g Johannsenite 0.963 (417-2).

^h Kosmochlor 0.90 (522-1).

ⁱ Petedunnite 0.37 (Table 2, footnote with asterisk).

TABLE 5. List of adjectival modifiers to be used for pyroxene mineral names

Cation	Content*	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	manganian
Mn ³⁺	>0.01	manganian
Na ⁺	>0.10	sodian
Ni ²⁺	>0.01	nickeloan
Si ⁴⁺	<1.75	subsilicic
Ti ³⁺	>0.01	titanian
Ti ⁴⁺	>0.10	titanian
Zn ²⁺	>0.01	zincian

Note: The limit of the content is based on the values listed in Table 4.

* Number of cations per formula unit $\text{M}_2\text{M}_1\text{T}_2\text{O}_6$. If the mineral name itself implies the presence of certain cations, adjectival modifiers for these cations should not be used ("subsilicic" is an exception).

occur with the $P2/n$ structure. The classification of the Ca-Na pyroxenes by Essene and Fyfe (1967) is not followed in this report.

Classification of other pyroxenes

Most naturally occurring pyroxenes in the Others area are johannsenite ($\text{CaMnSi}_2\text{O}_6$), petedunnite ($\text{CaZnSi}_2\text{O}_6$), and spodumene ($\text{LiAlSi}_2\text{O}_6$) (Fig. 2). Recent investigations of natural Mn-bearing pyroxenes have yielded two new minerals, kanoite and its dimorph donpeacorite, $(\text{Mn,Mg})\text{MgSi}_2\text{O}_6$, which seem to form a solid solution with En (Peterson et al., 1984). They too occur in the Others area. These results suggest a possible Mn-Mg-Fe pyroxene quadrilateral. Esseneite ($\text{CaFe}^{3+}\text{AlSiO}_6$) is the first pyroxene with the substitution 3 as described in Table 1.

Classification of unusual pyroxenes

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

These pyroxenes can be divided into two groups: first, Ca-rich pyroxenes with $\text{CaR}^{3+}\text{AlSiO}_6$ (S3, Fig. 7) and $\text{CaR}_{0.5}^{2+}\text{Ti}_{0.5}^{4+}\text{AlSiO}_6$ (S4, Fig. 7) components representing substitutions 3 and 4, respectively, and second, Na-rich pyroxenes with the $\text{NaR}_{0.5}^{2+}\text{Ti}_{0.5}^{4+}\text{Si}_2\text{O}_6$ component representing substitution 2 (S2, Fig. 7). The former shows a significant deficiency of Si atoms such as $\text{Si} < 1.60$ in the standard formula resulting in the Q value close to or less than 1.5 (S4, 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

TABLE 6. Obsolete pyroxene names

acmite = *aegirine*
aegirite (aegyrite) = *aegirine*
aegerine-hedenbergite = *augite*
agalite = probably *enstatite* partly altered to talc
aglaite = altered *spodumene*
alalite = *diopside*
alkali augite = *aegirine-augite*
amblystegite = *enstatite*
anthochroite = *augite*
asteroite = iron-rich (or Fe-rich) *augite*
baikalite = *diopside*
bastite = *enstatite* that 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 *clinoferroisilite*
cocolite (kokkolith) = iron-rich (or Fe-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 (or Mg-rich) *augite*
enstatite-diopside = magnesium-rich (or Mg-rich) *augite*
eulite = *ferrosilite*
eulysite = *ferrosilite*
fassaite = ferrian aluminian *diopside* or *augite*
fedorovite = *diopside*
ferroaugite = *augite*
ferrohedenbergite = *augite*
ferrohypersthene = *ferrosilite*
ferro-johannsenite = iron-rich (or Fe-rich) *johannsenite*
ferropigeonite = iron-rich (or Fe-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* plus *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 = *dipside*
orthobronzite = *enstatite*
orthoenstatite = *enstatite*
orthoaulite = *ferrosilite*
orthoferrosilite = *ferrosilite*
orthohypersthene = *enstatite* or *ferrosilite*
paulite = *enstatite*
peckhamite = *enstatite*
pashine = altered *enstatite*

TABLE 6—Continued

picrophyll = altered *pyroxene*?
pigeonite-augite = probably subcalcic *augite*
pitkarantite = *pyroxene*?
potash-aegirine = synthetic product, probably not properly characterized
protheite = *augite*
protobastite = *enstatite*
pyralloite = 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 (or Fe-rich) *augite* or *aegirine-augite*
ureyite = *kosmochlor*
vanadinaugite = vanadium-bearing (or V-bearing) *augite*
vanadinbronzite = vanadium-bearing (or V-bearing) *enstatite*
vargasite = altered *pyroxene*?
victorite = *enstatite*
violaitite = *augite*
violane = magnesium-rich (or Mg-rich) *augite* or *dipside*

Note: The above pyroxene mineral names, or names that refer to altered pyroxenes, have been formally discarded by the CNMMN. The correct names are italicized. The original form of this table was compiled by Malcolm Ross using the following references: Dana (1892); Tschermak (1897); Chester (1886); Ford (1932); Winchell and 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.

below, except the Allende pyroxene (Table 3, no. 4), which is called subsilicic titanian aluminian pyroxene.

The Allende pyroxene (no. 4) contains 39% of the S3(Ti) (for notation, see note in Table 3) component $\text{CaR}^{3+}\text{AlSiO}_6$, where $\text{R}^{3+} = \text{Ti}$, and can be considered as a new mineral. However, we have decided only to use the accepted names in this report and if a species has not yet been approved, we use "pyroxene" as for no. 4 in Table 3. The names used in 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. Deer et al. (1978) and Robinson's (1980) table were mainly used in constructing Table 4.

An element specified as a modifier should be present as a general rule in a quantity larger than 0.1 atoms (or

0.01 for less abundant elements) in the standard chemical formula of 6 oxygens or 4 metal atoms (Table 5) depending on the maximum content in Table 4.

The suffixes are those proposed by Schaller (1930) and adapted by CNMMN (Nickel and 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 are obviously 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, a modifier “Al-bearing” may be used. This second type of modifier should be used also (1) if only an incomplete analysis is 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 limit of $Si < 5.75$ 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: Fe-rich, Mg-rich, and subcalcic. A prefix actually attached or hyphenated to a mineral name, however, is incorrect and should be avoided (Nickel and Mandarino, 1987), because it would cause the mineral to be indexed alphabetically under the prefix rather than under 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 when 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-*C2/c* vs. omphacite-*P2/n*, or by adding the lattice-type symbol, i.e., omphacite-*C* vs. omphacite-*P* (Bailey, 1977).

OBSOLETE PYROXENE NAMES

The names of 105 pyroxenes or altered pyroxenes listed in Table 6 have formally been discarded by the CNMMN and are therefore obsolete. The preferred name is italicized in the same table.

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REFERENCES CITED

- Bailey, S.W. (1977) Report of the IMA-IUCr joint committee on nomenclature. *American Mineralogist*, 62, 411–415.
- Bokij, G.B., and Ginzburg, J.V. (1985) The systematics of mineral species in pyroxene family. *Trudy Instituta Geologii i Geofiziki (Novosibirsk)*, 610, 12–35.
- Cameron, M. and Papike, J.J. (1981) Structural and chemical variations in pyroxenes. *American Mineralogist*, 66, 1–50.
- Chester, A.H. (1886) *Catalogue of minerals*. John Wiley and Sons, N.Y.
- Cosca, M.A., and Peacor, D.R. (1987) Chemistry and structure of esseneite ($CaFe^{3+}AlSiO_6$), a new pyroxene produced by pyrometamorphism. *American Mineralogist*, 72, 148–156.
- Curtis, L.W., and Gittins, J. (1979) Aluminous and titaniferous clinopyroxenes from regionally metamorphosed apaitic rocks in central Labrador. *Journal of Petrology*, 20, 165–186.
- Dana, E.S. (1892) *The system of mineralogy* (6th edition). Wiley, New York.
- Deer, W.A., Howie, R.A., and Zussman, J. (1963) *Rock-forming minerals*, vol. 2, Single-chain silicates (first edition). Longman, Green and Co. Ltd., London.
- (1978) *Rock-forming minerals*, vol. 2A, Single-chain silicates (2nd edition). Longman, U.K. and Wiley, New York.
- DeVine, J.D., and Sigurdsson, H. (1980) Garnet-fassaite calc-silicate nodule from La Soufriere, St. Vincent. *American Mineralogist*, 65, 302–305.
- Dowty, E. and Clark, J.R. (1973) Crystal structure refinement and optical properties of a Ti^{3+} fassaite from the Allende meteorite. *American Mineralogist*, 58, 230–240.
- Essene, E.J., and Fyfe, W.S. (1967) Omphacite in California metamorphic rocks. *Contributions to Mineralogy and Petrology*, 15, 1–23.
- Essene, E.J., and Peacor, D.R. (1987) Petedunnite ($CaZnSi_2O_6$), a new zinc clinopyroxene from Franklin, New Jersey, and phase equilibria for zincian pyroxenes. *American Mineralogist*, 72, 157–166.
- Ford, W.E. (1932) *A textbook of mineralogy*. Wiley, New York.
- Jaffe, H.W., Jaffe, E.B., and Tracy, R.J. (1978) Orthoferrosilite and other iron-rich pyroxenes in micropertite gneiss of the Mount Marcy area, Adirondack Mountains. *American Mineralogist*, 63, 116–136.
- Kobayashi, H. (1977) Kanoite, $(Mn^{2+}Mg)_2[Si_2O_6]$, a new clinopyroxene in the metamorphic rock from Tatehira, Oshima Peninsula, Hokkaido, Japan. *Journal of the Geological Society of Japan*, 83, 537–542.
- Leake, B.E., and Winchell, H. (1978) Nomenclature of amphiboles. *American Mineralogist*, 63, 1023–1052.
- Mason, B. (1974) Aluminum-titanium-rich pyroxenes, with special reference to the Allende meteorite. *American Mineralogist*, 59, 1198–1202.
- Mellini, M., Merlini, S., Orlandi, P., and Rinaldi, R. (1982) Cascadite and jervisite, two new scandium silicates from Baveno, Italy. *American Mineralogist*, 67, 599–603.
- Morimoto, N., and Kitamura, M. (1983) *Q-J* diagram for classification of pyroxenes. *Journal of the Japanese Association of Mineralogists, Petrologists and Economic Geologists*, 78, 141 (in Japanese).
- Nickel, E.H., and Mandarino, J.A. (1987) Procedures involving the IMA Commission on New Minerals and Mineral Names and guidelines on mineral nomenclature. *Canadian Mineralogist*, 25, 353–377; *American Mineralogist*, 72, 1031–1042.
- Papike, J.J., Ed. (1969) *Pyroxenes and amphiboles: Crystal chemistry and phase petrology*. Mineralogical Society of America Special Paper 2.
- Peterson, E.U., Anovitz, L.M., and Essene, E.J. (1984) Donpeacorite, $(Mn,Mg)MgSi_2O_6$, a new orthopyroxene and its proposed phase relations in the system $MnSiO_3$ - $MgSiO_3$ - $FeSiO_3$. *American Mineralogist*, 69, 472–480.
- Prewitt, C.T., Ed. (1980) *Reviews in mineralogy*, vol. 7. Pyroxenes. Mineralogical Society of America, Washington, D.C.
- Robinson, P. (1980) The composition space of terrestrial pyroxenes—Internal and external limits. *Mineralogical Society of America Reviews in Mineralogy*, 7, 419–494.
- Schaller, W.T. (1930) Adjectival endings of chemical elements used as modifiers to mineral names. *American Mineralogist*, 15, 566–574.

- Strunz, H. (1970) Mineralogische Tabellen, 5 Auflage. Akademische Verlagsgesellschaft Geest and Portig K.-G., Leipzig.
- Tracy, R.J., and Robinson, P. (1977) Zonal titanian augite in alkali olivine basalt from Tahiti and the nature of titanium substitutions in augite. *American Mineralogist*, 62, 634-645.
- Tschermak, G. (1897) *Lehrbuch der Mineralogie*. Alfred Holder, Wien.
- Vieten, K. and Hamm, H.M. (1978) Additional notes "On the calculation of the crystal chemical formula of clinopyroxenes and their contents of Fe³⁺ from microprobe analyses. *Neues Jahrbuch für Mineralogie Monatshefte*, 71-83.
- Winchell, A.N., and Winchell, H. (1951) *Elements of optical mineralogy*. Wiley, New York.

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