

Nomenclature of pyroxenes

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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: nomenclature, pyroxenes, IMA.

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 (20th May, 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 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 and iron-rich augite); the other to specify elemental substitutions that are not essential constituents (e.g. titanian augite). 105 previously used pyroxene names, mostly synonyms, obsolete or almost unused, recommended for rejection, have formally been discredited by the CNMMN.

General publications dealing with the pyroxene group include *Rock-Forming Minerals* (Deer *et al.*, 1978) (hereafter DHZ), the *Special Papers* (ed. Papike, 1969) and *Reviews in Mineralogy* (ed. Prewitt, 1980) of the Mineralogical Society of America, which 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 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 $M_2M_1T_2O_6$, where *M2* refers to cations 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 *P2/n*, depending on their chemical composition and genetic history.

Throughout this report, the standard pyroxene formula is used with superscripted Arabic numerals (e.g. Fe^{2+}) referring to charges, and subscripted numerals (e.g. Mg_2) 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 Fe^{2+} and Fe^{3+} 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) show 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 totalled to six oxygens and four cations by adjusting the ratios $\text{Fe}^{2+}/\text{Fe}^{3+}$, $\text{Ti}^{4+}/\text{Ti}^{3+}$, etc.

The standard pyroxene formula $M_2M_1T_2O_6$ 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+} .
- (2) Sum *M1* 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.
- (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.

* Footnotes, indicated by superscript numbers, are to be found at the end of the paper.

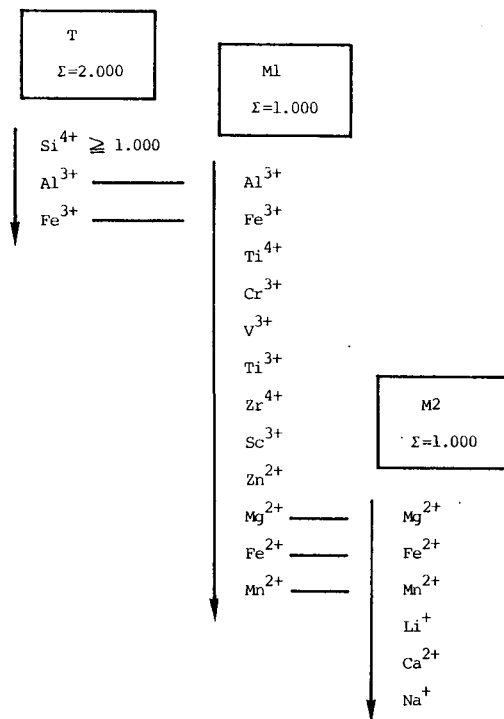


FIG. 1. Flow chart for ideal site occupancy of cations between the *T*, *M1* and *M2* sites of pyroxenes. Only representative cations are included. Arrows indicate order of filling of sites. Real site occupancy is usually slightly different from the ideal site occupancy.

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 Fig. 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, $M_2(R^{2+})M_1(R^{2+})T_2(2R^{4+})O_6$, 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.

Table 1. Four coupled substitutions of pyroxenes in the standard chemical formula $R^{2+}R^{2+}R^{4+}_2O_6$.

Substitution site	M2	M1	T	examples
standard	R^{2+}	R^{2+}	$2R^{4+}$	
substitution(1)	(R^+)	(R^{3+})	$2R^{4+}$	$\left\{ \begin{array}{l} \text{Na-Al} \\ \text{Na-Fe}^{3+} \\ \text{Na-Cr}^{3+} \\ \text{Na-Sc}^{3+} \end{array} \right.$
substitution(2)	(R^+)	$R^{2+}_{0.5}(R^{4+}_{0.5})$	$2R^{4+}$	$\text{Na}-(\text{Ti}^{4+}/2)$
substitution(3)	R^{2+}	(R^{3+})	$(R^{3+})R^{4+}$	$\left\{ \begin{array}{l} \text{Al-Al} \\ \text{Fe}^{3+}\text{-Al} \\ \text{Cr}^{3+}\text{-Al} \end{array} \right.$
Substitution(4)	R^{2+}	$R^{2+}_{0.5}(R^{4+}_{0.5})$	$(R^{3+})R^{4+}$	$(\text{Ti}^{4+}/2)\text{-Al}$

Substitution (1) encompasses the end-members jadeite ($\text{NaAlSi}_2\text{O}_6$), aegirine³ ($\text{NaFe}^{3+}\text{Si}_2\text{O}_6$), kosmochlor⁴ ($\text{NaCr}^{3+}\text{Si}_2\text{O}_6$), and jervisite ($\text{NaScSi}_2\text{O}_6$). Substitution (2) results in components such as $\text{NaFe}^{2+}_{0.5}\text{Ti}^{4+}_{0.5}\text{Si}_2\text{O}_6$, but 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 esseneite⁵, $\text{CaFe}^{3+}\text{AlSiO}_6$, is obtained by this type of substitution. This substitution is also important in 'fassaite'⁶. Substitution resulting in $\text{CaTi}^{3+}\text{AlSiO}_6$ 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 $\text{CaMg}_{0.5}\text{Ti}^{4+}_{0.5}\text{AlSiO}_6$ 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 (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 which 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 thirteen end-members, or chemical components, listed 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 DHZ (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 which 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. Secondly, Na pyroxenes form continuous solid-solution series with the Ca-Mg-Fe pyroxenes, forming the Na-Ca pyroxenes. Thirdly, 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' pyroxenes⁸.

All the pyroxenes are thus divided into four

Table 2. Accepted pyroxene mineral names and their chemical subdivisions. 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. Space groups are also given.

mineral names	composition as end-member	main composition as solid solution	space group
I. Mg-Fe pyroxenes			
1. enstatite (En)(1)	$Mg_2Si_2O_6$	} $(Mg,Fe)_2Si_2O_6$	<u>Pbca</u>
2. ferrosilite(Fs)(2)	$Fe_2^{2+}Si_2O_6$		
3. clinoenstatite		} $(Mg,Fe)_2Si_2O_6$	<u>P2₁/c</u>
4. clinoferrosilite			
5. pigeonite		$(Mg,Fe,Ca)_2Si_2O_6$	<u>P2₁/c</u>
II. Mn-Mg pyroxenes			
6. donpeacorite		$(Mn,Mg)MgSi_2O_6$	<u>Pbca</u>
7. kanoite (Ka)(3)	$MnMgSi_2O_6$	$(Mn,Mg)MgSi_2O_6$	<u>P2₁/c</u>
III. Ca pyroxenes			
8. diopside (Di)(4)	$CaMgSi_2O_6$	} $Ca(Mg,Fe)Si_2O_6$	<u>C2/c</u>
9. hedenbergite(Hd)(5)	$CaFe^{2+}Si_2O_6$		
10. augite		$(Ca,Mg,Fe)_2Si_2O_6$	<u>C2/c</u>
11. johannsenite(Jo)(6)	$CaMnSi_2O_6$		<u>C2/c</u>
12. petedunnite(Pe)(7)* ¹	$CaZnSi_2O_6$		<u>C2/c</u>
13. esseneite(Es)(8)* ²	$CaFe^{3+}AlSiO_6$		<u>C2/c</u>

IV. Ca-Na pyroxenes

14. omphacite	$(Ca,Na)(R^{2+},Al)Si_2O_6$	<u>C2/c, P2₁/n</u>
15. aegirine-augite	$(Ca,Na)(R^{2+},Fe^{3+})Si_2O_6$	<u>C2/c</u>

V. Na pyroxenes

16. jadeite (Jd)(9)	$NaAlSi_2O_6$	} $Na(Al,Fe^{3+})Si_2O_6$	<u>C2/c</u>
17. aegirine (Ae)(10)	$NaFe^{3+}Si_2O_6$		
18. kosmochlor(Ko)(11)	$NaCr^{3+}Si_2O_6$		<u>C2/c</u>
19. jervisite (Je)(12)* ³	$NaSc^{3+}Si_2O_6$		<u>C2/c</u>

VI. Li pyroxene

20. spodumene (Sp)(13)	$LiAlSi_2O_6$	<u>C2/c</u>
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*1 Petedunnite has been determined by Essene and Peacor (1987) to have the composition $(Ca_{0.92}Na_{0.06}Mn_{0.02})(Zn_{0.37}Mn_{0.19}Fe_{0.19}^{2+}Fe_{0.12}^{3+}Mg_{0.14})(Si_{1.94}Al_{0.06})O_6$ by means of an electron microprobe. This mineral was approved as a valid species CNMMN, IMA, in 1983.

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

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

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 abbreviations of the groups and the numbers of the 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. 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-clinoferrrosilite series), Ca pyroxene series (diopside-hedenbergite series) and Na pyroxene series (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 respectively for (pale) emerald-green and lilac coloured 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 SiO₃ single chains. However, the repeat of the chains, which is two SiO₄ tetrahedra in the pyroxenes, is three or more SiO₄ tetrahedra in the pyroxenoids. Though the tetrahedral sites are mostly occupied by Si ions, the large cations are mostly Ca, Mn and Fe²⁺ ions 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, heden-

bergite and johannsenite. These show pyroxenoid structures at high temperatures or pressures. Secondly, the wollastonite chemical component (Ca₂Si₂O₆) 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* (*M*1 and *M*2) sites on the basis of six oxygens. The *M*1 and *M*2 sites are considered together as *M* sites, without considering the site preference of atoms between the two sites.

The numbers of Ca, Mg, Fe²⁺ 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 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 labelled (Fig. 2) **Quad**, **Ca-Na**, **Na**, and **Others**, respectively.

In this diagram, *J* is meant to include the total number of Na and R³⁺, usually Al, Fe³⁺, Cr³⁺ and Sc³⁺, that couple with Na in substitution (1) mentioned in Table 1. When 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 R³⁺ 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 Na pyroxenes area. Thus the *J* (= 2Na) values in the Na-rich pyroxenes represent, to a good approximation, the total number of Na and R³⁺ (Al, Fe³⁺, Cr³⁺ and Sc³⁺) at the *M* sites.

The boundary $Q + J = 2.0$ represents the upper limit of $Q + J$ at the *M* sites. The boundary

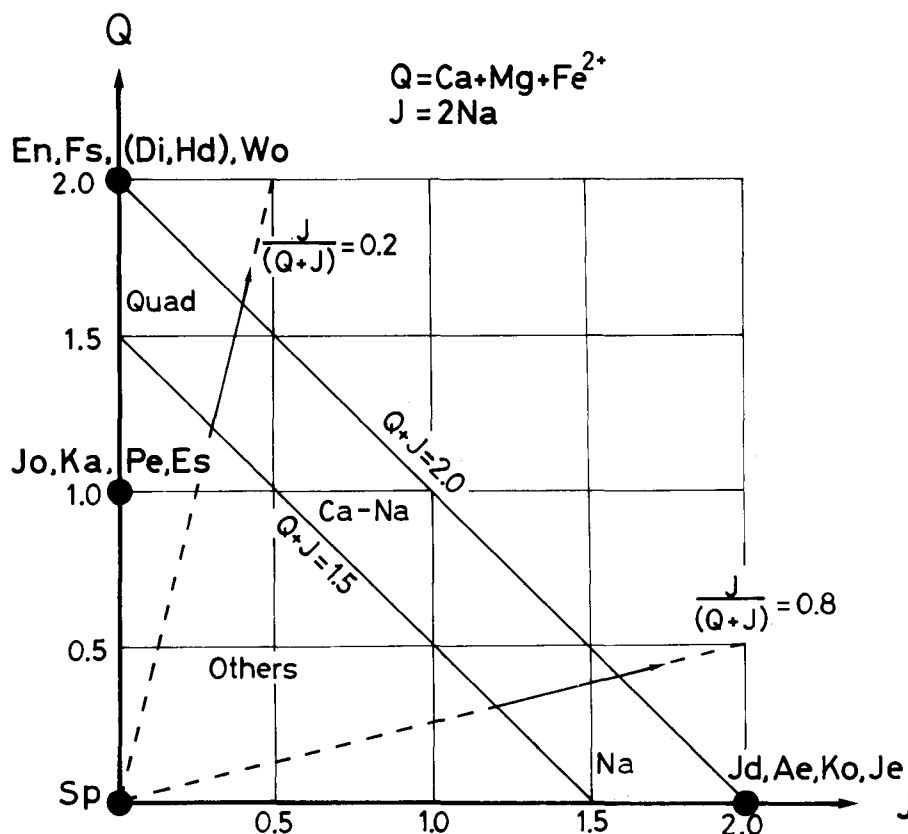


FIG. 2. Q - J diagram for the pyroxenes, on which the positions of the 13 accepted end-members have been indicated. Abbreviations and compositions of the end-members are listed in Table 2.

$Q+J = 1.5$ 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 DHZ (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 appear along the Q axis between 1.0 and 1.5 of the Q value in the Q - J diagram. Similarly, petedunnite and esseneite appear along the Q axis with its Q value between 1.0 and 1.5. Spodumene concentrates 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 DHZ 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 1.5 . The 103 DHZ 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 unit, are plotted in the Q - J diagram of Fig. 3. The 'CaMg TAL' pyroxene (Cameron and Papike, 1981) is included in the Quad area as described later (Table 3, No. 1). Only twenty 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 DHZ (1978) and by Cameron and Papike (1981). A few unusual pyroxenes with Mn less than 0.08

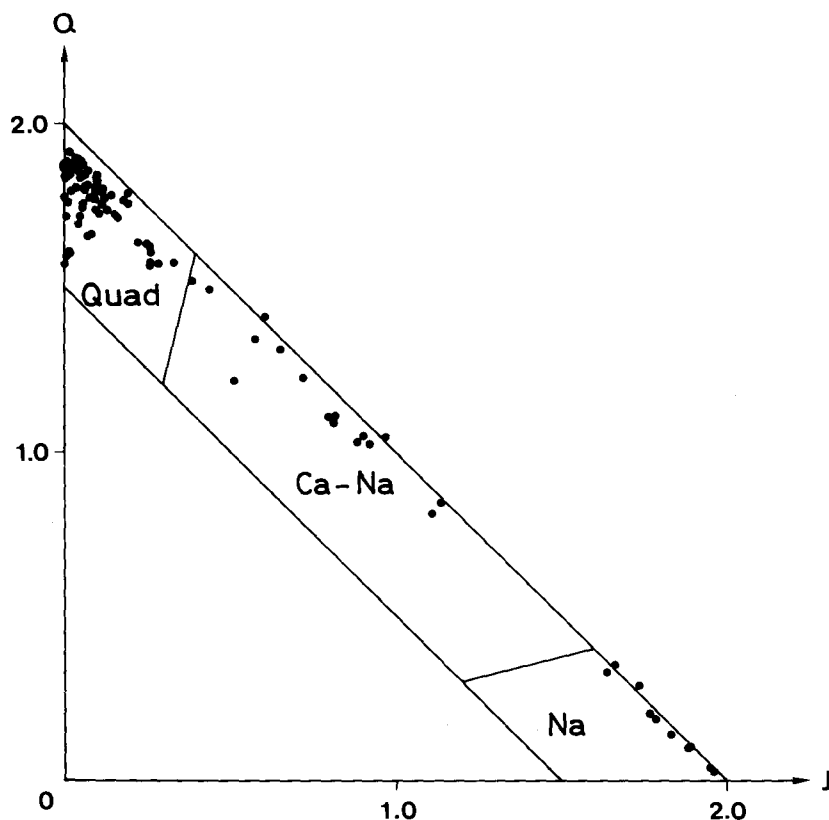


Fig. 3. The 103 DHZ pyroxenes selected by Cameron and Papike (1981) plotted on the Q - J diagram. For these pyroxenes the Q values are less than 1.90, and Mn is less than 0.08 atoms per formula unit.

atoms for 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 ($= \text{Fe}^{2+} + \text{Fe}^{3+} + \text{Mn}$) atoms.

(2) The pyroxenes in the **Na** area are jadeite, aegirine, kosmochlor and jervisite. Because kosmochlor and jervisite show little or no solid solution towards 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 by the pyroxene quadrilateral of the $\text{Mg}_2\text{Si}_2\text{O}_6(\text{En})$ - $\text{Fe}_2^{2+}\text{Si}_2\text{O}_6$ (Fs)- $\text{CaMgSi}_2\text{O}_6(\text{Di})$ - $\text{CaFe}^{2+}\text{Si}_2\text{O}_6$ (Hd) system. The Ca-Mg-Fe pyroxenes include varieties that have orthorhombic symmetry. They consist essentially of a simple chemical series $(\text{Mg,Fe})_2\text{Si}_2\text{O}_6$, 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 $\text{Ca}_2\text{Si}_2\text{O}_6(\text{Wo})$, $\text{Mg}_2\text{Si}_2\text{O}_6(\text{En})$ and $\text{Fe}_2^{2+}\text{Si}_2\text{O}_6(\text{Fs})$. The composition ranges of the clinopyroxenes and orthopyroxenes are indicated in Figs. 4 and 5, respectively, where the

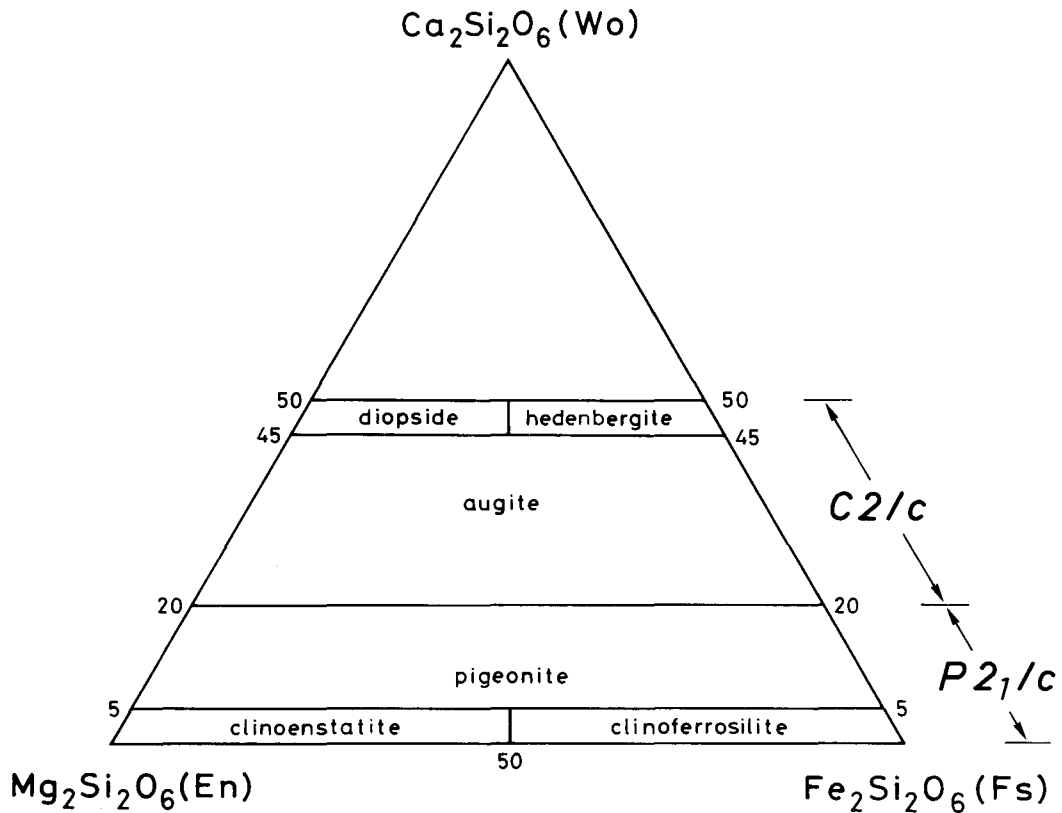


FIG. 4. Composition ranges of the Ca-Mg-Fe clinopyroxenes with accepted names.

composition is normalized to $\text{Ca} + \text{Mg} + \Sigma\text{Fe} = 100$ with $\Sigma\text{Fe} = \text{Fe}^{2+} + \text{Fe}^{3+} + \text{Mn}^{2+}$ (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

which 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

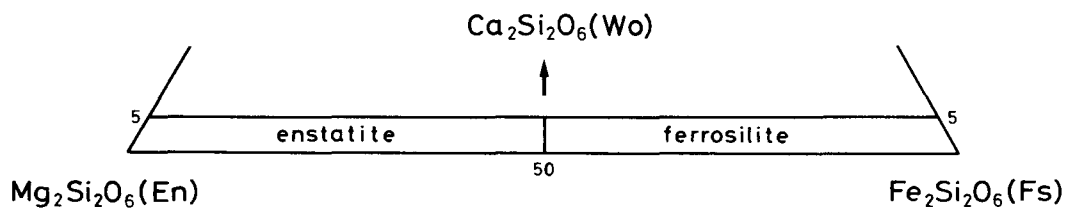


FIG. 5. Composition ranges of orthopyroxenes with accepted names.

