

**Zeitschrift:** Schweizerische mineralogische und petrographische Mitteilungen = Bulletin suisse de minéralogie et pétrographie  
**Band:** 68 (1988)  
**Heft:** 1  
  
**Artikel:** Nomenclature of pyroxenes  
**Autor:** Morimoto, N. / Fabries, J. / Ferguson, A.K.  
**DOI:** <https://doi.org/10.5169/seals-52052>

### **Nutzungsbedingungen**

Die ETH-Bibliothek ist die Anbieterin der digitalisierten Zeitschriften auf E-Periodica. Sie besitzt keine Urheberrechte an den Zeitschriften und ist nicht verantwortlich für deren Inhalte. Die Rechte liegen in der Regel bei den Herausgebern beziehungsweise den externen Rechteinhabern. Das Veröffentlichen von Bildern in Print- und Online-Publikationen sowie auf Social Media-Kanälen oder Webseiten ist nur mit vorheriger Genehmigung der Rechteinhaber erlaubt. [Mehr erfahren](#)

### **Conditions d'utilisation**

L'ETH Library est le fournisseur des revues numérisées. Elle ne détient aucun droit d'auteur sur les revues et n'est pas responsable de leur contenu. En règle générale, les droits sont détenus par les éditeurs ou les détenteurs de droits externes. La reproduction d'images dans des publications imprimées ou en ligne ainsi que sur des canaux de médias sociaux ou des sites web n'est autorisée qu'avec l'accord préalable des détenteurs des droits. [En savoir plus](#)

### **Terms of use**

The ETH Library is the provider of the digitised journals. It does not own any copyrights to the journals and is not responsible for their content. The rights usually lie with the publishers or the external rights holders. Publishing images in print and online publications, as well as on social media channels or websites, is only permitted with the prior consent of the rights holders. [Find out more](#)

**Download PDF:** 27.01.2026

**ETH-Bibliothek Zürich, E-Periodica, <https://www.e-periodica.ch>**

# Nomenclature of Pyroxenes

Subcommittee on Pyroxenes  
Commission on New Minerals and Mineral Names (CNMMN)  
International Mineral Association (IMA)

by *N. Morimoto, Chairman*<sup>1</sup>

## Subcommittee Members

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

## 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, chemical composition, solid-solution series.

## 1. 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

<sup>1</sup> Department of Geology and Mineralogy, Kyoto University, Kyoto 606, Japan.

*Reprint requests should be addressed to the editor.*

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.

## 2. Crystal chemistry of the pyroxenes

Pyroxenes are silicates that, in their simplest form, contain single  $\text{SiO}_3$  chains of linked  $\text{SiO}_4$  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 pyroxenes<sup>1)</sup> is  $\text{M}_2\text{M}_1\text{T}_2\text{O}_6$ , 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*)<sup>2)</sup>. Only the former has been found in nature. Monoclinic pyroxenes are called clinopyroxenes. Their space groups are  $\text{C}2/c$ ,  $\text{P}2_1/c$

and  $\text{P}2/n$ , depending on their chemical composition and genetic history.

Throughout this report, the standard pyroxene formula is used with superscripted arabic numerals (e.g.  $\text{Fe}^{2+}$ ) referring to charges, and subscripted numerals (e.g.  $\text{Mg}_2$ ) 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  $\text{Fe}^{2+}$  and  $\text{Fe}^{3+}$  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  $\text{M}_2\text{M}_1\text{T}_2\text{O}_6$  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  $\text{Si}^{4+}$ , then  $\text{Al}^{3+}$ , then  $\text{Fe}^{3+}$ .
- 2) Sum M1 to 1.000 using all  $\text{Al}^{3+}$  and  $\text{Fe}^{3+}$  in excess of that used to fill the T sites. If there is insufficient  $\text{Al}^{3+}$  and  $\text{Fe}^{3+}$  to sum to 1.000, then add  $\text{Ti}^{4+}$ ,  $\text{Cr}^{3+}$ ,  $\text{V}^{3+}$ ,  $\text{Ti}^{3+}$ ,  $\text{Zr}^{4+}$ ,  $\text{Sc}^{3+}$ ,  $\text{Zn}^{2+}$ ,  $\text{Mg}^{2+}$ ,  $\text{Fe}^{2+}$  and finally  $\text{Mn}^{2+}$  until the sum is 1.000.
- 3) Sum M2 using all  $\text{Mg}^{2+}$ ,  $\text{Fe}^{2+}$  and  $\text{Mn}^{2+}$  in excess of that used to fill the M1 sites. Then add  $\text{Li}^+$ ,  $\text{Ca}^{2+}$  and  $\text{Na}^+$  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

<sup>1)</sup> In omphacite- $\text{P}2/n$ , the M1 and M2 sites are further divided into M1a and M1b (for M1) and M2a and M2b (for M2).

<sup>2)</sup> Orthopyroxene (*Pbcn*) is stable only at elevated temperatures for a limited composition near  $\text{MgSiO}_3$ .

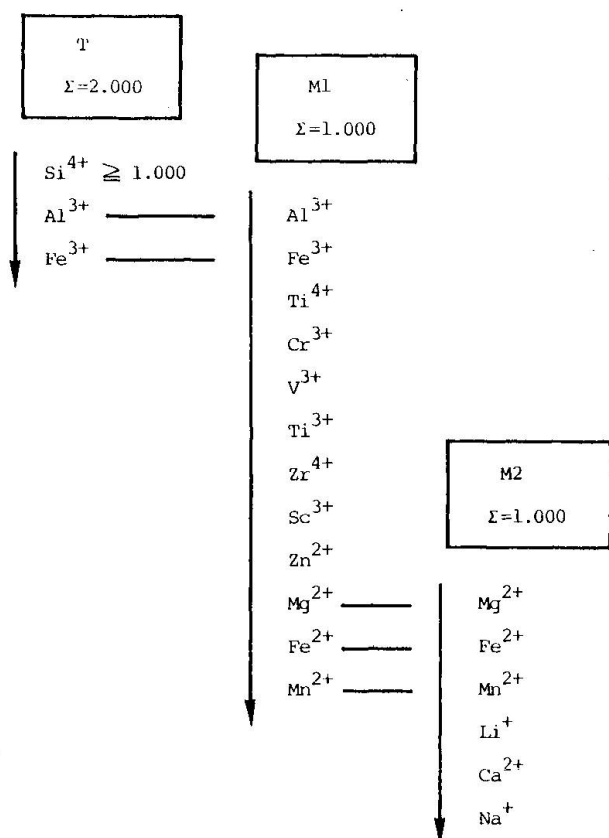


Fig. 1 Flow chart for ideal site occupancy of cations between the T, M1 and M2 sites of pyroxenes. Only representative cations are included. Arrows indicate order of filling of sites. Real site occupancy is usually slightly different from the ideal site occupancy.

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,  $M2(R^{2+})M1(R^{2+})T_2(2R^{4+})O_6$ , four coupled substitutions are possible if one assumes more than one  $R^{4+}$  in the T site. They are listed in Table 1 (p. 100), where the elements in parentheses are coupled substitutions.

Substitution (1) encompasses the end-members jadeite ( $NaAlSi_2O_6$ ), aegirine<sup>3)</sup>

( $NaFe^{3+}Si_2O_6$ ), kosmochlor<sup>4)</sup> ( $NaCr^{3+}Si_2O_6$ ), and jervisite ( $NaScSi_2O_6$ ). Substitution (2) results in components such as  $NaFe_{0.5}^{2+}Ti_{0.5}^{4+}Si_2O_6$ , 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 eseneite<sup>5)</sup>,  $CaFe^{3+}AlSiO_6$ , is obtained by this type of substitution. This substitution is also important in "fassaite"<sup>6)</sup>. 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 names are given for the end member components of substitutions (2) and (4).

### 3. Mineral names of the pyroxenes

#### 3.1. 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

rine-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 now be used instead.

<sup>4)</sup> The CNMMN, IMA, has recently voted in favour of the name kosmochlor instead of "ureyite" for the pyroxene of generalized composition  $NaCrSi_2O_6$ .

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

<sup>6)</sup> "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.

<sup>3)</sup> 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 aegi-



Tab. 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)	$(R^+)$	$(R^{3+})$	$2R^{4+}$	Na-Al Na-Fe <sup>3+</sup> Na-Cr <sup>3+</sup> Na-Sc <sup>3+</sup>
substitution(2)	$(R^+)$	$R^{2+}_{0.5}(R^{4+}_{0.5})$	$2R^{4+}$	Na-(Ti <sup>4+</sup> /2)
substitution(3)	$R^{2+}$	$(R^{3+})$	$(R^{3+})R^{4+}$	Al-Al Fe <sup>3+</sup> -Al Cr <sup>3+</sup> -Al
Substitution(4)	$R^{2+}$	$R^{2+}_{0.5}(R^{4+}_{0.5})$	$(R^{3+})R^{4+}$	(Ti <sup>4+</sup> /2)-Al

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  $Ca_2Si_2O_6$  (Wo)<sup>7)</sup>. 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).

<sup>7)</sup>  $Ca_2Si_2O_6$  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  $Ca_2Si_2O_6$ (Wo) -  $Mg_2Si_2O_6$ (En) -  $Fe_2Si_2O_6$ (Fs) system has been used, e.g.  $En_{20}Fs_{38}Wo_{42}$ .

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  $Ca_2Si_2O_6$  (Wo) -  $Mg_2Si_2O_6$  (En) -  $Fe_2Si_2O_6$  (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' pyroxenes<sup>8)</sup>.

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 abbreviations of the groups and the numbers of the accepted species are given between paren-

<sup>8)</sup> Definition of the 'Other' pyroxenes is different from that given by CAMERON and PAPIKE (1981).

theses. *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).

### 3.2. 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 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-augite<sup>9)</sup> have been retained.

### 3.3. GEM NAMES OF SPODUMENE

Two names, "hiddenite" and "kunzite", are often 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.

### 3.4. RELATIONSHIPS WITH THE PYROXENOIDS

Pyroxenoids are closely related to pyroxenes in that they have a similar type of chemi-

cal composition and a structure that also consists of  $\text{SiO}_3$  single chains. However, the repeat of the chains, which is two  $\text{SiO}_4$  tetrahedra in the pyroxenes, is three or more  $\text{SiO}_4$  tetrahedra in the pyroxenoids. Though the tetrahedral sites are mostly occupied by Si ions, the large cations are mostly Ca, Mn and  $\text{Fe}^{2+}$  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 ferrosolite, hedenbergite and johannsenite. These show pyroxenoid structures at high temperatures or pressures. Secondly, 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.

## 4. Classification and nomenclature of the pyroxenes

### 4.1. 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,  $\text{Fe}^{2+}$  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 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

<sup>9)</sup> The name aegirine-augite appears to be in more common usage than "aegirineaugite", and "acmite-augite".

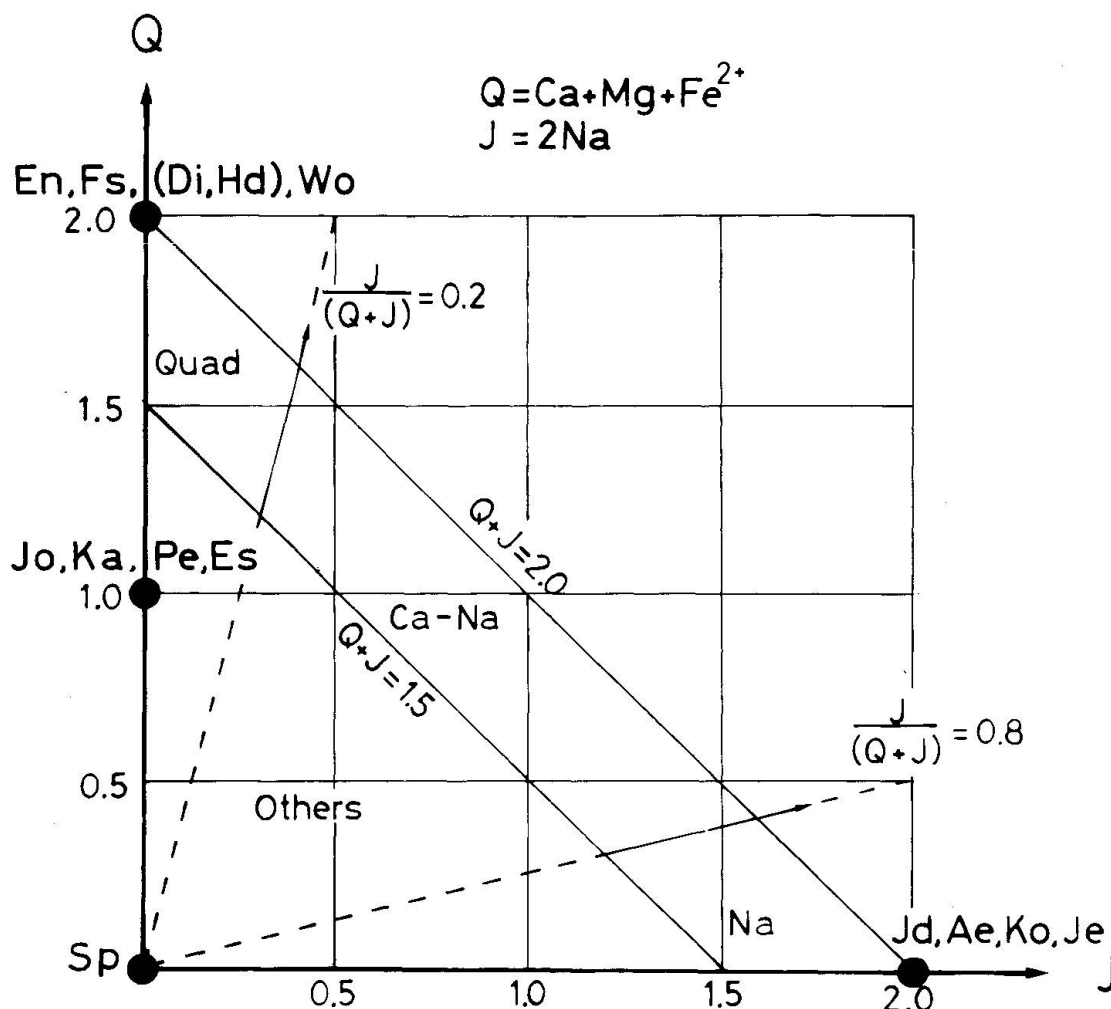


Fig. 2: Q-J diagram for the pyroxenes, on which the positions of the 13 accepted end-members have been indicated. Abbreviations and compositions of the end-members are listed in Table 2.

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 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 Na pyroxenes area. 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 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 'CaMgTAL' 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

Tab. 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
<b>I. Mg-Fe pyroxenes</b>			
1. enstatite (En)(1)	$\text{Mg}_2\text{Si}_2\text{O}_6$	} $(\text{Mg}, \text{Fe})_2\text{Si}_2\text{O}_6$	<i>Pbca</i>
2. ferrosilite(Fs)(2)	$\text{Fe}_2^{2+}\text{Si}_2\text{O}_6$		
3. clinoenstatite		} $(\text{Mg}, \text{Fe})_2\text{Si}_2\text{O}_6$	<i>P2<sub>1</sub>/c</i>
4. clinoferrosilite			
5. pigeonite		$(\text{Mg}, \text{Fe}, \text{Ca})_2\text{Si}_2\text{O}_6$	<i>P2<sub>1</sub>/c</i>
<b>II. Mn-Mg pyroxenes</b>			
6. donpeacorite		$(\text{Mn}, \text{Mg})\text{MgSi}_2\text{O}_6$	<i>Pbca</i>
7. kanoite (Ka)(3)	$\text{MnMgSi}_2\text{O}_6$	$(\text{Mn}, \text{Mg})\text{MgSi}_2\text{O}_6$	<i>P2<sub>1</sub>/c</i>
<b>III. Ca pyroxenes</b>			
8. diopside (Di)(4)	$\text{CaMgSi}_2\text{O}_6$	} $\text{Ca}(\text{Mg}, \text{Fe})\text{Si}_2\text{O}_6$	<i>C2/c</i>
9. hedenbergite(Hd)(5)	$\text{CaFe}^{2+}\text{Si}_2\text{O}_6$		
10. augite		$(\text{Ca}, \text{Mg}, \text{Fe})_2\text{Si}_2\text{O}_6$	<i>C2/c</i>
11. johannsenite(Jo)(6)	$\text{CaMnSi}_2\text{O}_6$		<i>C2/c</i>
12. petedunnite(Pe)(7)* <sup>1</sup>	$\text{CaZnSi}_2\text{O}_6$		<i>C2/c</i>
13. esseneite(Es)(8)* <sup>2</sup>	$\text{CaFe}^{3+}\text{AlSiO}_6$		<i>C2/c</i>

Tab.2 Continued

IV. Ca-Na pyroxenes			
14. omphacite	$(\text{Ca}, \text{Na})(\text{R}^{2+}, \text{Al})\text{Si}_2\text{O}_6$	$\text{C2}/c, \text{P2}/n$	
15. aegirine-augite	$(\text{Ca}, \text{Na})(\text{R}^{2+}, \text{Fe}^{3+})\text{Si}_2\text{O}_6$	$\text{C2}/c$	
V. Na pyroxenes			
16. jadeite (Jd)(9)	$\text{NaAlSi}_2\text{O}_6$	} $\text{Na}(\text{Al}, \text{Fe}^{3+})\text{Si}_2\text{O}_6$	$\text{C2}/c$
17. aegirine (Ae)(10)	$\text{NaFe}^{3+}\text{Si}_2\text{O}_6$		
18. kosmochlor(Ko)(11)	$\text{NaCr}^{3+}\text{Si}_2\text{O}_6$	$\text{C2}/c$	
19. jervisite (Je)(12)*3	$\text{NaSc}^{3+}\text{Si}_2\text{O}_6$	$\text{C2}/c$	
VI. Li pyroxene			
20. spodumene (Sp)(13)	$\text{LiAlSi}_2\text{O}_6$	$\text{C2}/c$	

\*1 Petedunnite has been determined by ESSENE and PEACOR (1987) to have the composition  $(\text{Ca}_{0.92}\text{Na}_{0.06}\text{Mn}_{0.02})(\text{Zn}_{0.37}\text{Mn}_{0.19}\text{Fe}_{0.19}^{2+}\text{Fe}_{0.12}^{3+}\text{Mg}_{0.14})(\text{Si}_{1.94}\text{Al}_{0.06})\text{O}_6$  by means of an electron microprobe. This mineral was approved as a valid species by the CNMMN, IMA, in 1983.

\*2 Esseneite has been determined by COSCA and PEACOR (1987) to have the composition  $(\text{Ca}_{1.01}\text{Na}_{0.01})(\text{Fe}_{0.72}^{3+}\text{Mg}_{0.16}\text{Al}_{0.04}\text{Ti}_{0.03}\text{Fe}_{0.02}^{2+})(\text{Si}_{1.19}\text{Al}_{0.81})\text{O}_{6.00}$  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  $(\text{Na}_{0.43}\text{Ca}_{0.31}\text{Fe}_{0.14-0.12}^{2+})(\text{Sc}_{0.66}\text{Fe}_{0.15}^{2+}\text{Mg}_{0.19})\text{Si}_2\text{O}_6$  by means of an electron microprobe. This mineral was approved as a valid species by the CNMMN, IMA, in 1982.

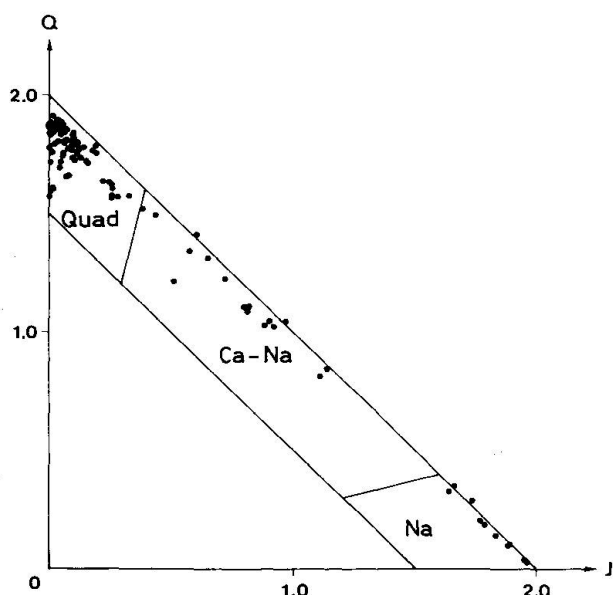


Fig. 3: The 103 DHZ pyroxenes selected by CAMERON and PAPIKE (1981) plotted on the Q-J diagram. For these pyroxenes the Q values are less than 1.90, and Mn is less than 0.08 atoms per formula unit.

pyroxenes with Mn less than 0.08 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  $\Sigma \text{Fe} = \text{Fe}^{2+} + \text{Fe}^{3+} + \text{Mn}$  atoms.
- 2) The pyroxenes in the *Na* area are jadeite,

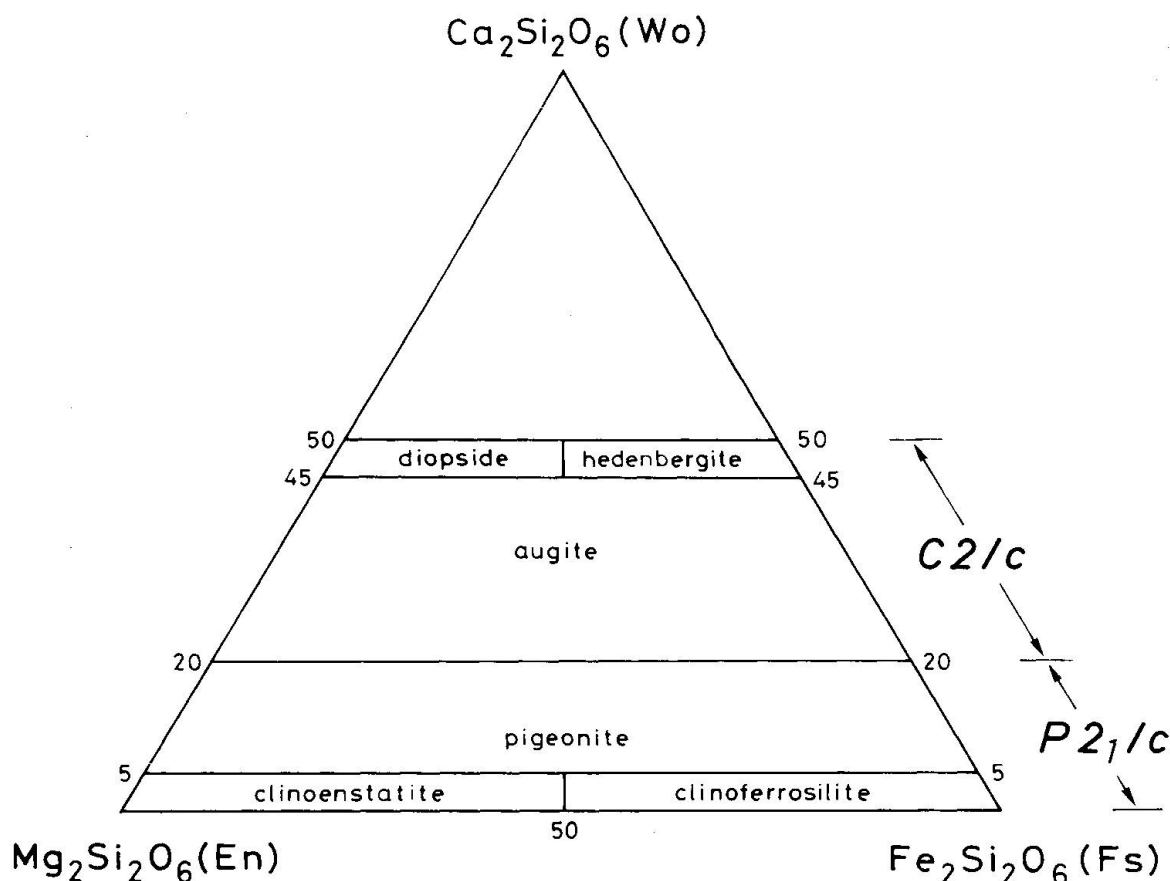


Fig. 4: Composition ranges of the Ca-Mg-Fe clinopyroxenes with accepted names.

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.

#### 4.2. CLASSIFICATION OF THE Ca-Mg-Fe "QUADRILATERAL" PYROXENES

The common rock-forming pyroxenes form wide ranges of solid solution of the Ca-Mg-Fe pyroxenes and can be expressed by the pyroxene quadrilateral of the  $\text{Mg}_2\text{Si}_2\text{O}_6$  (En) -  $\text{Fe}_2^{2+}\text{Si}_2\text{O}_6$  (Fs) -  $\text{CaMgSi}_2\text{O}_6$  (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  $\text{Ca}_2\text{Si}_2\text{O}_6$  (Wo),  $\text{Mg}_2\text{Si}_2\text{O}_6$  (En) and  $\text{Fe}_2^{2+}\text{Si}_2\text{O}_6$  (Fs). The composition ranges of the clinopyroxenes and orthopyroxenes are indicated in Figures 4 and 5, respectively, where the composition is normalized to

$$\text{Ca} + \text{Mg} + \Sigma\text{Fe} = 100 \text{ with}$$

$$\Sigma\text{Fe} = \text{Fe}^{2+} + \text{Fe}^{3+} + \text{Mn}^{2+} \text{ } ^{10)}.$$

<sup>10)</sup> For the nomenclature of the Ca-Mg-Fe pyroxenes, normalization must be made to  $\text{Ca} + \text{Mg} + \Sigma\text{Fe} = 100$ , where  $\Sigma\text{Fe} = \text{Fe}^{2+} + \text{Fe}^{3+} + \text{Mn}$ . Hereafter the mol percent of the end-member components is always used without remark and is represented simply by %. If the mole % quadrilateral components are calculated by the atomic % of Ca to the total cations at the M sites, no pyroxenes should contain more than 50%  $\text{Ca}_2\text{Si}_2\text{O}_6$ . However, if Ca, Mg and Fe are normalized, or, calculated as  $100 \text{ Ca}/(\text{Ca} + \text{Mg} + \Sigma\text{Fe})$ ,  $100 \text{ Mg}/(\text{Ca} + \text{Mg} + \Sigma\text{Fe})$  and  $100 \Sigma\text{Fe}/(\text{Ca} + \text{Mg} + \Sigma\text{Fe})$ , respectively, then some augites will plot on a Wo-En-Fs triangular diagram above the 50%  $\text{Ca}_2\text{Si}_2\text{O}_6$  line. Especially, when the plot in the Q-J diagram is very close to



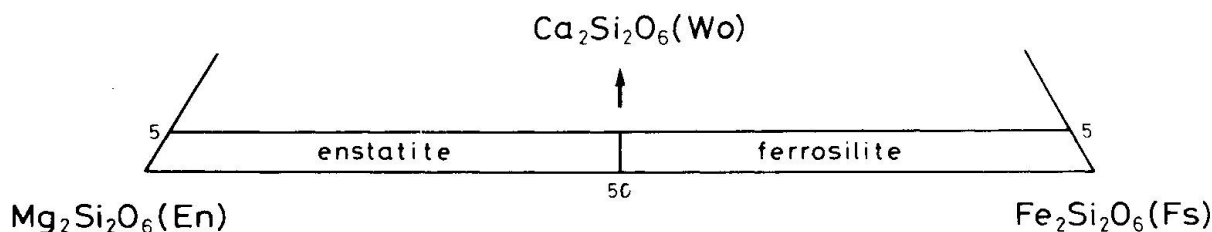


Fig. 5: Composition ranges of orthopyroxenes with accepted names.

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

#### 4.3. 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, 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<sup>11</sup>). 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 and FYFE (1967) is not followed in this report.

#### 4.4. THE CLASSIFICATION OF OTHER PYROXENES

Most naturally occurring pyroxenes in the 'Others' area are johannsenite ( $CaMnSi_2O_6$ ),

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.

<sup>11</sup>) To 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 to the ratio of  $Al/Fe^{3+}$  to give the ratio of Jd/Ae. Thus  $Q+Jd+Ae$  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.

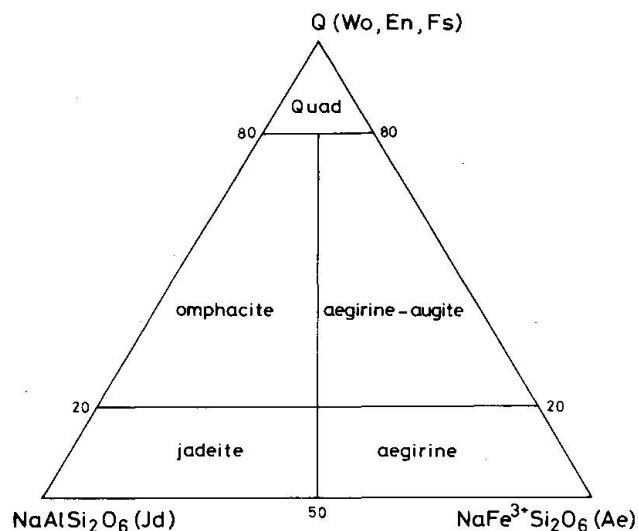


Fig. 6: Ca-Mg-Fe and Na pyroxenes with accepted names. Quad represents the Ca-Mg-Fe pyroxene area (see Fig. 4).

petedunnite ( $\text{CaZnSi}_2\text{O}_6$ ) and spodumene ( $\text{LiAlSi}_2\text{O}_6$ ) (Fig. 2). Recent investigations of natural manganese-bearing pyroxenes have yielded two new minerals, kanoite and its dimorph donpeacorite,  $(\text{Mn}, \text{Mg})\text{MgSi}_2\text{O}_6$ , 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 ( $\text{CaFe}^{3+}\text{AlSiO}_6$ ) is the first pyroxene with the substitution (3) as described in Table 1.

#### 4.5. 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 ( $\text{CaR}^{3+}\text{AlSiO}_6$ ) and S4 ( $\text{CaR}_{0.5}^{2+}\text{Ti}_{0.5}^{4+}\text{AlSiO}_6$ ) components representing substitutions (3) and (4), respectively, and secondly Na-rich pyroxenes with the S2 component ( $\text{NaR}_{0.5}^{2+}\text{Ti}_{0.5}^{4+}\text{Si}_2\text{O}_6$ ) representing substitution (2). 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 (point S4 in Fig. 7). The latter appears outside the line  $Q+J=2.0$  approaching point S2 in Fig. 7. All these unusual pyroxenes are classified by using the accepted pyroxene names and the adjectival modifiers mentioned below, except 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 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.

#### 5. Adjectival modifiers

Adjectival modifiers for mineral names are used to indicate unusual amounts of chemical

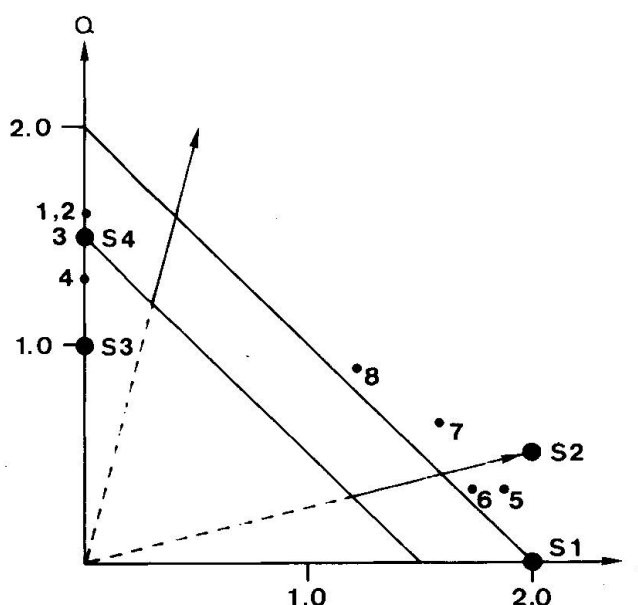


Fig. 7: Q-J diagram for eight unusual pyroxenes with Q-value less than 1.62 and Mn less than 0.08 atoms per formula unit (Table 3). The components formed by the substitutions (1) to (4), as indicated in Table 1, are plotted in the diagram. They represent the following compositions:

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 =  $\text{CaR}_{0.5}^{2+}\text{Ti}_{0.5}^{4+}\text{AlSiO}_6$ .

Tab. 3 Chemical composition and classification of eight unusual pyroxenes. 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 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:  $S2 = NaR_{0.5}^{2+}Ti_{0.5}^{4+}Si_2O_6$ ,  $S3 = CaR^{3+}AlSiO_6$ , and  $S4 = CaR_{0.5}^{2+}Ti_{0.5}^{4+}AlSiO_6$ . 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).

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		1.506		1.434		1.196		
Al	.557	2.00	.494	2.00	.566	2.00	.804		2.00
Al	.091		.171		.306		.186		
Ti <sup>4+</sup>	.165		.065		.022		Ti <sup>4+</sup> .111		
Fe <sup>3+</sup>	.128		.159		.218		Ti <sup>3+</sup> .394		
Mg	.385		.570		.408		.289		
Fe <sup>2+</sup>	.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		

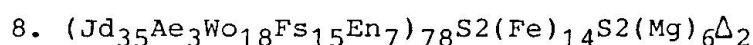
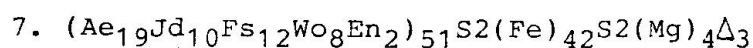
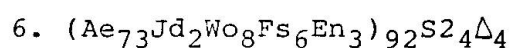
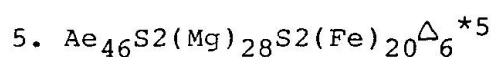
Component ratios;

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.  $S3(Ti)_{39}S4(Mg)_{22}(Wo_{11}Fs_9)_{20}S3(Al)_{19}$

## 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 <sup>4+</sup>	.265		.023		.227		.104	
Fe <sup>3+</sup>	.458		.728		.192		.031	
Mg	.150		.070		.070		.168	
Fe <sup>2+</sup>	.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	

Component ratios;



\*1 DEVINE and SIGURDSSON (1980), Table 1 for fassaite.

\*2 TRACY and ROBINSON (1977), Table 3, Analysis I for pyroxenes from the Allende meteorite (MASON, 1974).

\*3 CAMERON and PAPIKE (1981), Table A3, Analysis 320-8 and 406-16.

\*4 CURTIS and GITTINS (1979), Table 2, Analysis 5 for No. 7 and Table 5, Analysis 5 for No. 8.

\*5  $\Delta$  represents minor components, some of which have unusual metal ratios for the pyroxene structure.

Tab. 4 Extreme chemical compositions of pyroxenes in DHZ (1978). 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 DHZ (1978). Other references are in text.

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

\*<sup>1</sup> Table 3, No. 1. Table 3, No. 4: Pyroxene from the Allende meteorite 1.20 (MASON, 1974; TRACY and ROBINSON, 1977).

\*<sup>2</sup> Probe analysis 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).

\*<sup>3</sup> Table 3, No. 5. Half of  $\text{NaR}_{0.5}^{2+}\text{Ti}_{0.5}^{4+}\text{Si}_2\text{O}_6$  (S2).

\*<sup>4</sup> 406-15 0.67, omitted because of possible errors in chemical analysis.

\*<sup>5</sup> Probe analysis 1.880 (JAFTE et al., 1978).

\*<sup>6</sup> Probe analysis 0.301 (ROBINSON, 1980), Kanoite 1.04 (KOBAYASHI, 1977).

\*<sup>7</sup> Johannsenite 0.963 (417-2).

\*<sup>8</sup> Kosmochlor 0.90 (522-1).

\*<sup>9</sup> Petedunnite 0.37 (Table 2, remark \*<sup>1</sup>).

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. DHZ (1978) and ROBINSON'S (1980) table were mainly 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.

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 non-variable state (e.g., lithian). The suffix -oan implies the lower valence state (e.g., ferroan). It is recom-

mended 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  $Al < 0.1$ , but if the increased content of the element must be stressed, a modifier 'aluminum-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  $Si < 5.75$  limit for 'subsilicic' in amphiboles corresponds to  $Si < 1.5$  for pyroxenes.

Tab. 5 List of adjectival modifiers to be used for pyroxene mineral names. The limit of the content is determined based on the values listed in Table 4.

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

\*<sup>1</sup> Number of cations per formula unit  $M_2M_1T_2O_6$ . If the mineral name itself implies the presence of certain cations, adjectival modifiers for these cations should not be used ('subsilicic' is an exception).

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 and 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 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, omphacite-P2/n, or by adding the lattice-type symbol, i.e., omphacite-C, omphacite-P (BAILEY, 1977).

## 6. Obsolete pyroxene names

The names of 105 pyroxenes or altered pyroxenes listed in Appendix have formally been discarded by the CNMMN and are therefore obsolete. The preferred name is printed in *italics* in the same table.

### Acknowledgements

We are thankful to Professor J.H.D. Donnay, McGill University, Montreal, who contributed greatly to the improvement of the report by his careful review. We also appreciate criticisms and comments by Dr. A. Kato, National Science Museum, Tokyo, Dr. M. Kitamura, Kyoto University, Kyoto, and the members of the Commission on New Minerals and Mineral Names, IMA.

Tab. 6 Obsolete pyroxene names (p. 110).

The following pyroxene mineral names, or names which refer to altered pyroxenes, have been formally discarded by the CNMMN. The correct names are printed in *italics*. 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, HOWIE and ZUSSMAN (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*  
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 *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*  
diacrasite = altered *enstatite*  
diallage = *diopside* which has altered or which 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* 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*  
mellcritite = *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* which 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*  
violane = magnesium-rich *augite* or *diopside*

## References

- BAILEY, S.W. (1977): Report of the IMA-IUCr joint committee on nomenclature. *American Mineralogist*, 62, 411-415.
- BOKII, G.B. and J.V. GINZBURG (1985): The systematics of mineral species in pyroxene family. *Trans. IGG Academy of Sciences, Novosibirsk*, 610, 12-35.
- CAMERON, M. and J.J. PAPIKE (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 D.R. PEACOR (1987): Chemistry and structure of esseneite ( $\text{CaFe}^{3+}\text{AlSiO}_6$ ), a new pyroxene produced by pyrometamorphism. *American Mineralogist*, 72, 148-156.
- CURTIS, L.W. and J. GITTINS (1979): Aluminous and titaniferous clinopyroxenes from regionally metamorphosed agpaitic rocks in central Labrador. *Journal of Petrology*, 20, 165-186.
- DANA, E.S. (1892): *The System of Mineralogy*, 6th edition, John Wiley and Sons, N.Y.
- DEER, W.A., R.A. HOWIE and J. ZUSSMAN (1963): *Rock-forming minerals*. Vol. 2, First ed., Single-chain silicates, Longman, Green and Co. LTD, London.
- DEER, W.A., R.A. HOWIE and J. ZUSSMAN (1978): *Rock-forming minerals*. Vol. 2A, Second ed., Single-chain silicates, Longman, U.K. and John Wiley and Sons Inc., N.Y.
- DEVINE, J.D. and H. SIGURDSSON (1980): Garnet-fassaite calc-silicate nodule from La Soufrière, St. Vincent. *American Mineralogist*, 65, 302-305.
- DOWTY, E. and J.R. CLARK (1973): Crystal structure refinement and optical properties of a  $\text{Ti}^{3+}$  fassaite from the Allende meteorite. *American Mineralogist*, 58, 230-240.
- ESSENE, E.J. and W.S. FYFE (1967): Omphacite in California metamorphic rocks. *Contributions to Mineralogy and Petrology*, 15, 1-23.
- ESSENE, E.J. and D.R. PEACOR (1987): Petedunnite ( $\text{CaZnSi}_2\text{O}_6$ ), 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*, John Wiley and Sons, Inc., N.Y.
- JAFFE, H.W., E.B. JAFFE and R.J. TRACY (1978): Orthoferrosilite and other iron-rich pyroxenes in micropertthite gneiss of the Mount Marcy area, Adirondack Mountains. *American Mineralogist*, 63, 116-136.
- KOBAYASHI, H. (1977): Kanoite,  $(\text{Mn}^{++}\text{Mg})_2[\text{Si}_2\text{O}_6]$ , 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 H. WINCHELL (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., S. MERLINO, P. ORLANDI and R. RINALDI (1982): Cascadite and jervisite, two new scandium silicates from Baveno, Italy. *American Mineralogist*, 67, 599-603.
- MORIMOTO, N. and M. KITAMURA (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 J. A. MANDARINO (1987): Procedures involving the IMA Commission on New Minerals and Mineral Names, and guidelines on mineral nomenclature. *Canadian Mineralogist*, 25, 353-377; *Schweiz. mineral. petrogr. Mitt.*, 67, 185-210.
- PAPIKE, J.J. (ed.) (1969): *Pyroxenes and Amphiboles: Crystal chemistry and phase petrology*. Mineralogical Society of America, Special Paper No. 2.
- PETERSEN, E.U., L.M. ANOVITZ and E.J. ESSENE (1984): Donpeacorite,  $(\text{Mn,Mg})\text{MgSi}_2\text{O}_6$ , a new orthopyroxene and its proposed phase relations in the system  $\text{MnSiO}_3 - \text{MgSiO}_3 - \text{FeSiO}_3$ . *American Mineralogist*, 69, 472-480.
- PREWITT, C.T. (ed.) (1980): *Reviews in Mineralogy*, 7. Pyroxenes. Mineralogical Society of America, Washington, D.C.
- ROBINSON, P. (1980): The composition space of terrestrial pyroxenes - Internal and external limits. *Reviews in Mineralogy of the MSA* (ed. PREWITT, 1980), 419-494.
- SCHALLER, W.T. (1930): Adjectival ending 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 KG, Leipzig.
- TRACY, R.J. and P. ROBINSON (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 H.M. HAMM (1978): Additional notes "On the calculation of the crystal chemical formula of clinopyroxenes and their contents of  $\text{Fe}^{3+}$  from microprobe analyses. *Neues Jahrbuch der Mineralogie, Monatshefte*, 71-83.
- WINCHELL, A.N. and H. WINCHELL (1951): *Elements of Optical Mineralogy*, John Wiley and Sons, Inc., N.Y.

Manuscript received March 8, 1988; accepted April 8, 1988.