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 (Kake 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 (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 SiO4 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 pyroxenes is M2M1O4, 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). Only the former has been found in nature. Monoclinic pyroxenes are called clinopyroxenes. Their space groups are C2/c, P2/n, and P2/c, 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., Mg) 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 oxygen and four cations by adjusting the ratios Fe²⁺/Fe³⁺, Ti⁴⁺/Ti³⁺, etc.

The standard pyroxene formula M₂M₁TrO₆ 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⁺, V⁵⁺, 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(R⁺²)M₁(R²⁺)Tr(2R⁴⁺)O₆, four coupled substitutions are possible if one assumes more than one R⁺ in the T site. They are listed in Table 1, where the elements in parentheses are coupled substitutions.

In substitution 3, the Al-Al couple is often referred to as “Tschermak’s component”; CaAl₁AlSiO₄, in particular, is called “calcium Tschermak’s component.” Substitution in esseneite, CaFe³⁺AlSiO₄, is obtained by this type of substitution. This substitution is also important in...
Four coupled substitutions of pyroxenes in the standard chemical formula $R^{2+}R^{2+}R^{4+}O_{6}$

<table>
<thead>
<tr>
<th>Substitution site</th>
<th>Examples</th>
</tr>
</thead>
<tbody>
<tr>
<td>Standard occupancy</td>
<td>$R^{2+}$ $R^{2+}$ $2R^{4+}$</td>
</tr>
<tr>
<td>Substitution 1</td>
<td>(R*) $2R^{4+}$</td>
</tr>
<tr>
<td></td>
<td>Na-Al</td>
</tr>
<tr>
<td></td>
<td>Na-Fe$^{3+}$</td>
</tr>
<tr>
<td></td>
<td>Na-Cr$^{3+}$</td>
</tr>
<tr>
<td></td>
<td>Na-Si$^{4+}$</td>
</tr>
<tr>
<td>Substitution 2</td>
<td>$R^{2+} (R^{2+}) (R^{4+})$</td>
</tr>
<tr>
<td></td>
<td>Na-(Ti$^{4+}$/2)</td>
</tr>
<tr>
<td></td>
<td>Al-Fe$^{3+}$</td>
</tr>
<tr>
<td></td>
<td>Fe$^{2+}$-Al</td>
</tr>
<tr>
<td>Substitution 3</td>
<td>$R^{2+} (R^{2+}) (R^{4+})$</td>
</tr>
<tr>
<td></td>
<td>Ca-(Ti$^{4+}$/2)-Al</td>
</tr>
<tr>
<td>Substitution 4</td>
<td>$2R^{4+}$</td>
</tr>
<tr>
<td></td>
<td>Ca-(Ti$^{4+}$/2)-Al</td>
</tr>
</tbody>
</table>

* Shown by parentheses.

“fassaite.” Substitution resulting in CaTi$^{4+}$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$_{3}$Ti$_{7}$Al$_{1}$SiO$_{6}$ 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 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

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**Table 1.** Accepted pyroxene mineral names and their chemical subdivisions

<table>
<thead>
<tr>
<th>Mineral names</th>
<th>Composition as end member</th>
<th>Main composition as solid solution</th>
<th>Space group</th>
</tr>
</thead>
<tbody>
<tr>
<td>A. Mg-Fe pyroxenes</td>
<td></td>
<td></td>
<td>Pbca</td>
</tr>
<tr>
<td>1. enstatite (En)</td>
<td>Mg$<em>{2}$Si$</em>{2}$O$_{6}$</td>
<td>Ca$<em>{2}$Mg$</em>{2}$Si$<em>{2}$O$</em>{6}$</td>
<td>Pbca</td>
</tr>
<tr>
<td>2. forsterite (Fe)</td>
<td>Fe$<em>{2}$Si$</em>{2}$O$_{6}$</td>
<td>(Mg,Fe)$<em>{2}$Si$</em>{2}$O$_{6}$</td>
<td>P2/c</td>
</tr>
<tr>
<td>3. clinopyroxene</td>
<td>Fe$<em>{2}$Si$</em>{2}$O$_{6}$</td>
<td>(Mg,Fe)$<em>{2}$Si$</em>{2}$O$_{6}$</td>
<td>P2/c</td>
</tr>
<tr>
<td>4. clinoferrosilite</td>
<td>Fe$<em>{2}$Si$</em>{2}$O$_{6}$</td>
<td>(Mg,Fe)$<em>{2}$Si$</em>{2}$O$_{6}$</td>
<td>P2/c</td>
</tr>
<tr>
<td>5. pigeonite</td>
<td>Fe$<em>{2}$Si$</em>{2}$O$_{6}$</td>
<td>(Mg,Fe)$<em>{2}$Si$</em>{2}$O$_{6}$</td>
<td>P2/c</td>
</tr>
<tr>
<td>B. Mn-Mg pyroxenes</td>
<td></td>
<td></td>
<td>Pbca</td>
</tr>
<tr>
<td>6. donpeacorite</td>
<td>Mn$<em>{2}$Si$</em>{2}$O$_{6}$</td>
<td>Mn$<em>{2}$Si$</em>{2}$O$_{6}$</td>
<td>P2/c</td>
</tr>
<tr>
<td>7. kanoite (Ka)</td>
<td>Mn$<em>{2}$Si$</em>{2}$O$_{6}$</td>
<td>Mn$<em>{2}$Si$</em>{2}$O$_{6}$</td>
<td>P2/c</td>
</tr>
<tr>
<td>C. Ca pyroxenes</td>
<td></td>
<td></td>
<td>Pbca</td>
</tr>
<tr>
<td>8. diopside (Di)</td>
<td>Ca$<em>{2}$Si$</em>{2}$O$_{6}$</td>
<td>Ca$<em>{2}$Si$</em>{2}$O$_{6}$</td>
<td>C2/c</td>
</tr>
<tr>
<td>9. hedenbergite (Hd)</td>
<td>Ca$<em>{2}$Si$</em>{2}$O$_{6}$</td>
<td>Ca$<em>{2}$Si$</em>{2}$O$_{6}$</td>
<td>C2/c</td>
</tr>
<tr>
<td>10. augite</td>
<td>Ca$<em>{2}$Si$</em>{2}$O$_{6}$</td>
<td>Ca$<em>{2}$Si$</em>{2}$O$_{6}$</td>
<td>C2/c</td>
</tr>
<tr>
<td>11. johannsenite (Jo)</td>
<td>Ca$<em>{2}$Si$</em>{2}$O$_{6}$</td>
<td>Ca$<em>{2}$Si$</em>{2}$O$_{6}$</td>
<td>C2/c</td>
</tr>
<tr>
<td>12. petedunnite (Pe)*</td>
<td>Ca$<em>{2}$Si$</em>{2}$O$_{6}$</td>
<td>Ca$<em>{2}$Si$</em>{2}$O$_{6}$</td>
<td>C2/c</td>
</tr>
<tr>
<td>13. esseneite (Es)*</td>
<td>Ca$<em>{2}$Si$</em>{2}$O$_{6}$</td>
<td>Ca$<em>{2}$Si$</em>{2}$O$_{6}$</td>
<td>C2/c</td>
</tr>
<tr>
<td>D. Ca-Na pyroxenes</td>
<td></td>
<td></td>
<td>C2/c, P2/n</td>
</tr>
<tr>
<td>14. omphacite</td>
<td>(Ca$<em>{2}$Na)$</em>{2}$Si$<em>{2}$O$</em>{6}$</td>
<td>(Ca$<em>{2}$Na)$</em>{2}$Si$<em>{2}$O$</em>{6}$</td>
<td>C2/c, P2/n</td>
</tr>
<tr>
<td>15. aegirine-augite</td>
<td>Ca$<em>{2}$Si$</em>{2}$O$_{6}$</td>
<td>Ca$<em>{2}$Si$</em>{2}$O$_{6}$</td>
<td>C2/c, P2/n</td>
</tr>
<tr>
<td>E. Na pyroxenes</td>
<td></td>
<td></td>
<td>C2/c</td>
</tr>
<tr>
<td>16. jadeite (Jd)</td>
<td>Na$<em>{2}$Si$</em>{2}$O$_{6}$</td>
<td>Na$<em>{2}$Si$</em>{2}$O$_{6}$</td>
<td>C2/c</td>
</tr>
<tr>
<td>17. aegirine (Ae)</td>
<td>Na$<em>{2}$Si$</em>{2}$O$_{6}$</td>
<td>Na$<em>{2}$Si$</em>{2}$O$_{6}$</td>
<td>C2/c</td>
</tr>
<tr>
<td>18. kosmochlor (Ko)</td>
<td>Na$<em>{2}$Si$</em>{2}$O$_{6}$</td>
<td>Na$<em>{2}$Si$</em>{2}$O$_{6}$</td>
<td>C2/c</td>
</tr>
<tr>
<td>19. jervisite (Je)**</td>
<td>Na$<em>{2}$Si$</em>{2}$O$_{6}$</td>
<td>Na$<em>{2}$Si$</em>{2}$O$_{6}$</td>
<td>C2/c</td>
</tr>
<tr>
<td>F. Li pyroxene</td>
<td></td>
<td></td>
<td>C2/c</td>
</tr>
<tr>
<td>20. spodumene (Sp)</td>
<td>LiAl$<em>{2}$SiO$</em>{6}$</td>
<td>LiAl$<em>{2}$SiO$</em>{6}$</td>
<td>C2/c</td>
</tr>
</tbody>
</table>

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$_{2}$Na)$_{2}$Mn$_{2}$Si$_{2}$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$_{2}$Na)$_{2}$Fe$_{2}$Si$_{2}$O$_{6}$ by means of an electron microprobe. This mineral was approved as a valid species by the CNMMN, IMA, in 1983.

† Jervisite has been determined by M. Mellini et al. (1982) to have the composition Na$_{2}$Si$_{2}$O$_{6}$ 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 Ca$_3$Si$_2$O$_6$ (Wo). 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 Ca$_3$Si$_2$O$_6$ (Wo)-Mg$_2$Si$_2$O$_6$ (En)-Fe$_2$Si$_2$O$_6$ (Fs) system. Therefore, these pyroxenes are better treated 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, donpeaciortite 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-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 and salite and ferrosilite 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$_4$ 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$^{2+}$. 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 (Ca$_2$SiO$_4$) 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 $Q = Ca + Mg + Fe^{2+}$ and $J = 2Na$. The lines representing the

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7 Ca$_3$Si$_2$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 Ca$_3$Si$_2$O$_6$ (Wo)-Mg$_2$Si$_2$O$_6$ (En)-Fe$_2$Si$_2$O$_6$ (Fs) system has been used, e.g., En$_{6-}$Fs$_{8-}$Wo$_{6-}$.

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

9 The name “aegirine-augite” appears to be in more common usage than “aegirine-augite,” and “acmite-augite.”
The following equations are used to subdivide the $Q$-$J$ diagram:

$$
\begin{align*}
Q + J &= 2.0 \\
Q + J &= 1.5 \\
J/(Q + J) &= 0.2 \\
J/(Q + J) &= 0.8
\end{align*}
$$

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-Ti$^{4+}$) to move the $J$ value farther away from the $Q$ axis of ordinates. Therefore, the effects of substitutions 2 and 3 tend to cancel each other out in and near the area of 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 + 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 Papke (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 Papke (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 Papke, 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 Papke (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
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 $\Sigma$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 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 $\text{Mg}_2\text{Si}_2\text{O}_5$ (FS)-$\text{CaMgSi}_2\text{O}_5$ (DI)-$\text{CaFe}_2\text{Si}_2\text{O}_5$ (HD) system. The Ca-Mg-Fe pyroxenes include varieties that have orthorhombic symmetry. These orthopyroxenes consist essentially of a simple chemical series ($\text{Mg}_2\text{Fe}_2\text{Si}_2\text{O}_7$) and thus contrast with the Ca-Mg-Fe clinopyroxenes, which have wide ranges of chemical composition. Therefore, the Ca-Mg-Fe pyroxenes are defined on the basis of symmetry and relative amounts of $\text{Ca}_2\text{Si}_2\text{O}_5$ (Wo), $\text{Mg}_2\text{Si}_2\text{O}_5$ (En), and $\text{Fe}^{2+}\text{Si}_2\text{O}_5$ (Fs). The composition ranges of the clinopyroxenes and orthopyroxenes are indicated in Figures 4 and 5, respectively, where the composition is normalized to $\text{Ca} + \text{Mg} + \Sigma\text{Fe} = 100$ with $\Sigma\text{Fe} = \text{Fe}^{2+} + \text{Fe}^{3+} + \text{Mn}^{2+}$. 

### Table 3. Chemical composition and classification of eight unusual pyroxenes

<table>
<thead>
<tr>
<th>Mineral names</th>
<th>Subsilicic titanian ferrian diopside</th>
<th>Subsilicic titanian aluminian ferrian diopside</th>
<th>Subsilicic aluminian ferrian diopside</th>
<th>Subsilicic titanian aluminian pyroxene</th>
<th>Titanian magnesian ferrian aegirine</th>
<th>Calciac ferrian aegirine</th>
<th>Titanian aegirine-augite</th>
<th>Titanian ferroan omphacite</th>
</tr>
</thead>
<tbody>
<tr>
<td>Names in literature</td>
<td>titanaugite (320-8)</td>
<td>titanium fassaite (406-16)</td>
<td>CalMgTAL (C and F)</td>
<td>C and G</td>
<td>C and G</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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 O-J diagram (Fig. 7). $S2$, $S3$, and $S4$ represent the following components of substitutions (1) $\text{WO}_2\text{En}_n\text{Fs}_{2-n}\text{Si}_2\text{O}_5$; $S4(\text{Mg})$, $S4(\text{Fe})$, $S4(\text{En})$; (2) $\text{WO}_2\text{En}_n\text{Fs}_{2-n}\text{Si}_2\text{O}_5$; $S3(\text{Mg})$, $S3(\text{En})$; (3) $\text{WO}_2\text{En}_n\text{Fs}_{2-n}\text{Si}_2\text{O}_5$; $S2(\text{Mg})$, $S2(\text{En})$; (4) $\text{WO}_2\text{En}_n\text{Fs}_{2-n}\text{Si}_2\text{O}_5$; $S4(\text{Mg})$, $S4(\text{En})$, $S4(\text{Si})$; (5) $\text{WO}_2\text{En}_n\text{Fs}_{2-n}\text{Si}_2\text{O}_5$; $S3(\text{Mg})$, $S3(\text{En})$, $S3(\text{Si})$; (6) $\text{WO}_2\text{En}_n\text{Fs}_{2-n}\text{Si}_2\text{O}_5$; $S2(\text{Mg})$, $S2(\text{En})$, $S2(\text{Si})$; (7) $\text{WO}_2\text{En}_n\text{Fs}_{2-n}\text{Si}_2\text{O}_5$; $S1(\text{Mg})$, $S1(\text{En})$, $S1(\text{Si})$; (8) $\text{WO}_2\text{En}_n\text{Fs}_{2-n}\text{Si}_2\text{O}_5$; $S0(\text{Mg})$, $S0(\text{En})$, $S0(\text{Si})$. The symbol $\Delta$ represents minor components, some of which have unusual metal ratios for the pyroxene structure.

*Devine and Sigurdsson (1980), Table 1 for fassaite.
†Cameron and Robinson (1977), Table 3, analysis 1 for pyroxene from the Allende meteorite (Mason, 1974).
‡Curtis and Gittins (1979), Table 2, analysis 5 for no. 7 and Table 2, analysis 5 no. 8.

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 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% $\text{Ca}_2\text{Si}_2\text{O}_5$. However, if Ca, Mg, and Fe are normalized, or calculated as 100$\text{Ca}/(\text{Ca} + \text{Mg} + \Sigma\text{Fe})$, 100 $\Sigma\text{Fe}/(\text{Ca} + \text{Mg} + \Sigma\text{Fe})$, 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% $\text{Ca}_2\text{Si}_2\text{O}_5$ 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.
The distinction between augite and pigeonite in the Ca-Mg-Fe pyroxenes is primarily structural, their space groups being $C_2/c$ and $P_{2_1}/c$, 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 $C_2/c$ 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 $Pbcm$ and can be expressed as “enstatite-Pbcm.” 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-Pbcm” does not exceed 2%, and the En value commonly exceeds 90%. Thus the composition field of “enstatite-Pbcm” 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 NaAlSi$_2$O$_6$ or NaFe$^{3+}$Si$_2$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.\(^\text{11}\) The arbitrary division...
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.

Classification of other pyroxenes

Most naturally occurring pyroxenes in the Others area are johannsenite (CaMnSi$_3$O$_6$), petedunnite (CaZnSi$_3$O$_6$), and spodumene (LiAl$_2$Si$_2$O$_6$) (Fig. 2). Recent investigations of natural Mn-bearing pyroxenes have yielded two new minerals, kanoite and its dimorph donpeacorite, (Mn,Mg)MgSi$_3$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 (CaFe$_3$Al$_2$Si$_3$O$_9$) is the first pyroxene with the substitution 3 as described in Table 1.

Several pyroxenes with unusual chemical compositions (Table 3) appear outside the area between the lines $Q + J < 1.5$ 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 CaR$_3^+$AlSiO$_6$ (S3, Fig. 7) and CaR$_2^+$Ti$_2^+$_Si$_6$O$_{18}$ (S4, Fig. 7) components representing substitutions 3 and 4, respectively, and second, Na-rich pyroxenes with the NaR$_3^+$Ti$_2^+$_Si$_6$O$_{18}$ component representing substitution 2 (S2, Fig. 7). The former shows a significant deficiency of Si atoms such as Si < 1.60 in the standard formula resulting in the $Q$ value close to or less than 1.5 (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 in Table 5.

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

<table>
<thead>
<tr>
<th>Cation</th>
<th>Content</th>
<th>Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>Al$^{3+}$</td>
<td>&gt;0.10</td>
<td>aluminian</td>
</tr>
<tr>
<td>Ca$^{2+}$</td>
<td>&gt;0.10</td>
<td>calcian</td>
</tr>
<tr>
<td>Cr$^{3+}$</td>
<td>&gt;0.01</td>
<td>chromian</td>
</tr>
<tr>
<td>Fe$^{2+}$</td>
<td>&gt;0.10</td>
<td>ferran</td>
</tr>
<tr>
<td>Fe$^{3+}$</td>
<td>&gt;0.10</td>
<td>ferran</td>
</tr>
<tr>
<td>Li$^+$</td>
<td>&gt;0.01</td>
<td>lithium</td>
</tr>
<tr>
<td>Mg$^{2+}$</td>
<td>&gt;0.10</td>
<td>magnesrian</td>
</tr>
<tr>
<td>Mn$^{2+}$</td>
<td>&gt;0.10</td>
<td>managanian</td>
</tr>
<tr>
<td>Na$^+$</td>
<td>&gt;0.10</td>
<td>sodium</td>
</tr>
<tr>
<td>Ni$^{2+}$</td>
<td>&gt;0.01</td>
<td>nickelan</td>
</tr>
<tr>
<td>Si$^{4+}$</td>
<td>&lt;1.75</td>
<td>subsilicic</td>
</tr>
<tr>
<td>Ti$^{4+}$</td>
<td>&gt;0.01</td>
<td>titanian</td>
</tr>
<tr>
<td>Zn$^{2+}$</td>
<td>&gt;0.01</td>
<td>zincian</td>
</tr>
</tbody>
</table>

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

* Number of cations per formula unit M2M1Ti$_6$O$_{18}$. If the mineral name itself implies the presence of certain cations, adjectival modifiers for these cations should not be used ("subsilicic" is an exception).

**Fig. 7.** $Q$-$J$ diagram for eight unusual pyroxenes with $Q$ value less than 1.62 and Mn less than 0.08 atoms per formula unit (Table 3). The components formed by the substitutions 1 to 4, as indicated in Table 1, are plotted in the diagram. They represent the following compositions: S1 = NaR$_3^+$Si$_6$O$_{18}$, S2 = NaR$_2^+$Ti$_2^+$_Si$_6$O$_{18}$, S3 = CaR$_3^+$AlSiO$_6$, and S4 = CaR$_2^+$Ti$_2^+$_AlSiO$_6$.
Table 6. Obsolete pyroxene names

<table>
<thead>
<tr>
<th>Name</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>acmite = aegirine</td>
<td></td>
</tr>
<tr>
<td>aegirite (aegyte)</td>
<td>aegirine</td>
</tr>
<tr>
<td>aegirine-hedenbergite</td>
<td>aegirite</td>
</tr>
<tr>
<td>aklase = probably enstatite partly altered to talc</td>
<td></td>
</tr>
<tr>
<td>aglise = altered spodumene</td>
<td></td>
</tr>
<tr>
<td>alabi = diopside</td>
<td></td>
</tr>
<tr>
<td>alkali aegirine-augite</td>
<td>aegirine-augite</td>
</tr>
<tr>
<td>ambydyste = enstatite</td>
<td></td>
</tr>
<tr>
<td>anthochlorite = augite</td>
<td></td>
</tr>
<tr>
<td>astroite = iron-rich (or Fe-rich) aegirine</td>
<td></td>
</tr>
<tr>
<td>balkalite = diopside</td>
<td></td>
</tr>
<tr>
<td>batiste = enstatite that has altered to serpentine, talc, or perhaps anthropyrite</td>
<td></td>
</tr>
<tr>
<td>blanforite = manganese aegirine-augite</td>
<td></td>
</tr>
<tr>
<td>bronzite = enstatite</td>
<td></td>
</tr>
<tr>
<td>calc-cilninbronze = pigeonte</td>
<td></td>
</tr>
<tr>
<td>calci-cionoestanne = pigeonite</td>
<td></td>
</tr>
<tr>
<td>calc-ciclopyrosilite = pigeonite</td>
<td></td>
</tr>
<tr>
<td>calc-cape = subcalcic augite</td>
<td></td>
</tr>
<tr>
<td>canaanite = diopside</td>
<td></td>
</tr>
<tr>
<td>chlapidate = enstatite</td>
<td></td>
</tr>
<tr>
<td>chlothomelinite = omphacite or aegirine-augite</td>
<td></td>
</tr>
<tr>
<td>chrome-some = chromian aegirine</td>
<td></td>
</tr>
<tr>
<td>chromerejadaite = chromian jadeite</td>
<td></td>
</tr>
<tr>
<td>clinichypersthene = clinosestatite or clinoforosilite</td>
<td></td>
</tr>
<tr>
<td>coccolite (kokkolith) = iron-rich (or Fe-rich) aegirine</td>
<td></td>
</tr>
<tr>
<td>cymatsilite = altered spodumene</td>
<td></td>
</tr>
<tr>
<td>dacliatite = altered enstatite</td>
<td></td>
</tr>
<tr>
<td>diallage = diopside that has altered or that has good (100) paring; also used for alteration products of other pyroxenes</td>
<td></td>
</tr>
<tr>
<td>diopside = omphacite</td>
<td></td>
</tr>
<tr>
<td>endopside = magnesium-rich (or Mg-rich) aegirine</td>
<td></td>
</tr>
<tr>
<td>enstatite-diopside = magnesium-rich (or Mg-rich) aegirine</td>
<td></td>
</tr>
<tr>
<td>eurtite = ferrorsilite</td>
<td></td>
</tr>
<tr>
<td>eutite = ferrosilite</td>
<td></td>
</tr>
<tr>
<td>fassait = ferian aluminum diopside or aegirine</td>
<td></td>
</tr>
<tr>
<td>fedorovite = diopside</td>
<td></td>
</tr>
<tr>
<td>ferroaugite = aegirine</td>
<td></td>
</tr>
<tr>
<td>ferrohedenbergite = augite</td>
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<tr>
<td>ferrohypersthene = ferrosilite</td>
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</tr>
<tr>
<td>ferrohypersthene = ferrosilite</td>
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<td>ferrohendenbergite = augite</td>
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<td>ferrohypersthene = ferrosilite</td>
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<td>ferrohendenbergite = augite</td>
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<tr>
<td>ferrohypersthene = ferrosilite</td>
<td></td>
</tr>
<tr>
<td>fellone = iron-rich (or Fe-rich) hedenbergite</td>
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</tr>
<tr>
<td>fellone = iron-rich (or Fe-rich) hedenbergite</td>
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</tr>
<tr>
<td>ferrugite = iron-rich (or Fe-rich) pigeonite</td>
<td></td>
</tr>
<tr>
<td>ferrosilate = hedenbergite</td>
<td></td>
</tr>
<tr>
<td>ficanite = enstatite</td>
<td></td>
</tr>
<tr>
<td>funkite = hedenbergite</td>
<td></td>
</tr>
<tr>
<td>gerrmarite = altered enstatite</td>
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</tr>
<tr>
<td>hidingite = spodumene</td>
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</tr>
<tr>
<td>hudsonite = hedenbergite</td>
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</tr>
<tr>
<td>hypersthene = enstatite or ferrosilite</td>
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<tr>
<td>jadeite-aegirine (jadeite-aegrite) = jadeite or aegirine</td>
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<td>jeffersonite = zincian manganese diopside or aegirite</td>
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<tr>
<td>knee-augite = aegirite</td>
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</tr>
<tr>
<td>kunzite = spodumene</td>
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</tr>
<tr>
<td>lovatrite = diopside</td>
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<td>lawrivite = diopside</td>
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</tr>
<tr>
<td>lawrivite = diopside</td>
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<tr>
<td>leucaugite = diopside</td>
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<td>lime-bronze = probably pigeonite or enstatite plus augite (&quot;inverted&quot; pigeonite)</td>
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<tr>
<td>loganite = diopside + actinolite + talc</td>
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<tr>
<td>lotalite = hedenbergite</td>
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</tr>
<tr>
<td>maficolite = diopside with good (001) paring, also diopside from Sala, Sweden</td>
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<tr>
<td>mansoite = aegirite or diopside or hedenbergite</td>
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<tr>
<td>mayanite = omphacite</td>
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<td>melrite = orthopyroxene</td>
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<td>mondradite = probably an altered pyroxene</td>
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<tr>
<td>musrite = diopside</td>
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<td>orthobronzite = enstatite</td>
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<td>orthoerustine = enstatite</td>
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<td>orthoerustine = ferrosilite</td>
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<td>phasesenite = enstatite or ferrosilite</td>
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<td>peckamite = enstatite</td>
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<td>phasitine = altered enstatite</td>
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Table 6—Continued

<table>
<thead>
<tr>
<th>Name</th>
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<tbody>
<tr>
<td>picrophyll = altered pyroxene?</td>
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<tr>
<td>pigeonite-augite = probably subcalcic augite</td>
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<tr>
<td>pitkaranite = pyroxene</td>
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</tr>
<tr>
<td>potash-aegirine = synthetic product, probably not properly characterized</td>
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<td>prohete = augite</td>
<td></td>
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<tr>
<td>proteoste = enstatite</td>
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<td>pyrolalite = altered pyroxene?</td>
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<tr>
<td>pyrom = pyroxene</td>
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<tr>
<td>sahlite = diopside</td>
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</tr>
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<td>salite = diopside</td>
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</tr>
<tr>
<td>schefflerite = manganese diopside</td>
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<td>schillerspar (schillerspat) = enstatite that is altered to serpentine, talc, or anthropyrite</td>
<td></td>
</tr>
<tr>
<td>shaulite = enstatite</td>
<td></td>
</tr>
<tr>
<td>soda-spodumene = sodian spodumene</td>
<td></td>
</tr>
<tr>
<td>strakonite = altered pyroxene, steatite?</td>
<td></td>
</tr>
<tr>
<td>szabante = partly altered enstatite</td>
<td></td>
</tr>
<tr>
<td>titaunite = titanian augite</td>
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<tr>
<td>titandopside = titanian diopside</td>
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<tr>
<td>tianpigeonite = titanian pigeonite</td>
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<td>trachayugite = augite</td>
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<td>traversellite = diopside</td>
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<td>triphane = spodumene</td>
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<tr>
<td>turtite = omphacite</td>
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<tr>
<td>uralite = pseudomorph of amphibole after pyroxenes</td>
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</tr>
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<td>urbanite = iron-rich (or Fe-rich) aegirine-augite</td>
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<tr>
<td>uryeite = kosmochlor</td>
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<td>vanadinaugite = vanadium-bearing (or V-bearing) augite</td>
<td></td>
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<td>vanadinnbronzite = vanadium-bearing (or V-bearing) enstatite</td>
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<td>vargaste = altered pyroxene?</td>
<td></td>
</tr>
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<td>victorite = enstatite</td>
<td></td>
</tr>
<tr>
<td>violate = augite</td>
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<tr>
<td>violan = magnesium-rich (or Mg-rich) aegirite or diopside</td>
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</tbody>
</table>

Note: The above pyroxene mineral names, or names that refer to altered pyroxenes, have been formally discarded by the CMMN. The correct names are italicized. The original form of this table was compiled by Malcom Ross using the following references: Dana (1892); Tschermak (1897); Chester (1886); Ford (1932); Winchell and Winchell (1951); Deer et al. (1978); Robinson's (1980) 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 titanohedraminum pyroxene.

The Allende pyroxene (no. 4) contains 39% of the S3(Ti) (for notation, see note in Table 3) component CaR^+AlSeO_4, where R^+ = 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., ferrooan). It is recommended that such modifiers never be used for main cations normally contained in the named mineral, for example, in terms like “calcian aegirine,” “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: Ferri-, Mg-rich, and subsilicic. 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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