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CLINOPYROXENES FROM ECLOGITES AND BASIC GRANULITES

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ABSTRACT

A study of clinopyroxenes from undoubted eclogites and basic granulites has been made in an attempt to define some parameter that may be used to distinguish them. When first-class analyses of eclogitic and granulitic clinopyroxenes published since 1920, are recast into the molecular percentage of the various end members Ac, Jd, Ts, Hd, Di, in this order, a clear distinction can be made. Undoubted eclogite-facies clinopyroxenes have a molecular ratio Jd:Ts$>\frac{4}{5}$, whereas those from basic rocks of lower pressure facies (such as basic granulites) have a Jd:Ts ratio$<\frac{1}{2}$. These data are consistent with the theory that aluminum in 6-fold co-ordination increases with pressure while aluminum in 4-fold co-ordination increases with temperature, and hence the nature of the clinopyroxene may be taken as diagnostic of grade. Some apparently anomolous and borderline examples are discussed.

INTRODUCTION

The distinction between eclogites and high-grade granulites of basic and picritic compositions, has led to much confusion and argument because the assemblages garnet-clinopyroxene and garnet-clinopyroxene-orthopyroxene ± hornblende may occur in both the eclogite and granulite facies in rocks low in silica (Davidson, 1943; Subramaniam, 1956; Yoder and Tilley, 1962, p. 515).

The garnets of these assemblages are characteristically pyrope-almandine-grossular solid solutions but as pointed out by O'Hara (1960, p. 152) and Yoder and Tilley (1962, p. 472) there is a similar range in composition for both eclogitic and granulitic garnets.

Diagnostic eclogite or granulite facies assemblages in the associated rocks have been used to interpret these silica-poor parageneses (*e.g.* O'Hara, 1960; 1961), but this criterion cannot be applied in the study of garnet-clinopyroxene rocks occurring as inclusions in certain deep-seated pipes at present being studied by Dr. J. F. Lovering and the author. In this paper a comparison is made of the composition of analyzed clinopyroxenes from undoubted eclogites and basic granulites in an attempt to define some parameter that may serve to distinguish otherwise ambiguous types. Although a chemical comparison is made here, it is hoped that any differences in the composition of the clinopyroxenes will be reflected in their optical properties, thus enabling petrographic distinctions to be made between true eclogites and eclogite-like rocks without recourse to chemical analysis.

SELECTION AND CALCULATION OF PYROXENE ANALYSES

All analyses published since 1920 and rated as first class quality on the basis of addition and structural formula requirements, have been considered.

Clinopyroxenes are taken to be eclogitic when they have either been separated from rocks with the critical assemblages: garnet (pyrope-almandine)-clinopyroxene-quartz, garnet (pyrope-almandine)-clinopyroxene-kyanite, garnet (grossular-pyrope-almandine)-clinopyroxene-kyanite, or are intimately interbanded with these or the other critical assemblage, garnet-olivine(O'Hara, 1960, p. 154). Pyroxenes are taken as granulitic when they are from or intimately associated with the assemblages plagioclase-clinopyroxene-orthopyroxene ± hornblende and plagioclase-garnet (pyrope-almandine)-clinopyroxene ± hornblende.

The number of cations in each pyroxene has been calculated on the basis of 12 anion equivalents, grouped according to the general pyroxene structure XYZ_2O_6 and then assigned to the hypothetical end members Ac, Jd, Ts,[1] Hd, Di, in this order, according to the convention adopted by Yoder and Tilley (1962, p. 366–7) except that all the Fe^{3+} in the Y position is first assigned to acmite ($NaFe^{3+}Si_2O_6$) and the remaining Na+K in the X position is then allotted to an equal number of Al atoms to form jadeite ($NaAlSi_2O_6$). Thus the pyroxene from the Loch Duich eclogite reduced to $Di_{53}\ Hd_{24}\ Ts_7\ Jd+Ac_{16}$ by Yoder and Tilley (1962, p. 480) is here calculated as $Ac_{10}\ Jd_6\ Ts_7\ Hd_{24}\ Di_{53}$.

This separation of acmite and jadeite has been made because sodic pyroxenes such as aegirine and diopsidic pyroxenes with varying amounts of the acmite component may form in rocks of appropriate composition under a very wide range of physical conditions (White, 1962). Aluminous pyroxenes with high ferric iron and sodium contents have already been confused with jadeitic pyroxenes: Knorring and Kennedy (1958, p. 851) referred to such a pyroxene from an "eclogitic" gneiss with the assemblage garnet (pyrope-almandine)-clinopyroxene-scapolite ± plagioclase as omphacitic with 10% of the jadeite component. This reduced to $Ac_{11}\ Jd_2\ Ts_{15}\ Hd_{18}\ Di_{54}$ and is no more jadeitic than a clinopyroxene ($Ac_6\ Jd_2\ Ts_7\ Hd_{25}\ Di_{60}$) from an "intermediate rock" from the Madras Charnockite suite (Howie, 1955).

COMPARISON OF CLINOPYROXENE ANALYSES

Using the method of reduction outlined above, it was noticed (Lovering and White, 1964) that the clinopyroxenes from basic and picritic high-

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[1] Ts is here used as an abbreviation for Tschermak's molecule $(CaMg)Al_2SiO_6$. No distinction is made between calcium and magnesium Tschermak's molecule.

grade granulites occurring as inclusions in deep-seated pipes, were all rich in Tschermak's molecule but poor in the jadeite component in comparison with the pyroxenes from eclogites studied by Yoder and Tilley (1962). A study of 64 clinopyroxenes in undoubted granulites and eclogites obtained from the literature shows that this is always applicable. When the percentage of Jd is plotted against the percentage of Ts (Fig. 1) there is a clear distinction between eclogite and granulite facies pyroxenes. The line separating the field of granulite pyroxenes from that of eclogite pyroxenes is drawn to include all pyroxenes co-existing with plagioclase, a mineral which does not occur in eclogite facies rocks or at least in those eclogites with a basic or picritic composition. All pyroxenes with the molecular ratio jadeite: Tschermak's molecule less than $\frac{1}{2}$ are from granulites while those with a ratio greater than $\frac{4}{5}$ are from eclogites . Only one pyroxene has a ratio between $\frac{1}{3}$ and $\frac{4}{5}$ giving an almost vacant field on the diagram.

It has been pointed out that the clinopyroxenes of eclogites[1] "are not always as soda-rich as often alleged" (Yoder, 1950, p. 226). Nevertheless these pyroxenes plot within the eclogite field since they are also low in Tschermak's molecule.

The theoretical basis for this separation into two well defined groups is to be found in Thompson's (1947) suggestion that the amount of aluminum in four-fold co-ordination increases with temperature whilst that in six-fold co-ordination increases with pressure. The percentage of Tschermak's molecule is a direct measure of aluminum in four-fold co-ordination while the amount of jadeite is a measure of the amount of aluminum in six-fold co-ordination coupled with soda. This latter measure is more critical than the actual percentage of aluminum in six-fold co-ordination since it is not dependent on the analytical precision of the alumina determination and it does not include the aluminum in the Y positions of Tschermak's molecule which occurs in nature as fassaite and is known to be stable at low pressures (Tilley, 1938; Segnit, 1953).

Thus there is both theoretical and geological evidence that the distribution of aluminum between the two contrasting sites in pyroxenes depends on the pressure-temperature conditions of formation and is therefore diagnostic of grade: in the eclogite facies pyroxenes, Al is concentrated in the Y sites with six-fold co-ordination whereas in granulite facies pyroxenes Al is approximately equally partitioned between Y and Z sites, the latter in four-fold co-ordination.

It is possible that rocks of eclogite facies, deficient in silica, low in soda, but rich in alumina may contain aluminous (fassaitic) pyroxenes and hence lead to ambiguities. However, no such pyroxene has yet been found

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[1] Such rocks have sometimes been referred to as "griquaites."

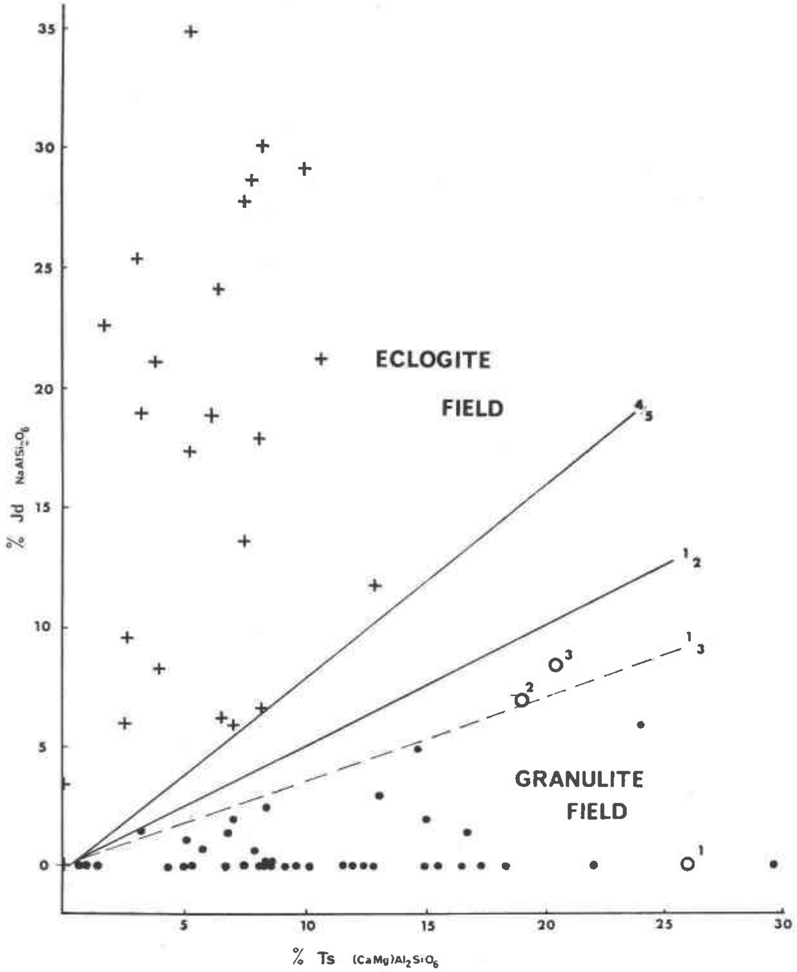

FIG. 1. Plot of mol. percent jadeite against Tschermak's molecule showing the clear separation of eclogitic and granulitic clinopyroxenes.

- + Clinopyroxenes from undoubted eclogites
- ● Clinopyroxenes from undoubted granulites
- ○ 1. Clinopyroxene from Knockormal "eclogite" (Bloxam and Allen, 1960)
- ○ 2. Clinopyroxene from Oahu "eclogite" (Yoder and Tilley, 1962)
- ○ 3. Clinopyroxene from Oahu "eclogite" (J. F. Lovering, unpubl. data).

in rocks proven to be of eclogite facies from other considerations. Furthermore the following postulated reactions are expected to proceed to the right at the high pressures of the eclogite facies:

1. For magnesian+iron-rich assemblages
   $MgAl_2SiO_6+2(MgFe)SiO_3 \rightleftharpoons (MgFe_3)Al_2(SiO_4)_3$
   MgTs hypersthene pyrope-almandine
2. For magnesian+calcium-rich assemblages (e.g. Tilley, 1921)
   $xCaMgSi_2O_6 \cdot MgAl_2Si_2O_6 \rightleftharpoons CaMg_2Al_2Si_3O_{12}+x-1\ CaMgSi_2O_6$
   aluminous augite pyrope-grossular diopside
3. For calcium-rich assemblages
   $3CaAl_2SiO_6 \rightleftharpoons Ca_3Al_2Si_3O_{12}+2Al_2SiO_5$
   CaTs grossular kyanite

In detailed experiments on the basalt-eclogite transition, Ringwood and Green (pers. comm.) have shown that at pressures below those required to produce true eclogites, assemblages containing aluminous pyroxenes are formed. With increasing pressure, more garnet is produced at the expense of the aluminous pyroxene. These data provide experimental evidence that the reactions postulated above proceed to the right under eclogite facies conditions and that pyroxenes rich in Tschermak's molecule are only stable under the pressure-temperature conditions of the granulite or lower pressure facies.

DISCUSSION OF SOME ANOMOLOUS AND BORDERLINE PYROXENES

Very few pyroxenes from rocks referred to in the literature as eclogites but which neither contain, nor are intimately associated with the critical assemblages, plot outside the eclogite field.

One notable exception is an analyzed fassaite ($Ac_3Jd_0Ts_{26}Hd_{10}Di_{62}$ from a small "eclogite" mass from Knockormal, Scotland (Bloxam and Allen, 1960). Calculation of the structural formula of this pyroxene on the basis of 6 oxygens in the formula unit gives a deficiency of cations in the Y group and an excess of aluminum in 6-fold co-ordination over that required to make Tschermak's molecule. Nevertheless the very large negative error in the soda determination necessary to make enough jadeite for the pyroxene to plot in the eclogite field is unlikely. The assemblage is hornblende-clinopyroxene-garnet (pyrope-almandine)-saussurite-spinel. Zoisite has been recognised in the saussurite aggregate and this mineral sometimes appears as veins. Furthermore the composition of the rock shows that it falls in the kyanite-eclogite field of O'Hara's (1960, p. 153) ternary A.C.F. diagram and hence it should develop the assemblage kyanite-garnet-diopsidic pyroxene under eclogite facies conditions (see reaction 3). Thus the mineralogy and chemistry of the Knockormal "eclogite" strongly suggest that it is an altered plagioclase-bearing granulite.

A clinopyroxene from a hypersthene "eclogite" nodule from the tuffs of Salt Lake crater, Oahu, described by Yoder and Tilley (1962, p. 482) reduced to ($Ac_6Jd_7Ts_{19}He_{13}Di_{55}$). This is almost identical to a clinopyroxene ($Ac_4Jd_8Ts_{20}Hd_{22}Di_{46}$) in an "eclogite" collected from the same locality (Lovering, unpublished data). Both plot within the "almost vacant" area but just within the granulite field as here defined. It is obvious that further data on pyroxenes from high-grade plagioclase granulites are needed to define the granulite field more precisely. On present data, however, the Hawaiian inclusions appear to be granulites.

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