THE AMERICAN MINERALOGIST, VOL. 55, JULY–AUGUST, 1970

PYROPE IN KIMBERLITE

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ABSTRACT

The chemical composition of kimberlite pyropes from Kimberley, South Africa, from Trebenice, Czechoslovakia and from Northern Arizona, have been determined by electron probe microanalysis. The most common garnet in each locality is a magnesium-rich chrome pyrope (approximately pyrope$_{70}$almandine$_{16}$grossular$_{8}$uvarovite$_{5}$espessartine$_{1}$). The Kimberley pyropes have a grossular content of approximately 8 mole percent over a wide range of Mg/Fe ratios, whereas in the Czechoslovakia and Arizona pyropes grossular content increases with decreasing Mg/Fe ratio. Pyrope analyses for each occurrence do not plot in discontinuous groups but define a continuous series of compositions.

As part of a study of phase compositions in ultrabasic rocks, a series of kimberlite garnets were analyzed. Three suites of garnets were studied: U.S. National Museum number R3421 from Kimberley, South Africa, number 107199 from Trebenice, Bohemia, Czechoslovakia, and a third suite from the Navajo Indian Reservation in Northern Arizona. The precise sample locations within each area and the nature of the coexisting minerals in the original assemblage are unknown.

Pyropes from the Kimberley area, described by Williams (1932), Nixon, *et al.* (1963), O'Hara and Mercy (1963) and by Rickwood, *et al.* (1968), are derived primarily from garnet peridotite nodules in kimberlite. Bohemian pyropes, described by Fiala (1965), have as their major source garnet peridotites associated with granulites and gneisses. Davidson (1967) cites the work of Kopecký and Sattran (1962) to demonstrate that some of the Czechoslovakian garnet peridotites, found as xenoliths in kimberlitoid pipes, may have originated from ultrabasic lenses in the basement complex. This does not rule out the possibility of tectonic emplacement of the garnet peridotites from a mantle source, as argued cogently by Fiala (1966). Arizona pyropes, associated with diatremes, are discussed by O'Hara and Mercy (1966), Watson (1967) and Watson and Morton (1969). McGetchin (1969) from a study of inclusions in pyropes from Moses Rock, Southern Utah, has shown that such pyropes are at least in part derived from garnet peridotite.

Fifty homogeneous garnet crystals from each suite were analyzed using electron microprobe techniques. Analytical techniques, correction procedures, and the 150 analyses are given in full in Reid *et al.* (1969) along

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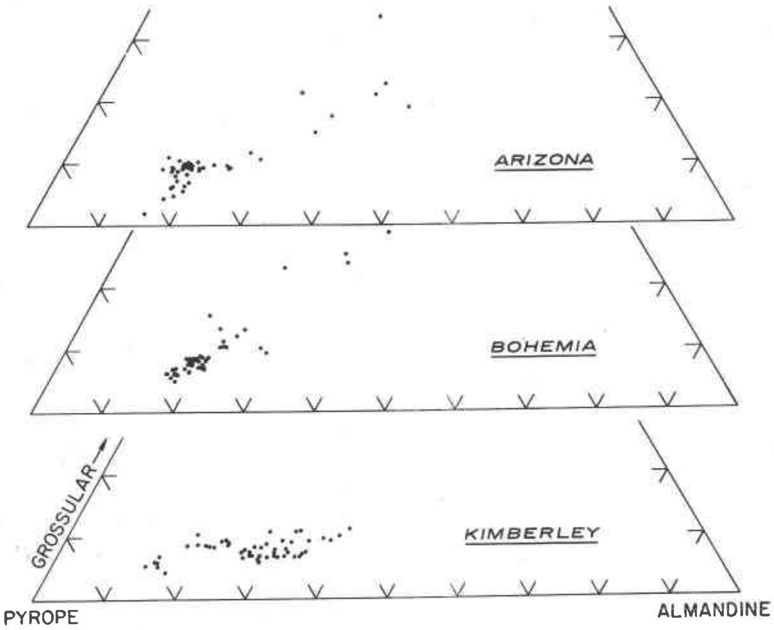

FIG. 1. Molecular proportions of selected end-members in analyzed garnets.

with recalculations of the analyses into structural formulae and garnet end-member molecules.[3] All garnets were analyzed for Si, Al, Cr, Fe, Mn, Mg and Ca. (All iron is treated as ferrous iron and ferric iron is neglected.) Na and K, sought only in the Bohemia and Arizona garnets, are below 0.1 weight percent.

The garnets from Kimberley are pyropes with mole ratios of Mg/(Mg+Fe) ranging from 0.86 to 0.56. Over this wide range of pyrope/almandine ratios the grossular component of the garnet ranges between 4 and 11 percent (averaging ~8 percent) and the analyses, plotted in terms of the three components pyrope, almandine and grossular, define a fairly narrow band parallel to the pyrope-almandine join (Fig. 1). Chromium content is low ($Cr_2O_3 < 0.6$ weight percent) except in the more magnesian pyropes [$Mg/(Mg+Fe) > 0.81$] where Cr_2O_3 varies from 1.6 to 2.7 weight percent (Fig. 2). Manganese is low throughout ($MnO \leq 0.4$ weight percent).

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[3] Tables listing the 150 garnet analyses and the garnet compositions in terms of structural formulae and of end-member molecules may be ordered as NAPS Document #1049 from National Auxiliary Publications Service, c/o CCM Information Corporation, 909 Third Avenue, New York, N. Y. 10022; remitting in advance $2.00 for microfiche or $5.00 for photocopies, in advance payable to ASIS-NAPS.

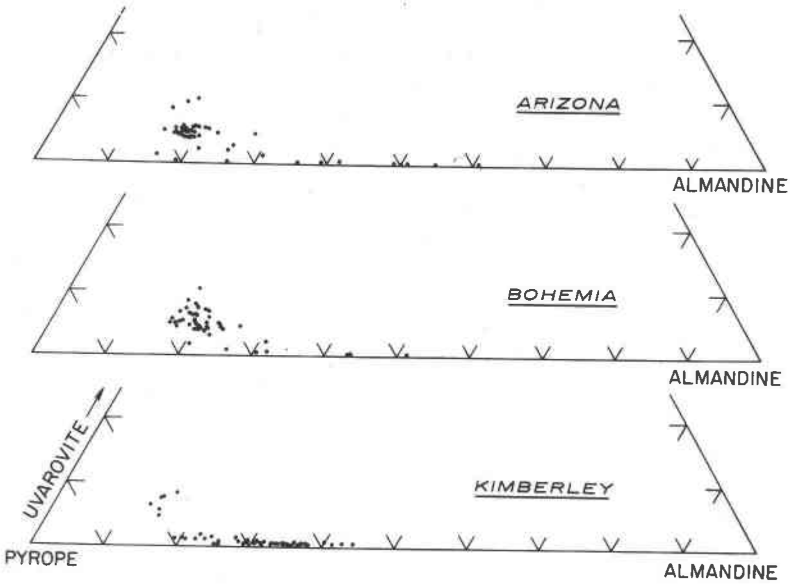

FIG. 2. Molecular proportions of selected end-members in analyzed garnets.

Mg/(Mg+Fe) ratios for the Bohemian pyropes are similar to those for the Kimberley garnets, ranging from 0.83 to 0.49. In contrast to the Kimberley samples, there is an increase in calcium with increasing iron content, so that the grossular component varies from 5 mole percent to 28 at the iron-rich end of the sequence (Fig. 1). A remarkably similar trend in the Arizona garnet analyses extends to slightly lower Mg/(Mg+Fe) values (0.84 to 0.39) and covers a wider range of grossular values, from 2 mole percent at the Mg-rich end to 33 percent in the iron-rich garnets. In both suites of garnets the manganese content is low (MnO$<$0.8 weight percent with one exception). Chromium is low in the more iron-rich garnets [$Cr_2O_3 < 0.15$ weight percent for Mg/(Mg+Fe) $<$0.68] but ranges up to 3.2 weight percent in the Mg-rich pyropes. The range in compositions and the clustering of analyses at the high magnesium values are very similar for the Bohemia and Arizona garnet suites.

Figure 3 compares the analyzed garnets with pyropes from kimberlite in Basutoland (Nixon, *et al.*, 1963), from garnet peridotite nodules in a carbonatitic tuff (Dawson, *et al.*, 1969), and from garnet peridotites occurring in gneisses in Norway and Switzerland (O'Hara and Mercy, 1963). The characteristic garnet from all of these occurrences is a magnesium-rich chrome pyrope (a typical composition would be $pyrope_{70}almandine_{16}grossular_8uvarovite_5spessartine_1$). The composition is also close to Sobolev's (1964) average of garnets from ultrabasics.

These garnets as a group are significantly different from the common garnets of regional metamorphic rocks and are distinct from the eclogite garnets in the Arizona kimberlites (O'Hara and Mercy, 1966, Watson and Morton, 1969). They do, however, resemble the garnets of group A eclogites as reported by Coleman, *et al.* (1965). A study by Rickwood, *et al.*, (1968) showed well-defined compositional trends for pyrope from South African kimberlites. The trends demonstrated by Rickwood, *et al.*, however, are based on compositional estimates from measurement of refractive index and unit cell edge length, and a direct comparison of results is therefore not possible.

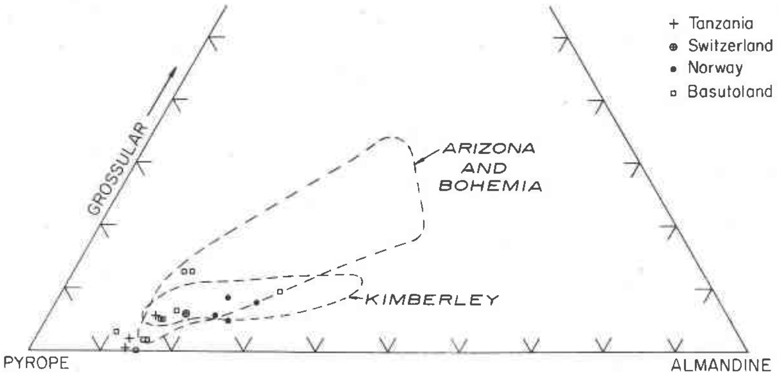

FIG. 3. Molecular proportions of selected end-members in analyzed garnets compared with other garnet peridotites.

Each of the three suites of samples examined shows a wide range of garnet compositions that from the well-defined compositional trends (Figs. 1, 2) represent, not a random aggregate, but a series of compositions related by some continuous process. When the three are compared, the compositional trends are similar and the most common garnet composition in each is a magnesium-rich chrome pyrope. There is particularly close correspondence between the Bohemia and Arizona pyropes, suggesting that each suite of garnets has been generated by similar processes acting on essentially similar starting materials.

The ranges in garnet compositions may reflect a range in bulk rock compositions, a range of physical conditions of formation, or, more probably, a combination of both. Increase in the Fe/Mg ratio of garnet with no change in bulk composition could occur if there were a compensatory compositional change in a coexisting phase. Studies of garnet peridotite assemblages, however, show that an increase in the Fe/Mg ratio in garnet is commonly accompanied by increases of Fe/Mg in the coexisting phases (*e.g.* O'Hara and Mercy, 1963, Fig. 22; Fiala, 1965,

Table 5). Thus it appears most likely that the range of garnets encountered derives from a distinct series of bulk rock compositions.

MacGregor (1967) has shown that at high pressures in the system CaO–MgO–Al_2O_3–SiO_2, garnet with the composition pyrope$_{87}$grossular$_{13}$ is stable in the four-phase assemblage garnet, olivine, orthopyroxene and clinopyroxene over a wide range of temperature and pressure. Nearly constant grossular content is also found in natural four-phase garnet peridotites over a range of iron contents (*e.g.* O'Hara and Mercy, 1963, Fig. 22). The Kimberley garnets also show a narrow range of grossular contents (approximately grossular$_8$) over a wide range of Fe/Mg values.

In contrast, the Bohemia and Arizona garnets display a considerable range in grossular content with an increase in Fe paralleled by an increase in Ca. If the grossular content of garnet is fixed in the four-phase assemblage, olivine–enstatite–diopside–garnet, then removal of a phase could eliminate this constraint on garnet composition. A different phase assemblage may be the result of differences in bulk composition or of environment, particularly the depth at which the assemblage crystallized. Many of the pertinent phase relations have been demonstrated by Green and Ringwood (1967), Ito and Kennedy (1967) and O'Hara and Yoder (1967). Ito, *et al.*, (1968) suggest that a kimberlite magma, as it rises within the mantle, may crystallize olivine+orthopyroxene+clinopyroxene+garnet, olivine+clinopyroxene+garnet, and clinopyroxene +garnet, in this sequence. The Kimberley garnets and the majority of the Arizona and Bohemia garnets thus may be derived largely from four-phase garnet peridotite. The less magnesian Arizona and Bohemia garnets may have crystallized in a modified phase assemblage at shallower depths. However, any detailed interpretation of garnet compositional trends must remain speculative until the nature of the coexisting phases is determined.

Any estimate of the nature of the source materials based solely on garnet compositions must also be speculative. The predominance of high pyrope compositions, however, suggests a parent material with a high Mg/Fe ratio in which highly magnesian pyrope is a stable phase. Such rocks occur as garnet peridotite inclusions in many kimberlites. The mineral assemblages of such garnet peridotites and their association with diamond-bearing kimberlites implies formation at high pressures, compatible with a source in the upper mantle. The similarities among the three areas studied and with other garnet peridotites (Fig. 3) favor a source at depth in a comparatively uniform upper mantle.

ACKNOWLEDGMENTS

We thank J. Frazer for help in data handling, B. Swope for preparing the illustrations, J. Sinkankas for providing the garnets and J. Sinkankas, G. Arrhenius and E. Essene for discussions of this and related problems. This research was supported by the National Aeronautics and Space Administration grant NGL-OS-009-002.

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Manuscript received, October 24, 1969; accepted for publication, February 24, 1970.