ORIGIN OF THE DISCRETE NODULES IN THE KIMBERLITES OF NORTHERN LESOTHO

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Coarse, single crystals of garnet, pyroxene and ilmenite are abundantly developed in the kimberlites of northern Lesotho and of the neighboring Monastery Pipe, O. F. S. Commonly these crystals form rounded nodules several centimeters in diameter and occasionally they attain a diameter of 10-20 centimeters. Intergrowths are rare, but a variety have been studied in this investigation. Inclusions in discrete nodules consist of garnet, pyroxene, ilmenite and olivine, but chromite and phlogopite are not included. Among the intergrowths are the much-studied diopside-ilmenite lamellar intergrowths and similar crystals in which enstatite and ilmenite are interlaminated.

Compositions of garnet megacrysts (Fig. 1) are distinguished from those of the garnets in compound, lherzolite nodules because the former have a wide range in Mg/(Mg + Fe) and restricted range in Ca (average 10.5 mole per cent Ca). The lherzolite garnets show a range in Ca and are predominantly more magnesian than the discrete nodule garnets. The most Fe-rich garnets are sometimes intergrown with ilmenite in a host or inclusion relationship.

Enstatite megacrysts also show a range in Mg/(Mg + Fe) and these relationships are believed to be due to an igneous fractionation which has not been experienced by the phases in the compound nodules.

Diopside discrete nodules (Fig. 2) are uniformly more Fe-rich than the diopsides in the lherzolites and they are also usually subcalcic. Diopside-ilmenite megacrysts are distinctive in that they appear to have formed in a lower temperature range than their more magnesian, ilmenite-free counterparts.

Compositions of intergrown phases in discrete nodules and the relatively restricted ranges of composition of the minerals involved suggest that the discrete nodules crystallized as a part of the assemblage diopside + enstatite + garnet + olivine $\pm$ ilmenite, but that the original associations were usually fragmented during eruption. If this assemblage is assumed to have existed, it becomes possible to make estimates of the equilibration conditions of the pyroxene discrete nodules.

Equilibration temperatures of the enstatite nodules can be estimated from a curve which relates Ca/(Ca + Mg) in the lherzolite enstatites to the equilibration temperatures of their associated diopsides. Equilibration pressures of the enstatite discrete nodules can be estimated from their Al_2O_3 contents, making a Wood-Banno correction (1973) with the aid of a curve which relates Mg/(Mg + Fe) in enstatites to Mg/(Mg + Fe) in coexisting garnets.

Temperature-depth points for twenty-two enstatite discrete nodules cluster along the sheared limb of the lherzolite geotherm (Fig. 3). This consistent relationship would not have been obtained if the original assumption that the enstatite nodules crystallized in equilibrium with diopside and garnet were not true. Moreover the range of equilibration temperature obtained for the diopside discrete nodules spans the range found for the sheared lherzolites (Fig. 3). Thus it appears that the discrete nodules have come from the same depth range in the mantle as have the sheared lherzolites.

Crystals of pyroxene and olivine as coarse-grained as the discrete nodules have been found in pegmatitic zones and metasomatic rocks in other kinds of ultramafic intrusions. Irvine (1973) has described occurrences of such rocks in the Duke Island ultramafic complex and attributed their origin to the action of volatiles emanating from crystallizing interstitial liquids. The action of volatiles alone would not appear to explain the strong fractionation in Mg/(Mg + Fe) shown by the discrete nodules (e.g., Fig. 1). But it is possible that crystallization in the presence of an H_2O-rich melt over a long period of time might produce ultracoarse crystals and might also provide an environment in which fractionation could occur.

The idea that the discrete nodules might be phenocrysts in the magmas that initiated the kimberlite eruptions (e.g., Nixon, et al. 1963) now seems improbable because of the large ranges in equilibration temperature exhibted by suites of discrete pyroxene nodules from individual kimberlite pipes. For example, fourteen bronzite nodules from Letseng-La-Terai have equilibration temperatures ranging from 1170° to 1360°C and five diopside nodules from Monastery (including diopside-ilmenite varieties) have a range of equilibration temperatures of 1200°-1365°C.

Nevertheless, the large range in equilibration temperature found for the discrete nodules could be explained by a model in which the discrete nodules are taken to be megacrysts in large volumes of H_2O-bearing, crystal-mush magmas in the low-velocity zone. Moreover, such a model appears to be consistent with the occurrence of phlogopite in the lherzolites and with experimental studies of the lherzolite solidus in the presence of H_2O (Mysen and Boettcher, 1972). Thus we suggest that the point of inflection of the geotherm, which occurs at a depth of about 140 km, might have been the top of the low-velocity zone in Late Cretaceous time.

Ilmenite-bearing discrete nodules appear to be confined to shallow depths in the low-velocity zone (Fig. 3) where they are associated with ilmenite-bearing rocks and granular aggregates (Boyd and Nixon, 1973). Green (1971) has suggested that magmas in the low-velocity zone may initially contain less than about 5% liquid. If such liquids gradually seep and ooze upward through large volumes of crystal-mush, following a P-T path along the geotherm, some crystallization must occur as they cool. The effect of such a process over a long period of time might be to enrich the upper portion of the asthenosphere in Fe and Ti and also in certain trace elements (Green, 1971). The concentration of ilmenite-bearing rocks and magmas (?) near the top of the low-velocity zone might be caused by such enrichment.

If the interpretation of the discrete nodules as megacrysts in crystal-mush magmas is correct, it appears inescapable that erupting kimberlites would pick up and include the interstitial liquids as well as the crystalline grains. If so, the liquid phase in a kimberlite eruption may be hybrid. Various authors, including Dawson and Hawthorne (1973), have suggested a genetic relationship between carbonatites and kimberlites. It is interesting to speculate that kimberlite magmas might be carbonatite/silicate hybrids.

Boyd, F. R., and P. H. Nixon, 1973, in Lesotho Kimberlites, Cape Town, in press; Dawson, J. B., and J. B. Hawthorne, 1973, J. Geol. Soc. London 129, p. 61-85; Green, D. H., 1971, Phil. Trans. Royal Soc. London, Ser. A 268, p. 707-725; Irvine, T. N., 1973, Geol. Soc. Amer. Mem. 138, in press; Mysen, B. O., and A. L. Boettcher, 1972, Geol. Soc. Amer. Abs. with Programs 4, p. 608; Nixon, P. H., O. von Knorring, and J. M. Rooke, 1963, Amer. Min. 48, p. 1090-1132; Wood, B. J., and S. Banno, 1973, Contrib. Min. and Pet., in press.

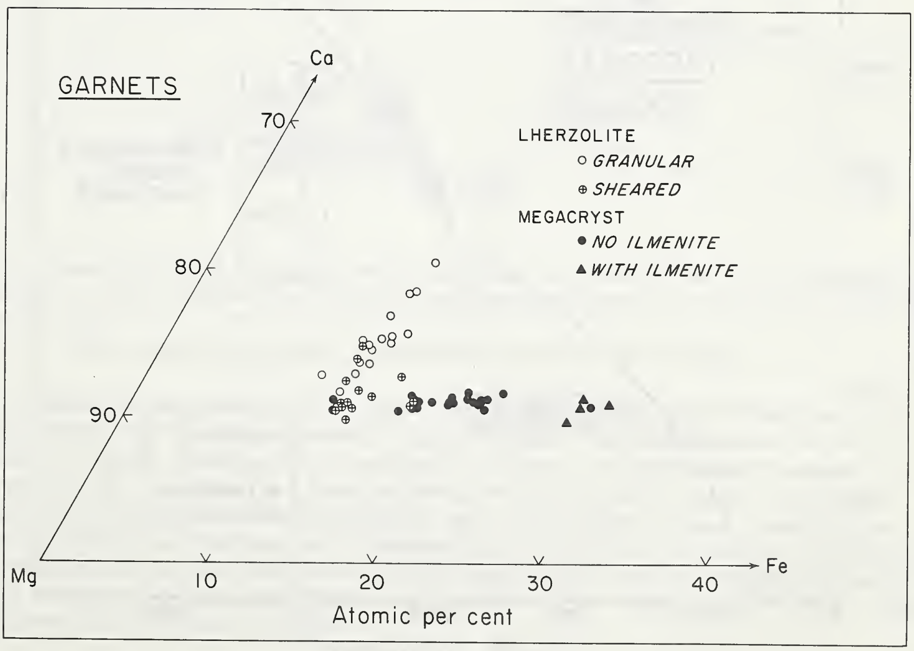
Figure Legends

Fig. 1: Compositions of garnet discrete nodules compared with those from the lherzolites.

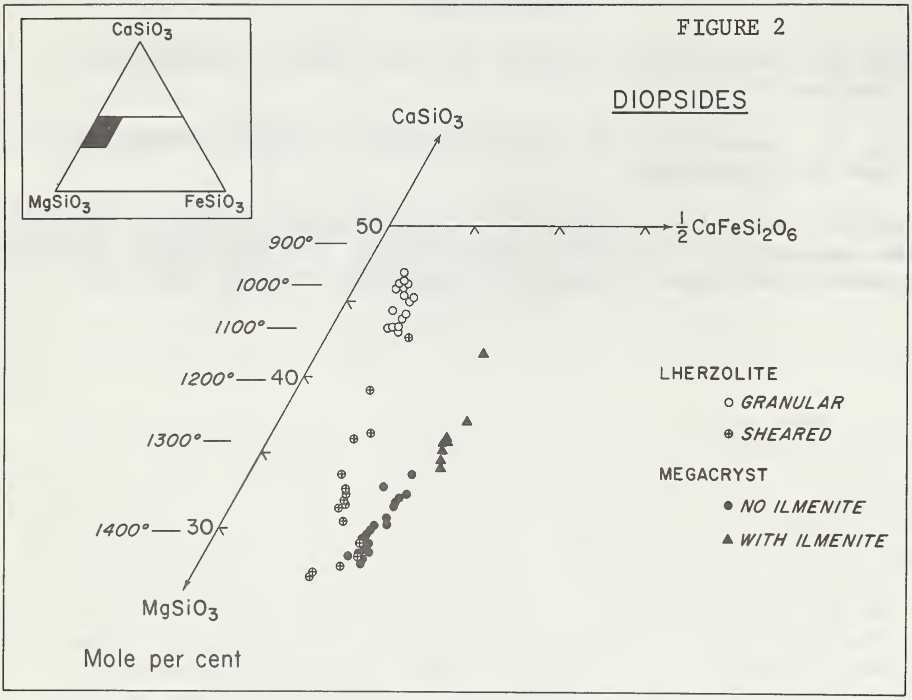
Fig. 2: Compositions of diopside discrete nodules compared with those from the lherzolites.

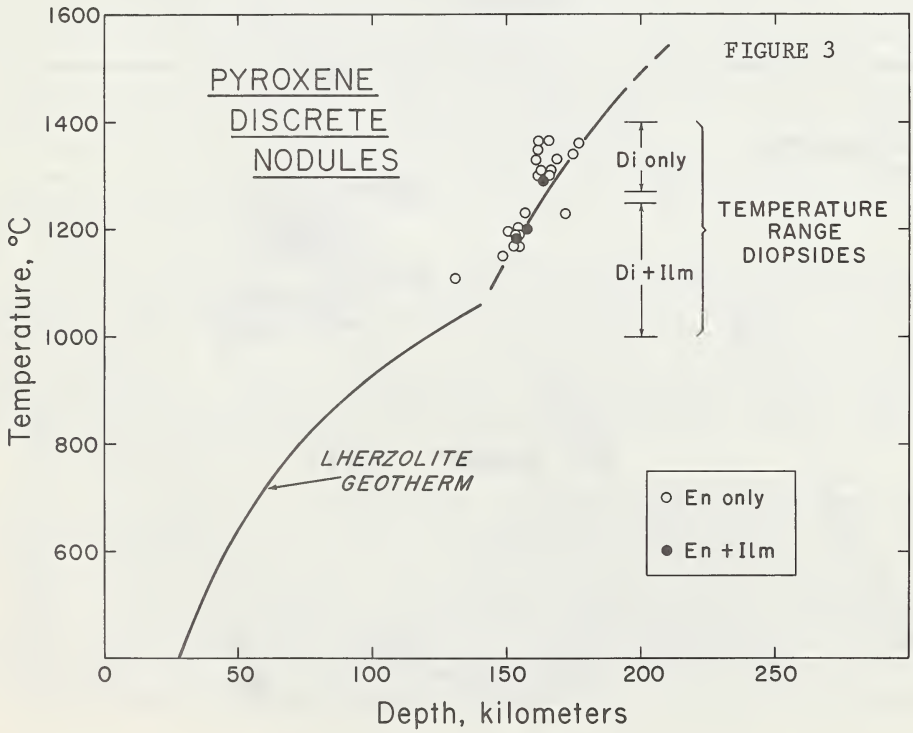
Fig. 3: Estimated equilibration conditions for pyroxene discrete nodules compared with the lherzolite geotherm. The calculated equilibration pressures have been corrected by the method of Wood and Banno.

FIGURE 1



Boyd and Nixon (2)





Boyd and Nixon (2)