DO PERIDOTITE-SUITE DIAMONDS FORM IN SUBDUCTED SERPENTINITES?

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Based on the abundance and composition of silicate and oxide inclusions in natural diamonds, most diamonds are thought to represent xenocrysts derived by disaggregation of dunites or harzburgites that contain low-calcium garnet and chromite. Although current models explaining the origin of such Ca-poor ultrabasic rocks involve magmatic depletion through high degrees of partial melting (e.g., Boyd and Gurney, 1982), virtually Ca-free ultrabasic rocks are also produced by thorough serpentinization of peridotite. Subduction of oceanic serpentinites, and subsequent prograde metamorphism to garnet peridotite facies would, therefore, result in low-calcium garnet harzburgites, the host rocks of most diamonds in the upper mantle.

To test this hypothesis, an ACF diagram has been constructed (Fig. 1), corresponding to equilibration conditions of approximately 1100°C and 55-60 kb. The data used in the construction of this figure were taken from diamondiferous garnet lherzolites and peridotite-suite minerals included in diamonds from the Finsch pipe in South Africa (Shee et al., 1982; Gurney et al., 1979; Tsai et al., 1979). These data were chosen because they represent the best documentation of diamond-related minerals from a single pipe. By plotting serpentinite bulk chemical analyses in this diagram, the serpentinites are effectively recast into approximate proportions of the various minerals that are stable under these conditions.

The results of this exercise are shown in Fig. 1. Of the 57 published analyses of serpentinites taken from the literature, the majority (44) are compositionally equivalent to harzburgites in which low-calcium garnet is stable. The Mg/(Mg + Fe) values of these 44 rocks range from 0.88-0.98. Exclusion of the vein serpentinites (Mg/(Mg + Fe) >0.97), however, results in an approximately bimodal distribution with a major peak at ∿0.940 and a broader peak at ∿0.915. These data correlate well with the Mg/(Mg + Fe) values of olivine inclusions in diamonds (J.J. Gurney, unpublished data), which have a perfect bimodal distribution with maxima near 0.920 and 0.945.

Elemental carbon is not uniformly distributed within the upper mantle but, excluding the eclogite suite, is preferentially associated with the low-Ca ("depleted") peridotite association. Diamond-bearing low-Ca garnet dunites and harzburgites are more abundant than are diamondiferous garnet lherzolites, just as peridotite-suite garnets included in diamonds are generally calcium-poor, and not of lherzolite affinity. Furthermore, a high percentage of diamond-free low-Ca garnet harzburgites contain graphite (Nixon et al., in press), whereas it is rare in garnet lherzolites. Therefore, the process that produces the Ca-poor characteristics of the peridotite must be related to the introduction of carbon. Most current hypotheses of formation of peridotite-suite diamonds do not explain the carbon source, although Haggerty (1986) states that the Ca-poor peridotites are more reducing than are the abundant garnet lherzolites, thus reducing CO_2 or oxidizing CH_4 when these volatiles are introduced into the peridotite. In the present model, graphite is formed during the serpentinization process, as documented by Pasteris (1981). The ultimate source for carbon is uncertain, but could be methane-bearing fluids, CO_2 fluid inclusions in olivine or pyroxene, or elemental carbon present in the fresh olivine. It is clear, however, that the carbon that could eventually form as diamond originates in the process of serpentinization, as does the chemical signature of the Ca-deficient host peridotite.

Boyd and Gurney (1982) proposed that the apparent restriction of both diamonds and low-calcium garnet xenocrysts to stable Archean cratons was due to the fact that generation of komatiitic magmas during the Archean was responsible for the calcium-depleted residual harzburgites, in which diamond subsequently formed. Archean ages for Ca-poor garnets and diamonds were demonstrated by Richardson et al. (1984). In the subducted serpentinite model, the apparent geographic restriction of these phases would be due to high convergence rates in the Archean that would promote shallow subduction of the partially serpentinized oceanic lithosphere. Repeated episodes of shallow subduction (underthrusting) would be primarily responsible for the formation of the relatively cool, subcratonic lithosphere (Helmstaedt and Schulze, this volume), a process analogous to "dealing onto the bottom of the deck". This would allow for emplacement of metaserpentinites at relatively low temperatures, thus avoiding partial melting that might destroy both the low-calcium nature of the peridotites and their diamonds by heating and metasomatic hybridization. This origin and emplacement mechanism would also account for the lack of evidence for a high temperature protolith of the low-Ca peridotites, as required by komatiite residue models. Emplacement beneath Archean cratons would protect the metaserpentinites from tectonism and magma production during subsequent orogenesis that occurred in adjacent mobile belts.

Boyd, F.R., and Gurney, J.J. 1982. Low-calcium garnets: Keys to craton structure and diamond crystallization. Carnegie Institution of Washington Year Book, 261-267.

Gurney, J.J., Harris, J.W., and Rickard, R.S. 1979. Silicate and oxide inclusions in diamonds from the Finsch kimberlite pipe. In Boyd, F.R., and Meyer, H.O.A. eds., Kimberlites, Diatremes, and Diamonds: Their Geology, Petrology, and Geochemistry, pp. 1-15, A.G.U., Washington.

Haggerty, S.E. 1986. Diamond genesis in a multiply-constrained model. Nature 320, 34-38.

Nixon, P.H., van Carlsteren, P., Boyd, F.R., and Hawkesworth, C.J. in press. Harzburgites with garnets of diamond facies from southern African kimberlites. In Nixon, P.H. ed., Mantle Xenoliths, Wiley, London.

Pasteris, J.D. 1981. Occurrence of graphite in serpentinized olivine in kimberlite. Geology 9, 356-359.

Richardson, S.H., Gurney, J.J., Erlank, A.J., and Harris, J.W. 1984. Origin of diamonds in an old enriched mantle. Nature 310, 198-202.

Shee, S.R., Gurney, J.J., and Robinson, D.N. 1982. Two diamond-bearing peridotite xenoliths from the Finsch kimberlite, South Africa. Contributions to Mineralogy and Petrology 81, 79-87.

Tsai, H.M., Meyer, H.O.A., Moreau, J., and Milledge, H.J. 1979. Mineral inclusions in diamond: Premier, Jagersfontein, and Finsch kimberlites, South Africa, and Williamson Mine, Tanzania. In Boyd, F.R., and Meyer, H.O.A. eds., Kimberlites, Diatremes, and Diamonds: Their Geology, Petrology, and Geochemistry, pp. 16-26, A.G.U., Washington.

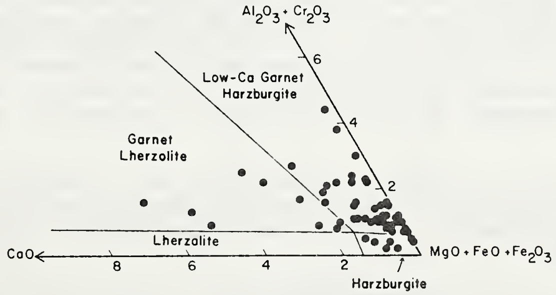

Fig. 1. Serpentinite bulk compositions plotted in an ACF diagram, applicable to equilibration conditions of approximately 1100°C and 55-60 kb.