A simple model for the pressure preservation index of inclusions in diamond

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ABSTRACT

The isovolume locus for a diamond-mineral inclusion pair occurs where the relative volumes of the two minerals respond identically to changes in pressure-temperature (P-T) conditions. Thirty potential inclusion minerals have been assessed with a simple linear model of this system. The remnant pressure on the inclusion (diamond at the Earth’s surface) can be estimated by extrapolating the conditions of diamond formation to 0 °C using the slope of the isovolume locus. Remnant pressures can be positive (isovolume locus lower than formation pressure) or negative (locus higher than formation pressure), the latter indicating the inclusion has decompressed completely. When placed in order of increasing isovolume slope, this mineral list defines a pressure preservation index (PPI). Published work confirms that the model is quantitative up to diamond formation pressures of 50 Kb and qualitative beyond. Ten minerals are identified as key PPI indicators—in decreasing order of PPI they are: sanidine, coesite, dolomite, (sphene, garnet, diopside, zircon), magnesioiwustite, spinel, Mg0.9Fe0.1SiO3 perovskite. For most diamond formation conditions, inclusions of the first three minerals will retain high remnant pressures, whereas the last three will decompress completely. The central four minerals in brackets will have a highly variable response because their isovolume loci pass through diamond formation conditions. Preliminary calculations suggest that fluid inclusions (H2O, CO2) fall at or near the top of the list.

For inclusion-bearing diamonds at the Earth’s surface, the model predicts: (1) remnant pressures; (2) confining pressure on inclusion during delivery; (3) the stability of high-pressure poly-morphs; (4) retention vs. resetting of radiometric ages; (5) those minerals suited for determining the conditions of formation based on measured remnant pressure; (6) those minerals capable of stabilizing a microdiamond inclusion; and (7) that supercritical fluids preserve inclusions of microdiamond in most minerals.

INTRODUCTION

Minerals included in diamonds have been used extensively to estimate the conditions of formation of diamonds. Mostly, this approach has depended on the mineral type and its composition. An independent technique involves estimating the remnant pressure on mineral inclusions sealed in diamond using lattice spacings determined by X-ray or Laser Raman spectra [see Liu et al. (1990), Izraeli et al. (1996), and Sobolev et al. (2000)]. To date, these measurements have indicated that some minerals are under little or no remnant pressure, whereas others remain under substantial remnant pressure. The main factor causing these differences is the contrast between the P-T volume coefficients of the mineral and those of diamond. In order to characterize the diamond/inclusion system, a linear first-approximation model is used to assess thirty minerals according to their capacity to preserve the pressure of diamond formation (the pressure preservation index = PPI). The minerals considered herein either have been found as inclusions in diamond, found as minerals in diamond-hosting rocks, or have been suggested as possible inclusions. However, the intention is not to focus on mineral stability, rather to provide a numerical framework showing how different minerals would respond theoretically as inclusions in diamonds during delivery to the Earth’s surface. The model presumes that an inclusion is sealed in an inclusion chamber that remains pristine during delivery to the Earth’s surface. Although most inclusion chambers in diamond show signs of fracturing and healing under cathodoluminescence imaging, the validity of the PPI model predictions will test whether this is an early stage growth feature or a late-stage one. Depending on these results, the model either would act as an upper limit, or would need to be modified. Initially the model is developed for silicates, oxides, and carbides. Sulfides dominate numerically as inclusions in diamonds around the world, so there is merit in extending the model to such minerals.

Basis for PPI

To a first approximation, the volume of the host mineral, diamond, varies across P-T space according to the linear equation \( V_d(P, T) = V_0^d(1 + A_d T - B_d P) \) where \( V_0^d \) is the volume of diamond at the reference state (0 °C, 0 bars), A is the coefficient of thermal expansion, and B is the coefficient of compressibility (T in °C and P in Kb). The included mineral will have an analogous equation, namely \( V_i(P, T) = V_0^i(1 + A_i T - B_i P) \). Rearranging each equation as a relative volume \( (V_d/V_0^d, V_i/V_0^i) \)