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Diamonds are forever - but when and how did they form?

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Studies of mineral inclusions in diamond over the past 40 years have conclusively established that the principal sources of natural diamond are peridotitic (about 2/3) and eclogitic (about 1/3) domains located at 140-200 km depth in the subcratonic (i.e. beneath crust older than ∼2.5 Ga) lithospheric mantle. There, diamond probably forms during redox reactions in the presence of melt (likely for eclogitic and lherzolitic diamond) or under sub-solidus conditions in the presence of C-H-O fluids (likely for harzburgitic diamond). Direct conversion of graphitized subducted organic matter is not considered to be an important process for the formation of diamond.

For diamond related to peridotitic sources, formation ages inferred from radiometric dating of silicate and sulphide inclusions generally fall into two fairly narrow time intervals: ∼3.5-3.2 Ga (Paleoarchean) for diamond from harzburgitic sources and ∼2.3-1.9 Ga for diamond from lherzolitic sources (e.g., Gurney et al. 2010, Econ. Geol. 105). Formation of diamond in eclogitic sources covers a much larger time interval, extending from 2.9-0.6 Ga (Mesoarchean to Neoproterozoic), and may possibly continue to the present day. Based on analyses of the time dependent aggregation of nitrogen impurities in diamond, the formation of non-gem fibrous diamond continued close to the time of host kimberlite eruptions, i.e., at least up to the Cretaceous.

Co-variations in carbon isotopic ($^{13}C/^{12}C$) composition and nitrogen content of diamond suggests that two modes of formation have been operational in peridotitic sources: (1.) reduction of carbonates, that during closed system fractionation drives diamond compositions to higher $\delta^{13}C$ values and lower nitrogen concentrations and (2.) oxidation of methane, that in a closed system leads to a trend of decreasing $\delta^{13}C$ with decreasing nitrogen. Carbonate reduction has also been demonstrated as an important process for the precipitation for eclogitic suite and non-gem (clouded and fibrous) diamonds.

Model calculations based on a large data base of inclusion-bearing gem diamonds from world-wide sources suggest that a shift occurred from methane dominated precipitation of mainly harzburgitic diamond in the Archean to carbonate dominated crystallization of lherzolitic, eclogitic and fibrous diamond in the Proterozoic to Phanerozoic. This may relate to decreasing mantle temperature through time – allowing for successful subduction of marine carbonates into the deep mantle from the Proterozoic onwards – and hence may document a proposed fundamental switch in the deep carbon cycle from outgassing (through volcanic activity) to ingassing to the Earth's interior (Dasgupta & Hirschmann 2010, EPSL 298).