American Mineralogist, Volume 101, pages 780–787, 2016

Outlooks in Earth and Planetary Materials

CHEMISTRY AND MINERALOGY OF EARTH'S MANTLE

A petrological assessment of diamond as a recorder of the mantle nitrogen cycle

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Abstract

Nitrogen is fundamental to the evolution of Earth and the life it supports, but for reasons poorly understood, it is cosmochemically the most depleted of the volatile elements. The largest reservoir in the bulk silicate Earth is the mantle, and knowledge of its nitrogen geochemistry is biased, because ≥90% of the mantle nitrogen database comes from diamonds. However, it is not clear to what extent diamonds record the nitrogen characteristics of the fluids/melts from which they precipitate. There is ongoing debate regarding the fundamental concept of nitrogen compatibility in diamond, and empirical global data sets reveal trends indicative of nitrogen being both compatible (fibrous diamonds) and incompatible (non-fibrous monocrystalline diamonds). A more significant and widely overlooked aspect of this assessment is that nitrogen is initially incorporated into the diamond lattice as single nitrogen atoms. However, this form of nitrogen is highly unstable in the mantle, where nitrogen occurs as molecular forms like N_2 or NH_4^+, both of which are incompatible in the diamond lattice. A review of the available data shows that in classic terms, nitrogen is the most common substitutional impurity found in natural diamonds because it is of very similar atomic size and charge to carbon. However, the speciation of nitrogen, and how these different species disassociate during diamond formation to create transient monatomic nitrogen, are the factors governing nitrogen abundance in diamonds. This suggests the counter-intuitive notion that a nitrogen-free (Type II) diamond could grow from a N-rich media that is simply not undergoing reactions that liberate monatomic N. In contrast, a nitrogen-bearing (Type I) diamond could grow from a fluid with a lower N abundance, in which reactions are occurring to generate (unstable) N atoms during diamond formation. This implies that diamond's relevance to nitrogen abundance in the mantle is far more complicated than currently understood. Therefore, further petrological investigations are required to enable accurate interpretations of what nitrogen data from mantle diamonds can tell us about the deep nitrogen budget and cycle.

Keywords: Diamond formation, deep carbon cycle, deep nitrogen cycle, trace element partitioning