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Non-destructive, multi-method, internal analysis of multiple inclusions in a single diamond: First occurrence of mackinawite $(Fe,Ni)_{1+x}S$

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Abstract

A single gem lithospheric diamond with five sulfide inclusions from the Udachnaya kimberlite (Siberia, Russia) has been analyzed non-destructively to track the growth conditions of the diamond. Sulfides are the most abundant mineral inclusions in many lithospheric diamond crystals and are the most favorable minerals to date diamond crystals by Re-Os isotope systematics. Our investigation used non-destructive, micro-techniques, combining X-ray tomography, X-ray fluorescence, X-ray powder diffraction, and Raman spectroscopy. This approach allowed us to determine the spatial distribution of the inclusions, their chemical and mineralogical composition on the microscale, and, finally, the paragenetic association, leaving the diamond host completely unaffected. The sample was also studied by X-ray diffraction topography to characterize the structural defects of the diamond and to obtain genetic information about its growth history. The X-ray topographic images show that the sample investigated exhibits plastic deformation. One set of {111} slip lamellae, corresponding to polysynthetic twinning, affects the entire sample. Chemical data on the inclusions still trapped within the diamond show they are monosulfide solid solutions of Fe, Ni and indicate a peridotitic paragenesis. Micro-X-ray diffraction reveals that the inclusions mainly consist of a polycrystalline aggregate of pentlandite and pyrrothite. A thorough analysis of the Raman data suggests the presence of a further Fe, Ni sulfide, never reported so far in diamonds: mackinawite. The total absence of any oxides in the sulfide assemblage clearly indicates that mackinawite is not simply a "late" alteration of pyrrhotite and pentlandite due to secondary oxidizing fluids entering diamond fractures after the diamond transport to the surface. Instead, it is likely formed as a low-temperature phase that grew in a closed system within the diamond host. It is possible that mackinawite is a more common phase in sulfide assemblages within diamond crystals than has previously been presumed, and that the percentage of mackinawite within a given sulfide assemblage could vary from diamond to diamond and from locality to locality.

Keywords: Diamond, sulfide, mackinawite, non-destructive analyses