

SUB-MICRON INCLUSIONS IN DIAMONDS - SAMPLES OF PRISTINE UPPER MANTLE FLUIDS?
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Due to its mechanical strength and chemical inertness, diamond is probably the best material for trapping and transporting deep mantle fluids to the surface. Such fluids (either melts or supercritical fluids) are important for the transport of volatiles and incompatible elements in the mantle and control processes such as mantle metasomatism and diamond genesis.

We used ion microprobe (SIMS), electron probe (EP), SEM and IR spectroscopic analyses to examine the chemical composition of sub-micron inclusions in 4 cubic and 9 coated diamonds from Zaire, Botswana and some unknown localities. Inclusions are about 0.1- μm in size and are concentrated in concentric bands throughout the volume of the cubic diamonds and in the mantles of the coated diamonds. The individual inclusions are isolated and their number density generally decreases toward the outer rim of the diamond. Cracks are common; however, it is clear that they were formed after the formation of the inclusions since they do not disturb the band pattern. The transition from the transparent cores to the inclusion-bearing coats is sharp. The different natures of the coat and core are also evident from X-ray and isotopic studies [1,2]. These textural features suggest that the inclusions were trapped during the growth of the diamond and are syngenetic.

IR spectra of the inclusion-rich zones (Fig. 1) indicate the presence of bound molecular water (3440 and 1640cm^{-1}), carbonate (1430 , 877cm^{-1}), and phosphate (606 , 575cm^{-1}). Additional, still unassigned peaks are probably due to silicates (main lines at ~ 1000 and $\sim 1100\text{cm}^{-1}$). All the lines appear in the spectra of each diamond. Variations in the relative peak intensities indicate differences in the relative abundances of the different phases, e.g. water and carbonate. In an individual diamond, the relative peak intensities are roughly constant among the different zones; the absolute intensity of all lines may change, reflecting variation in the number density of inclusions. Using available IR absorption coefficients, we estimate that the diamonds contain 60-1000 ppm water and 20-500 ppm CO_2 (in carbonates); the $\text{H}_2\text{O}/(\text{CO}_2+\text{H}_2\text{O})$ varies from 0.4 to 0.8.

SIMS analyses with PANURGE were performed at a mass resolving power of $m/\Delta m=2000$ and a 10nA O^- primary beam. Ion yields for each element were calculated using a working curve approach. We compared secondary ion intensities, normalized to the C^+ signal, with EP measurements on inclusion-rich diamonds. Abundances of Li, Be, B, Na, Mg, Al, Si, K, Ti, V, Cr, Mn and Fe were below detection limit, and IR detected no water or carbonate, in gem quality diamonds. SIMS and EP analyses of the inclusion-rich diamonds indicate a similar chemical composition for all diamonds. The analyses fall within the following limits: SiO_2 , 30-60%; TiO_2 , 2-6%; Al_2O_3 , 2-10%; FeO^* , 5-22%; MgO , 2-7%; CaO , 6-18%; Na_2O , 1-8%; K_2O , 8-22%; P_2O_5 , 0-3%; and detectable amounts of Cr_2O_3 and Cl. Total concentration of all the above oxides varies between 20-2000 ppm. Compositional variations follow the same pattern exhibited by the IR data. The inclusions within any individual diamond have a similar composition (Fig.2). Differences in inclusion composition are apparent among the suite of diamonds, but inclusion compositions for diamonds of similar shape and from the same locality are very similar.

SEM was used to study the composition of individual inclusions. The average composition of the inclusions in any one diamond is close to that determined by IP. More importantly, no monomineralic inclusions have been found.

Conclusions. Sub-micron inclusions in cubic and coated diamonds are completely different in composition from the peridotitic or eclogitic "normal" diamond inclusions. They are rich in water, carbonate, SiO_2 , K_2O , FeO and CaO and contain smaller amounts of Na_2O , MgO , Al_2O_3 , TiO_2 , Cr_2O_3 , P_2O_5 and Cl . Combining SIMS, IP, EP and IR data for the different diamonds, the inclusions are composed of 40-70% metal oxides, 20-50% water, and 10-30% CO_2 (in carbonates).

We suggest that these inclusions represent a quenched, trapped fluid (either a volatile-rich melt or a supercritical phase). Their composition is clearly distinct from that of kimberlites (Fig.1). Thus, the growth of these diamonds preceded the eruptive, kimberlitic event. The coated diamonds were formed in two stages. First, the transparent cores grew in a similar way to diamonds of the eclogitic or peridotitic environments; the coats grew later in contact with the potassic fluid they trapped. The cubic diamonds grew entirely during the second stage. The close relationship between cubic diamonds and the mantles of coated diamonds is also suggested by the close similarity in their $\delta^{13}\text{C}$ values [2].

Many mantle-derived nodules have been affected by metasomatism, commonly characterized by formation of hydrous or carbonaceous phases and the addition of K, Fe, Ti and incompatible elements. The high content of these components in the sub-micron inclusions suggests that the trapped material may be related to fluids responsible for the widespread metasomatism of the sub-continental mantle.

References: [1] A.R.Lang (1974) *J. Cryst. Growth* 24, 108; [2] E.M. Galimov (1984) *GCA* 8, 1091; Boyd et al. (1988) *EPSL* 86, 341. (#610)

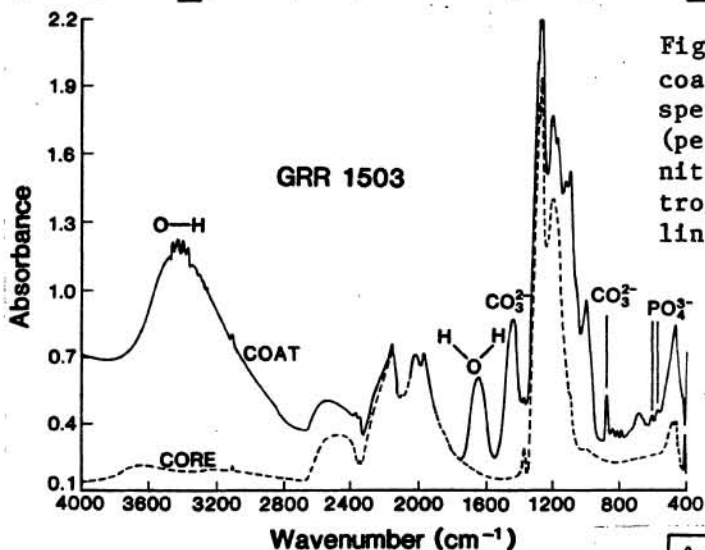


Fig. 1. IR spectra of the core and coat of a coated diamond. The core spectrum is of a normal diamond (peaks around 1100-1400 are due to nitrogen). The coat is richer in nitrogen and shows many additional lines. The higher baseline of the coat spectrum is due to light scattered by the inclusions. Sample thickness = 0.10cm.

Fig. 2. Ion probe analyses of inclusion-bearing diamonds compared with average composition of some alkaline rocks (A = alkaline basalts, K = kimberlites, L = lamproites). Octahedral diamonds are shown by diamond symbols, cubic diamonds by squares. GRR1503-GRR1518 from same unknown locality; GRR1155.2, GRR1155.3 from Zaire; GRR861.1 unknown.

