INFERENCES ON THE EXHUMATION HISTORY OF LOWER MANTLE INCLUSIONS IN DIAMONDS.

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The presence of periclase-wustite (fPer) coexisting with $(Mg,Fe)SiO_3$ (MgSiPvk) and $CaSiO_3$ (CaSiPvk) as inclusions in diamonds from Sao Luiz, Brazil indicates that these diamonds have an origin in the lower mantle (Wilding et al., 1991, Harte and Harris, 1993). This paragenesis has been predicted as stable below 670km in depth by experimental petrology (Irifune and Ringwood, 1993, Ito and Takahashi, 1987) and is supported by geophysical research (Ito and Takahashi, 1989) and work in solid state physics (Sherman, 1993, D'Arco et al., 1994). A comprehensive study of the compositional characteristics of fPer suite inclusions including garnet from Sao Luiz and involving both major and trace elements has been undertaken and provides a direct glimpse into the nature of the Lower Mantle (Wilding et al., 1991 and Harte et al., 1994). Details of the nature of individual inclusions and their diamond hosts also provide a glimpse into their history of exhumation. This has been approached so far from three directions; a study of the nature of fracture systems around the inclusions, a programme of structural investigation by XRD to determine the degree to which the inclusions are held in a high pressure state and an investigation of stable isotope characteristics around fracture systems. The compressibility of diamond is much smaller than that of most rock-forming minerals which means that, on ascent, the internal pressure exerted on the diamond host, due to the relative expansion of its inclusions, will be, potentially, large. This internal pressure will be further enhanced in the case of MgSiPvk and CaSiPvk if they invert to their low pressure polymorphs. Due to this high internal stress, there exists a potential for communication between inclusions and the chemical atmosphere surrounding the diamonds subsequent to the incorporation of the inclusions within their hosts. Whether this scenario occurs or not depends on the integrity of the diamond structure and it is partly the aim of this programme of research to assess this likelihood. Chemical and visual examination and measurement of any remnant internal pressure would provide an indication of the degree to which a particular diamond has acted as an inpenetrable tomb for its inclusions.

Fracture systems

Visual observation of some diamonds have shown a few inclusions where fractures allow communication between the inclusions and the diamond surface. Inclusions fitting into such a group are rare, look distinctly oxidised due to a light brown colouration and give low totals on electron probe analysis. Without exception, all other inclusions in which such fractures are absent, look pristine and give good, consistent electron probe analyses. A number of diamonds containing inclusions all all types of Lower Mantle phases available were selected and polished down through the host matrix to reveal the inclusions on the surface. Analysis with BS electron microscopy, SPM and electron probe of fracture systems around inclusions on these polished diamond flats yield no evidence for secondary mineralisation along fracture planes. Any material infilling fractures has been identified as specific to the preparation process; iron metal from girnding, indium metal from mounting and 1/4 μm diamond from the polishing process, or is primary inclusion material.

Many fractures have particularly blunt terminations (0.5mm) indicating a high micro-dislocation density (Main, 1994 pers. commun.) and show evidence of annealing ('augen' terminations) without a change in cathodoluminescence wavelength. Such features are indicative of a regime of fluctuating but high pressure allowing modification of the diamond form in response to stress by localised dislocation but prohibiting catastrophic propagation of fractures. Such a situation is also consistent with the scarcity of diamonds with large surface reaching fractures; such diamonds would generally break up. Thus the visual evidence would suggest that in the cases of diamonds surviving the exhumation process at all, fracture systems are prohibited from allowing communication between inclusions and the external environment by being purely internal.

Pressure-Volume relationships

Collation of literature data has shown that there should be a relative isothermal expansion on exhumation from 250kbar of 6.8, 5.6, 2.2 and 1.4% for fPer, Grt, MgSiPvk and CaSiPvk respectively (Mao et al., 1978, Graham and Ahrens, 1973, Mao et al., 1978 and Mao et al., 1989), and a further 20.1 and 14.54% if inversion from perovskite to enstatite and wollastonite structures occurs. These data are relative to expansion of the diamond host of 5.7% (McSkimin and Bond, 1957). The thermal effect of contraction on ascent is a less significant consideration. Cell parameters of inclusions contained within their diamond hosts can be determined by Debye-Shearer type X-Ray diffraction using a Gandolfi camera. Preliminary work using MoKα radiation, on one fPer inclusion, has shown a change of cell parameter from 4.188A to 4.219A after release from its diamond host. This suggests that the confining pressure on the inclusion was 80kbar, and therefore, that 33 % of the volume expansion on ascent from 700km had been retained despite internal fracturing and plastic deformation of the diamond. This gives a quantitive indication that the diamond hosts are exceptionally strong. Further study on inclusions of other phases is being pursued.

Stable Isotope Signatures

The pressure difference between inclusion and diamond due to the difference in compressibility will be dominant near to the surface where any contamination is likely to have a very distinctive crustal isotopic signature (Harmon and Hoefs, 1994). The polished flats used in the fracture system study have been investigated for variations in nitrogen content and carbon isotope signature. This analysis was conducted using the Edinburgh University/NERC Cameca ims4f ion microprobe with a Cs^+ beam and spot size of 15µm. Calibration was acheived against a number of synthetic diamond blocks.Emphasis was placed on analysing areas of varying cathodoluminescence, transects across inclusion sourced fracture systems and the terminations of both blunt and sharp fractures. The nitrogen content was found to be low, consistent with the general observation that Lower Mantle diamonds are of Type II and showed no marked variation from point to point. Carbon isotope ratios also yielded consistent values of $\delta^{13}C$ -2 to -6 ppt with no obvious variation at the termination points of fractures. This would imply that healed fractures have either been healed by reprecipitation of diamond in the same chemical environment as that of its initial formation, such fractures have been halted by cross cutting micro-fractures or these fractures have been annealed simply by internally re-zipping under an altered condition of stress on exhumation. The presence of fractures showing 'augen' type features would support the re-zipping suggestion. In any case, however, the ion-probe evidence precludes any influx of crustal signature carbon and provides further strong evidence in favour of the inclusions having been kept free from the influence of shallow earth chemical contamination.

Conclusion

On exhumation, the diamonds seem to have seen a number of fracturing events, both related and unrelated to inclusion expansion, followed by a period of internal annealing and plastic deformation. Despite this fairly active life, however, results, so far, indicate that the Sao Luiz lower mantle diamonds have been capable of holding their inclusions in a state of enhanced pressure and have precluded any contamination of inclusions by an environment distinct from that in which they formed in the Lower Mantle.

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