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Metasomatic diamond formation revealed by X-Ray CT scanning of diamondiferous eclogites from southern Africa

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In terms of understanding the origins of diamond, it is now widely accepted that they form at depth mainly, though not exclusively, in the continental lithospheric roots of ancient cratons. There they reside until sampled and conveyed to the Earth's surface, most frequently in a rapidly emplaced kimberlite eruption. Current wisdom holds that most diamonds formed early in the history of their craton hosts, and so are themselves ancient. Diamonds are observed in association with both peridotite and eclogite populations at specific localities and may be dominated by peridotitic diamonds (e.g. Kimberley mines), or by eclogitic diamonds (e.g. Orapa). In this study, attention has been focused only on eclogitic diamonds. The collection consists of a suite of diamondiferous eclogite xenoliths, ranging in size from sub-centimetre to approximately 4 cm in the longest dimension. All of these samples have at least one diamond visible on the surface of the xenolith. The samples are sourced from the Excelsior (11) and Newlands (5) mines, both near Barkly West (Northern Cape, South Africa), with two additional samples from Orapa (Botswana). Excelsior and Newlands are small occurrences (mainly thin dykes) of Group II kimberlite. Both kimberlite occurrences are on cratonic lithosphere ~170 km thick. Orapa, in contrast, is the largest mined kimberlite in the world. The pipe is on the N. side of the Kalahari craton, where the lithosphere is ~180 km thick. (McKenzie & Priestley, 2008).

Visual inspection of the samples suggests that the diamonds are located in fluid pathways. The diamonds occur in both altered garnet (gt) and altered clinopyroxene (cpx). There appears to be a dominance of cpx hosting, even though gt is considerably more abundant than cpx. The samples have been subjected to X-ray tomography analysis, in order to create three-dimensional (3-D) images of the surfaces and the interiors of the samples (Figs 1 & 2). The 3-D images reveal that the samples contain abundant, in some cases pervasive, secondary veining that is clearly younger than the eclogite. In all but one case, diamonds occur along veins, but most of the veining is unrelated to the spatial positioning of diamond in the samples (Fig 1). In some instances, early veining through a host-mineral has annealed or partially annealed (Fig 2), suggesting a range in timing of at least some of the several metasomatic events that have affected the rock. Our findings (Fig 3) can be summarised as:

• Diamonds may be associated with either cpx or gt; they may be enclosed entirely within one mineral phase, or lie along grain boundaries between different minerals (Fig 1).

• Samples contain between ~1% and ~9% diamond (± 47 diamonds). At Newlands and Excelsior generally these crystals are unresorbed octahedra. In contrast the diamonds in the Orapa xenoliths are resorbed wherever situated.

• In all but one of the eclogites, the diamonds lie in clear metasomatic pathways or planes (Figs 1 & 2 and cartoon (Fig 3)). These structures may retain evidence of fluid flow, in the form of secondary phases; may have been re-opened late in the history of the sample, perhaps during kimberlite eruption; or may have been completely annealed (Fig 1 and cartoon (Fig 3)). In one case, the diamonds appear to be more uniformly distributed throughout the xenolith.

• Of the xenoliths that contain more than a single diamond, some contain one population of diamonds. However, in many of the centimetre-scale xenoliths, more than one population of diamonds can be recognised based on morphology and/or size.

• Primary metasomatic high-absorption phases identified by SEM scanning are Fe-Cu-Ni sulphides and rutile; they may follow the diamond planes, or lie along clear planes that are completely independent, and differently oriented, to the diamond planes (Figs 1 & 2 and cartoon (Fig 3)). In one case, a sulphide inclusion is observed in a diamond (implying that the sulphide pre-dated the diamond or formed at the same time). In one case, a plane of sulphides is deflected around the diamond plane. This can be interpreted either as the sulphide-bearing fluid being deflected around a pre-existing diamond, or that a diamond grew after the sulphides and led to deformation of the plane.

• Secondary minerals include barite, found in association with diamonds and in some cases along metasomatic channels as noted by Schulze et al. (1996) in a diamond eclogite from Roberts Victor.

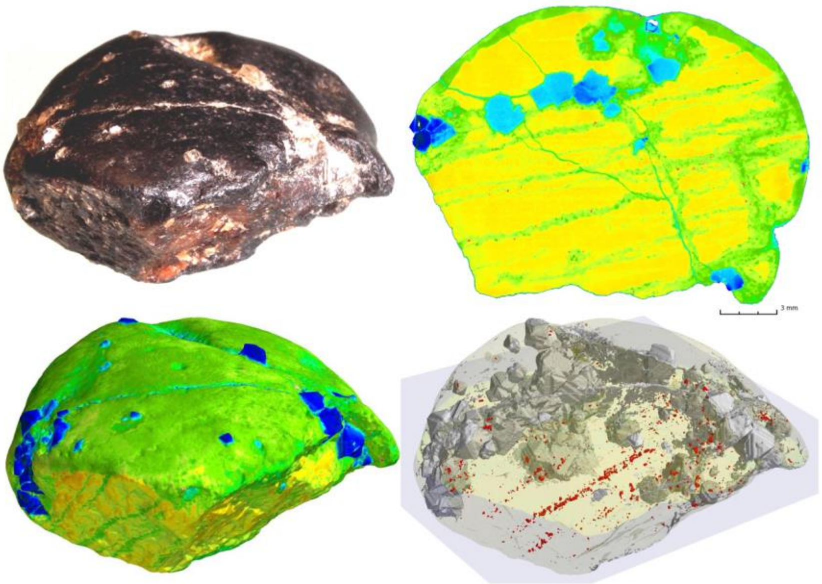

Figure 1: X-ray CT results for sample EX22 (Excelsior). Clockwise from top left: (i) photograph of sample showing visible diamonds on surface; (ii) cross section through X-ray CT results (blue = diamond, yellow = garnet, green = alteration material, red = high absorption phases interpreted to be sulphides; (iii) 3-D volume rendered transparent to highlight diamonds (grey) and sulphides (red), which lie on clear, though unrelated, planes; (iv) 3-D volume from X-ray C-T results (compare with photograph above) with identical colour palette to ii.

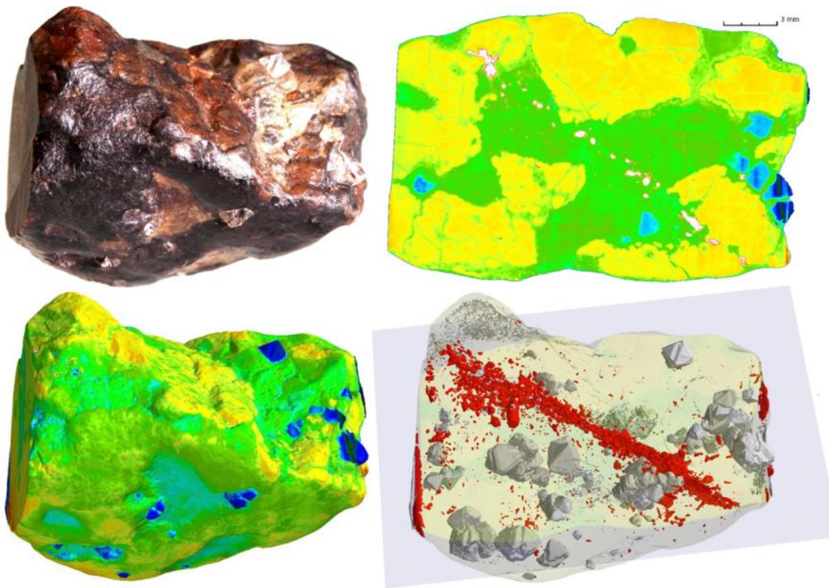

Figure 2: X-ray CT results for sample EX23 (Excelsior). Clockwise from top left: (i) photograph of sample showing visible diamonds on surface; (ii) cross section through X-ray CT results (blue = diamond, yellow = garnet, green = cpx and alteration material, red = high absorption phases interpreted to be sulphides; (iii) 3-D volume rendered transparent to highlight diamonds (grey) and sulphides (red); (iv) 3-D volume from X-ray C-T results (compare with photograph above) with identical colour palette to ii. Note the annealing of the sulphide-bearing vein.

Conclusions

Diamond grade in mantle eclogites can be orders of magnitude higher than found in any kimberlite or lamproite. Metasomatism is a common process in mantle eclogites. Metasomatism plays an important role in eclogitic diamond formation in the lithospheric mantle. Evidence has been provided that in the studied eclogites both non-diamondiferous, but “diamond friendly” and “diamond unfriendly” metasomatic events can be traced along with the mineralised veins, of which there may also be more than one. SEM scans have identified Fe-C-Ni sulphide rutile and secondary barite in both diamondiferous and non-diamondiferous examples. Several studies have previously described similar features to those reported here in Siberian diamondiferous eclogites (e.g. Anand et al., 2003; Spetsius and Taylor, 2003; Taylor et al., 2003; Howarth et al., 2014)

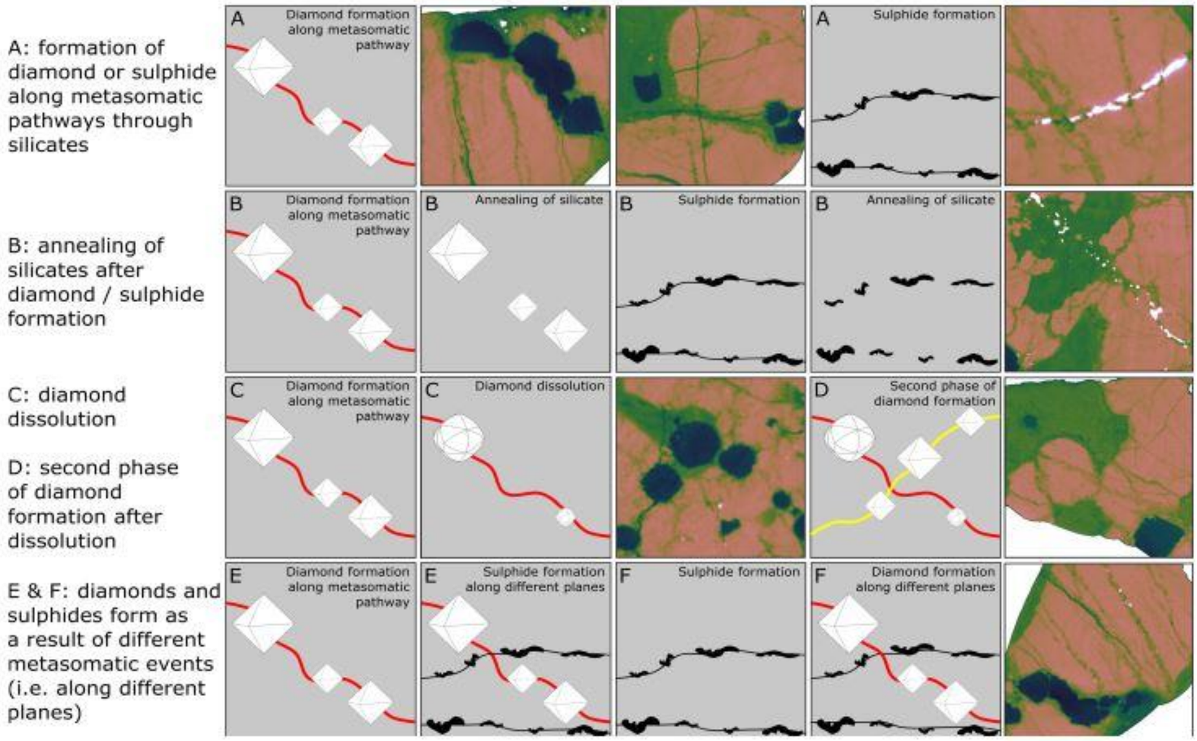

Figure 3: Cartoon summarising our interpretation of X-ray CT results. Examples of X-ray CT cross-sections have the following colour palette: blue = diamond; red = gt; green = cpx and alteration material; white = high absorption phases interpreted to be sulphides.

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