

Inclusions in diamonds from Mwadui (Tanzania) - chemical mush in the source

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The Mwadui kimberlite pipe was emplaced on the Tanzania Archon of the Central African Craton (Janse, 1994) during the Eocene (Gobba, 1991 and references therein). Syngenetic inclusions in diamonds from the Mwadui Mine thus may provide insights in the state of the lithospheric upper mantle before the onset of rifting in Eastern Africa in the Miocene (Dawson, 1992).

For the present study an initial population of several thousand diamonds from Mwadui was examined to select a total of 100 stones which then were crushed to release representative mineral inclusions. From their mineral inclusion content Mwadui diamonds can be grouped into peridotitic (88%), eclogitic (2%), mixed (low-Ca pyrope plus SiO_2 -phase, 1%) and unknown (sulphides, native iron and iron oxides, ferropericlasite, dolomite, 9%) suites. Inclusion chemistry shows Mwadui diamonds to reflect sampling of a lithosphere with an unusually high proportion of undepleted or re-fertilised mantle peridotite. This is documented mainly by the high ratio of lherzolitic to harzburgitic garnet inclusions (1:2, Fig. 1) as well as by the low Mg-numbers of olivines (about 92, Fig. 2) and orthopyroxenes (about 93, Fig. 2). High Ni-contents in olivine (mode 0.40 wt%, max 0.43 wt% NiO) could suggest that this fertility actually represents re-enrichment of a previously depleted source. An explanation may lay in the positive correlation of the proportion of orthopyroxene and the Ni contents in olivine from peridotitic xenoliths. Kelemen and Hart (1996) interpret this as a metasomatic reaction which creates orthopyroxene at the expense of olivine (which increases the Ni content of the remaining olivine). Metasomatic enrichment processes may also be indicated by high titanium contents in some lherzolitic and harzburgitic garnets (up to 1.1 wt% TiO_2) and orthopyroxenes (up to 0.09 wt%).

Application of geothermometers based on garnet-olivine (O'Neill and Wood, 1979, O'Neill, 1980), garnet-opx (Harley, 1984, Brey and Köhler, 1990) and cpx-opx (Brey and Köhler, 1990) equilibria indicate that the mode of equilibration temperatures for Mwadui diamonds lies between 1050-1150 °C. However, the application of various thermometers to the same inclusion-pairs reveals evidence for common disequilibrium between non-touching inclusions. Apparent high temperatures calculated for garnet-opx and garnet-olivine pairs may be attributed to diamond formation in the course of a metasomatic enrichment event whereby successive inclusions become

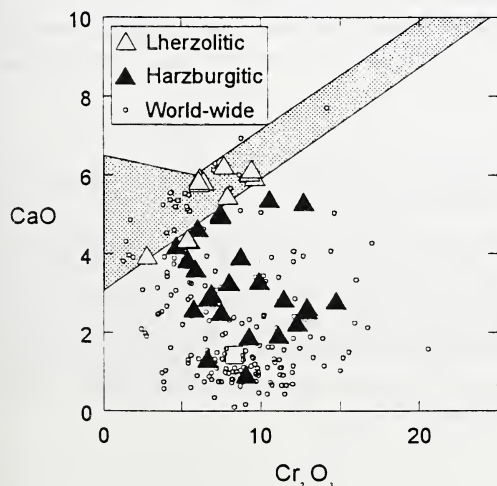


Fig. 1. Diagram of CaO versus Cr_2O_3 (wt%) in garnet with the lherzolite field (shaded area) as defined by Sobolev et al. (1973). The open square refers to the harzburgitic garnet coexisting with a SiO_2 -phase inclusion (see text). Small open circles refer to our world-wide inclusion database (for references see Stachel and Harris, 1997).

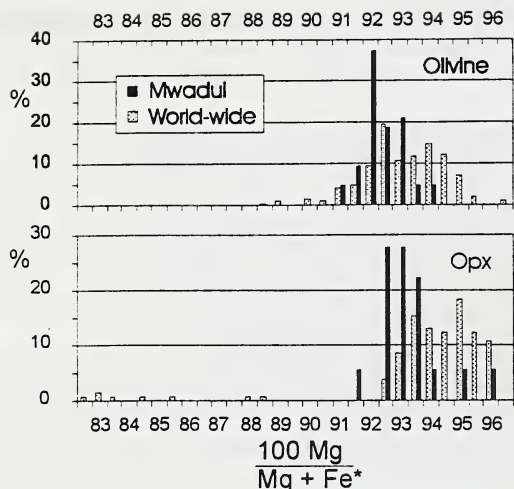


Fig.4. Histogram (frequency in %) of the molar Mg-numbers of olivine and orthopyroxene inclusions from Mwadui and from world-wide sources (world-wide inclusion data base: 217 olivines and 135 orthopyroxenes). The unusually high proportion of ilherzolitic inclusions for Mwadui is well displayed in generally low Mg-numbers, relative to the world-wide database.

richer in Fe. Further indications of large variations in the chemical environment during diamond growth may come from the coexistence of a SiO_2 -phase and harzburgitic garnet in the same diamond. An ultra-deep (> 400 km) origin of this paragenesis, as suggested by Kopylova et al. (1997), is excluded because of the non-majoritic nature of the garnet. However, localised extreme carbonation of mantle peridotite could eventually also result in the formation of a free SiO_2 -phase (Wyllie and Huang, 1976). The additional observation of a lone dolomite inclusion fits into such a scenario of high, localised CO_2 influx.

In addition to the standard peridotitic mineral suite Mwadui diamonds contain a number of rare or unusual inclusions. Among these is an ilmenite group inclusion with unprecedented eskolaite content (14.5 mol%) occurring together with harzburgitic garnet and olivine. For upper mantle derived ilmenites high chromium contents are characteristic for ilmenite-spinel (\pm rutile) assemblages formed by subsolidus reduction but rarely exceed 10 mol% Cr_2O_3 (Haggerty, 1991). In two diamonds magnetite inclusions were observed with sub- μm exsolution lamellae of a high silica phase (possibly fayalite, Fig. 3). New experimental data on the binary system Fe_2SiO_4 - Fe_3O_4 (Woodland, 1997) indicate that at pressures above 30 kbar (at 1100 °C) an intermediate spinelloid phase appears. Assuming that the spinelloid phase is not restricted to Mg-free systems, this result excludes coexistence of magnetite and olivine in the diamond stability field.

The presence of two diamonds, one containing inclusions of moderately majoritic eclogitic garnet, the other of ferropericlasite, may indicate a small diamond contribution from the sub-

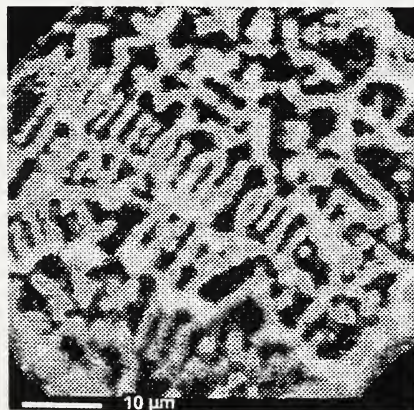


Fig. 3. Image of the distribution of Si in magnetite inclusion MW96-136. A matrix of 200x200 points (0.1 seconds per point) was collected as beam scan at 15 kV and 20 nA. The contrast was enhanced after data collection by histogram equalisation, for noise reduction a median filter was applied. Bright colours imply high Si contents. The grain boundaries can be seen in the four corners of the image. Grain diameter is about 70 μm .

lithosphere. Although the evidence of a single ferropericlasite inclusion is ambiguous, its presence might testify to a lower mantle origin. An inclusion of native iron rimmed by wustite (plus a coexisting inclusion of magnetite) also might be indicative of an ultra-deep origin and indicates rather large variations in oxygen fugacity from below WI (FeO-Fe) to above MW (Fe₃O₄-FeO).

To account for the disequilibrium conditions during diamond formation beneath Mwadui, we conclude that diamonds grew in metasomatic fronts, where steep compositional gradients existed and where carbon was deposited as diamond from redox reactions between the metasomatic fluid or melt and the peridotitic wall rocks.

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