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Trace element geochemistry of olivine inclusions in diamonds from Akwatia, Ghana: Implications for diamond paragenesis and mantle processes

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Olivine is a common silicate mineral inclusion in diamonds, but its potential for the study of the geochemical and physical properties of the lithospheric mantle remains largely unexplored. Here we present new trace-element data for olivine inclusions and coexisting garnets from 25 well-characterised diamonds [1] from Akwatia (Ghana).

Paragenesis. Distinction between harzburgitic (hrz) and lherzolitic (lhz) paragenesis olivines is traditionally based on minerals coexisting in the same diamond, such as Cpx (lhz) or Ca saturation of garnet (lhz or hrz). Following this scheme, five olivines are lherzolitic and 19 are harzburgitic, the remaining four are peridotitic (unknown paragenesis). Lherzolitic olivines have higher Ti, Na and Ca contents than harzburgitic olivines, but the latter overlap with olivine from lherzolitic mantle xenoliths [2]. However, if Ca/Al ratios of olivine are below the mantle xenolith trend (Ca/Al<2.5), coexisting garnets are without exception subcalcic G10 garnets. Na contents <60 ppm as well as Na/Al<0.7 are also restricted to harzburgitic olivine inclusions. Based on these criteria, the four olivines of unknown paragenesis are in fact harzburgitic.

Thermobarometry. Calcium and Al contents of olivines in mantle xenoliths are strongly dependent on temperature, as Al and Ca activities are buffered by co-existing Cpx or garnet [2]. For the Akwatia olivines, $T_{Al-in-Ol}$ ranges from 1050-1270˚C (at 50 kb), whereas $T_{Ca-in-Ol}$ ranges from 947-1326˚C. However, the Akwatia suite is dominated by subcalcic Cr-rich garnets, so T_{Ca-ol} only yields minimum T, whereas the correction of T_{Al-ol} based on Cr# suffers from poor correlation between Cr# of olivine and garnet. Ni-in-garnet thermometry resulted in a range of 1140-1330˚C, but correlation with $T_{Al-in-Ol}$ is weak. Both agree roughly with major element thermometry (T_{Gt-Ol}[OW79] = 960-1380˚C at 50 kb; T_{Cpx}[NT00] = 1190˚C at 53 kb to 1320˚ at 58 kb) but correlations are weak. It appears that even though temperature ranges are similar and mineral inclusions are homogenous, local disequilibrium between co-existing grains within diamond or large uncertainties of the geothermometers precludes high-precision T estimates.

Mantle processes. Titanium contents are below the xenolith average in lherzolitic olivine (12-70 ppm) and very low in harzburgitic olivines (0.15-10 ppm). Despite its high variability, olivine Ti contents correlate well with Ti in garnet (7-4000 ppm), which indicates that coexisting inclusions in diamonds were derived from a similar mantle domain. Olivine compositions indicate diamond growth in a mostly extremely depleted (low Ti, Ca, Na, high Cr#) environment. They are distinct from olivines from xenoliths which show higher and more variable Ti contents and lower Cr#. In addition, Na contents of lherzolitic olivines from Akwatia are low compared to mantle xenolith olivines, similar to Na contents of coexisting Cpx. This suggests that Cpx and olivine in mantle xenoliths are generally modified by metasomatism after the ancient diamond formation event.

A surprising find was that several elements, particularly Cr and V, show considerable variation within single olivine grains whereas other elements such as Li, Ti, Mn and Ni show no variation. The relation between V and Cr is significant, as both are redox-sensitive elements with strongly different behaviours in olivine based on their oxidation state. As H_2O contents in Akwatia olivines are invariably low [3] and long term preservation of zoning patterns in hot mantle lithosphere is unlikely, we suspect that minor element zoning is related to self-oxidation due to diffusive hydrogen loss during ascent (e.g., $Cr_2^{II}[](OH)_4 = H_2 + Cr_2O_3$). This may indicate that ancient subcontinental mantle was not as poor in water as currently thought. Alternatively, Cr^{2+} present at high temperatures may have been oxidized during cooling by pre-existing Fe^{3+} in olivine.

References. [1] Stachel and Harris (1997) Contrib. Mineral. Petrol. 127, 336-352. [2] De Hoog et al., 2010. Chem. Geol. 270, 196-215 [3] Matveev and Stachel (2009) Lithos 112, 36-40.