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Redox estimates on uniquely high-temperature eclogite inclusions from Cullinan diamonds bear a signature of a mantle plume event

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The lithospheric mantle of the Kaapvaal craton experienced a large-scale mantle upwelling, which led to formation of the Bushveld Large Igneous Province about 2 Ga. Later (∼1150 Ma), the Cullinan kimberlites were emplaced in this region, and they brought out diamonds with mineral inclusions that recorded a signature of the plume activity. To constrain the redox conditions, we analysed 6 non-touching garnet-clinopyroxene pairs of inclusions from the Cullinan diamonds by Synchrotron Mössbauer Source spectroscopy. Temperatures for these inclusions range from 1310 to 1530 °C at 5.9–7.2 GPa. The oxygen fugacites relative to the fayalite–magnetite–quartz buffer ($\Delta\log fO_2$(FMQ)) range from -3.9 to -5.7.

A comparison of redox estimates for eclogite and peridotite xenoliths of the Kaapvaal craton (based on Mössbauer data) from different pipes with redox estimates for the studied inclusions showed the following results. The $\Delta\log fO_2$(FMQ) values of the Cullinan inclusions (-3.9 – -5.7) are often lower than those for the Kaapvaal peridotite mantle (-0.2 – -4.5; [1]). However, these values overlap with the $\Delta\log fO_2$(FMQ) estimates for eclogite xenoliths from other pipes within the Kaapvaal craton: -1.2 – -4.0 (Bellsbank [1]), -2.7 – -5.4 (Lace [2]), and -1.5 – -5.3 (Roberts Victor, Jagersfontein, Kimberley, and Kamfersdam pipes [3]). Our results suggest that, apparently, neither the emplacement of the plume nor the subsequent diamond-forming event, involving metasomatic fluids, had a significant effect on the redox conditions within the Kaapvaal lithosphere. Although the plume may have brought more reduced material from the deep mantle, including carbon-rich fluids with $\delta^{13}C_{VPDB}$ of -1.3 – -7.8 ‰ [4], this did not lead to a rapid overall re-equilibration of redox conditions. The Cullinan inclusions, showing the distinctive PT-signature of the plume event, also reveal that the redox conditions and oxygen activity in the lithosphere proved to be resistant to the large-scale mantle upwelling. The reduced deeper mantle material seems to re-equilibrate with the more oxidized upper mantle quicker than pressures and temperatures.

[1] Smart *et al.* (2021) *EPSL* **556**, 116720. [2] Aulbach *et al.* (2017) *EPSL* **474**, 283-295. [3] Burness *et al.* (2020) *ChemGeo* **542**, 119476. [4] *Korolev et al.* (2018) *Mineralogy and Petrology* **112**, 275-289.