Goldschmidt 2025 Abstract
https://doi.org/10.7185/gold2025.31298

Chromium in peridotite and pyrope: constraining the melting conditions of the cratonic lithosphere

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Pyrope garnet from the cratonic lithosphere are typically Cr-rich. Cr-pyropes in lithospheric peridotites have Cr-numbers (100Cr/(Al+Cr) mol.) of 10-40%, while Cr-pyrope diamond inclusions skew towards higher Cr#, occasionally reaching 60%. The association between Cr-rich garnet and diamond means that garnet Cr# is an important tool in diamond exploration. Garnet Cr# also conveys information about conditions during formation of the diamond host lithology.

The cratonic lithosphere formed by extensive mantle melting that left a residue of olivine+orthopyroxene±garnet. However, the conditions at which melting took place are unclear. This lithosphere subsequently cooled and may have undergone a change in pressure, leading to subsolidus re-equilibration and garnet formation. Within the residue phases, Cr# increases and Al_2O_3 decreases in the order garnet-pyroxene–olivine, therefore high Cr# reflects melting in the absence of garnet and is hence suggestive of a shallow origin, although it may also reflect high pressure melting after garnet exhaustion. The degree of melting at which garnet is exhausted increases with pressure, therefore the Mg# at which a given Cr# is achieved increases with pressure. This relationship provides a framework for interpreting the pressures of peridotite melting.

Bulk compositions of garnet harzburgites from Kimberley (Kaapvaal craton) plot at 5-7GPa in Cr#-Mg# space, and most samples sit in the experimentally-defined olivine+orthopyroxene field (Fig.1). However, those with the lowest Cr# plot within the garnet-bearing field and have high HREE contents, confirming the presence of garnet in the residue. Similarly, we can use the Cr#-Mg# systematics of Cr-pyrope inclusions in diamond to estimate the formation conditions of the diamond-bearing lithology, by assuming that garnet Cr# represents Cr# of the host peridotite and calculating bulk Mg# from garnet-olivine equilibria. Using this approach, we show that the mantle host for the majority of Cr-pyrope diamond inclusions formed by melting at 4-6GPa in the (spinel-free) olivine+orthopyroxene field, however those from Kimberley plot at >7GPa. A key takeaway is that high Cr# is due to melting in the absence of garnet but does not necessarily indicate shallow melting, a Cr-rich xenolith or Cr-pyrope diamond inclusion may have formed at high pressure if high Cr# is accompanied by high Mg#.

Figure 1: