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On the nature and origin of garnet in highly-refractory Archean lithosphere: implications for continent stabilisation

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The nature and timescales of garnet formation in the Earth's subcontinental lithospheric mantle (SCLM) are important to our understanding of how this rigid outer shell has evolved and stabilised since the Archean. Nevertheless, the widespread occurrence of pyrope garnet in the sub-cratonic mantle remains one of the 'holy grails' of mantle petrology. The paradox is that garnet often occurs in mantle lithologies (dunites and harzburgites) which represent residues of major melting events (up to 40 %) whereas experimental studies on fertile peridotite suggest this phase should be exhausted by <20 % melting. Furthermore, garnets commonly found in mantle peridotite suites have diverse compositions that are typically in equilibrium with high-pressure, small-fraction, mantle melts suggesting they formed as a result of enrichment of the lithospheric mantle following cratonisation. This refertilisation – which typically involves addition of Fe, incompatible trace elements and volatiles – affects the lower 30 km of the lithosphere and potentially leads to negative buoyancy and destabilisation.

Pyrope garnets found in mantle xenoliths from the eastern margin of the Tanzanian Craton (Lashaine) have diverse compositions and provide major constraints on how the underlying deep (120 to 160 km) mantle stabilised and evolved during the last 3 billion years. The garnets display systematic trends from ultra-depleted to enriched compositions that have not been recognised in peridotite suites from elsewhere (Gibson et al., 2013). Certain harzburgite members of the xenolith suite contain the first reported occurrence of pyrope garnets with rare-earth element (REE) patterns similar to hypothetical garnets proposed by Stachel et al. (2004) to have formed in the Earth's SCLM during the Archean, prior to metasomatism. These rare ultra-depleted low-Cr garnets occur in low temperature ($\sim$1050 oC) xenoliths derived from depths of $\sim$120 km and coexist in chemical and textural equilibrium with highly-refractory olivine (Fo95.4) and orthopyroxene (Mg#=96.4). These phases are all more magnesian than generally encountered in global samples of depleted mantle, i.e. harzburgites and diamond inclusion suites. The Tanzanian ultra-depleted garnets form interconnecting networks ('necklaces') around grains of orthopyroxene, which is of key importance to their origin. This close spatial relationship of garnet and orthopyroxene together with the major, trace and REE contents of the ultra-depleted garnets, are consistent with an origin by isochemical exsolution.

The significance of ultra-depleted low-Cr garnets has not previously been recognised in global suites of mantle xenoliths or diamond inclusions: they appear to have been overlooked, primarily because of their unusual pre-metasomatic compositions. We believe they are rare because the low concentrations of trace elements make them readily susceptible to geochemical overprinting. This highly-refractory low-density peridotite may be common in the 'shallow' SCLM but is not normally brought to the surface by ascending melts, which tend to metasomatise and preferentially sample their source regions. The modal abundance of garnet formed by isochemical exsolution from orthopyroxene in sub-cratonic mantle is unclear but may prove to be an important consideration in isopycnic models related to the long-term stability of the Earth's continental lithosphere, e.g. Lee et al. (2011).

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