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Lu-Hf chronometry of continuous metasomatic enrichment of the cratonic mantle

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Introduction

The Archean cratonic crust is a repository of Earth's ancient geological history and has been extensively studied as a result. In contrast, our understanding of the mantle roots underneath it is relatively limited, thus obscuring crucial interplays and mechanisms that allowed cratonic growth. Garnet provides thermobarometric constraints and hosts trace elements indicative of melting and refertilization events. This mineral may hold the key to deciphering mantle evolution, especially when information gained from it can be placed in time. Obtaining robust geochronological constraints from garnet in mantle xenoliths has nevertheless proven challenging due to various issues, such as low daughter-element concentrations, the limited xenolith size, melt contamination, and potential open-system behavior of chronometers. To constrain the history of the subcontinental lithospheric mantle (SCLM), this study employs Lu-Hf chronometry on garnet-bearing xenoliths of different lithology from three major Archean cratons: the Slave, Siberian, and Kaapvaal cratons. The analytical approach involves a refined low-blank chemical separation technique that allows high sample/blank Hf, even for total Hf loads of 5 ng or lower, and yields relatively precise (0.3-2%, 2 SD) Lu-Hf garnet ages from multi-point internal isochrons for single xenoliths.

Results and Discussion

Garnet-bearing SCLM xenoliths of different lithology and textures were subjected to elemental analysis and Lu-Hf chronometry. The analysis yielded multi-point internal Lu-Hf isochrons with ages spanning from 3.1 to 0.2 Ga. Archean ages (3.1-2.7 Ga) were obtained from depleted garnet-bearing orthopyroxenites and harzburgites from the Kaapvaal and Siberian cratons. Proterozoic ages, ranging from 1.89 to 0.75 Ga, were observed in all cratons, and were obtained from samples containing abundant clinopyroxene, e.g., coarse lherzolite. Garnet extracted from sheared peridotites yielded the youngest ages (380-230 Ma). These either match or closely approximate the age of eruption for the given kimberlites recorded (Smith et al. 1994; Kjarsgaard et al. 2022). No discernible correlation was observed between age and a position on the steady state geotherm or on transient thermal excursions from a geotherm. Although the samples exhibited varying degrees of serpentinization and some exhibit phlogopite rims around garnet crystals, these features do not appear to have affected garnet compositions or their age signature.

The lherzolitic composition of garnet in the Proterozoic sample group, coupled with its textural association with abundant clinopyroxene, suggests their equilibrium growth/recrystallization (Hill et al. 2015). The formation of clinopyroxene and the re-equilibration or growth of garnet are connected to the metasomatic refertilization of the SCLM (Howarth et al. 2014; Hill et al. 2015). Sheared peridotite samples are characterized by the presence of olivine and pyroxene neoblasts in porphyroclastic and mosaic textures. Garnet grains in these samples show varying degrees of deformation and recrystallization, with geothermometric calculations suggesting high-temperature conditions consistent with fluid-assisted metasomatism and deformation during the formation of sheared peridotites (Harte 1983; Tappe et al. 2021). Lu-Hf isochrons for garnets from sheared samples indicate plausible ages of garnet recrystallization concurrent with kimberlite emplacement.

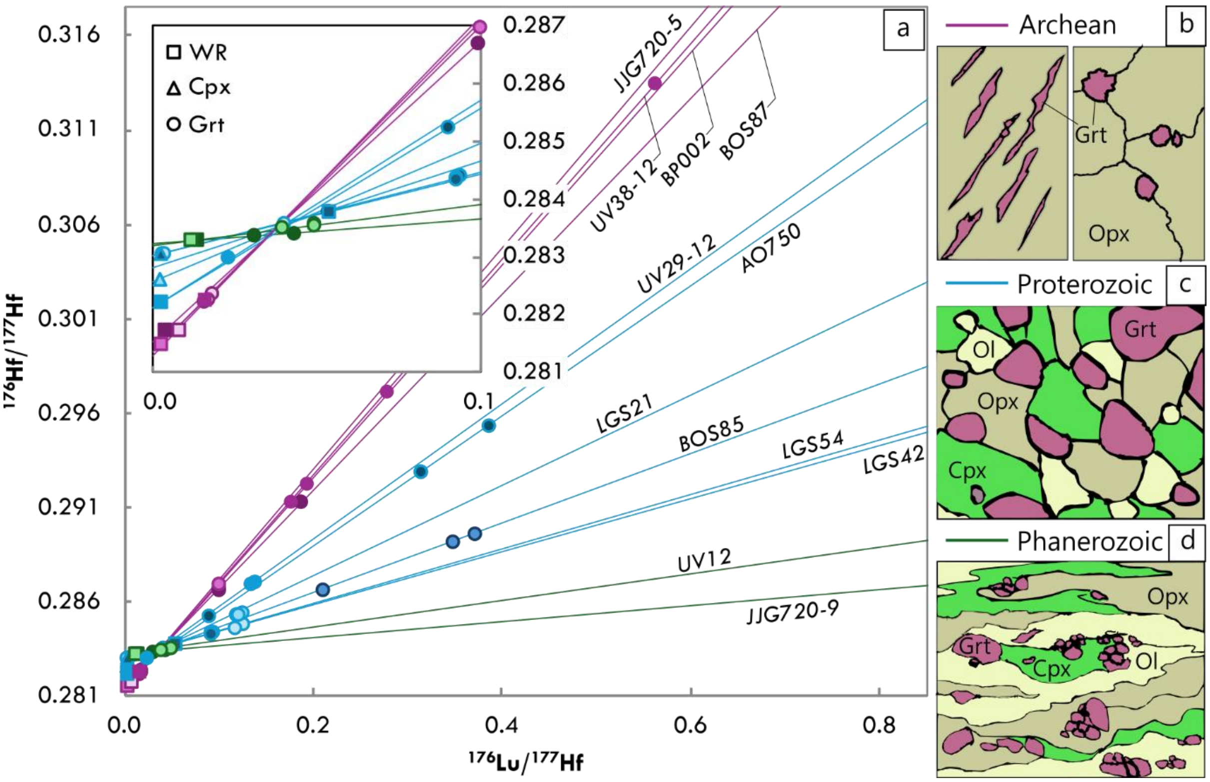

Figure 1. (a) Lu-Hf isochrons for garnet bearing mantle xenoliths, grouped according to their age. Purple – Archean, blue – Proterozoic, green – Phanerozoic (b-d) Schematic drawing of the characteristic textures for each age group.

The apparent relationship between Lu-Hf ages, and composition and texture, could indicate true age differences, but could equally show that composition or texture play a pivotal role in preserving Lu-Hf age signatures in garnet. The only materials that appear unaffected by re-equilibration and metasomatism are the exsolved garnet lamellae found in depleted orthopyroxenites and harzburgite. The Lu-Hf ages obtained from these materials document SCLM formation through upwelling, decompression and high-degree melting of the mantle during the Meso- and Neoarchean (Tomlinson et al. 2017). The presence of clinopyroxene in samples that yielded Proterozoic ages suggests that this phase is an important diffusive sink for Hf. The phase likely allowed transient fluid/melt-assisted re-equilibration of Lu-Hf age systematics in garnet during the metasomatic event during which clinopyroxene was formed. Lu-Hf ages of the garnet in this case represent the age of the metasomatic enrichment that either promoted the crystallization of the Proterozoic garnet or re-equilibrated the existing Archean garnet. The spread of the Proterozoic garnet Lu-Hf ages from lherzolites, even from single cratons, indicates that metasomatism affected the SCLM in several distinct pulses distributed through the Proterozoic. The same principle applies to the Phanerozoic ages observed in the sheared peridotites. The young age could be indicative of either an open system behavior due the high temperatures of re-equilibration (1200-1300°C) or the (re)crystallization of garnet and clinopyroxene resulting from interaction with the proto-kimberlitic fluids prior to entrapment.

These new data show that high-precision garnet Lu-Hf dating through internal isochrons for individual xenoliths can be done routinely and demonstrate that this technique can provide valuable new insights into the timing and nature of SCLM formation, metasomatism and deformation.

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