TTG Lu-Hf isotope evidence for a deep mantle-continental crust connection

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The principle that growth of continents depletes the upper mantle from its most fertile fraction goes back several decades [1,2]. A widely held tenet is that continental crust grows either by melting of oceanic crust [3,4] or by fluxing the mantle wedge above subduction zones [5]. An alternative view holds that continents form through magmatic processing at subduction zones, not of regular oceanic crust, but of oceanic plateaus [6,7]; this would account for the apparent episodic character of crustal growth [8]. The present work reports MC-ICP-MS Lu-Hf isotope data for a large collection of Archean granitoids belonging to typical TTG (Tonalite-Trondhjemite-Granodiorite) suites. Both the whole-rock and zircons were analyzed, and the results are discussed in the broader context of the extensive literature database on Hf isotopes in zircons. Our results demonstrate that the Lu/Hf ratio of the mantle source of TTGs has not significantly changed over the last 4 Gyr. Continents therefore most likely grew from nearly primordial unfractionated material extracted from the deep mantle via rising plumes that left a depleted melt residue in the upper mantle. The deep mantle could retain its primitive relative element abundances over time because sinking plates are stripped barren of their oceanic and continental crustal components at subduction zones; this process results in only small proportions (<15-25%) of present-day continental mass getting recycled to great depths. Zircon populations extracted from the analyzed TTGs have Hf isotopic compositions very consistent with those of their host whole-rocks, whereas the U-Pb system in the same grains is often disturbed. This discrepancy creates spurious positive correlations with age when variable initial ε_{Hf} values are determined. The problem is endemic to the Archean detrital zircon record and consistent with experimental results bearing on the relative retentivity of Hf vs. U and Pb in zircon [9]. We argue that this behavior accounts for the generally negative ε_{Hf} values reported for Archean zircons and which are at odds with the present TTG data set. If Hadean Jack Hills zircons are considered in light of our results, the mantle source of continents appears to have remained unchanged for the last 4.3 Gyr.

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Phase Equilibria constraints on the origin of the Peridot Mesa basanite

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Peridot Mesa is well-known for its gem quality peridot (Wrucke et al. 2004) and xenoliths of spinel-bearing peridotite (Frey and Prinz, 1978). Little is known of the lava that brought these mantle xenoliths to the surface however. The purpose of this study was to gain a better understanding of the origins of alkali basalts, and in particular the pre-eruptive conditions of the Peridot Mesa basanite. Phase equilibria experiments were performed on the Peridot Mesa basanite, over a range of various pressures, temperatures, and volatile content.

The phenocryst assemblage of the Peridot Mesa basanite is clinopyroxene, olivine, plagioclase, and spinel. An important feature of this lava is the presence of two phenocrystic olivine compositions. The first population is Mg-rich (Fo 73-80), and averages in size from 20-100 microns, and does not appear to have been in equilibrium at the time of eruption. The observation of prominent diffusion rims, re-equilibrating to a higher Fe content around the outer portion of the crystal supports this conclusion. The second olivine group has a lower Mg content, ranging between Fo 65-69. This population of olivine is 4-10 microns in size, with a less common, reversed zoning, making the rim slightly more Mg-rich (Fo 70). The presence of two compositionally different olivine phenocrysts can possibly be explained by a magma mixing event that occurred just before eruption, although these features are not seen in any of the other phenocryst phases.

In order to replicate the natural phase assemblage and determine magma conditions prior to eruption, a series of phase equilibria experiments were performed using a 1-atm Deltech furnace and a non-end loaded piston cylinder. The starting material for all runs was made by melting the natural sample at 1 atm and an oxygen fugacity of NNO, and quenching to a glass to ensure homogeneity. For the high P runs, glass chips were sealed in an AuPd capsule and run under anhydrous, CO_2-rich, or H_2O under-saturated conditions, ranging between 1050°C-1250°C and 0.1 MPa up to 2 GPa of pressure. The majority of H_2O under-saturated experiments contained 2wt% H_2O or less, with a few runs conducted at 5 wt% added H_2O.

Despite numerous experiments performed at a wide range of conditions, the mineral assemblage of this lava has yet to be reproduced experimentally. Plagioclase, a ubiquitous mineral in the Peridot Mesa lava, has failed to crystallize in any experiment. Significant temperature, pressure, and volatile constraints have been placed on the basanite by the presence of hydrous minerals, and the stability of olivine and clinopyroxene. Samples run under pressures greater than 500 MPa, and temperatures cooler than 1150°C crystallized phlogopite and amphibole minerals readily, neither of which are found in the lava. Also, olivine phenocrysts only occurred at temperatures 1100°C or cooler, and the amount of water present in the system is restricted by the appearance of hydrous minerals and/or the lack of olivine and clinopyroxene.

Phase equilibria experiments on the Peridot Mesa basanite have provided insight into the poorly understood history of this alkali basalt. The fact that hydrous minerals are present at 500 MPa or greater in pressure, even in anhydrous runs, leads to the conclusion that the phenocrysts formed under low pressure and low-H_2O content conditions. The stability of olivine also requires crystallization temperatures at or below 1100°C. The observation of two olivine populations in the natural sample, and the fact that plagioclase could not be reproduced in the lab, supports the possibility of magma mixing and a complex origin and eruption history for this lava.