Distribution of rare earth elements in lunar zircon

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ABSTRACT

An investigation of rare earth elements (REE) in 15 zircon grains from lunar breccia sample 14321, combined with published analyses, has allowed lunar zircon grains to be separated into four distinctive types. Type-1 zircon is characterized by the relative depletion of light REE (LREE) resulting in a steep chondrite-normalized pattern. Type-2 zircon shows relative enrichment in the LREE compared to type-1 grains. Type-3 zircon also shows relatively high concentrations of LREE as well as a relative depletion in the heavy REE (HREE), which results in a relatively flat chondrite-normalized pattern. Type-4 zircon grains are characterized by the steepest chondrite-normalized REE pattern, with the lowest LREE and the highest HREE as well as by a distinctive positive Ce anomaly. Multiple analyses of REE in a complex impact modified zircon from breccia sample 73235 suggest a possibility that the very light REE from La to Nd were mobilized during impact. However, the main differences between the identified zircon types appear to be primary and reflect the original crystallization environment of zircon grains. These differences are not linked to major changes associated with the different suites of plutonic rocks, such as Mg- and alkali-suites, and quartz monzodiorites (QMD), but instead reflect small-scale variations in residual pockets of melt where zircon grains crystallized. For example, the presence of plagioclase in the immediate vicinity of zircon was responsible for the type-1 zircon REE pattern, whereas type-2 zircon was formed in the presence of pyroxene. The only exception is type-4 zircon, which was probably associated with some felsite and “granite” samples representing very late differentiates of lunar mafic magmas.

Keywords: Moon, zircon, REE, lunar breccias

INTRODUCTION

The unique ability of zircon to concentrate U, its wide distribution in various rocks of different origins and compositions, and its stability under a range of P-T conditions have made this mineral one of the most extensively studied accessory phases. The initial application of zircon as a reliable geochronological tool has evolved into an investigation of its chemistry and textural characteristics to identify the petrological, geochemical, and genetic significance of the recorded U-Pb ages. Prominent among trace element studies of zircon have been investigations of the petrological significance of chondrite-normalized REE patterns. This work aimed to (1) determine limits of variation of REE concentrations in lunar zircon of different origin, particularly those formed from magmas of different composition and use this information as a petrogenetic indicator, and (2) determine zircon-melt distribution coefficients for REE \((zircon/melt)D_{REE}\) to enable calculation of REE content of melts coexisting with the zircon. Understanding REE distribution in zircon is particularly relevant to lunar rocks where zircon grains occur as separate mineral fragments and as components in small igneous clasts of uncertain affinity. The REE signatures of these zircon grains may provide a basis for correlation and petrologic interpretation, which can be used to understand the age data.

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Studies of REE variation in zircon grains from different terrestrial rocks, summarized by Hoskin and Schaltegger (2003), suggest that the total REE abundance appears to be lower in zircon from mantle-derived rocks (e.g., kimberlites) compared to zircon formed in crustal rocks (e.g., Hoskin and Ireland 2000). However, large variations are commonly observed at the intra- and inter-grain level, even within a single rock unit, which results in a significant overlap between the REE concentrations of zircon grains originating from various magmatic rocks ranging from gabbro to granite. Likewise, chondrite-normalized REE patterns of zircon from rocks with a large compositional range are remarkably similar. The observed similarities resulted in several unresolved controversies linked to the interpretation of zircon trace element data and made data difficult to use for petrologic correlations. In addition, variability of REE concentrations on the scale of individual grains, together with the general similarity of REE patterns in zircon from different magmatic rocks has resulted in a wide variation in estimates of \((zircon/melt)D_{REE}\) (Nagasawa 1970; Watson 1980; Green and Pearson 1983; Mahood and Hildreth 1983; Murali et al. 1983; Fujimaki 1986; Sawka and Chappell 1988; Heaman et al. 1990; Hinton and Upton 1991; Bea et al. 1994; Hoskin et al. 2000; Thomas et al. 2002; Sano et al. 2002).

Additional insights into processes that control distribution of REE in zircon can be gained by studying grains found in