American Mineralogist, Volume 96, pages 1673–1685, 2011

Element diffusion rates in lunar granulitic breccias: Evidence for contact metamorphism on the Moon

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Abstract

Lunar granulitic breccias are a group of clast-bearing impact-melt lithologies that have been brecciated, and then metamorphosed at high temperature (~1000 °C) to generate annealed (granoblastic to poikiloblastic) textures. They are ubiquitous among lunar samples, but occur in small volumes, typically as clasts in other lunar rocks. We have determined major, minor, and trace element diffusion profiles in olivines, orthopyroxenes, and clinopyroxenes from one Apollo 16 (60035), three Apollo 17 (77017, 78155, 79215), and two paired lunar meteorites (NWA 3163 and NWA 4881) by means of electron microscopy and electron probe microanalysis. The results show that relic igneous clasts exhibit an absence of, or limited, major element zoning, yet retain minor and trace element profiles. We exploit this characteristic to estimate the duration of high-temperature metamorphism responsible for their recrystallization. To achieve this we have completed pyroxene thermometry, element linescans, X-ray mapping, and modeling of heating and cooling of hanging wall and footwall lithologies juxtaposed with a hot body. The high equilibration temperatures, moderately high siderophile contents, and time scales of metamorphism of the lunar granulites indicate that they were metamorphosed in relatively near-surface settings. Diffusion calculations indicate that most granulitic breccias were heated for 13 000–300 000 yr. We conclude that they formed above or beneath superheated impact-melt sheets associated with medium-size (100–200 km) craters.

Keywords: Lunar geology, diffusion, trace element zoning, thermometry, superheated impact-melt sheets, contact metamorphism