*American Mineralogist, Volume 99, pages 355–368, 2014*

# Magma chamber dynamics recorded by oscillatory zoning in pyroxene and olivine phenocrysts in basaltic lunar meteorite Northwest Africa 032

**Stephen M. Elardo* and Charles K. Shearer Jr.**

Institute of Meteoritics, Department of Earth & Planetary Sciences, University of New Mexico, Albuquerque, New Mexico 87131, U.S.A.

## Abstract

Oscillatory zoning in silicate minerals, especially plagioclase, is a common feature found in volcanic rocks from various terrestrial tectonic settings, but is nearly absent in the lunar environment. Here we report backscattered electron images, quantitative wavelength-dispersive spectrometry (WDS) analyses, and qualitative WDS elemental X-ray maps that reveal oscillatory zoning of Mg, Ca, Fe, Ti, Al, Cr, and Mn in euhedral pyroxene phenocrysts, and faint oscillatory zoning of P in olivine phenocrysts in basaltic lunar meteorite Northwest Africa (NWA) 032. This is only the third known occurrence of oscillatory zoning in lunar silicate minerals. Zoning bands in pyroxene range from ~3–5 μm up to ~60 μm in width, but are typically ~10–20 μm in width. Oscillatory bands are variable in width over short distances, often within a single grain. Most oscillatory bands preserve a euhedral form and have sharp edges; however some bands have jagged or uneven edges indicative of resorption surfaces. The short-scale oscillatory nature of the zoning in pyroxene is overprinted on longer-scale core to rim normal magmatic zoning from pigeonite to augite compositions. Oscillatory zoning of P in olivine is faint and only resolvable with high beam current (400 nA) mapping. Bands of higher P are typically only a few micrometers in width, and although they preserve a euhedral form, they are not traceable around the full circumference of a grain and have variable spacing.

Resorption surfaces, longer-scale normal magmatic zoning, and relatively thick oscillatory bands are indicative of the formation of these chemical oscillations as a result of variable magma composition. Pyroxenes likely experienced variable liquid compositions as a result of convection in a differentially cooling, chemically stratified magma chamber. Periodic replenishments of progressively decreasing volumes of primitive parental magma are also permissible and may have enabled convection. In a convection model, Mg-rich bands reflect growth in the lower, warmer, more crystal-poor regions of the chamber, whereas Ca-Al-Ti-Cr-rich bands reflect growth in the upper, cooler, more crystal-rich regions of the chamber. The limited duration of crystallization in the magma chamber and the slow diffusion rates of multiple elements among multiple crystallographic sites in clinopyroxene, combined with fast cooling upon eruption, act to preserve the oscillatory zoning. Oscillatory zoning of P in olivine is a product of solute trapping resulting from the slow diffusion of P in silicate melts and minerals, and relatively fast magma cooling rates that may be related to magma chamber convection. Differential cooling of the chamber and the fast cooling rates within the chamber are likely a product of the thermal state of the lunar crust at 2.93 Ga when NWA 032, which is currently the youngest dated lunar igneous rock, erupted onto the surface of the Moon.

**Keywords:** Oscillatory zoning, magma chamber, convection, Moon, basalt, lunar meteorite, zoning, NWA 032, pyroxene