NEW OBSERVATIONS OF NAKHLA, GOVERNADOR VALADARES AND LAFAYETTE, AND THEIR BEARING ON PETROGENESIS. R.P. Harvey and Harry Y. McSween Jr., Department of Geological Sciences, University of Tennessee, Knoxville, TN 37996-1410 USA

The nakhlite meteorites are augite-olivine cumulate rocks which appear to have experienced late quenching. Although their relatively simple mineralogy (over 80% augite and olivine) might suggest a straightforward petrogenesis, there has been much debate over the interpretation of the source of the two major cumulate phases. Most recently it has been argued that the cores of both augite and olivine in Nakhla are xenocrysts, or were far from equilibrium during growth, based predominantly on detailed analysis of the zoning profiles of these minerals [1]. Others have argued that the diffusion of Mg and Fe at temperatures near the solidus of the intercumulus liquid is so much faster in olivine than in clinopyroxene (nearly an order of magnitude) that differences in core composition between the two minerals in Nakhla are due to different levels of re-equilibration rather than distinct parent magmas[2]. Resolution of the conflict between these models is important for accurate calculation of parental magma composition. Our recent investigations of all three nakhlites point toward significant amounts of re-equilibration between the cumulus phases and intercumulate liquid, and also indicate several systematic variations among these meteorites which may offer further clues into their petrogenesis.

Olivine and augite zoned during magmatic growth should show a linear decrease in Mg/Fe values when plotted versus crystal volume[3]. Several such profiles were shown by [1], and their relatively linear trend was used to support the argument that both phases show primarily original zoning. Late magmatic or subsolidus diffusion of Mg and Fe can be expected to alter these profiles, resulting in erasure of zoning given sufficient time at temperature[4]. Our analyses of olivines in both Nakhla (NK) and Governador Valadares (GV) show Mg/Fe profiles which are steep and linear in the core regions but progressively flatter towards crystal boundaries (fig. 1a,b). Our interpretation is that these grains exhibit remnant magmatic profiles very close to their cores, and have been "overprinted" by later diffusion of Mg and Fe at near solidus temperatures. In both of these meteorites olivine also exhibits Ca zoning which can be interpreted in a similar fashion. For a short distance outward from the center of the crystal, the content of Ca increases; further out, the slope changes sign, possibly signifying the onset of crystallization of a Ca-rich phase (augite). Most importantly, the Ca zoning is only evident where olivine is in direct contact with mesostasis, and is not evident in the direction of olivine-augite borders (fig. 2). Therefore we conclude that the Ca zones are predominantly produced by reaction with intercumulus melt. Given that Ca diffuses much more slowly than Mg or Fe [5] it seems unlikely that these zones are not also the product of diffusion. None of the olivines examined in Lafayette (LF) show zoning of Mg/Fe or Ca (fig. 1c); we attribute this to a higher degree of re-equilibration of olivine than experienced by GV or NK.

The zonation exhibited by augite is distinct from that of olivine. In GV and NK the zonation is a narrow rim of Fe enrichment that, in turn, is mantled by an outer zone of uniformly high Fe (fig. 1d,e), whereas in LF the zoning is much more diffuse (fig. 1f). None of these zones show a smooth linear (and thus presumably magmatic) zoning profile. The transition between the core and rim is sharpest in NK, intermediate in GV and much broader in LF. As with olivine this Fe-rich zone is most evident where augite is in contact with mesostasis, supporting the idea that these zones were predominantly produced by reaction with intercumulus liquid.

We have observed other differences besides mineral zoning patterns among the nakhlites which suggest systematic variation in the amount of reaction with intercumulus liquid. The meteorites show a continuum of textures, GV showing extremely euhedral augite grains with very narrow rim zones, NK showing less euhedral grains with slightly broader rims, and LF showing even fewer euhedral augites, many of which have grown together. Olivine shows a wide range of grain sizes in GV and NK, but is much more uniform in LF. Mesostasis in GV and NK often includes olivine grains, and occasionally olivine occurs as Ca-poor unzoned poikilitic grains. LF contains large poikilitic grains of orthopyroxene, while GV and NK show only occasional overgrowths of this mineral on olivine. These poikilitic orthopyroxenes often contain small, highly rounded olivine grains, suggesting that these areas of mesostasis are the result of olivine "digestion" or reaction with an evolving intercumulus liquid.

NEW OBSERVATIONS OF THE NAKHLITES: Harvey R.P. and McSween H.Y. Jr

We feel that much of this evidence points toward the nakhlites being a series of rocks which have undergone significant reaction between the assembled cumulus grains and an evolving intercumulus liquid prior to complete crystallization. GV appears to be the least equilibrated, NK has experienced slightly more reaction, and LF appears to have experienced significant levels of re-equilibration. The relationship of the three nakhlites therefore suggests a rock series in which depth in a cooling cumulus pile may have controlled the level of reaction with intercumulus melt. In such a pile varying degrees of re-equilibration might result from different amounts of time spent at near-solidus temperatures before quenching or differences in the availability of intercumulus liquid.

References: [1] Treiman,1990, *Proc. 21st LPSC*, p. 273-280, Pergamon. [2] Longhi & Pan, 1989, *Proc. 20th LPSC*, p.451-464, Pergamon. [3] Pearce, 1987, *Contr. Min. Pet.* **97**, p. 451-459. [4] Crank, 1975, *The Mathematics of Diffusion*, Clarendon. [5] Jurewicz & Watson, 1988, *Contr. Min. Pet.* **99**, p.176-185.

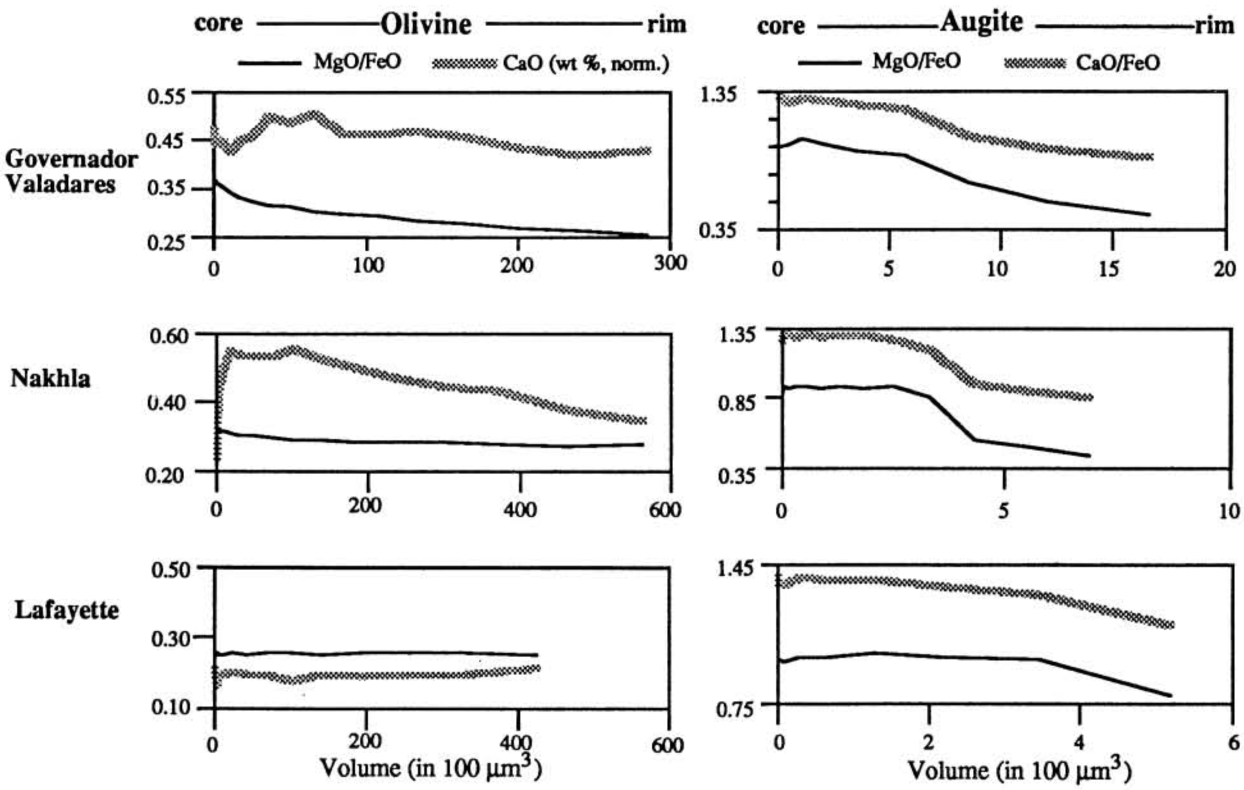

Figure 1. Representative zoning profiles of olivine (left column) and augite (right column) grains in the three nakhlite meteorites (Governador Valadares, Nakhla, and Lafayette). Stippled profiles are values of CaO (normalized to 100 wt%) for olivine and CaO/FeO for augite. Solid line is MgO/FeO for both phases. X-axis is crystal volume, calculated as (2 x radius) ^{3}.

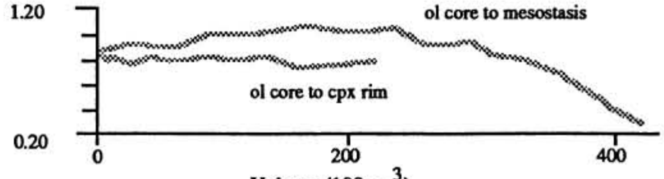

Figure 2. Ca zoning of a single olivine grain in Nakhla. Ca is strongly zoned towards borders with mesostasis, and essentially unzoned against augite.