CONSTRAINTS ON THE PHYSICAL DETAILS OF NAKHLITE FORMATION;

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Past studies of the nakhlites have concentrated on determining the magmatic source and interrelation of its constituent phases [eg.1,2] . In contrast, our interest in nakhlites concerns the physical setting of their formation to gain further understanding of volcanologic processes on Mars. We have begun by examining the heterogeneity of the original Nakhla meteorite. Modal analyses of eight sections demonstrate a significant variation in pyroxene:olivine ratios from 4:1 to over 17:1. There is no apparent correlation between olivine and mesostasis. This suggests that the amount of olivine is governed by a primary mechanism rather than later chemical interactions with remaining melt. We have also measured the crystal size distribution (CSD) of augites. Calculations based on CSD data suggest a growth period of about 1-5 yrs was necessary to produce the current grain sizes. This cooling period implies the host body was at least 11-26 m thick.

Modal heterogeneity

Previous workers have been limited to studying only one or two distinct Nakhla thin sections; we feel this ignores the real likelihood that the original Nakhla body, perhaps 30 cm on a side, may have been significantly varied in texture and chemistry. For example, recent studies of the shergottite Zagami have revealed a previously unnoticed 5 cm area (in a 15-20 cm body) that has a unique composition and displays crystals 50% larger than those in the main mass. We have, therefore, obtained 10 samples of different Nakhla stones to determine the extent of heterogeneity on a 10-cm scale. In principle, the extent of differences between nakhlites could help constrain magma-body size.

To date, we have determined the modes of eight Nakhla sections, from seven distinct stones; proper identification of olivines and mesostasis in weathered or disrupted sections was verified by backscattered electron imaging. As shown in Figure 1, pyroxene content varied by 15 vol%, olivine by 13 vol% and mesostasis by 6 vol%. These ranges reflect real heterogeneities beyond the inherent uncertainties of the method.

The ultimate source of these olivines has been hotly debated; they may be phenocrysts or xenocrysts or they may have grown in the magma after emplacement [1,2]. The increase in olivine correlates with a decrease in augite, but there is no definitive correlation with mesostasis content. This pattern suggests to us that the heterogeneity in olivine distribution is due to uneven mixing of phenocrysts. In fact, clumping of olivine grains is clearly visible in hand sample and thin section.

Textural analysis

A convenient method for quantifying textural properties of a sample is crystal size distribution (CSD) analysis. The method involves calculating population density of different size bins; theory predicts that steady-state growth would generate a negative linear correlation between the size and the log of the density [3].

For our study, widths of over 1000 augite grains were measured in Nakhla section USNM 2435. Figure 2 shows the observed distribution of grain sizes; note the nearly Gaussian distribution of the primary mode. From this data, a cumulative CSD was generated, plotting size vs. ln (n), where n is the number of crystals per unit length per unit area [3]. Figure 3 demonstrates the negative linear nature of the main body of the plot. We take this to indicate that the sample experienced a significant period of steady-state grain growth in contact with melt.

NAKHLITE FORMATION: R.C. Friedman *et al.*

There are two other features of note. First, the overabundance of large grains is perhaps due to the presence of augite phenocrysts. Second, the deficit at small sizes indicates a period of Ostwald ripening, in the presence of residual silicate melt, that preferentially removed smaller grains. Using an average initial grain size from the reciprocal of the slope (80μm) and a average final grain size from the measures distribution (242μm), a period of ripening can be calculated [4]. Using a diffusion coefficient of 10^{-6} cm^2/s, we get a ripening period of about 10 months.

We get alternate, but comparable, estimates of cooling time from diffusion considerations. Studies of mineral zoning in nakhlites have found Lafayette grains show no Fe or Ca zoning profiles [1], suggesting the grains reacted long enough with the melt to undergo complete diffusion. Using reasonable ranges of grain size, we calculate a time necessary for complete diffusion of 1-5 years, consistent with the above estimate. As a cooling time, this would imply a magma body at least 11-26 m thick.

References: (1) Harvey, R.P. and H.Y. McSween, Jr. (1992), *GCA* **56**,1655-1663. (2) Treiman, A.H. (1990), *Proc. LPSC* **20**, 273-280. (3) Marsh, B.D. (1988), *Contrib. Mineral Petrol.* **99**, 277-291. (4) Taylor, G.J. *et al.* (1993), *Meteoritics* **28**, 34-52.

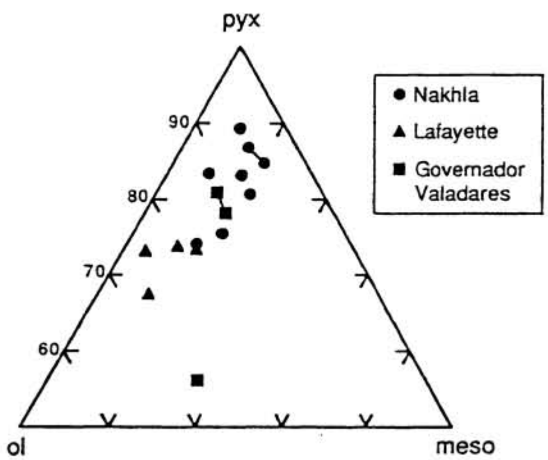

Figure 1. Modal properties of augite (pyx), olivine (ol), and mesostasis (meso) in nakhlites. Range in pyx:ol suggests variation in the abundance of primary phenocrysts in the nakhlite magma body.

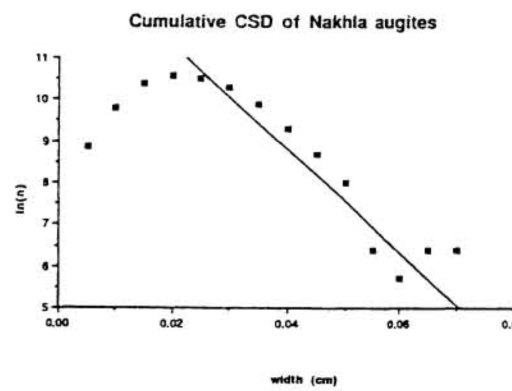

Figure 3. Crystal-size distribution (CSD) plot of augite widths. The line ($m=125/cm^3$) fits data in the main part of the trend and indicates steady-state nucleation and growth. The trail off at small sizes suggests coarsening before crystallization was complete. The overabundance at the largest sizes suggests the presence of primary phenocrysts.

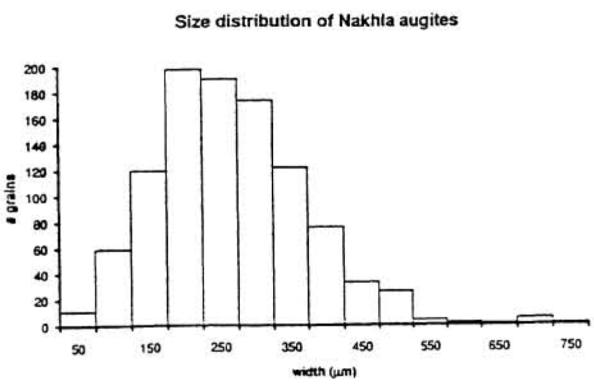

Figure 2. Size distributions in Nakhla sample USNM 2435.