PB-HF-SR-ND ISOTOPIC SYSTEMATICS AND AGE OF NAKHLITE NWA 998

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Introduction: Nakhlite NWA 998 was discovered in Algeria in 2001, and is unique among the six known members of this group of Martian meteorites in containing significant modal orthopyroxene. Initial petrologic and isotopic data were reported by Irving et al. [1]. This 456 gram stone consists mainly of sub-calcic augite with subordinate olivine and minor orthopyroxene, titanomagnetite, pyrrhotite, chlorapatite, and intercumulus An_{35} plagioclase (see Figures 1, 2 , 3). We report here preliminary results of radiogenic isotopic analyses conducted on fragmental material from the main mass kindly provided for this study by Adam and Greg Hupé.

Samples Analyzed: Mineral fractions were obtained mainly by handpicking, and some by magnetic and heavy liquid methods. Analyzed samples include three augite separates (Px-1 and Px-2 containing only handpicked grains with clear surfaces, and Px-3 containing handpicked grains with a cloudy, secondary surface coating); two plagioclase separates (Plag-1 consisting mainly of handpicked clear grains, and "Plag"-2 obtained by flotation of crushed sample in bromoform, and probably including some secondary grain boundary phases); a handpicked olivine separate (Oliv); and a magnetic separate (consisting mainly of magnetite and pyrrhotite with attached plagioclase and apatite) obtained from the crushed sample with a small magnet wrapped in parafilm (Mag). Before dissolution the augite separates were leached ultrasonically in 2.5N HCl for 15 minutes, followed by an additional 10 minutes with approximately 0.1 ml of added concentrated HF. The Oliv and Plag-2 separates were leached with HCl only, and both the Plag-1 and Mag separates were washed only with deionized water before dissolution. All separates were dissolved in HF-HNO3 after adding appropriate quantities of spikes for Rb, Sr, Sm, Nd, Lu, Hf and Pb concentration determination, guided by ion microprobe analyses of the minerals [2]. Isotopic compositions of Sr and Pb were determined by TIMS, and data for other elements were obtained on the DTM VG-P54 multicollector ICPMS.

Sm-Nd Isotopic Compositions: The results from all isotopic systems provide a chronology for NWA 998 broadly consistent with previous analyses of other nakhlites, but with ample evidence for disturbance by both shock and terrestrial (and perhaps Martian) contamination. The most precise

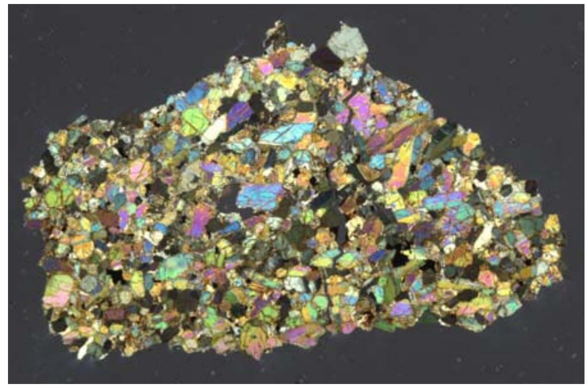

Figure 1. Partially cross-polarized thin section image (width of sample = 11 mm)

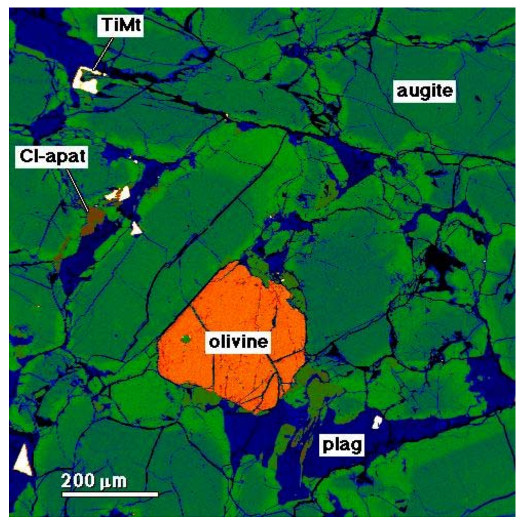

Figure 2. False-color BSE image

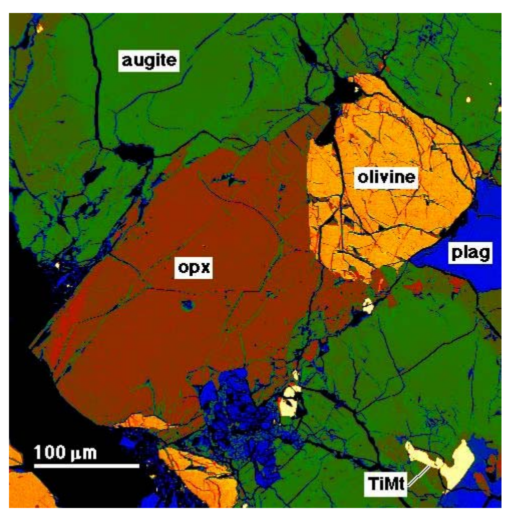

Figure 3. False-color BSE image

result is obtained from the Sm-Nd line fit through the Px-1, Plag-1 and Mag separates, which gives an age of 1.29 ± 0.05 Ga (MSWD = 0.07) and an initial εNd = 15.3 ± 0.9 (see Figure 4). All line fitting reported here was done with the Isoplot program [3], with errors reported at the 95% confidence level. [Note that the Sm concentration for Px-1 was misreported by [1], and is 0.589 ppm]. The datum for the Px-2 plus Px-3 combined leach falls precisely on this line, whereas the datum for Px-3 is just outside of error above the line. The Nd analysis for Px-2 failed. Data for Oliv and Oliv leach lie well below this line, but the line connecting these points provides a similar isochron age of 1.28 ± 0.10 Ga, with lower initial εNd of 11.9. The datum for "Plag"-2 lies well below that of the Oliv datum with an initial εNd at 1.29 Ga of 7.4. The combined data for Px-3 and Px-2/Px-3 leach have a slightly positive ε^{142}Nd = 0.60 ± 0.20. The 1.29 Ga age is similar to ages reported [4] for the four other dated nakhlites (Nakhla, 1.26 ± 0.07 Ga; Lafayette, 1.32 ± 0.05 Ga; Governador Valadares, 1.37 ± 0.02 Ga; Y 000593, 1.31 ± 0.03 Ga). The offset of the "Plag"-2 and Oliv data from the line defined by the other samples is suggestive of disturbance, but the fact that the Oliv to Oliv leach tie line gives an age similar to that of other nakhlites may indicate that this disturbance occurred near 1.3 Ga and involved the addition of Nd with relatively low ^{143}Nd/^{144}Nd.

Pb Isotopic Compositions: Contamination by terrestrial components is most obvious in the Pb-Pb systematics where the data lie on a broadly linear array connecting the most unradiogenic Pb (Px-1 with ^{206}Pb/^{204}Pb = 11.81, ^{207}Pb/^{204}Pb = 11.80, ^{208}Pb/^{204}Pb = 32.16) with the leaches that extend almost to the isotopic composition of modern terrestrial Pb (Oliv leach with ^{206}Pb/^{204}Pb = 17.74, ^{207}Pb/^{204}Pb = 15.26, ^{208}Pb/^{204}Pb = 38.08). The tie line passing through the Pb data for all samples, including leaches, corresponds to an age of 4.44 ± 0.09 Ga (MSWD = 175. The best fit line to the Pb data is obtained by excluding data for the leaches and "Plag"-2, which lie to slightly higher ^{207}Pb/^{204}Pb compared to the line defined by the remaining samples. This line corresponds to an "age" of 4.29 ± 0.04 Ga (MSWD = 2.2), but probably is simply a mixing line between terrestrial contamination and an unradiogenic Martian lead composition intrinsic to the sample. This possibility is supported by the linearity of these data on a ^{206}Pb/^{204}Pb - ^{208}Pb/^{204}Pb plot, and by the fact that none of the other radiometric systems applied to the very same mineral separates give circa 4 Ga ages.

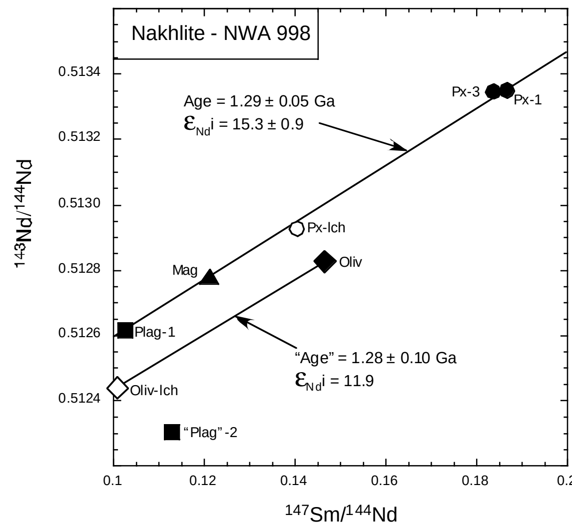

Figure 4. Sm-Nd isochron plot

Lu-Hf and Rb-Sr Isotopic Compositions: The disturbance seen in the Sm-Nd results also is apparent in the Lu-Hf and particularly Rb-Sr results. The Lu-Hf data for Oliv, Px-1, Mag and "Plag"-2 define a linear array corresponding to an age of 1.54 ± 0.3 Ga (using a ^{176}Lu decay constant = 1.865 x 10-11 yr-1 [5], MSWD = 59) and initial ^{176}Hf/^{177}Hf = 0.28226 ± 0.00034. Hf was not measured in Plag-1, and Hf runs failed for Px-2 and Px-3. The datum for the Px-2/Px-3 leach lies slightly above this line. The Lu-Hf line is primarily defined by Oliv, that contains melt inclusions and has relatively high Lu/Hf (^{176}Lu/^{177}Hf = 0.189). If Oliv is excluded, the remaining three separates define an imprecise age of 1.7 ± 1.3 Ga. Multi-isotopic analysis of another augite separate (including a more precise determination of ε^{142}Nd) is in progress. The best fit Rb-Sr line includes the two plagioclase and three augite separates, and defines a surprisingly young age of 921 ± 85 Ma (MSWD = 4, ^{87}Rb decay constant = 1.402 x 10-11 yr-1). Rb-Sr data were not obtained for the Oliv or leaches. The datum for the Mag separate lies well above this line at moderately high Rb/Sr. A line through the Px-1, Px-2, Px-3 and Mag separates gives an age of 1.47 ± 0.021 Ga (MSWD = 0.85), with initial ^{87}Sr/^{86}Sr = 0.70243, but the low MSWD of this essentially 2-point line is a result of the limited spread in Rb/Sr of the augite separates.

References: [1] Irving A. J. et al. (2002) *MAPS, 37*, A70. [2] Wadhwa M. and Crozaz G. (2003) *LPSC34*, #2075. [3] Ludwig K. (1991) *USGS Open File Report 91-445*. [4] Nakamura N. et al. (1982) *GCA, 46* 1555-1573; Shih C.-Y. et al. (1998) *LPSC29*, #1145; Shih C.-Y. et al. (1999) *MAPS 34*, 647-655; Misawa K. et al. (2003) *LPSC34*, #1556. [5] Scherer E. et al. (2001) *Science, 293*, 683-687.