

CHEMICAL CHARACTERISTICS OF NAKHLITES: IMPLICATIONS TO THE GEOLOGICAL SETTING FOR NAKHLITES. N. Shirai and M. Ebihara, Department of Chemistry, Tokyo Metropolitan University, Hachioji, Tokyo 193-0397, Japan (shirai@comp.metro-u.ac.jp).

Introduction: The findings of nakhlites (NWA 817, NWA 998, Y 000593 and MIL 03346) from the hot desert of Sahara and Antarctica have doubled the number of nakhlites. There are now seven nakhlites (Nakhla, Lafayette, Governador Valadares, NWA 817, NWA 998, Y 000593 and MIL 03346). Nakhlites have similar petrography, mineralogy, chemistry, isotopic composition and ages. However, slight differences in petrology, mineralogy and isotopic compositions among nakhlites are noticed [1, 2, 3]. Those differences offer information on the formation condition and geological setting of nakhlites. We conducted a chemical study of nakhlites to place constraints on the geological environments for nakhlites based on their chemical compositions.

Analytical procedures: Three nakhlites (Nakhla, Y 000593 and MIL 03346) were analyzed for bulk major, minor and trace element compositions by using prompt gamma-ray analysis, instrumental neutron activation analysis, instrumental photon activation analysis and inductively coupled plasma mass spectrometry. For Y 000593, six powdered samples were prepared by grinding g-scale of lumps located at different positions [4].

Results: A part of incompatible element abundances are shown in Fig. 1. Elements are ordered with increasing of compatibility during igneous processes (partial melting and/or fractional crystallization) in Martian upper mantle as well as the terrestrial upper mantle. CI-normalized abundances of incompatible elements for nakhlites decrease with increasing of compatibility. It can be seen that incompatible element abundances of Nakhla, Lafayette, Governador Valadares and Y 000593 are similar to each other and are systematically lower than those of MIL 03346 and NWA 817. Petrographically, Nakhla, Lafayette, Governador Valadares and Y 000593 were reported to have lower abundances of mesostasis than those of MIL 03346 and NWA 817 [5]. Considering that incompatible elements are mostly partitioned in mesostasis, chemical and petrographical characteristics are consistent with each other. For compatible elements (Co, Cr, Fe, Mn, Mg and Ni), Nakhla, Lafayette, Governador Valadares, Y 000593 and NWA 817 have similar abundances, which are higher than those of MIL 03346. Such difference is attributable to the difference in abundances of augite and/or olivine. Thus, elemental abundances for nakhlites reflect their modal abundances of major constituent phases.

There can be seen interesting chemical characteristics in Zr/Hf ratios among nakhlites (Fig. 1). Zr/Hf ratios increase with increasing of Zr and Hf abundances. Zirconium abundances and Zr/Hf ratios for nakhlites are shown in Fig. 2, where some literature values are also shown. Although having larger errors than those of literature values, our Zr/Hf ratio of Nakhla is consistent with those of [6,7]. Zr/Hf ratios of Nakhla, Lafayette and Y 000593 are consistent with each other and subchondritic. NWA 817 has a chondritic Zr/Hf ratio. Our Zr/Hf ratio of MIL 03346 is superchondritic, while literature values [8,9] are subchondritic.

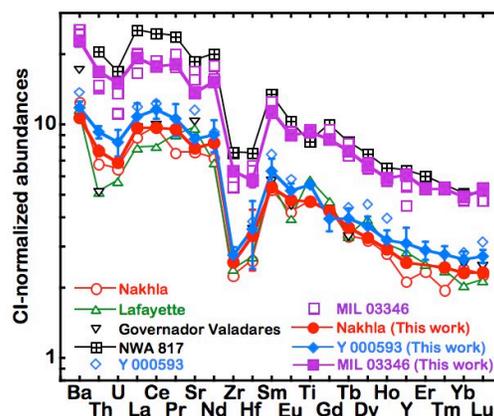


Fig. 1. CI-normalized abundances of lithophile elements for nakhlites. Solid and open symbols represent our data and literature values [16], respectively.

Zirconium and Hf are present in such minerals as zircon and baddelyite. Nakhlites are reported to have both zircon and baddelyite in mesostasis [5]. It is well acknowledged that these minerals are hard to be dissolved in acid digestion. It is also noted that these elements have large instability in most mineral acids. These difficulties may lead to poor accuracy of Zr and Hf abundances in rock samples. In this study, Zr and Hf abundances were obtained by using IPAA and INAA, respectively. As these methods are non-destructive, they are exempted from the above-mentioned analytical problems. Considering that Barrat et al. [8] and Day et al. [9] determined Zr and Hf abundances of MIL 03346 by using ICP-MS with the analyte solution of nitric acid, it is likely that the inconsistency between our data and their values was caused by analytical problems.

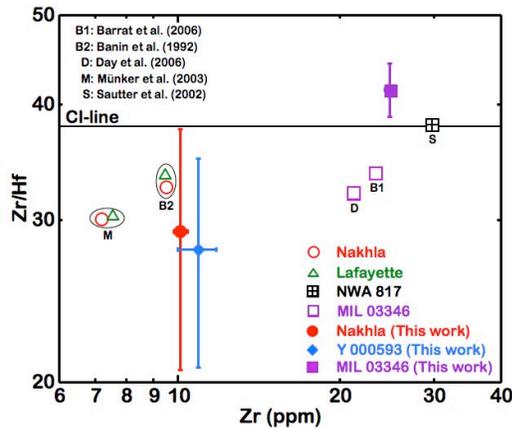


Fig. 2. Zr abundances vs. Zr/Hf ratios for nakhlites. Solid and open symbols represent our data and literature values [16], respectively.

Discussions: Based on Zr/Hf ratios, nakhlites are divided into three subgroups having subchondritic, chondritic and superchondritic Zr/Hf ratios. They tend to have a positive correlation between Zr abundances and Zr/Hf ratios (Fig. 2), indicating that Zr is more incompatible than Hf during igneous processes on Mars. This trend is consistent with experimental partitionings of Zr and Hf between any of clinopyroxene, garnet, ilmenite, majorite and Mg-pervoskite, and melt [10,11,12,13]. In consideration of petrographic features and experimental data of partition coefficients, the fractionation of Zr and Hf in nakhlites could be best explained by the crystallization of clinopyroxene. In Fig. 3, the Zr/Hf ratios of nakhlites are plotted against La/Yb ratios. As La is more incompatible than Yb in clinopyroxene, a positive correlation would be expected. As shown in Fig. 3, however, there is no apparent correlation between Zr/Hf and La/Yb ratios. Even with Sc, a compatible element in clinopyroxene, no correlation against Zr/Hf ratios can be confirmed, either. Thus, the fractionation of Zr and Hf in nakhlites is unlikely due to the crystallization of clinopyroxene. Wadhwa and Crozaz [14], Wadhwa et al. [15] and Day et al. [9] determined rare earth element (REE) abundances of clinopyroxene in nakhlites and estimated REE abundances of the parent magma of nakhlites by coupling the REE abundances and partition coefficients of REE for clinopyroxene. The REE abundance patterns derived are similar to those of bulk rocks, indicating that nakhlites were crystallized in a close-system [9,14,15]. Considering that Zr and Hf behave as incompatible elements similarly to REE in clinopyroxene, Zr/Hf ratios of bulk rock for nakhlites represent those of the parent magma of nakhlites. As nakhlites are divided into three groups based on Zr/Hf ratios; Nakhla, Lafayette and Y 000593 with subchondritic Zr/Hf ratio, NWA 817 with chondritic Zr/Hf ratios and MIL 03346 with superchondritic Zr/Hf ratios, there

must have been at least three parent magmas on Mars where nakhlites formed.

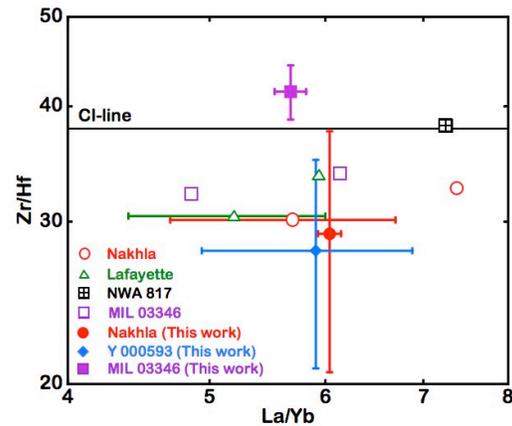


Fig. 3. La/Yb ratios vs. Zr/Hf ratios for nakhlites. Solid and open symbols represent our data and literature values [16], respectively. Horizontal bars of literature values show the standard deviations of literature values [16].

Mikouchi et al. [2] observed the differences in chemical zonings of olivine and pyroxene, modal abundances of mesostasis and texture and size of plagioclase in mesostasis among nakhlites, and suggested that these differences are due to the difference in cooling rate of the source material for nakhlites in a common cumulate pile. Considering that Zr/Hf ratios of the parent magmas for nakhlites are variable, it seems to be unlikely that all nakhlites were derived from a single cumulate pile. Based on the texture and distribution of olivines in nakhlites, Lentz et al. [1] proposed that nakhlites were derived from several flows. Our conclusion of multiple reservoirs for nakhlites derived from the chemical characteristics is consistent with the suggestion of [1]. It is suggested that Nakhla and Y 000593 came from a common magma source while MIL 03346 from a difference source.

References: [1] Lentz R. C. F. et al. (2005) *Meteoritics & Planet. Sci.*, 40, A74. [2] Mikouchi T. et al. (2006) *LPS XXXVII*, Abstract #1865. [3] Shih C.-Y. et al. (2006) *LPS XXXVII*, Abstract #1701. [4] Misawa K. et al. (2003) *Antarct. Meteorite Res.*, 16, 1-12. [5] Treiman A. H. (2005) *Chimie de Erde*, 65, 203-296. [6] Banin A. et al. (1992) In *Mars*, 594-625. [7] Münker C. et al. (2005) *Science*, 301, 84-87. [8] Barrat J. A. et al. (2006) *LPS XXXVII*, Abstract #1569. [9] Day J. M. D. et al. (2006) *Meteoritics & Planet. Sci.*, 41, 581-606. [10] McKay G. A. et al. (1986) *JGR*, 91, D229-D237. [11] Kato T. et al. (1989) *Earth Planet. Sci. Lett.*, 89, 123-145. [12] Ohtani E. et al. (1989) *Contrib. Mineral Petrol.*, 10, 263-269. [13] Salters V. J. M. and Longhi J. (1999) *Earth Planet. Sci. Lett.*, 166, 15-30. [14] Wadhwa M. and Crozaz G. (1995) *Geochim. Cosmochim. Acta* 59, 3629-3645. [15] Wadhwa M. et al. (2004) *Antarct. Meteorite Res.*, 17, 97-116. [16] Meyer C. (2007) *Mars Meteorite Compendium*.