U-Pb systematics of phosphates in Nakhlites. K. Terada[1,2] and Y. Sano[3], [1]Department of Earth and Planetary System Sciences, Hiroshima University, Higashi-Hiroshima 739-8526, JAPAN (terada@sci.hiroshima-u.ac.jp), [2]MIRAGE Project Center, Hiroshima University, Higashi-Hiroshima 739-8526, JAPAN, [3]Center for Advanced Marine Research, Ocean Research Institute, The University of Tokyo, Nakano-ku 164-8639, JAPAN.

Introduction: Studies of the SNC (Shergottite, Nakhlite, Chassignite) meteorites, which are thought to be impact ejecta from the planet Mars, have contributed significantly to understanding of the igneous history of the planet. Nakhlites, which are fine-grained clinopyroxenites, have not been subjected to severe shock metamorphism like shergottites. Their original igneous textures are well preserved. So far, an enormous amount of work on radiometric dating of nakhlites (mainly Nakhla, Lafayette and Governador Valadares) has been reported. The results of the $^{40}Ar/^{39}Ar$ ages, Rb-Sr ages and Sm-Nd ages clearly indicate a formation age of ~1.3 Ga for Nakhlites (for recent review, [1]). On the other hand, U-Pb work also has been carried out only for Nakhla, however the interpretations of the U-Pb isotopic system are debatable [2-6]. On the whole, Pb-Pb isochron plots of leach-residue fractions show considerable scatter, indicating that ^{207}Pb-^{206}Pb ages are >2 Ga. Nakamura et al. [4] reported a U-Pb Concordia plot after common lead correction and subtraction of contaminant of Pb, which showed the data intersecting the Concordia curve at 4.33 ± 0.08 Ga and 1.28 ± 0.05 Ga. Taking into account the REE measurement and Rb-Sr age of 1.26 Ga, and assuming appropriate common lead correction, Nakamura et al. [4] concluded that the age of the light REE-depleted Nakhla source is < 4.33 Ga. Thus, a U-Pb age of 1.3 Ga age has not yet been reported for Nakhlite, and a consensus has not been attained to the U-Pb systematics in Nakhlites.

For further understanding of U-Pb systematics of Nakhlites, the inner areas of individual phosphate grains from Nakhla, Lafayette and Yamato-000593/000749, which are the major host phases of U, were investigated by using the Sensitive High Resolution Ion Micro Probe (SHRIMP) installed at Hiroshima University, JAPAN.

Sample Description and Analytical Methods: The polished thin section of Lafayette was provided by the U. S. National Museum of Natural History, Smithsonian Institution, and polished thin sections of Yamato-000593 and Yamato-000749 were provided by the National Institute of Polar Research in Japan, respectively. The samples were carbon-coated and backscattered electron images were taken by an Electron Probe Micro Analyzer (EPMA; JEOL JCMA-733II). Major chemical compositions were also determined in order to identify the location and mineralogy of phosphates. Sizes of the observed phosphates generally ranged from 20 to 60 µm and the largest one has a size of 160 µm. Some of the grains have small inclusions or cracks. All of the observed phosphates were apatites, and were surrounded by pyroxene/augite and/or plagioclase. We found no whitlockite, which is often observed in some shergottites and ALH84001 [7, 8]. Inclusion and crack-free areas were selected for SHRIMP analysis.

An ~ 1 nA O_2^- primary beam accelerated through a voltage of 10kV was focused to sputter an area ~ 10 μm in diameter on the phosphates and positive secondary ions were extracted with 10 kV. The mass resolution was set to ~ 5800 at ^{208}Pb for U-Pb analyses. The abundance ratio of ^{238}U to ^{206}Pb was obtained from the observed $^{238}U^+/^{206}Pb^+$ ratio using an empirical quadratic relationship between the $^{206}Pb^+/^{238}U^+$ and $^{238}U^{16}O^+/^{238}U^+$ ratios of the standard apatite PRAP dated at 1156 Ma. Experimental details of the U-Pb analysis and the calibration of the data were given in [7,9]

Result and Discussion: To reduce the model dependency on common lead composition, the three-dimensional U-Pb plot (total Pb/U isochron method) was used. The crucial advantages of this method are that it is not necessary to assume the isotopic composition of common Pb, and that both ^{238}U and ^{235}U decay schemes are used at the same time, yielding a smaller justifiable age uncertainty for the U-Pb systematics [10].

The U-Pb data of twelve apatite grains from Yamato-000593/000749 are well expressed by LINEAR regressions in both "conventional" 2D isochron plots and in $^{238}U/^{206}Pb$ - $^{207}Pb/^{206}Pb$ - $^{204}Pb/^{206}Pb$ 3-D space, indicating a formation age of 1.53 ± 0.46 Ga (2σ). On the other hand, those of nine apatite grains from Lafayette are well expressed by a PLANAR regression rather than LINEAR regressions in $^{238}U/^{206}Pb$ - $^{207}Pb/^{206}Pb$ - $^{204}Pb/^{206}Pb$ 3-D space, indicating concordia intercept ages of 4.32 ± 0.32 Ga and 1.15 ± 0.34 Ga (2σ), respectively. The U-Pb systematics of Lafayette is very similar to those of Nakhla, where the data correlation line intersects the concordia curve at 4.33 ± 0.08 Ga and 1.28 ± 0.05 Ga after corrections for both Canyon Diablo troilite Pb and terrestrial Pb contamination[4] and the two intercepts with the concordia curve at 4.26 ± 0.04 Ga and 1.13 ± 0.10 Ga by investigating an interior piece of Nakhla [3]. It is noted that our results do not assume the isotopic composition of common lead.

In general, the PLANAR regression of U-Pb discordia data in the $^{238}U/^{206}Pb$ - $^{207}Pb/^{206}Pb$ – $^{204}Pb/^{206}Pb$ 3-D space can be interpreted by two kinds of geological case. One is the combination of a linear discordia on the X-Y plane and one point of common Pb component on the Y-Z plane (case-I). In this case, both upper and lower intercept ages are geologically valid, corresponding to a formation age and an alteration age, respectively. Another case is the combination of the one concordant age on the X-Y plane and a mixing line on the Y-Z plane (case II). In case-II, the upper intercept age is an artifact, not the geological age. It should be noted that the younger age is chronologically valid in both case I and II. Taking into account of the data obtained from other radiometric systems (Rb-Sr age of 1.27 ± 0.07 Ga, Sm-Nd age of 1.32 ± 0.05 Ga [11] and Ar/Ar plateau age of 1.33 ± 0.03 Ga [12-13], we conclude that the age of Yamato-000593/000749 (1.53 ± 0.46 Ga) and younger age of Lafayette (1.15 ± 0.34 Ga) define the crystallization age of apatites in Nakhlite, and that the PLANAR distribution of data points in the 3D space for Lafayette can be explained by a secondary alteration process as previously discussed for Nakhla [14].

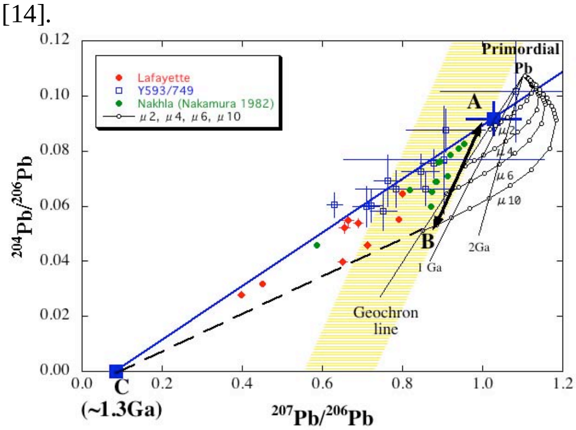

Figure illustrates this complicated U-Pb systematics for Lafayette, Yamato-000593/000749 and Nakhla. It is noted that this diagram is a projection onto the Y-Z plane of $^{238}U/^{206}Pb$ - $^{207}Pb/^{206}Pb$ – $^{204}Pb/^{206}Pb$ 3-D space. Data of Lafayette and Yamato-000593/000749 are plotted as red circle and blue squares, respectively. For comparison, those of Nakhla (Nakamura et al. 1982) are also shown as green circles. The blue line is an isochron line determined from the initial lead composition of Yamato-000593/000749 ("A") and the radiogenic Pb isotopic ratio of 1.3Ga ("C"), which is the projected regression line on the Y-Z plane of Yamato-000593/000749. The yellow area is the intersection (with uncertainties) between the PLANAR regression for Lafayette and the Y-Z plane, corresponding to a mixing array in the case-II. Lead growth curves with various μ values for the U-Pb system (single stage model) are also shown in black. This diagram suggests the followings. 1) The initial lead composition of Yamato-000593/000749 (filled square) plots on the mixing array (yellow area) and on the lead growth curve, whose μ values is roughly ~2. 2) The data of Lafayette (red circles) and Nakhla (green circles) plot below the isochron line (blue line) and in the region of a triangle A-B-C, where A, B, C are the initial lead composition at 1.3Ga, that of an unknown source and the radiogenic isotopic composition of 1.3Ga, respectively. These features are interpreted as follows. An original U-Pb systems (blue line, A-C) was disturbed by an exotic source (B), whose μ value is roughly ~10. Therefore, the Lafayette data, which were much affected by secondary process, are expressed by a PLANAR regression in 3-D space. The regression plane is composed of the mixing array A-B and a concordant age of 1.3Ga. The possible causes of disturbance might be a fluid alteration on Mars such as previously discussed for Nakhla, and/or a thermal/shock perturbation during launch to Earth [14].

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