TRAPPED NOBLE GAS COMPONENTS AND EXPOSURE HISTORY OF THE ENSTATITE CHONDRITE ALH84206. D. Nakashima[1,2] and T. Nakamura[2], [1]Department of Earth and Planetary Sciences, Kyushu University, Hakozaki, Fukuoka 812-8581, Japan, [2]Max-Planck-Institut für Chemie, Joh.-J.-Becher-Weg 27, D-55128 Mainz, Germany. (naka@mpch-mainz.mpg.de)

Introduction: Recently, some E3 chondrites with solar noble gases were found [1], but detailed studies of the solar-gas-bearing E3 chondrites have been seldom performed. We have studied noble gases in the solar-gas-bearing E3 chondrites so as to characterize energetic particle environments of E chondrites [2, 3]. Here we report the results of noble gas analyses of Allan Hills (ALH) 84206, one of the solar-gas-bearing EH3 chondrites [1], and discuss trapped noble gas components and exposure history.

Noble gas analysis: We measured noble gases in ALH84206 in two ways, stepwise heating and total extraction analyses.

Stepwise heating analysis: One of the ALH84206 samples, weighing 98.9mg, was used for the stepwise heating. Noble gases were extracted at 300-1700°C with 100°C intervals. The concentrations and isotopic ratios of extracted noble gases were measured with a noble gas mass spectrometer at Kyushu University [4].

Total extraction analysis: One of the ALH84206 samples was crushed into smaller pieces weighing 0.9-2.3mg. Each sample was heated at 1700°C. Concentrations and isotopic ratios of He, Ne, and Ar were measured as well as concentrations of ^{84}Kr and ^{132}Xe.

Results of stepwise heating: Isotopic ratios of He and Ne showed that ALH84206 contains solar and cosmogenic gases. The presence of solar gases indicates that constituents of ALH84206 had been exposed to the solar wind on the surface of the parent body.

The $^{36}Ar_{trap}/^{132}Xe$ ratios in the 300-600°C fractions (7-54) and those in 1200-1500°C fractions (52-76) were below or in the lower part of the Q range (50-100, [5]). In 300-600°C fractions, large amounts of Xe with isotopic ratios of Xe-Air [6] were released. It is likely that the $^{36}Ar_{trap}/^{132}Xe$ ratios in 300-600°C fractions were lowered by the contribution of this atmospheric-Xe. The low $^{36}Ar_{trap}/^{132}Xe$ ratios in 1200-1500°C fractions can not be explained by contribution of atmospheric-Xe, because Xe isotopic ratios are close to those of Xe-Q [5]. The low $^{36}Ar_{trap}/^{132}Xe$ ratios in these fractions suggest the presence of sub-Q gases ($^{36}Ar/^{132}Xe$ = 37±18 [1]). Sub-Q gases are characteristic for the solar-gas-free E3 chondrites [1], and are believed to originate from the fractionation of Q-gases [1]. The $^{36}Ar_{trap}/^{132}Xe$ ratios in 700-1100°C fractions (88-96) are in the upper part of the Q range. Xe isotopic ratios in these fractions are close to those of Xe-Q. The $^{36}Ar_{trap}/^{132}Xe$ ratios can be explained by contributions of sub-Q gases and solar ^{36}Ar.

We compared the isotopic ratios of $^{80}Kr/^{84}Kr$ with those of $^{82}Kr/^{84}Kr$. A fairly good correlation was found between the isotopic ratios of $^{80}Kr/^{84}Kr$ and $^{82}Kr/^{84}Kr$. The slope of the correlation line ($^{80}Kr/^{82}Kr$ = 2.75±0.07) is close to the production ratio for epithermal neutron capture on ^{79}Br and ^{81}Br [7], indicative of the presence of neutron-induced Kr. In contrast, neutron-induced Xe was not observed.

Results of total extraction: He and Ne in individual samples consist of solar and cosmogenic gases. The elemental ratios of solar gases in individual samples, $(^{4}He/^{20}Ne/^{36}Ar)_{Solar}$ = 5512/27.7/1 (on average), are comparable with the typical values for solar wind implanted species ($^{4}He/^{20}Ne/^{36}Ar$ = 6780/26.8/1, lunar soil ilmenites 12001, [8]), which suggests no large diffusive loss of solar gases from ALH84206.

Most individual samples showed $^{36}Ar_{trap}/^{132}Xe$ ratios below or in the lower part of the Q range, which is again explained by contributions of sub-Q and atmospheric heavy noble gases.

The cosmogenic $^{3}He/^{21}Ne$ ratios were lower than the $^{3}He/^{21}Ne$ ratio calculated from the Bern line [9], which suggests cosmogenic ^{3}He diffusive losses.

Cosmogenic ^{21}Ne ($^{21}Ne_{C}$) concentrations in individual small samples were higher than in the large sample analyzed by stepwise heating (Fig. 1). In principle, this may be due to enrichment of Mg in the small samples, because the main target element of $^{21}Ne_{C}$ production is Mg, which is present in forsterite and enstatite. However, the sample with highest $^{21}Ne_{C}$ excess ($8.0\times10^{-8}cm^{3}/g$) also showed the highest $^{38}Ar_{C}$ excess from $^{38}Ar_{C}$ in the stepwise heating sample. The main target elements of $^{38}Ar_{C}$ production are Fe and Ca, which are present in kamacite, troilite, and oldhamite. Since both the highest $^{21}Ne_{C}$ and $^{38}Ar_{C}$ excesses occur in the same sample, the variation in the chemical composition can not be responsible. Assuming that the lowest $^{21}Ne_{C}$ ($1.2\times10^{-7}cm^{3}/g$) was produced during the meteoroid exposure, the excesses can be taken as $^{21}Ne_{C}$ produced during the exposure on the parent body.

Discussion: The exposure duration for which the constituents of ALH84206 have been exposed to solar wind and cosmic rays on the surface of the parent body can be obtained from the highest $^{21}Ne_{C}$ excess and the production rate. The production rate is calculated from the data given in [10] and the chemical composition

[11]. The shielding depth is assumed to be $40g/cm^2$. The $^{21}Ne_C$ production rate reaches a maximum at $40g/cm^2$ [10]. The production rate at $40g/cm^2$ is overestimated and the exposure duration is underestimated. Therefore, a lower limit can be calculated by the assumption. The exposure duration is calculated to be >63Ma. This is actually also a lower limit, because the next sample we measure may have an even higher excess.

We assumed the lowest $^{21}Ne_C$ was produced during the meteoroid exposure. There is a possibility that the lowest $^{21}Ne_C$ contains $^{21}Ne_C$ produced during the parent body exposure, indicating that the concentration of $^{21}Ne_C$ produced during the meteoroid exposure is lower than the lowest $^{21}Ne_C$ concentration. Therefore, the calculated meteoroid exposure duration is an upper limit. The meteoroid exposure duration is calculated to be <39Ma. The $^{21}Ne_C$ production rate is derived from the data given in [12] and the shielding parameter $(^{22}Ne/^{21}Ne)_C$ (=1.08).

When was neutron-induced Kr (Kr_n) produced? There are two possible cases: (a) during the parent body exposure and (b) during the meteoroid exposure. The theoretical $(^{80}Kr/^{82}Kr)_n$ production ratio for the parent body exposure is calculated as 2.30-2.31 from the $^{80}Kr_n$ and $^{82}Kr_n$ production rates given in [10], whereas the theoretical $(^{80}Kr/^{82}Kr)_n$ production ratio for the meteoroid exposure is 2.6-2.7 [7]. The $(^{80}Kr/^{82}Kr)_n$ ratio of ALH84206 (2.75±0.07) is closer to the latter value than the former value. Therefore, it is likely that Kr_n was produced during the meteoroid exposure. Assuming that all $^{80}Kr_n$ was produced during the meteoroid exposure, the pre-atmospheric size of ALH84206 can be calculated from the $^{80}Kr_n$ concentration ($10.0\times10^{-11}cm^3/g$) and the method given in [13]. The minimum radius of the ALH84206 meteoroid is 27cm, assuming that ALH84206 was located on the center of the spherical meteoroid.

Trapped light noble gases are dominated by solar gases, whereas trapped heavy noble gases are dominated by fractionated Q-gases (sub-Q like) and atmospheric gases. Fractionated Q-gases reflect thermal metamorphism and aqueous alteration [5]. If solar wind exposure had occurred before Q-gas fractionation, constituents of ALH84206 should have lost abundant solar gases during the Q-gas fractionation induced by thermal metamorphism. However, the elemental ratios of solar gases in ALH84206 showed no large diffusive loss. Therefore, solar wind exposure most likely has occurred after Q-gas fractionation.

Conclusions: Based on the results of noble gas analyses, we have evaluated the exposure history of ALH84206. Constituents of ALH84206 had been exposed to solar wind and cosmic rays on the surface of the parent body, most likely after Q-gas fractionation. The cosmic ray exposure duration on the parent body was more than 63Ma. After consolidation, the ALH84206 meteoroid was ejected from the parent body and fell onto the earth after the transit time of less than 39Ma. The minimum radius of the ALH84206 meteoroid was 27cm.

References: [1] Patzer A. and Schultz L. (2002) *MAPS, 37*, 601-612. [2] Nakashima D. and Nakamura T. (2003) *NIPR Symp.*, 102-103. [3] Nakashima D. et al. (2004) *submitted to MAPS* [4] Nakamura T. et al. (2003) *EPSL, 207*, 83-101. [5] Busemann H. et al. (2000) *MAPS, 35*, 949-973. [6] Basford J. R. et al. (1973) *Proc. Lunar Sci. Conf., 4th*, 1915-1955. [7] Marti K. et al. (1966) *Z. Naturforsch. 21a*, 398-413. [8] Eberhardt P. et al. (1972) *Proc. Lunar Sci. Conf., 3rd*, 1821-1856. [9] Patzer A. and Schultz L. (2001) *MAPS, 36*, 947-961. [10] Hohenberg C. M. et al. (1978) *Proc. Lunar Planet. Sci. Conf., 9th*, 2311-2344. [11] Wasson J. T. and Kallemeyn G. W. (1988) *Philos. Trans. R. Soc. London, A325*, 535-544. [12] Eugster O. (1988) *GCA, 52*, 1649-1662. [13] Eberhardt P. et al. (1963) in *Earth Science and Meteoritics* (eds. Geiss J. and Goldberg E. D.), 143-168.

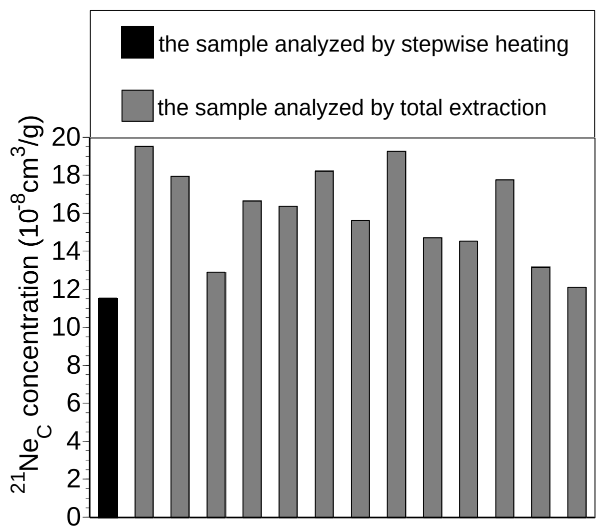

Fig. 1. The $^{21}Ne_C$ concentrations in the samples analyzed by stepwise heating and total extraction analyses.