NOBLE GAS ISOTOPIC COMPOSITIONS OF FOUR STANNERN–GROUP EUCRITES. S. Kagami[1], M. K. Haba[1], K. Nagao[2], T. Yokoyama[1], and A. Yamaguchi[3], [1]Dept. of Earth & Planetary Sciences, Tokyo Institute of Technology, 2-12-1 Ookayama, Meguro-ku, Tokyo 152-8551, Japan, (e-mail: kagami.s.ab@m.titech.ac.jp), [2]Korea Polar Research Institute (KOPRI), 26 Songdomirae-ro, Yeonsu-gu, Incheon 21990, South Korea, [3]National Institute of Polar Research, Tachikawa, Tokyo 190-8518, Japan.

Introduction: Eucrites are most likely originated from the crust of asteroid 4-Vesta and divided petrologically and textually into basaltic and cumulate eucrites. Basaltic eucrites are subdivided into main group, Nuevo Laredo group, Stannern group, and residual eucrites based on their bulk chemical compositions (e.g., [1]). The thermal history of the main-group eucrites, which has been extensively investigated with petrological observation and chronological data (e.g., [2]), is summarized as follows: 1) igneous crystallization and initial global metamorphism by internal heat source (~4.54–4.56 Ga: e.g., [3]) and 2) later reheating events by impacts (e.g., ^{39}Ar–^{40}Ar: >3.3 Ga [4]). In contrast, the formation process of the Stannern group has not been fully investigated due to the rarity of the Stannern group (e.g., [5]). In the most recent and accepted model [6], the Stannern group is considered to have formed by the incorporation of partial melt of a pristine basaltic crust into the main-group eucritic magma. However, it is uncertain whether this process has occurred locally or globally on the eucrite parent body (EPB). Moreover, the comprehensive thermal history of the Stannern group on the EPB has been scarcely discussed by chronological studies in spite of the unique formation process of the Stannern group.

Here, we focus on noble gases in meteorites, which provide multiple chronological data including ^{244}Pu–Xe, ^{40}K–^{40}Ar, (U–Th)/He, and cosmic-ray exposure (CRE) ages. The (U–Th)/He, ^{40}K–^{40}Ar, and ^{244}Pu–Xe decay systems have diverse closure temperatures of 100–200, ~300, and >900 ºC, respectively [7–9]. The dating systems with different closure temperatures are useful to discuss the timing of multiple thermal events on the EPB during a long period. To provide the spatial-temporal constraints on the formation process of the Stannern group, we measured all noble gas isotopes including cosmogenic and radioactive ^{81}Kr ($t_{1/2}$ = 0.23 Myr).

Samples and methods: We used four monomict Stannern-group eucrites: Northwest Africa (NWA) 7188 (0.40 g), NWA 4523 (0.45 g), Bouvante (0.40 g), and Stannern (0.26 g). All samples have the metamorphic grade of type 4 in the classification by [10].

The samples were cleaned with acetone and H_2O. Noble gases were extracted by heating at 1800 ºC for achieving complete sample melting. The extracted gases were measured with a noble gas mass spectrometer, modified-VG5400 (MS-3), installed at KOPRI. The detail of the experiment has been described in [11].

Results and Discussion: As shown in Fig. 1, the ^{244}Pu–Xe ages of the Stannern group vary from ~4430 Ma to ~4570 Ma, which is consistent with the main group (~4470–4570 Ma: e.g., [12]). The ^{244}Pu–Xe ages of Bouvante and Stannern are consistent with those reported previously [12, 13]. The ^{244}Pu–Xe ages of NWA 7188 and Bouvante correspond to the timing of the initial crystallization and/or the global metamorphism of the EPB's crust as is deduced from the chronological data of main-group eucrites. In contrast, the younger ^{244}Pu–Xe ages of NWA 4523 and Stannern reflect the resetting by later reheating events. Because the Pb–Pb age of zircon in Stannern [14] does not match the young ^{244}Pu–Xe age of this meteorite, the thermal event at ~4420 Ma was probably a short-term reheating triggered by a local impact event.

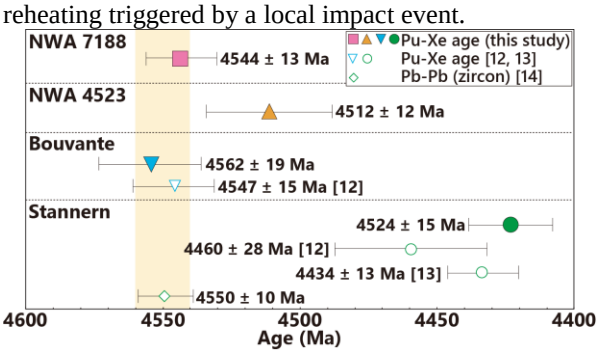

Fig. 1 *Comparison of ^{244}Pu–Xe and Pb–Pb ages of the Stannern group obtained in this and previous studies.*

The ^{40}K–^{40}Ar ages of NWA 7188, Bouvante, and Stannern are 3.56 ± 0.22, 3.40 ± 0.16, and 3.56 ± 0.16 Ga, respectively, whereas that of NWA 4523 is 2.60 ± 0.14 Ga. The ages of all samples excluding NWA 4523 are consistent with the ^{39}Ar–^{40}Ar ages (3.3–4.1 Ga: [4]) of brecciated basaltic eucrites. The youngest age of NWA 4523 may be an artifact caused by the heterogeneous K concentration in NWA 4523 because we arbitrarily used the K concentration reported by [6]. The ages obtained in this study represent the timing of reheating events by later impacts long after the initial magmatism or global metamorphism of the EPB. This implies that heating by local impact events, which reached a temperature above ~300 °C, could have continued until 3.4 Ga at least at the region where the Stannern group resided.

The obtained (U–Th)/He ages are shown in Fig. 2. Although eucrites commonly have a wide (U–Th)/He ages of 0.08–4.5 Ga [15], those of the Stannern group obtained in this study are divided into two groups of ~1 and ~2 Ga. These ages coincidently match the formation ages of Rheasilvia (~1.0 ± 0.2 Ga) and Veneneia (~2.1 ± 0.2 Ga) craters [16], suggesting that these meteorites were derived from the southern hemisphere of Vesta. Moreover, feldspar grains in a howardite Kapoeta have the young Ar–Ar ages of ~1 Ga [17]. Therefore, the region where the Stannern group resided could have been disrupted by the large impacts that formed the Rheasilvia and Veneneia craters, resulting in the resetting of (U–Th)/He system. If not, other possibilities include (1) slow cooling from the closure temperatures of ^{40}K–^{40}Ar system to that of (U–Th)/He system due to deep burial under thick regolith, and (2) He degassing and diffusion in the EPB and/or degassing in space after launching from the EPB. If the former is the case, the cooling rate is estimated to be ~0.1 ºC/Myr from the differences of the ^{40}K–^{40}Ar and (U–Th)/He ages. However, the cooling rate of a highly-metamorphosed basaltic eucrite Agoult (~10 ºC/Myr [18]) is much faster than this estimation, negating the possibility of slow cooling. On the other hand, the possibility of He degassing in the EPB cannot be evaluated based on our data alone. However, the amount of cosmogenic He and Ne isotopes in the analyzed meteorites revealed that the loss of ^{3}He is ~0% for Stannern and <30% for NWA 7188, NWA 4523, and Bouvante. Therefore, at least for Stannern, the loss of ^{4}He during meteorite delivery to the Earth was negligible and would not affect the (U–Th)/He ages.

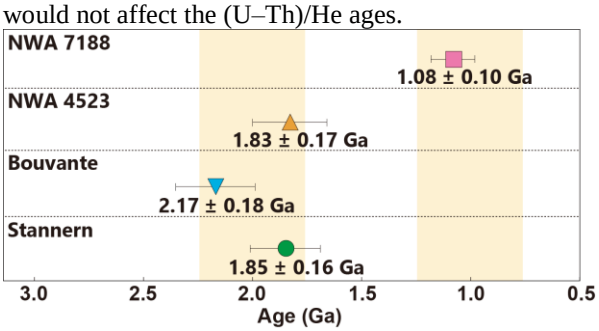

Fig. 2 *(U–Th)/He ages of the Stannern group obtained in this study.*

The CRE ages calculated from Kr isotopes and equations proposed by [19] are presented in Fig. 3. The exposure ages of the Stannern-group eucrites are likely to be divided into two groups: 1) ~9 Ma (Bouvante) and 2) ~35 Ma (the others). The two age population indicates that disruption of the area where the Stannern group resided occurred at least twice, implying that the Stannern group was derived from more than two locations on the EPB or the EPB's debris such as Vestoids.

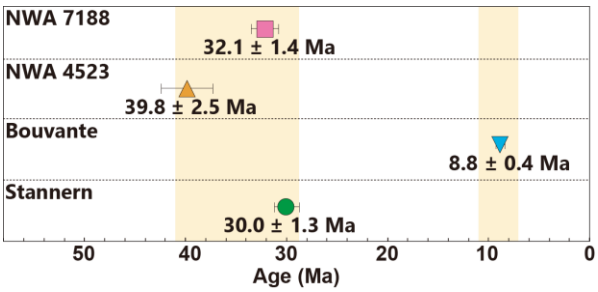

Fig. 3 *CRE ages of the Stannern group obtained in this study.*

The dating systems using noble gases revealed that the Stannern group most likely experienced complex thermal history as well as the main group. The Stannern group formed and underwent the initial global metamorphism at ~4550–4560 Ma and subsequently experienced local reheating events by impacts until 3.4–3.6 Ga. Long after that, the region(s) of the Stannern group on the EPB seems to have been broken up by the large impacts that formed south pole basins at ~1 and ~2 Ga, assuming that the (U–Th)/He system was reset at the timings of large crater formation. Finally, the precursors of the Stannern group were launched from the fragments of the EPB such as Vestoids and/or the EPB, possibly Vesta, at ~9 and ~35 Ma. All the Stannern-group eucrites examined in this study are monomict and have the same metamorphic grade of type 4, whereas their ^{244}Pu–Xe, ^{40}K–^{40}Ar, (U–Th)/He, and CRE ages show large variations within individual dating systems. We conclude that the Stannern group have formed not locally but in various regions of Vesta and experienced a similar thermal history to the main group, although the formation process of the two groups are different from each other.

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