Geochemistory and chronology of five howardites, Y-7308, Y-003125, Y-000428, NWA 1929, and NWA 6920

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Howardites are polymict breccias composed of eucrites and diogenites that are most likely originated from the crust of asteroid 4-Vesta. The global mapping with high resolution imagery conducted during the NASA's Dawn mission revealed that the Vestan surface is largely covered with howarditic materials (Ammannito et al., 2013). Thus, howardites would provide information on the crustal and surface evolution of Vesta entailing impact events. Here, we attempt to obtain multiple chronological data of howardites including ^{244}Pu-Xe, ^{40}K-^{40}Ar, and (U-Th)/He ages. Since these decay systems have diverse closure temperatures of ≧900, ~300, 100–200℃, respectively (Shukolyukov and Begemann, 1996; Cassata et al., 2009; Reiners et al., 2012), the multi-chronology of howardites are useful to discuss the timing of thermal events on Vesta during a long period. Additionally, we obtained major and trace element compositions and cosmic-ray exposure (CRE) ages of howardites to identify the geochemical characteristics of each howardite sample and to determine the ejection timing from the parent body.

Five howardites, Northwest Africa (NWA) 1929, NWA 6920, Yamato (Y) -7308, Y-000428, and Y-003125, were used in this study. Textual observations were performed by field emission-electron probe micro analysis (FE-EPMA). The major and trace element compositions of bulk samples (~50 mg) were measured with inductively coupled plasma-mass spectrometry (ICP-MS). All noble gas compositions were measured using a noble gas mass spectrometer, modified-VG5400/MS-3, with a sample amount of ~200 mg.

The proportion of eucrite and diogenite that contributed to the howardite samples were estimated by using the Al and Ca contents in individual howardites with an assumption that the two end-members are represented by a basaltic eucrite Juvinas and a diogenite Tatahouine. The five howardites are composed of basaltic eucrite and diogenite with a proportion of 95:5 for NWA 1929, 47:53 for NWA 6920, 39:61 for Y-000428, 37:63 for Y-003125, and 22:78 for Y-7308.

NWA 6920 and Y-003125 yielded the ^{244}Pu-Xe ages of ~4550 Ma, which corresponds to the timing of the initial crystallization of eucritic crust or global crustal metamorphism that were deduced from the of zircon ages of basaltic eucrites (e.g., Misawa et al., 2005; Iizuka et al., 2015). In contrast, younger ^{244}Pu-Xe ages (~4470 Ma) were obtained from NWA 1929, Y-7308, and Y-000428, indicating the timing of high-temperature reheating possibly due to impact events. The ^{40}K-^{40}Ar ages of NWA 1929, NWA 6920, and Y-003125 are 3.6 ±0.2, 3.6 ±0.2, and 3.2 ±0.2 Ga, respectively, which are consistent with the ^{39}Ar-^{40}Ar ages of brecciated eucrites (3.3–4.1 Ga; Bogard, 2011). The ages obtained in this study represent the timing of reheating by impacts, which reached a temperature above ~300 ℃, after the initial magmatism of eucritic crust. The (U-Th)/He ages of NWA 1929, NWA 6920, and Y-003125 are 2.3 ±0.2, 0.8 ±0.1, and 2.3 ±0.2 Ga, respectively. The (U-Th)/He systematics in the howardites could have been disturbed by degassing events that occurred at some points during the ejection from Vesta and delivery to the Earth, in addition to the impact events on Vesta. Some HED (Howardite-Eucrite-Diogenite) meteorites are considered to have derived from vestoids that were ejected from the Vesta's south pole craters (e.g., Clenet et al., 2014). Because the (U-Th)/He age of NWA 6920 is in good agreement with the age of the southern crater Rheasilvia (1.0 ±0.2 Ga, Schenk et al., 2012), NWA 6920 might have been severely suffered from the impact event that formed the Rheasilvia crater. The ^{81}Kr-Kr CRE ages vary from ~10 to

45 Ma, which is consistent with the previously reported CRE ages of howardites (~11–76 Ma, Eugster and Michel, 1995). Since the CRE ages of howardites cluster at the same period to those of eucrites and diogenites, the HED meteorite clan might have been launched from vestoids or Vestan surface at the same time.

Keywords: Howardite, noble gas, chronology

