

Chemical compositions of three Antarctic monomict eucrites A87272, A881467, and A881747. T. Setoyanagi¹ M. Ebihara¹, and A. Yamaguchi^{2,3}, ¹Department of Chemistry, Tokyo Metropolitan University, Hachioji, Tokyo 192-0397. ²Antarctic Meteorite Research Center, National Institute of Polar Research, Tokyo 173-8515. ³The Graduate University for Advanced Studies, Tokyo 173-8515.

Introduction: Most noncumulate eucrites have been considered as early crustal rocks of the HED parent body. Almost all noncumulate eucrites are metamorphic rocks. They have been classified into 7 metamorphic types mainly based on the pyroxene mineralogy [1,2]. If eucrites were metamorphosed by burial of countless lavas during crust formation, the degree of metamorphism may be directly related to the timing of eruption [2]. Therefore, there might be a correlation between the degrees of metamorphism, bulk compositions, and radiometric ages [3,4]. For geochemical study, it is essential to examine unbrecciated eucrites or monomict eucrites since some "monomict eucrites" [5] (e.g., Pasamonte and Sioux County) have been reclassified into polymict eucrites [6,7]. We performed a geochemical and petrologic study of two unbrecciated eucrites, Asuka (A) 87272 and A881467 and one monomict eucrite A881747. These meteorites are petrologically well-characterized eucrites [8,9] and give us an excellent opportunity to compare the petrogenesis of individual meteorites with the early evolution of the eucritic crust.

Petrology and mineralogy: A87272. Visual hand specimen inspection indicates that this meteorite is composed of a single coarse-grained lithology, composed of coarse-grained pyroxene and plagioclase. A87272 is one of the most severely shocked eucrites because the plagioclase is mostly converted into maskelynite. Pyroxenes in this rock have exsolution textures with two sets of augite lamellae: one set is coarsely spaced (60-70 μm apart), thick augite lamellae ($\sim 40 \mu\text{m}$ thick) and the other set is fine lamellae with spacing of $< 3\text{-}6 \mu\text{m}$ in the pigeonite host. Cores of pigeonites are partly inverted to orthopyroxenes. Some pyroxenes show a remnant Ca-zoning. These features indicate that A87272 is type 7 [2]. Chemical compositions of the pyroxenes are $\text{Wo}_{40.643.1}\text{En}_{28.430.1}$ (augites) and $\text{Wo}_{1.94.4}\text{En}_{35.536.4}$ (pigeonite). Plagioclases have relatively uniform compositions ($\text{An}_{90.491.3}$).

A881467. This rock is a eucritic granulite [8-10]. A881467 has a crystalline rock texture, which is apparent on the broken surface of the main mass. The PTS displays a granular texture of pigeonite, augite, and plagioclase. Chemical compositions of pyroxenes vary from $\text{Wo}_{8.6}\text{En}_{40.1}$ to $\text{Wo}_{33.2}\text{En}_{28.3}$. Compositional range of plagioclase is narrow ($\text{An}_{87.1-89.8}$).

A881747. The observation of the broken surface indicates that A881747 is mostly ($\sim 60\text{-}80\%$) composed of an angular subophitic lithology set in a gray matrix. The PTS displays a subophitic texture, consisting of coarse, lath-shaped plagioclase and anhedral, irregular pyroxene. The pyroxenes have a remnant Ca-zoning with closely spaced, thick ($\sim 10 \mu\text{m}$) augite lamellae at the rim and sparsely spaced ($\sim 50\text{-}100 \mu\text{m}$ in width) augite lamellae ($\sim 10 \mu\text{m}$ thick) in the core (i.e., type 4 [1]). Chemical compositions of pyroxenes vary from $\text{Wo}_{4.8}\text{En}_{35.5}$ to $\text{Wo}_{41.6}\text{En}_{30.3}$. Plagioclase in this rock is compositionally zoned from $\text{An}_{89.0}\text{Or}_{0.59}$ to $\text{An}_{78.0}\text{Or}_{1.7}$, similar to type 2 eucrites (e.g., Pasamonte clast) [6].

Analytical techniques: We obtained aliquots of powdered samples that were originally prepared from several grams of rock for bulk wet chemical analyses at the National Institute of Polar Research [e.g., 7]. We obtained bulk major, minor, and trace element composition using prompt gamma ray analysis (PGA) and instrumental neutron activation analysis (INAA). About 100 mg of each sample was used for PGA. subsequently its aliquant ($\sim 50 \text{mg}$) was used for INAA. In INAA, irradiations were performed successively at the Japan Atomic Energy Research Institute. Samples were irradiated for 10 sec at a neutron flux of $3 \times 10^{18} \text{m}^{-2}\text{s}^{-1}$, for 1 and 20 min at $5.3 \times 10^{17} \text{m}^{-2}\text{s}^{-1}$. JB-1 (basaltic standard rock of Geological Survey of Japan), Allende (Smithsonian), and some pure elements were irradiated with samples as standard materials in a series of irradiations.

Bulk chemistry: The mg# (=100x Mg/(Mg+Fe) molar) of A87272, A881467, and A881747 have limited values (mg#=37.7-38.9) and fall in the region of noncumulate eucrites. In contrast, the incompatible trace element abundances vary among the three samples. A87272 is one of the most incompatible-poor, ferroan eucrites. The REE abundances in this rock are 7-8 x CI, which are lower than those of main group eucrites (e.g., Juvinas [e.g., 11]). The REE pattern, which is characterized by a slight HREE-enrichment ($(\text{La/Lu})_{\text{CI}}=0.85$) and a significant positive Eu anomaly ($\text{Eu/Eu}^*=1.36$, where Eu^* is an interpolated value between CI-normalized Sm and Lu abundances), resembles those of cumulate eucrites, whereas most noncumulate eucrites show a flat or LREE enriched pattern with a significant negative Eu anomaly. Cumulate eucrites such as Moore County [e.g., 11] have lower

REE contents than A87272, with a larger positive Eu anomaly ($\text{Eu}/\text{Eu}^*=1.7$). A881747 (type 4) is the most incompatible element-rich among the three samples analyzed in this study. The REE abundances of 13~19 x CI are in the range for other type 4 eucrites and the REE pattern is characterized by LREE-enrichment ($(\text{La}/\text{Lu})_{\text{CI}}=1.44$) with a significant negative Eu anomaly ($\text{Eu}/\text{Eu}^*=0.7$). Similar patterns are commonly observed among REE-rich eucrites [5]. A881467 has intermediate abundances of REE of 9~12 x CI and is intermediate between the other two samples. This rock shows a slightly positive Eu anomaly ($\text{Eu}/\text{Eu}^*=1.02$) with LREE-enrichment ($(\text{La}/\text{Lu})_{\text{CI}}=1.28$).

Discussion: It appears the Takeda-Graham classification [1] is not always related to the total amount of thermal metamorphism. Yamaguchi et al. [2] suggested that types 5 and 6 eucrites may have been metamorphosed at ~1000 °C for a prolonged time to homogenize the Ca-Mg in the originally zoned pyroxenes, and those of types 4 and 7, which have remnant Ca-zoning in pyroxenes, could be less metamorphosed (peak metamorphic temperature <1000 °C). The strongly recrystallized texture of eucritic granulites [2] indicates that they may have been metamorphosed comparable to or more than types 5 and 6. Thus, we tentatively classified into the following groups: group A (types 1-3), B (types 4 and 7), C (types 5 and 6), and D (eucritic granulites). Several eucrites (e.g., Ibitira and EET90020) experienced higher temperatures. However, since the heat source of metamorphism could have been shock-related, we excluded these eucrites from this classification.

The variable incompatible element abundances with relatively constant mg# may be the result of the different degrees of partial melting. The amount of partial melt is largest for A87272 (group C) and smallest for A881747 (group C). The REE pattern of A881747 apparently represents a residual liquid after fractional crystallization. The pyroxene chemistry and relatively low mg# may suggest that A87272 is a non-cumulate eucrite. However, the REE contents of A87272 are intermediate between cumulates and non-cumulates, and the REE pattern of this rock is similar to those of cumulates. Thus, the parent liquid of A87272 may have been crystallized from liquid rich in Fe and some incompatible elements. The REE data of A881467 (group D) show a slight positive Eu anomaly, in contrast to the main group eucrites (mainly, group C). The Ti contents in A881467 are slightly higher than those of the main group eucrites. Although both A87272 and A881747 are classified into group C, we could not find any petrogenetic relationship between these two eucrites based on the REE data.

Warren and Kallemeyn [4] found an apparent composition-metamorphism correlation, and inferred that incompatible element rich Stannern trend eucrites (mostly type 4 [1,4]) are final products of magmatism. Apparently, they envisaged noncumulate eucrites as residual liquids after fractional crystallization in a large magma body (i.e., magma ocean) [12]. Such correlation would not be changed significantly by using our new classification (groups A-D). However, the presence of the REE-poor, ferroan eucrite, A87272, argues against this view. Eucrites in the same metamorphic group might have some chemical variation. Further geochemical and petrological studies of monomict eucrites are required to resolve this issue.

References: [1] Takeda H. and Graham A.L. (1991) *Meteoritics* 26, 129. [2] Yamaguchi A. et al. (1996) *Icarus* 124, 97. [3] Nyquist L.E. and Bogard D.D. (1997) LPI Tech. Rept. 96-02, 18. [4] Warren P.H. and Kallemeyn G.W. (2001) *Antarct. Meteorites* 26, 154. [5] Basaltic Volcanism Study Project (1980). [6] Metzler K. et al. (1995) *Planet. Space Sci.* 43, 499. [7] Yanai K. and Kojima H. (1995) *Catalog of the Antarctic Meteorites*. [8] Yamaguchi A. et al. (1997) *LPSC* 28, 1601. [9] Yamaguchi A. et al. (1997) *AMR* 10, 431. [10] Floss C. et al. (2000) *AMR* 13, 222. [11] Yanai K. (1993) *Symp. Antarct. Met.* 6, 148. [12] Barrat J.A. et al. (2000) *MAPS* 35, 1087. [12] Warren P.H. (1997) *MAPS* 32, 945.

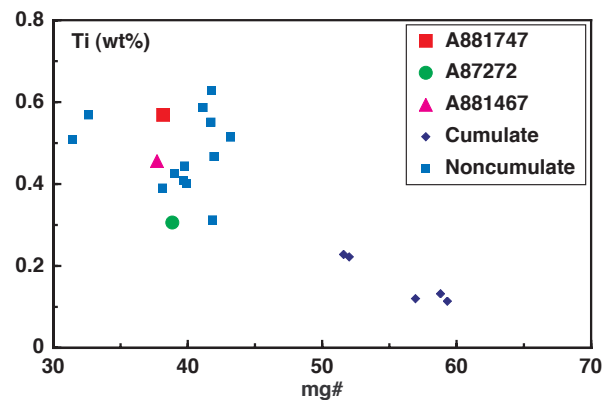


Fig. 1. Ti vs. mg# diagram for A881747, A87272, and A881467, with other cumulate and noncumulate eucrites.