U-PB ISOTOPE SYSTEMATICS OF EUCRITES IN RELATION TO THEIR THERMAL HISTORY. T. Iizuka[1,2], A. Kaltenbach[3], Y. Amelin[2], C. H. Stirling[3] and A. Yamaguchi[4]. [1]Department of Earth and Planetary Science, University of Tokyo, Hongo 7-3-1, Bunkyo, Tokyo 113-0033, Japan (iizuka@eps.s.u-tokyo.ac.jp), [2]Research School of Earth Sciences, Australian National University, Canberra ACT 0200, Australia, [3]Centre for Trace Element Analysis and Department of Chemistry, Univesity of Otago, Dunedin, New Zealand, [4]National Institute of Polar Research, Tachikawa, Tokyo 190-8518, Japan.

Introduction: Precise and accurate dating of meteorites is essential for understanding of the timescales of planetary formation and evolution. Recent developments in precise Pb isotopic analysis using a ^{202}Pb-^{205}Pb double spike, and in mineral washing procedures for the removal of common Pb, allow obtaining ^{207}Pb/^{206}Pb dates with a precision of less than 1 Ma for pristine meteorites [1,2]. Modern U-Pb chronometry has revealed that ^{207}Pb/^{206}Pb dates calculated assuming an invariant ^{238}U/^{235}U value of 137.88, as in conventional U-Pb chronology, can be inaccurate due to ^{238}U/^{235}U variations in meteorites [3-7]. To establish precise and accurate absolute ages of meteorites, therefore, both precise ^{238}U/^{235}U determination and U-Pb dating needs to be carried out on each meteorite, or at least each meteorite group.

Here we present the first combined high-precision U and Pb isotopic data for eucrites. Eucrites are pigeonite-plagioclase basaltic achondrites, and most of them are considered to have originated on the same asteroid, probably 4-Vesta [8]. In this study, we analyzed five eucrites: Camel Donga, a brecciated monomict eucrite enriched in metallic Fe [9]; Agoult, a fine-grained unbrecciated monomict eucrite having granulitic textures [10]; Northwest Africa (NWA) 049, a highly-metasomatized polymict eucrite comprising mostly unequilibriated subophitic clasts [11]; Dar al Gani (DAG) 380, a weakly shocked monomict eucrite [12]; Ibitira, a fine-grained (~200 µm) unbrecciated strongly recrystallized vesicular eucrite having an unique Δ^{17}O [13], indicating its derivation from an asteroid distinct from the other eucrites.

Procedures: *Determination of $^{238}U/^{235}U$.* Bulk samples of Camel Donga, Agoult and Ibitira were analyzed for precise ^{238}U/^{235}U determination following the procedures of [14,15]. The samples were spiked with a ^{233}U-^{236}U mixed tracer and digested utilizing a multi-step procedure using HF, HNO_3 and HCl at 120 °C on a hotplate for several days at each step. A two-stage ion exchange procedure using TRU.Spec and UTEVA resins (Eichrom) was utilized for U separation. Isotopic measurements of the purified U were performed on a Nu Plasma MC-ICPMS attached to a DSN-100 desolvating nebulizer at the University of Otago. Measured isotopic ratios were corrected both for the contributions of natural ^{235}U and ^{238}U present in the ^{233}U-^{236}U mixed tracer and for instrumental mass bias by normalization against ^{236}U/^{233}U. The ^{236}U/^{233}U was calibrated against the U metal standard CRM 145, assuming the ^{238}U/^{235}U value of 137.840 [16,17].

U-Pb dating. Pyroxene and plagioclase fractions of the five eucrites were analyzed for U-Pb isotopes. The multi-step acid leaching technique described by [2,4] was applied. The residues and leachates were spiked with a mixed ^{202}Pb-^{205}Pb-^{229}Th-^{233}U-^{236}U tracer before digestion [1]. The Pb separation was performed using anion exchange resin AG1x8 200–400 mesh. Pb isotopes were measured on MAT 261 and TRITON plus TIMS at the Australian National University (ANU) and a TRITON TI at the Geological Survey of Canada. The mass bias was corrected for using the measured ^{202}Pb/^{205}Pb normalized to the true value. U and Th concentrations were measured on a Neptune Plus MC-ICPMS at the ANU.

Results: The ^{238}U/^{235}U values of 137.770 ± 0.034, 137.708 ± 0.016 and 137.778 ± 0.013 (2σ) were obtained for Camel Donga, Agoult and Ibitira, respectively (Fig. 1). The model ^{207}Pb*/^{206}Pb* dates calculated using the measured ^{238}U/^{235}U values and assuming primordial Pb [18] as initial Pb are as follows (Fig. 2): 4510.9 ± 1.0 Ma for Camel Donga pyroxene; 4526.0 ± 2.0 Ma for Agout pyroxene; 4532.4 ± 0.8 Ma for Agout plagioclase; 4439.1 ± 4.5 Ma for NWA 049 pyroxene; 4527.1 ± 3.2 Ma for DAG 380 pyroxene; and 4555.8 ± 0.5 Ma for Ibitira pyroxene. Note that the Camel Donga ^{238}U/^{235}U value was applied to NWA 049 and DAG 380. The Ibitira pyroxene yields an isochron ^{207}Pb/^{206}Pb date of 4556.1 ± 2.3 Ma (Fig. 3). In contrast, pyroxenes of the other eucrites do not define precise isochrons (Fig. 3). The Agoult plagioclase yields an isochron ^{207}Pb/^{206}Pb date of 4532.2 ± 1.0 Ma, though the number of analysis is only three.

Discussion: All analyzed samples have ^{238}U/^{235}U values clearly lower than the previously assumed value of 137.88. The differences cause a -1.1–-1.8 Ma change in the ^{207}Pb/^{206}Pb dates, reinforcing the importance of combining ^{238}U/^{235}U determination and Pb isotopic measurement in early solar system U-Pb chronology.

The oldest and most precise ^{207}Pb*/^{206}Pb* date was obtained from Ibitira that originated from a distinct asteroid. This date is consistent with the results of previous less precise U-Pb isotopic studies [19,20]. In addition, the date is in good agreement with the Pb-Pb isochron date and the previously reported Mn-Cr date [21], indicating the robustness of the results. Considering that Ibitira experienced prolonged thermal metamorphism with a peak temperature up to 1115 ˚C [22] and that the Pb closure temperature of a ~200 µm pyroxene would be <1000 ˚C [23], we interpret these dates to reflect the timing of the thermal metamorphism rather than igneous crystallization.

In contrast to Ibitira, pyroxenes from the other studied eucrites gave scattered data in the Pb-Pb isochron plots (Fig. 3), indicating Pb isotopic disturbance. The model $^{207}Pb^{*}/^{206}Pb^{*}$ dates range from 4530 Ma to 4430 Ma, consistent with the results of previous U-Pb isotopic studies of eucrites [24,25]. These observations suggest a complex geological history of the parent asteroid over a period of ca. 100 Ma, including high temperature burial metamorphism to produce the granulite texture of Agoult at ca. 4530 Ma, an impact event associated with the brecciation and reduction (metal formation) of Camel Donga at ca. 4510 Ma, and fluid-rock interactions to metasomatize NWA 049 at ca. 4440 Ma.

Our U isotopic data suggest that Agoult has a lower $^{238}U/^{235}U$ value relative to Camel Donga and Ibitira, even though more analyses of Agoult are needed to conclude this rigorously. Given that Agoult and Camel Donga are thought to be derived from the same parent body, this observation may indicate that the geologic processes on the parent body caused resolvable U isotopic variation. The U isotopic variation may be linked to the Zn stable isotopic variation between brecciated and unbrecciated eucrites [26].

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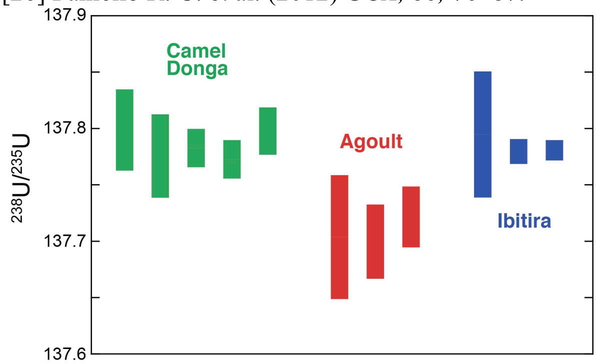

Fig. 1. U isotopic compositions of Camel Donga, Agoult and Ibitira. The weighted average values with 95% confidence intervals are shown with shaded areas.

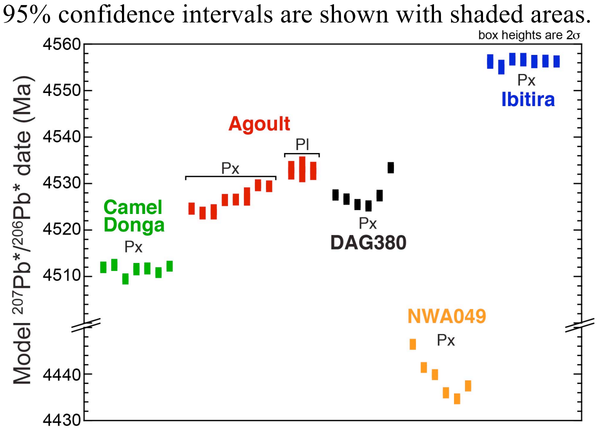

Fig. 2. Model $^{207}Pb^{*}/^{206}Pb^{*}$ dates for pyroxenes (Px) as well as plagioclase (Pl) from the five eucrites.

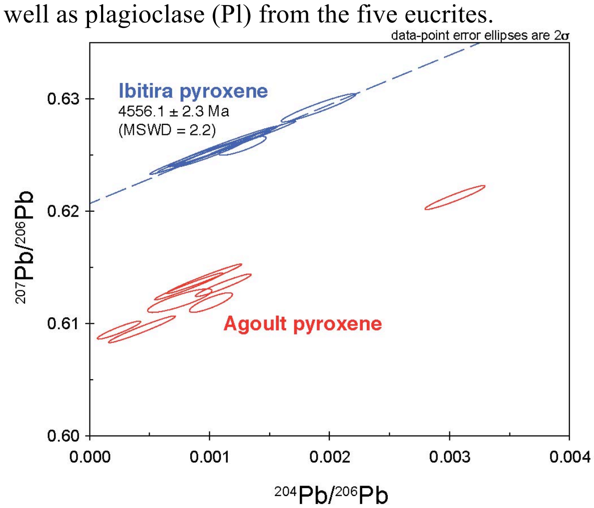

Fig. 3. Pb-Pb isochrons for acid-washed pyroxenes from Ibitira and Agoult.