THERMAL HISTORY OF BASALTIC EUCRITES AS RECORDED BY LEAD AND ARGON ISOTOPES.

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Introduction: Non-cumulate eucrites represent basaltic crust that underwent a complex thermal history involving multistage metamorphism, metasomatism and impact events, probably on asteroid Vesta [e.g., 1-4]. To better constrain the thermal history of the basaltic crust, we have conducted high-precision $^{207}Pb/^{206}Pb$ and $^{40}Ar/^{39}Ar$ dating for four basaltic eucrites: Agoult, a fine-grained unbrecciated monomict eucrite having granulitic textures [5]; Camel Donga, a brecciated monomict eucrite enriched in metallic Fe [6]; Dar al Gani (DaG) 380, a weakly shocked monomict eucrite [7]; Northwest Africa (NWA) 049, a highly-metasomatized polymict eucrite comprising mostly unequilibrated subophitic clasts [4].

Procedures: *Pb isotopic dating.* Pyroxene and plagioclase as well as whole-rock fractions of the four eucrites were analyzed for Pb isotopes. The multi-step acid washing technique described by [8,9] was applied: 1st-step with 0.5 N HNO_3 and 2nd-step with 6 N HNO_3 and 6 N HCl. All acid washes and residues were spiked with a mixed ^{202}Pb-^{205}Pb-^{229}Th-^{233}U-^{236}U tracer before digestion. Pb was separated using anion exchange resin AG1x8 200–400 mesh, following the method of [9]. The Pb isotopic ratio measurements were performed on MAT 261 and TRITON plus TIMS at the Australian National University. Instrumental mass bias was corrected for based on the measured $^{202}Pb/^{205}Pb$.

Ar isotopic dating. Plagioclase grains of the four eucrites were analyzed for Ar isotopic dating, following the protocol described by [10]. The sample aliquots were loaded into an aluminum disc and irradiated for 25h in the Hamilton McMaster University nuclear reactor. The Ar isotopic analysis was carried out using a 110 W Spectron laser system at the Western Australian Argon Isotope Facility, Curtin University. The ages were calculated using the ^{40}K decay constant of [11].

Results: *Pb isotopic data.* In a plot of $^{207}Pb/^{206}Pb$ v.s. $^{204}Pb/^{206}Pb$, acid washes and residues of Agoult define a line passing through the primordial Pb isotopic composition of [12]. By contrast, those of the other studied eucrites define lines projecting far above the primordial Pb point. In particular, 2nd washes of plagioclase fractions of DaG 380 and NWA 049 yielded remarkably high $^{207}Pb/^{206}Pb$ ratios (Fig. 1). Residues gave more radiogenic Pb than acid washes. The Agoult plagioclase residues yielded a precise Pb-Pb isochron age of 4534.21 ± 0.85 Ma (Fig. 1), while the Agoult pyroxene residues and all residues of the other three eucrites defined scattered array. The Agoult plagioclase residues gave a weighted model $^{207}Pb/^{206}Pb$ age of 4533.93 ± 0.73 Ma, consistent with the isochron age. The model ages of pyroxene residues are 4530–4525 Ma for Agoult and DaG 380, 4515–4510 Ma for Camel Donga, and 4450-4350 Ma for NWA 049, respectively.

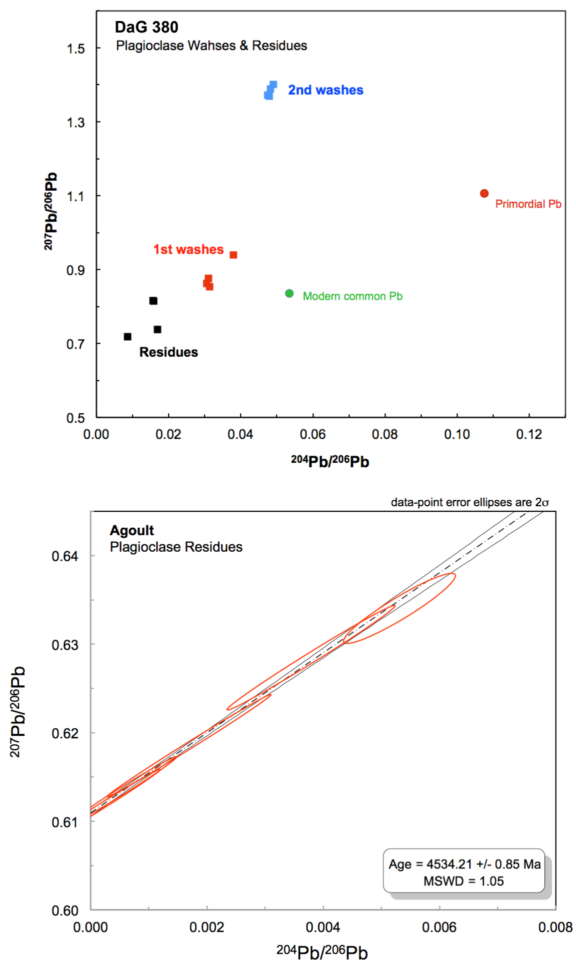

Fig. 1. Pb-Pb isochrons for DaG 380 and Agoult plagioclase fractions.

Ar isotopic data. Among five analyzed plagioclase fractions of Agoult, four yielded well-defined $^{40}Ar/^{39}Ar$ plateau ages of 4484 ± 13 Ma (Fig. 2), 4500 ± 12 Ma, 4519 ± 33 Ma and 4536 ± 49 Ma, with the weighted average of 4496 ± 8 Ma. One plagioclase fraction of Camel Donga yielded a plateau age of 3753 ± 58 Ma, consistent with the previously reported $^{40}Ar/^{39}Ar$ age for Camel Donga plagioclase [13]. On the other hand, DaG 380 and NWA 049 did not define any plateau and resulted in a series of minimum apparent ages at ca. 3900 Ma and 2500 Ma, respectively.

Discussion: The analyzed acid washed residues of the studied eucrites, except for Agoult plagioclase, defined scattered data in the Pb-Pb isochron plots, indicating Pb isotopic disturbance. The remarkably high $^{207}Pb/^{206}Pb$ ratios in the acid washes especially for plagioclase fractions of DaG 380, NWA 049 and Camel Donga require re-distribution of Pb between plagioclase and phase(s) with high U/Pb such as phosphate in the eucrites no later than 3 Ga. Considering that these three eucrites have shocked features and yielded clearly younger $^{40}Ar/^{39}Ar$ ages than the unbrecciated eucrite Agoult, the Pb re-distribution would occur during an impact event.

The Agoult eucrite, that records the highest degree of metamorphism among the studied eucrites, yielded well-defined Pb and Ar isotopic ages. The isochron and model $^{207}Pb/^{206}Pb$ ages (4534 ± 1 Ma) of Agoult plagioclase are distinctly younger than a $^{207}Pb/^{206}Pb$ age of 4554.5 ± 2.0 Ma for Agoult zircon which was interpreted as the timing of metamorphic zircon crystallization at 900 ˚C [14]. Furthermore, the plagioclase Ar isotopic age (4496 ± 8 Ma) is clearly younger than the plagioclase Pb isotopic ages. Given that the age differences reflect different closure temperatures of the chronometers during a single thermal event, the cooling rate of Agoult can be estimated as on the order of ~10 K/Myr. Notably, the Agoult $^{40}Ar/^{39}Ar$ age is distinctly younger than those of five unbrecciated metamorphosed eucrites analyzed by [15]. Such relatively young $^{40}Ar/^{39}Ar$ age, together with the presence of exceptionally large metamorphic zircon grains [14] in Agoult, implies that it was buried deeper than other unbrecciated basaltic eucrites. Assuming that the cooling proceeded by thermal conduction with a diffusivity of 10^{-6} m^2/sec, the burial depth can be estimated to be on the order of 1 km.

Besides, weakly-metamorphosed brecciated basaltic eucrites would have been located in relatively shallower part of the basaltic crust and disturbed by later impact events that led to Ar degassing and Pb re-distribution. Furthermore, since some weakly metamorphosed eucrites such as NWA 049 exhibit evidence of metasomatism [4], the shallow crust might undergo

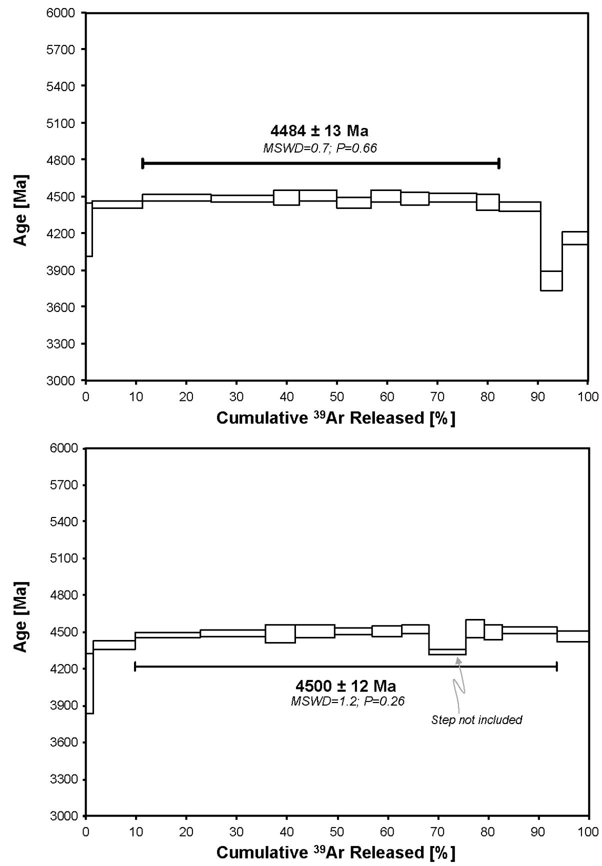

Fig. 2. Step-heating $^{40}Ar/^{39}Ar$ age spectra of Agoult plagioclase fractions.

fluid-rock interaction possibly at ~4.4 Ga, as recorded by Pb isotopes in NWA 049.

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