Vesta's impact silence: no *major* events recorded by eucrites after ~ 3.4 Ga

F. Jourdan[1] and T. Kennedy[1]
[1]*School of Earth and Planetary Sciences, Curtin University, Perth, Australia*

Eucrites are extraterrestrial basalts and cumulate gabbros formed at the crustal level of the HED (Howardite-Eucrite-Diogenite) parent body, thought to be the asteroid 4-Vesta, the only largely intact magmatic asteroid. The $^{40}Ar/^{39}Ar$ chronometer applied to brecciated eucrites is particularly well suited to record the bombardment history of Vesta since this isotopic system is sensitive to significant impact heating. In particular, $^{40}Ar/^{39}Ar$ plateau ages that indicate full resetting, require relatively large impacts with sufficient energy to reset the isotopic system. In layman terms, this technique can record decent size impacts…

We present a series of 13 new $^{40}Ar/^{39}Ar$ ages derived from 27 plateau and mini-plateau ages obtained from plagioclase crystals and groundmass particles extracted from 7 brecciated eucrites. Our new results substantially enlarge the ≤ 4.50 Ga impact age database of eucritic meteorites (n^{2023} = 32). These new ages range from 3366 ± 75 to 4009 ± 40 Ma, which is similar to the age range of 3469 ± 35 to 3851 ± 21 Ma derived from previous $^{40}Ar/^{39}Ar$ plateau ages obtained on post-4.50 Ga brecciated eucrites (Kennedy et al., 2013; Kennedy et al., 2019). Additional $^{40}Ar/^{39}Ar$ ages of 4500 ± 4 Ma and 4288 ± 38 Ma (Kennedy et al., 2019) and three phosphates $^{207}Pb/^{206}Pb$ ages ranging from 4143 ± 13 to 4150 ± 12 Ma (Koike et al., 2020; Liao and Hsu, 2017) suggest that more restricted record of major impact events exist during the period between ≤ 4.50 and > 4.0 Ga, possibly due to resetting by younger impacts.

However, no $^{40}Ar/^{39}Ar$ *plateau* (indicating full resetting) ages younger than ~3.4 Ga have been measured yet in plagioclase or groundmass in eucrites. Only in howardite (Cartwright et al., 2022; Lindsay et al., 2015) and diogenites (Jourdan et al., submitted) can one observe $^{40}Ar/^{39}Ar$ ages younger than ~3.4 Ga. Considering that (1) howardites record regolith surficial activity, (2) the $^{40}Ar/^{39}Ar$ system in diogenites is based on pyroxene which can only record small (ultra-transient, ultra-high temperature) events, and (3) a total of 32 impact ages show an absence of statistically robust ages younger than ca 3.4 Ga in eucrites, we are left with a mystery: Why no eucrites with *major* impact ages younger than 3.4 Ga?

The answer is not straightforward. A sample bias of some sort? Our preferred hypothesis involves a large impact around ~ 3.4 Ga that excavated material from Vesta into one or several rubble piles asteroid(s), possibly forming some of the Vestoids. Once formed, rubble pile asteroids are particularly suited to protect eucritic material inside the asteroid against further shock. This is due to their shock-absorbent 'space-cushion' like nature (e.g., Jourdan et al., 2023). By contrast, regolith material at the surface of the rubble pile asteroid and pyroxene crystals throughout the rubble pile will be more easily reset during impacts due to ultra-transient spikes in temperature, associated with pore collapse of porous material (Bland et al., 2014; Jourdan et al., submitted; Jourdan et al., 2023). Finally, we will discuss if the large excavation at ~3.4 Ga could correspond to one of the two big South Pole impact basins.

References

Bland, P., Collins, G., Davison, T., Abreu, N.M., Ciesla, F., Muxworthy, A. and Moore, J. (2014) Pressure–temperature evolution of primordial solar system solids during impact-induced compaction. Nature communications 5, 1-13.

Cartwright, J., Hodges, K. and Wadhwa, M. (2022) Evidence against a Late Heavy Bombardment event on Vesta. Earth Planet Sc Lett 590, 117576.

Jourdan, F., Timms, N.E., Nakamura, T., Rickard, W.D., Mayers, C., Reddy, S.M., Saxey, D., Daly, L., Bland, P.A. and Eroglu, E. (2023) Rubble pile asteroids are forever. Proceedings of the National Academy of Sciences 120, e2214353120.

Kennedy, T., Jourdan, F., Bevan, A.W.R., Mary Gee, M.A. and Frew, A. (2013) Impact history of the HED parent body(ies) clarified by new 40Ar/39Ar analyses of four HED meteorites and one anomalous basaltic achondrite. Geochim Cosmochim Ac 115, 162-182.

Kennedy, T., Jourdan, F., Eroglu, E. and Mayers, C. (2019) Bombardment history of asteroid 4 Vesta recorded by brecciated eucrites: Large impact event clusters at 4.50 Ga and discreet bombardment until 3.47 Ga. Geochim Cosmochim Ac 260, 99-123.

Koike, M., Sano, Y., Takahata, N., Iizuka, T., Ono, H. and Mikouchi, T. (2020) Evidence for early asteroidal collisions prior to 4.15 Ga from basaltic eucrite phosphate U–Pb chronology. Earth Planet Sc Lett 549, 116497.

Liao, S. and Hsu, W. (2017) The petrology and chronology of NWA 8009 impact melt breccia: Implication for early thermal and impact histories of Vesta. Geochim Cosmochim Ac 204, 159-178.

Lindsay, F.N., Delaney, J.S., Herzog, G.F., Turrin, B.D., Park, J. and Swisher III, C.C. (2015) Rheasilvia provenance of the Kapoeta howardite inferred from~ 1 Ga 40Ar/39Ar feldspar ages. Earth Planet Sc Lett 413, 208-213.