Itokawa, a >4.2 Ga old rubble pile asteroid

F. Jourdan[1], N.E. Timms[1], T. Nakamura[2], W.D.A. Rickard[1], E. Eroglu[1], C. Mayers[1], P.A. Bland[1], R. Oike[2] and T. Yada[3]

[1]*Curtin University, Perth, GPO Box U1987, WA, Australia*
[2]*Tohoku University, Aoba, Sendai, Miyagi 980-8578, Japan*
[3]*Institute of Space and Astronautical Science, JAXA, Sagamihara, Kanagawa 252-5210, Japan*

Asteroid 25143 Itokawa is a rubble pile asteroid consisting of reaccumulated fragments from a catastrophically disrupted monolithic parent asteroid, and from which regolith dust particles have been recovered by the Hayabusa space probe. When and how did the collision that resulted in the initial breakup of Itokawa's parent body occur? In a previous study [1], we obtained an age of 2291 ± 139 Ma on a single particle (#0013). Equilibration near the time of formation implies that this particle was formed deep inside the parent asteroid, yet a full reset of the K/Ar suggests that the particle was then close to the surface at 2.3 Ga. We then developed a novel temperature-pressure-porosity model, coupled with diffusion models to show that the relatively low pressure and high temperature involved in the impact process can be reconciled only if the asteroid was already made of porous material at ~2.3 Ga and thus, if asteroid Itokawa was already formed, thereby providing a *minimum* age for catastrophic asteroid breakup. In this study, we present SEM, EBSD, ToF-SIMS and $^{40}Ar/^{39}Ar$ dating results from four more particles (RA-QD02-0010, RA-QD02-0288, RB-CV-0082 and RB-QD04-1159). Unlike Particle #0013 [1], EBSD analyses show that none of these particles exhibit any noticeable sign of shock deformation, except perhaps one grain of troilite in particle #1159 which shows evidence of crystal-plastic deformation. Yet, $^{40}Ar/^{39}Ar$ analyses show the K/Ar system in all these particles has been reset at various ages.

Particle #0288 and #1159 yielded two well-defined plateau ages of 4219 ± 35 Ma (P=0.58) and 4149 ± 41 Ma (P=0.27), respectively best interpreted as recording a high temperature, yet very low shock impact event. Considering that the parent planetesimal of Itokawa is unlikely to have had an internal source of heat for ~340 Ma after formation, the equilibrated particles must have been by then close to the surface to be exposed to any impact related thermal event. The very low level of shock indicated by EBSD analysis (<10 GPa) suggest a high porosity of 35-40 % to allow the particle to reach the level of post-shock temperature required to reset plagioclase (cf. models by Jourdan et al., [1]). This suggests that Itokawa (probably a larger version at the time) was already formed by 4.2 Ga, almost twice as long as previously estimated.

Particle #0082 is a melt rock particle which petrography has been described by Nakamura et al. [2] and Timms et al. ([3]: this meeting). EBSD analysis shows no sign of shock in the pyroxene and olivine phenocrysts present amongst the glass. Unfortunately, $^{40}Ar/^{39}Ar$ analyses did not yield any resolvable plateau age but is consistent with recoil redistribution, an artifact caused by the neutron-activation of ^{39}Ar, thus suggesting an age of age of 4.4 – 4.5 Ga. Whereas initially considered as an impact melt rock, our preferred interpretation is currently that it is a fragment of a mesostasis-bearing porphyritic chondrule produced at the birth of the solar system (Timms et al., this meeting).

Particle #0010 did not yield any plateau age but a single hump-shaped age spectrum. ToF-SIMS compositional analyses of the plagioclase revealed the presence of sub-micrometer-wide K-feldspsar exolution lamellae (antiperthite). An argon diffusion model suggests that a brief yet high temperature heating event at ~500 Ma is able to decouple the K-feldspar and plagioclase $^{40}Ar^*$ reservoirs and reproduce the observed single hump-shape spectrum.

Conclusions: Plagioclase-bearing equilibrated particles have recorded a series of impact events {~500 Ma, 1350 ± 250 Ma (multi-particles, [3]), 2291 ± 139 Ma [1], 4149 ± 41 Ma and 4219 ± 35 Ma} best interpreted as occurring at / or near the surface of Itokawa, which implies a larger version of the rubble pile was already formed by at least ~4.2 Ga. This suggests that rubble pile asteroids can survive ambient solar system bombardment for extremely long periods. Such a long-term survival makes sense considering that the "cushiony" rubble pile nature of an asteroid makes it more prone to absorb shock during impacts without further breaking apart due to a drastically reduced radius of the impact-induced shock zone in porous media.

References

[1] Jourdan et al., 2017. Geology 45. [2] Nakamura et al., 2017. Hayabusa symposium 2017. [3] Timms et al., 2018. Hayabusa symposium 2018. [4] Park et al., 2015. Meteoritics & Planetary Science 50.