Asteroid Itokawa … but when did form exactly?

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Rubble piles asteroids consist of reassembled fragments from shattered monolithic asteroids and are much more abundant than previously thought in the solar system. In earlier studies (*1, 2*), we analysed five regolith dust particles recovered by the Hayabusa space probe from the rubble pile asteroid 25143 Itokawa, using a workflow of microstructural analysis by electron backscatter diffraction (EBSD), element mapping by time-of-flight secondary ion mass spectrometry (ToF-SIMS ± atom probe) and $^{40}Ar/^{39}Ar$ geochronology. We showed that Itokawa must have formed before or at ca. ≥ 4. 2 Ga and concluded that rubble pile asteroids can survive ambient solar system bombardment processes for extremely long periods. Here, we continue our quest to understand the bombardment history of Itokawa with the so far seemingly elusive goal of precisely pinpointing the age and nature of the catastrophic breakup of Itokawa's parent body. Only through a larger number of $^{40}Ar/^{39}Ar$ ages on single particles and U/Pb ages on phosphate grains (*3*) coupled with careful particle characterizations, will we be able to achieve this goal. With that in mind, we analysed three new particles.

RA-QD02-0300 (dia. = 190 µm) is composed of olivine, plagioclase, with minor troilite. EBSD and ToF-SIMS analyses show that the plagioclase in this particle is distributed in vein-like structures and has a fine polycrystalline texture of <10 µm grains with abundant inclusions and K-rich exsolutions. This suggests it represents recrystallised melt domains. Olivine crystals show no sign of shock deformation. We obtained a plateau age of **4130 ± 33 Ma** (P = 0.55). Noticeably, this age is very similar to previous results from other particles at 4219 ± 35 and 4149 ± 41 Ma (*1*), indicating an age concentration around that time. Could it be that the parent body of Itokawa broke up at ca. 4.2 Ga while some of the impact heated material slowly cooled down inside the newly formed insulating rubble pile asteroid over ca. 100 million years? This scenario is tantalizing as it would be similar to the scenario proposed by (*4*) for the breakup of an initially hot chondritic parent body at 4.5 Ga and with subsequent debris cooling at rates of ca. 1 to 10 °C/Ma inside the rubble pile asteroids.

RA-QD02-0306 (160 µm) is composed of olivine and plagioclase with minor troilite and chromite. This particle is the only $^{40}Ar/^{39}Ar$-dated particle which contains measurable solar wind, with a $^{38}Ar/^{36}Ar$ ratio of 0.188 ± 0.049 (2σ) that is indistinguishable from modern solar wind value. Along with the presence of abundant micro-craters, melt drop and blisters observed on the surface of the particle observed by (*5*), this indicates that this particle spent some time directly at the surface of the asteroid. This particle shows a structured $^{40}Ar/^{39}Ar$ age spectrum, with two different portions attributed to the gas released by the plagioclase and olivine phases. Plagioclase yielded a mini-plateau (59 % ^{39}Ar released) age of **4557 ± 61 Ma** (P = 0.71) similar to the U-Pb phosphate age of 4640 ± 360 Ma obtained by (*3*) on another particle, suggesting that it recorded the initial cooling deep inside Itokawa's parent asteroid and was not affected by heat during the breakup process. This demonstrates that, during the breakup of Itokawa's parent body, part of the asteroid experienced minimum to negligible shock pressure and temperature increase. This is similar to the conclusions reached via impact modelling calculated for the rubble pile asteroid Ryugu (*6*). This is also in excellent agreement with breakup models of structurally weakened monolith asteroids that do not require a particularly large impactor to shatter (*7*).

RA-QD02-0311 (108 µm) is composed of olivine, Ca-rich pyroxene, plagioclase and troilite. Elemental maps show that this particle contains very little plagioclase compared to the other particles and most of the K is contained in a rim-like structure exposed at the edge of the particle. Olivine crystals show no sign of shock deformation, yet $^{40}Ar/^{39}Ar$ dating reveals a complex age spectrum with maximum weighted-mean age of 705 ± 53 Ma (P=0.39) including 47% of ^{39}Ar released and indicating an impact ≤ 0.7 Ga. This maximum age, coupled with an available impact age of 2291 ± 139 Ma (*2*) and maximum age estimates (*1, 8*), suggests that impact events happened many times during the history of Itokawa and that the high porosity of the rubble pile material was able to convert low-shock events into high temperature spikes, sufficient to reset and/or partially reset the $^{40}Ar/^{39}Ar$ chronometer (*2*) in some material.

In summary, we propose that Itokawa's parent body was disrupted ca. 4.2 billion years ago in a process involving heterogenous temperature distribution during the impact. Some of the heated material, mixed with cold material, cooled down inside a larger version of Itokawa, possibly over a period of ca. 100 Ma. Itokawa kept being bombarded and eroded by small impactors since its formation with some of these events recorded by the $^{40}Ar/^{39}Ar$ system.

References

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