SOLAR ENERGETIC PARTICLE TRACKS IN ITOKAWA SAMPLES: IMPLICATIONS FOR REGOLITH DEVELOPMENT ON NEAR-EARTH ASTEROIDS AND SPACE WEATHERING.

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Introduction: JAXA's Hayabusa mission returned the first surface samples from a near-Earth asteroid for laboratory analyses. The Hayabusa samples thus provide a special opportunity to directly investigate the evolution of asteroidal surfaces, from the development and evolution of the regolith to the study of space weathering effects. The lack of a protective atmosphere on airless bodies results in regolith grains being exposed to a wide range of radiation sources and effects. We focus here on solar energetic particles (SEP) with Z>20, mainly Fe group nuclei, that leave trails of ionization damage (tracks) in insulating materials that accumulate with time and provide clues about the near-surface exposure age of regolith materials.

Methods: We measured SEP track densities in a total of 7 Itokawa particles, 3 olivine-dominated particles and 4 plagioclase particles [1,2]. For these measurements, we count the number of tracks in areas of uniform contrast in the scanning, transmission electron microscope (STEM) images and report the values in the traditional notation of number of tracks/cm^2. Focused ion beam (FIB) sections are preferable to microtome thin sections because they allow larger areas of uniform contrast to be scanned for tracks. Even with the size of typical FIB sections there are practical limits to the miminum track density than can be accurately measured, e.g., 1 track in 10 μm^2 is equivalent to a density of 10^7/cm^2 and is our lower limit of detection.

Exposure ages are calculated from the observed track densities using a track production rate of 4.4x10^4/cm^2/y at 1 AU determined for TEM measurements [3]. An additional correction needs to be applied to account for the elliptical orbit of Itokawa which has its perihelion (0.95 AU) just inside Earth's orbit and an aphelion (1.69 AU) slightly beyond Mars. We use a 1/r$^{1.7}$ model [4] to account for the decrease in SEP track production as a function of heliocentric distance for the parts of Itokawa's orbit that are beyond 1 AU to better estimate the track accumulation and inferred exposure age of Itokawa regolith grains.

Results and Discussion: In Table 1, we present the SEP track data for ~15 Itokawa particles, their mineralogy, and measured track densities, from our studies and from other workers [1,2,5-8]. Table 1 includes the estimated surface exposure ages that we calculated from the the observed track densities in each particle. The average track density of the Itokawa particles in Table 1 is ~1.5x10^9/cm^2, and ranges from a high of 5x10^9/cm^2 down to particles without TEM detectable tracks, i.e., $\lesssim$10^7/cm^2. Three particles (RA-QD02-0211, RA-QD02-0125, and RA-QD02-0192) show pronounced track gradients [9] that suggest they either maintained a relatively stable orientation in the Itokawa regolith as small grains, or that they accumulated tracks while part of larger objects (e.g., boulders) that were subsequently impacted or abraded to release smaller fragments.

The combined effects of the low gravity on asteroidal bodies, the high flux of non-catastrophic collisions [10], and tidal shaking from planetary encounters [11] predict short surface exposure times for asteroid regolith grains. These predictions are borne out by our calculated exposure ages where the average SEP track-based exposure age is ~50,000y and the longest exposure recorded is ~160,000y (Table 1). We predict that other near-Earth rubble-pile asteroids (e.g., Bennu and Ryugu) will show similar, relatively short SEP exposure ages. These results also provide important constraints on space weathering rates on S-type asteroids. Provided the track densities recorded by the Itokawa grains are representative of the fine-grained regions of Itokawa, then the space weathering rate to convert its reflectance spectrum to that of an S-type asteroid is also on the order of ~50,000y [9].

Table 1. Observed SEP Track Densities in Itokawa Grains

Particle	Host	t/cm^2	Age (y)	Ref
RA-QD02-0211	olivine	3.4x10^9	109000	[1]
RA-QD02-0192	olivine	2.9x10^9	93000	[1]
RA-QD02-0125	olivine	1.4x10^9	45000	[1]
RA-QD04-0090	plagioclase	5.0x10^9	161000	[2]
RA-QD04-0074	plagioclase	6.0x10^7	2200	[2]
RA-QD04-0058	plagioclase	1.0x10^9	32000	[2]
RA-QD02-0157	plagioclase	<1.0x10^7	<320	[2]
RB-QD04-0015	olivine	<1.0x10^9	<32000	[5]
RA-QD02-0009	pyroxene	2.0x10^9	64000	[5]
RA-QD02-0033	olivine	2.0x10^9	64000	[6]
RB-CV-0011	pyroxene	2.0x10^9	64000	[7]
RA-QD02-0205	pyroxene	<1.0x10^7	<320	[8]
RB-QD04-0092	pyx+oliv	9.6x10^8	31000	[8]
RB-CV-0192	pyroxene	<3x10^8	<9600	[8]
RB-CV-0144	pyroxene	1.4x10^8	4500	[8]

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