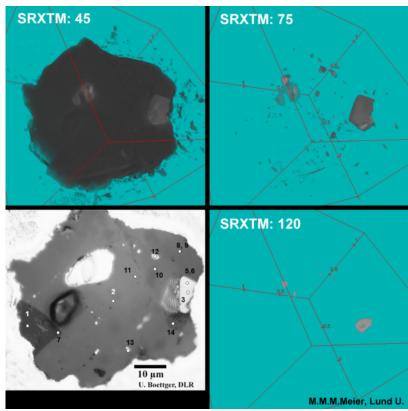
THE MASS, MORPHOLOGY, AND INTERNAL STRUCTURES OF THREE PARTICLES FROM THE HAYABUSA SAMPLE RETURN MISSION, ANALYZED WITH SYNCHROTRON RADIATION X-RAY TOMOGRAPHIC MICROSCOPY. M. M. M. Meier¹, C. Alwmark¹, S. Bajt², U. Böttger³, H. Busemann⁴, J. Gilmour⁴, U. Heitmann⁵, H.-W. Hübers³, F. Marone⁶, S. Pavlov³, U. Schade⁷, N. Spring⁴, M. Stampanoni^{6,8}, I. Weber⁵. ¹Dept. of Geology, Lund University, Sölvegatan 12, 22362 Lund, Sweden (matthias.meier@geol.lu.se), ²Photon Sci./DESY, Hamburg, Germany, ³DLR, Planet. Res. Inst., Berlin, Germany, ⁴SEAES, Univ. of Manchester, UK, ⁵Inst. f. Planetologie, Univ. of Münster, Germany, ⁶Swiss Light Source, Paul Scherrer Inst., Villigen, Switzerland, ⁷Helmholtz-Zentr., Berlin, Germany, ⁸Inst. for Biomed. Eng., Univ. & ETH Zürich, Switzerland.

Introduction: The Hayabusa sample return mission, launched in 2003 by the Japan Aerospace Exploration Agency (JAXA), was the first ever space mission to sample material from an asteroid: the S-type, near-Earth asteroid (25143) Itokawa. More than 1500 particles, varying in size from <1 μm to 180 μm, were recovered from the uppermost regolith layer of the asteroid [1-3]. The main aim of this study is to determine a precise mass for three of these particles. The mass will then be used in a forthcoming study where the concentration of solar wind-derived, trapped, and cosmogenic noble gases of the individual particles will be measured [4]. Due to the small particle size (75-145 µm), a normal weighing procedure on a micro-balance would result in large errors (up to 100%) in the mass and thus also in the noble gas concentrations, as well as the cosmic-ray-exposure (CRE) ages derived from cosmogenic noble the volume of the constituent mineral length of 50 µm. phases (with known densities), using

synchrotron radiation X-ray tomographic microscopy (SRXTM). This also allows non-destructive studies of the morphology and internal structure of the particles. While Hayabusa particles have been studied with SRXTM before [5], none of the particles from this study have so far been analyzed.

Samples & Methods: Three particles from the Hayabusa sample return mission were analyzed in this study: RA-QD02-0035, RA-QD02-0049-01 and RA-QD02-0049-04, subsequently called 35, 49-1 and 49-4. The latter two are fragments of the largest particle (orig. diam. 180 μm) from Hayabusa so far analyzed.



gases. A precise mass, combined with Figure 1: Comparison of SRXTM images (turquoise background) with mithe detection limit of the noble gas croscope image (lower left). The view is orthogonal onto the polished surspectrometer used, allows the determination of the minimum cosmic-ray-exphases visible) clockwise to lower right (120; only metal grains visible), posure age that could still be resolved. Progressively hiding mineral phases with low X-ray-attenuation coefficients. A unit distance on the grid in the SRXTM image corresponds to a the volume of the constituent mineral length of 50 um.

The particle has been neutron-activated [6], and these two fragments will therefore not be used for cosmogenic noble gas analysis. Particle 35 is a space-weathered grain with subsurface Fe,S nanospherules [7] and has been analyzed with SIMS for O isotopes [8]. Each of the three particles was mounted separately on a 300 µm diameter, PVDF fluorocarbon thread using a commercial, heptane-disolvable spray-on glue. The thread was inserted in a capillary made of low-X-ray-absorbing borate glass with 700 µm inner diameter, and analyzed using SRXTM at the TOMCAT beam-line of the Swiss Light Source at the Paul Scherrer Institute,

Switzerland. Two different beam energy settings were used: 10 and 20 keV, the latter for a better resolution of mineral phases with high X-ray attenuation coefficients. The tomographic reconstructions based on the raw X-ray images were carried out on a 30-node Linux PC cluster using a gridding procedure and a highly optimized Fourier transform routine [9]. The cubic voxel size of the reconstructed images is 325 nm.

Table 1: Volumes, densities and masses

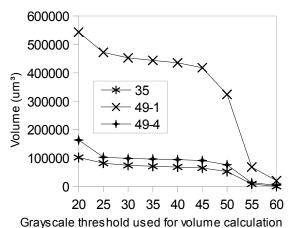
Grain	V (1000 um ³)	ρ (g/cm ³)	M (µg)
35	72.1±2.9	3.63 ± 0.03	0.26 ± 0.01
49-1	444±9		1.61 ± 0.04
49-4	96.9±1.9		0.35 ± 0.01

Table 2: Mineral production rates

Mineral	%	ρ	$P3_{max}$	$P21_{max}$	$P38_{max}$
Forsterite [MgSiO ₄]	68- 73	3.27	1.20 (8 – 12)	0.396 (12 – 16)	0.00 N/A
Fayalite [FeSiO ₄]	26- 31	4.39	0.866 (4 – 8)	0.0400 (8 – 12)	0.0217 (0 - 4)
Metal [Fe _{0.95} Ni _{0.05}]	1	7	0.638 (0 – 4)	0.00917 (0 - 4)	0.0394 (0 – 4)
LL olivine	100	3.63	1.07	0.261	0.0082

Maximum production rate (in 10⁻⁸ ccSTP/gMa). The corresponding burial depth (in cm) in brackets.

Results & Discussion: Morphology & Internal structure: Since 49-1 and 49-4 are fragments of a larger grain, their surfaces are angular, while 35 has been polished flat on one side. All particles contain spheroid inclusions of a material with high X-ray-attenuation, probably troilite or Fe,Ni-metal (Fig. 1)[11]. Volume & Mass determinations: The reconstructed data sets were 3D rendered, and the volume of the different phases of each particle was calculated, using the freely available image processing program Fiji [11] and the "3D object counter" plug-in [12] for Fiji, respectively. The plug-in identifies 3D-connected objects with a gray-scale value higher than a given threshold, within an allocated image stack. While the volume will depend on the threshold, a sloped "plateau" is visible in Fig. 2. The adopted volume (Table 1) is the average of five values on the plateau (25-45), the error is the corresponding standard error (σ/\sqrt{n}) . For the density, while we will eventually use the results from Raman / FTIR [4][11] once available, here we adopt the density of olivine with a Fa-number (26-31%) typical for LL chondrites, as observed by [3] for other Hayabusa olivine grains. Grains 49-1 and 49-4 have been determined to be almost monomineralic olivine [6], while for grain 35, some plagioclase and high-Ca-pyroxene is also present [7]. However, the volumetric contribution



Grayscale unestion used for volume calculation

Figure 2: Volume determination for the 3 particles.

of these phases proved to be negligible (<1%). In Table 2, we list the calculated maximal mineral production rates in Fo, Fa and metal for the cosmogenic noble gas isotopes ³He, ²¹Ne and ³⁸Ar. All values are based on the model by [13] for an object with 500 cm radius (the largest available in that model). Future detection of cosmogenic He, Ne: Typical detection limits of the ultra-high sensitivity, compressor-source noble gas mass spectrometer at ETH Zurich are (in units of 10⁻¹⁵ cc-STP) 0.5 for ³He, and 0.6 for ²¹Ne [14]. Given the inferred masses of the three particles, and the mineral production rates in Table 2, the shortest measurable CRE ages are 0.17, 0.03, 0.13 Ma for ³He, and 0.88, 0.14, 0.65 Ma for ²¹Ne, from particles 35, 49-1 and 49-4 respectively. However, the biggest obstacle to a precise determination of the cosmogenic noble gas content is the presence of solar-wind-derived noble gases [15]. We are currently studying possible techniques to remove the outermost ~1 µm of a particle, which contains the majority of the solar-wind-implanted ions.

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