Shocked regolith in asteroid 25143 Itokawa surface

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A major milestone in space exploration was to achieve the first sample return from an asteroid by the Japanese Space Agency (JAXA) [1]. The detailed images of asteroid 25143 Itokawa transformed a faint point of light seen by telescope into an intrincated rubble-pile asteroid, with a complexity that exemplifies the type of challenging bodies we need to confront as source of hazard to humans. These bodies surrounding our planet exhibit challenging properties because they have been exposed over the eons to space weathering processes and numerous impacts. As a consequence, their crumbly surfaces are covered by small particles, pebbles, and boulders [1]. The Japanese JAXA/ISAS Hayabusa mission collected micron-sized particles from the regolith of asteroid 25143 Itokawa [2]. We have studied some regolith grains using different analytical techniques in our Meteorite and Sample Return Clean Lab at the CSIC Institute of Space Sciences in Barcelona in order to unveil some of the processes in which they were formed [3].

There is an important debate about the dominant physical processes at work in the surface of these bodies. Certainly Near Earth Asteroids (NEAs) are exposed to short-perihelion approaches that produce significant thermal stress changes in the rock-forming minerals present in their surfaces. Nowadays, it is usually considered that most small regolith particles are produced by thermal fatigue [4], but obviously impacts should play an important role over longer time scales. Fine-grained regolith could be useful to apply future In Situ Resource Utilization (ISRU) tests in NEAs, so there is specific interest in deciphering the most dominant mechanisms. Then, which of these two mechanisms dominates the production of regolith over a body like Itokawa?. This can be tested in a non-destructive way, just by studying the silicate phases using Raman spectroscopy. Itokawa asteroid is a nice example of a rubble pile and its surface consists of heterogeneously distributed boulders, large rocks and pebbles: In addition, some regions contain fine-grained regolith made of pounded stones and small grits (Saito et al, 2006). A particularly useful mineral to infer the existence of shock is olivine, as pointed out by Harriss and Burchell [5].

We have studied 3 Itokawa particles provided by JAXA with numbers S14, S23 and S47 were investigated (Table 1). The polished upper sides of the three particles are shown in Figure 1. To study their specific mineralogy the samples were analyzed by SEM/EDX (Quanta 650 FEG equipped with EDX Inca 250 SSD XMax20 detector). To identify possible shocked minerals several regions of interest (ROIs) were defined. Then we have performed Micro-Raman spectra using a spot size of about 1 µm and a laser power of 0.6 mW cm-2. We studied carrefully the chemical and mineralogical structure to get some clues on their shock history. Raman spectra were taken at room temperature using the 5145 Å line of an Argon-ion laser with a Jobin-Yvon T-64000 Raman spectrometer attached to an Olympus microscope, and using a CCD detector cooled by liquid nitrogen. We concentrated in the silicate phases, so we decided to acquire the spectra in a working window between 100 and 1400 cm^{-1}. From the EDX images and the peaks found in the Raman spectra we are able to distinguish the major rock-forming minerals (Fig. 1).

Table 1. Catalog numbers, maximum size and composition of the studied regolith samples.

Sample#	**Size (µm)**	**Main mineral phases**
RA-QD02-0014	131.2 ± 0.1	Olivine, low-Ca pyroxene, plagioclase
RA-QD02-0023	149.4 ± 0.1	Olivine, troilite
RA-QD02-0047	108.0 ± 0.1	Olivine, low-Ca and high-Ca pyroxene

As the main results of the study of the selected ROIs, our Raman spectra of olivine, found for two out of three grains, show two drifted peaks P1=820 cm-1 and P2=850 cm-1 which are considered characteristics of a shocked phase [6]. A Raman spectrum for S14 particle is shown in Fig. 1. The precise peak location depends on the forsterite (Fo) and fayalite (Fa) content of the olivine [7,8]. A Raman spectrum for S14 particle is shown in Fig. 1. The precise peak location depends on the forsterite (Fo) and fayalite (Fa) content of the olivine [8-9]. In any case, Harriss and Burchell suggested that shocked olivines above 65 GPa exhibit permanent shifts in the 820 and 850 cm^{-1} peaks in their Raman spectra [5].

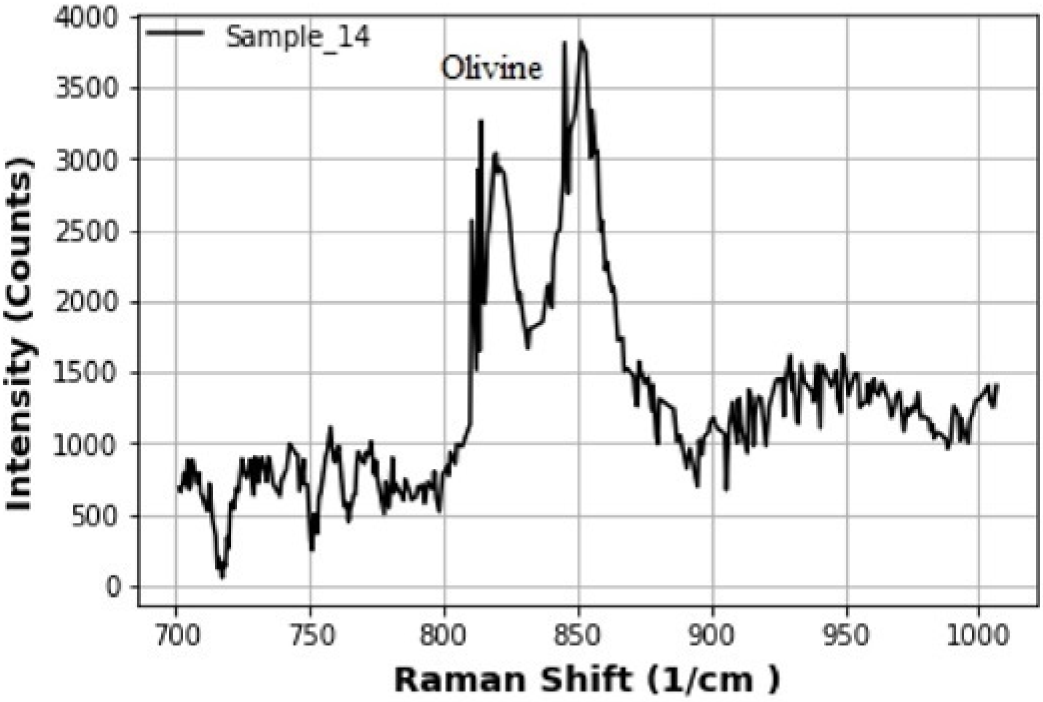

Figure 1. Raman spectrum obtained for olivine in sampleRA-QD02-0014

In conclusion, the shock experienced by Itokawa's regolith grains can be inferred from the deformation found in the lattice of the olivine grains. Our Raman study of three particles seems to indicate that a significant fraction of these grains could have experienced collisional processing. Obviously the number of studied grains so far is not statistically significant, but this finding could encourage other groups to complete a more comprehensive study. If these preliminary results are correct, a significant fraction of the regolith particles collected in the Muses Sea were shocked, and fragmented by impact excavation more than by thermal fatigue. In fact, such scenario is likely because nano-indentation studies we performed on these grains [1] seem to point that the minerals exhibit similar mechanical properties than ordinary chondrites of similar composition [3].

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