EPSC Abstracts
Vol. 7 EPSC2012-581 2012
European Planetary Science Congress 2012


# Regolith formation on asteroids via thermal fatigue

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## Abstract

Space-based [12] and remote sensing observations [4] reveal that regolith – a layer of loose unconsolidated material – is present on all asteroids, including very small, sub km-sized near-Earth asteroids (NEAs) such as (25143) Itokawa [7].

Classically, regolith is believed to be produced by impacts of small particles hitting asteroid surfaces. Such explanation works for bodies whose gravity field is strong enough for substantial reaccretion of impact debris, but it fails to account for the ubiquitous presence of regolith also on small asteroids with weaker gravity.

Several works [6, 5, 10] have proposed that the thermal fatigue due to a huge number of day/night temperature cycles is a process responsible for the formation of regolith on the Moon, Mercury, and on the NEA (433) Eros by fracturing boulders and rocks on their surfaces. However, this process lacks a demonstration.

Here we present laboratory experiments of thermal cycling of meteorites – taken as analogue of asteroid surface material – to study under which conditions rock cracking on NEAs occurs.

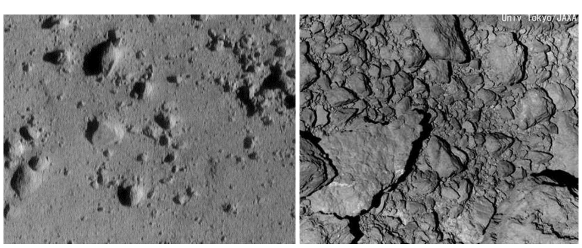

Figure 1: Regolith on NEAs from direct imaging. **Left panel**: the 30 km-size asteroid (433) Eros – the second largest NEA observed by the NASA NEAR Shoemaker mission [12]. **Right panel**: the 0.35 km-size Itokawa, visited by the JAXA Hayabusa spacecraft [7].

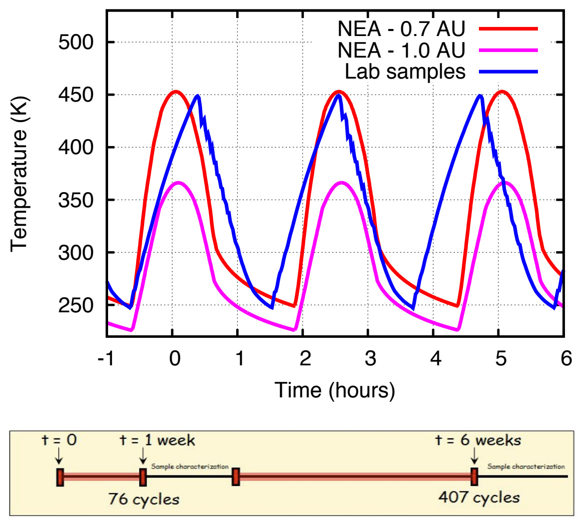


Figure 2: **Top:** The temperature cycling of the laboratory experiments (blue) compared to the typical temperature cycling experienced by NEAs at 1 AU (pink) and at 0.7 AU (red). **Bottom:** The laboratory experiment protocol. Sample characterisation is performed when t = 0 (t1), after 1 week (t2) and after 6 weeks (t3).

## 1. Laboratory Experiments

We performed laboratory experiments of temperature cycles on meteorites. Samples of the Murchinson meteorite (CM) were exposed to 410 temperature cycles between 243 and 410 K with a period of about 2.2 hours in a climatic chamber (Fig. 2). This temperature range is typical for the large majority of NEAs, including Eros (Fig. 2).

The growth of fractures – due to thermal fatigue – is expected to change the density of the samples as a function of the number of cycles. We used X-ray computer tomography (CT) to measure the density of our samples, initially (t1), after one week (t2) and after six weeks (t3) of temperature cycles.

## 2. Analysis of Experiments

To compare tomographic sections at different times the volumes had to first be accurately aligned and scaled to the same resolution. To do this, several markers (distinctive features) in the meteorite were identified within the volumes at t1, t2 and t3. Using the 3d coordinates of these markers a transformation matrix was found to align the volumes at t2 and t3 to the volume at t1 (See Fig. 3 for examples of aligned volumes at t1 and t3).

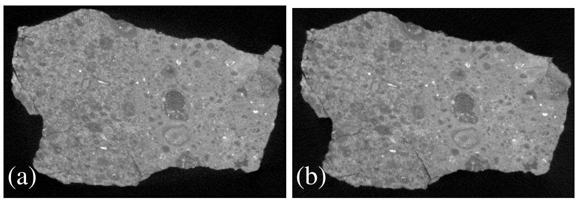


Figure 3: Tomographic sections of the Murchinson meteorite sample (a) before and (b) after 6 weeks.

Once aligned, the cracks within the tomographic sections were identified via a series of image analysis operations. This finally produces a binary mask showing the location of the voids within the volume. Shown in Fig. 4 are the voids detected in the Murchison meteorite at t1 and at t3. Two important features can be noticed. First, in the top right of the image, macrosopic parts have detached during the process of thermal cycling. Second, the fractures that existed in the meteorite at t1 have grown in size at t3.

To quantitatively compare the volume of cracks in t3 compared with t1, a closed binary mask was used. This closed mask has the form of the tomographic section at t3 but is slightly reduced in size. We then calculate the area within the closed mask at both t3 and t1, which consists of voids. This process is repeated for every 2D section within the tomographic volume.

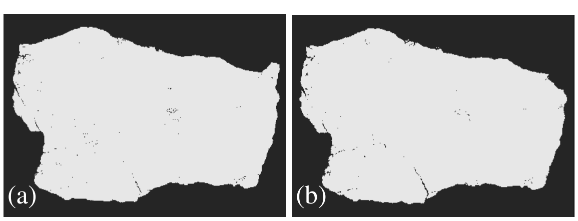


Figure 4: Binary masks showing the voids within the volume for tomographic sections of the Murchinson meteorite sample (a) before and (b) after 6 weeks. Note the part on the top right of the mask present in (a) that has disappeared in (b).

## 3. Summary and Conclusions

We performed laboratory experiments of thermal cycling of a meteorite using a value of the temperature time gradient that is similar to the large majority of NEAs. We have also presented the techniques used to analyse our experimental data. Our preliminary results show that fractures are developing within the CM chondrite as the thermal cycling progresses. This suggests, therefore, that thermal fatigue cracking is a process capable of regolith formation on NEAs analogous to CM chondrites.

## Acknowledgements

Part of this work is supported by a grant from the French National Research Agency, contract ANR-BS56-008, project Shocks. We also acknowledge the french PNP and the BQR program of OCA for their financial support.

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