

DIFFERENT EFFECTS OF THERMAL FATIGUE ACTING ON LUNAR AND HED SAMPLES.

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Introduction: Regolith evolution on airless planetary surfaces needs to be understood at the spatial scale from meters to microns. Diurnal temperature variations due to insolation on airless planetary surfaces is a common feature of planetary systems that can play a relevant role in regolith nature and evolution [e.g., 1-5], but is not fully understood. We describe a laboratory experiment designed to address open questions and present results obtained on the lunar anorthosite breccia Northwest Africa (NWA) 11273 and the eucrite Northwest Africa (NWA) 11050.

Diurnal temperature excursion: Diurnal temperature variations lead to stresses with a complex spatiotemporal pattern [5,6]. Crack propagation due to these stresses leads to block erosion and, together with meteoroid impacts [e.g., 7], transform a blocky surface into fine regolith. Recent observations have shown how surfaces of small bodies thought to be covered by cm-scale particles [e.g., 8] are blocky in nature with unexpected thermal behavior [9-11], requiring a better understanding of thermal fatigue acting on the evolution of airless surfaces. [2] have shown how meteorites subjected to thermal cycling (250-440K) develop grain-to-grain thermal fatigue with consequent cracks grow observable in micro computed tomography (micro-CT) scans. We changed the setup to investigate aspects previously not considered including effects due to different meteoritic components and their distribution [e.g. 12-14], avoiding terrestrially altered samples whose metal is oxidized resulting in a volume change [15], lower temperatures covering conditions on asteroids (i.e., 210-240K) and how water-bearing samples react to this [e.g., 16], and cycling under high vacuum to remove the atmosphere.

Experiment design: The experiment is based on an evacuated cryostat cooled with liquid nitrogen to remove most water molecules adsorbed on surface and allows the thermal conductivity of porous samples to be primarily controlled by the abundance of cement between grains [19]. Sample cubes, previously investigated by scanning electron microscopy (SEM) to proof their low degree of terrestrial weathering with sizes of $\sim 10 \times 10 \times 10$ mm³ are placed on a copper cold finger. To maintain optimal thermal conductivity between the cold finger and the sample a thermal grease is applied. Temperatures are measured on the bottom and the top of the cold finger, and on a monitor sample 10 mm wide (El Hammami, H5; i.e. Fig. 1). A

cartridge heater with a maximum power of 100W is installed at the base of the cold finger and is able to heat the cold finger to a maximum of 475K. The temperature measured inside the monitor sample allow us to ensure successful heat conduction through the samples and verify the temperature ranges.

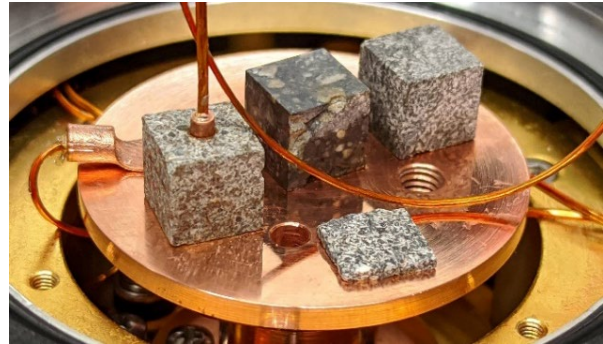


Fig. 1: Cu-coldfinger inside the vacuum chamber with the monitor sample (left) and the attached thermocouples. Crack monitoring is performed on the two additional cubic samples. The thin sample is a reference for additional thermography.

Results and Implications: The selected samples have been cycled between 175 K and 375 K in the evacuated cryostat with a ramping rate of ~ 2 K/min and investigated after 10, 20, 50, 100, and 400 total cycles. The low vacuum SEM images revealed different types of changes on the sample surfaces: (a) smaller flakes that move from run to run and eventually are lost or relocated; (b) larger parts that move or rotate; and (c) cracks forming and increasing in their length and width. The lunar anorthosite breccia NWA 11273 and the eucrite NWA 11050 somewhat differ in their response to the thermal cycling experiment. On NWA 11273, mainly flakes of different sizes (< 5 to ~ 30 μm) are moved or lost possibly either due to handling and transportation and/or by electrostatic charging during electron bombardment at the SEM. No crack formation nor crack extension on the surface of the lunar anorthosite breccia NWA 11273 has been observed after as many as 400 total cycles. Similar to NWA 11273, flakes of various size have been observed to be relocated or getting lost after additional runs on the surface of eucrite NWA 11050. There is also no indication that these flakes are limited to a specific mineralogy within the sample. In contrast to NWA 11273, the formation

and extension of cracks on the surface of the eucrite NWA 11050 can be observed after already 20 cycles (Fig. 2). The width of the newly formed cracks and the absolute growth in width for existing cracks is always $<10\text{ }\mu\text{m}$ after 400 cycles.

Usually, cracks propagating through the sample do not crosscut individual larger grains but often open up around the grain boundaries to the surrounding matrix material or other. In both samples, no structural changes in their interior have been observed by μ -CT with voxel resolution of $15\text{ }\mu\text{m}$ that are above the background noise indicating the absence of larger cracks in the interior of both samples.

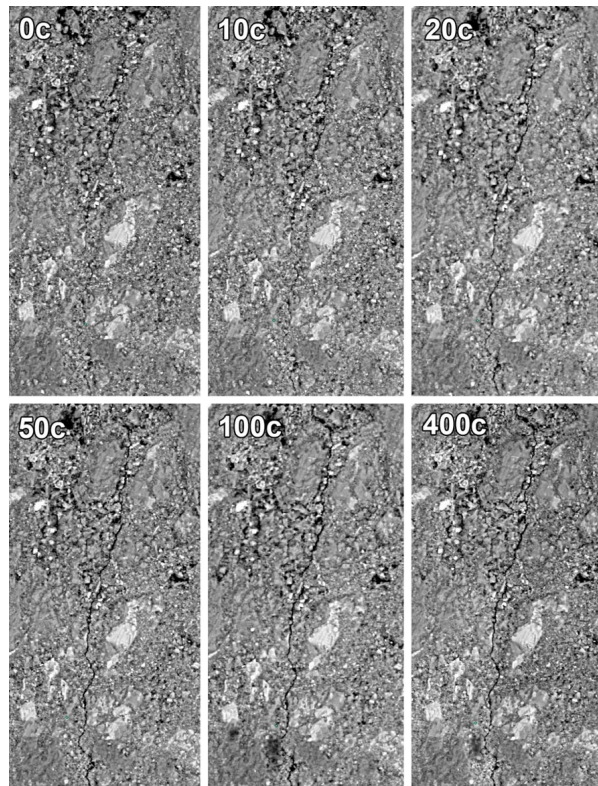


Fig. 2: Area of NWA 11050 eucrite showing a crack that successively opens up to a maximum of $\sim 5\text{ }\mu\text{m}$. Image width is $\sim 200\text{ }\mu\text{m}$. The crack was already visible in the untreated sample (0c) with a width of $\sim 1\text{ }\mu\text{m}$, but clearly widens up after 20 total cycles and extends southward. Image in backscattered electrons.

These preliminary results indicate, that eucrite (breccias) seem to be affected by thermal fatigue to different degrees than lunar anorthosite (breccias). This difference is possibly related to the maturity of the investigated material: NWA 11273 is highly reworked regolith from the Moon also including larger amounts of impact-related glasses that are wide-spread in the

sample. Although NWA 11050 is also brecciated, the amount of impact glass is much lower. This includes the lower crack width as well as the overall lower crack length. Since we are able to detect cracks on the surface with a resolution of $\sim 0.3\text{ }\mu\text{m/px}$, our method is able to detect incipient crack formation very early in contrast to methods having a lower resolution. Preliminary results indicate that the crack formation in the eucrite sample is possibly lower than proposed by [3] for CM chondrites and possibly also for ordinary chondrites. Similarly, the absence of new cracks in the lunar anorthosite is also not favoring the proposed (minimum) crack propagation rates and the required time for rock breakdown for lunar conditions. These observations might be due to the difference in mineralogy, terrestrial alteration, or the use of an evacuated experimental chamber removing remaining gas and most of the adsorbed water from the samples. The exact extent of the individual differences on the rate of crack formation is still unclear. Follow-up studies re-investigating ordinary, CM and other chondrites are required to verify and further precise the current findings for other solar system materials.

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