SURVIVAL TIMES OF METER-SIZED ROCK BOULDERS ON THE SURFACE OF AIRLESS BODIES.

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Introduction: This study considers the survival times of meter-sized rock boulders on the surfaces of several airless bodies. As the starting point, we employ estimates of the survival times of such boulders on the surface of the Moon by [1], then discuss the role of destruction due to day-night temperature cycling, consider the meteorite bombardment environment on the considered bodies in terms of projectile flux and velocities and finally estimate the survival times.

Survival times of meter-sized rocks on lunar surface: The survival times of hand specimen-sized rocks exposed to the lunar surface environment were estimated based on experiments modeling the destruction of rocks by meteorite impacts, combined with measurements of the lunar surface meteorite flux, (e.g.,[2]). For estimations of the survival times of meter-sized lunar boulders, [1] suggested a different approach based on analysis of the spatial density of boulders on the rims of small lunar craters of known absolute age. It was found that for a few million years, only a small fraction of the boulders ejected by cratering process are destroyed, for several tens of million years ~50% are destroyed, and for 200-300 Ma, ~90 to 99% are destroyed. Following [2] and other works, [1] considered that the rocks are mostly destroyed by meteorite impacts.

Destruction of rocks by thermal-stress. However, high diurnal temperature variations on the surface of the Moon and other airless bodies imply that thermal stresses may also be a cause of surface rock destruction. Delbo et al. [3] interpreted the observed presence of fine debris on the surface of small asteroids as due to thermal surface cycling. They stated that because of the very low gravity on the surface of these bodies, ejecta from meteorite impacts should leave the body, so formation there of fine debris has to be due to thermal cycling. Based on experiments on heating-cooling of cm-scale pieces of ordinary and carbonaceous chondrites and theoretical modeling of expansion of the cracks formed they concluded that thermal fragmentation breaks up rocks larger than a few centimeters more quickly than do micrometeoroid impacts. According to them at 1 AU distance from the Sun the lifetime of 10 cm rock fragments on asteroids with a period of rotation from 2.2 to 6 hours should be only ~10^3 to 10^4 years and the larger the rock the faster it gets destroyed.

But although [3] are obviously correct stating that impact ejecta should leave small asteroids, the low-velocity part of escaping ejecta will mostly stay in orbits close this given asteroid and part of them will eventually return to it. Moreover, directly beneath the impact point the target rock should be fractured and crushed but may not leave the body (Figure 1). These two points question the conclusions of [3].

Observations of lunar rocks of known age of surface exposure. We check the validity of estimates of [3] for the 1 AU asteroids through observations of rock fragments on the Moon which is also at 1 AU from the Sun and thermal cycling on its surface is strong. The thermal cycling period on the Moon is 708 hours, longer than the 2.2 to 6 hours assumed by Delbo et al. for asteroids. So for our comparisons we measure time not in years, but in number of thermal cycles. Then, the estimates by Delbo et al. of the survival times of several-centimeter-sized rocks on asteroids, are ~3.5 x 10^6 to 1.5 x 10^7 thermal cycles correspondingly.

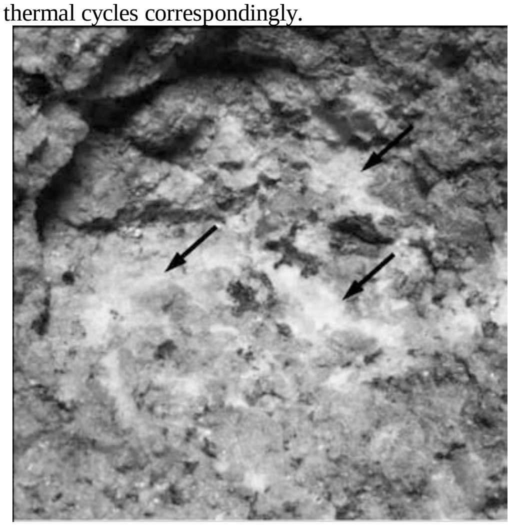

Figure 1. Crater ~5 cm in diameter formed in the 10x10x10 cm granodiorite cube by the horizontal impact of a 3.2 mm diameter stainless steel sphere at 5.47 km/s. Whitish coloration of the central part of the crater floor (arrows) is due to the presence of finely crushed target material.

We discuss two types of lunar rock fragments: 1) Rocks ~20 cm across that are close to the sizes considered by [3]; so if the survival time estimates of these authors are correct, one should expect that, when these values are reached, the rocks have to be destroyed. 2) Rock boulders of 3 to 5 m across; for these one should expect that when the survival time for the several-centimeter-size rock is reached, the several-centimeter-thick surface layer of these large blocks has to be destroyed and form a fillet at the boulder base. Figure 2 and 3 show an example of the rocks of the first type and Figure 4 - an example of the second type.

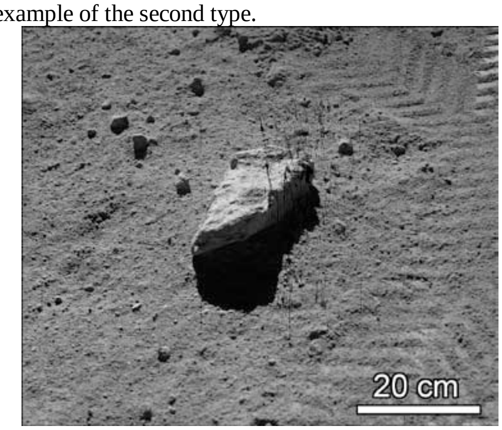

Figure 2. a) The 20-cm rock 67016 on the rim of 50 Ma-old North Ray Crater, Apollo 16;

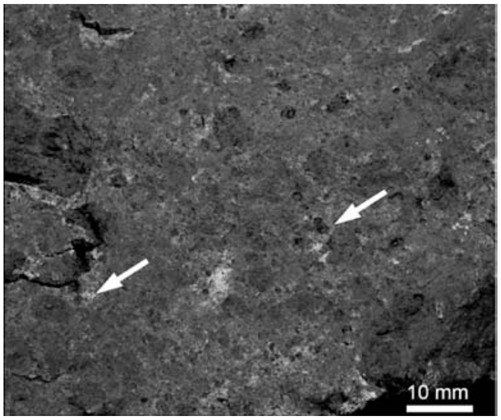

Figure 3. Microscopic view of the surface of rock 67016, arrows show microcraters .

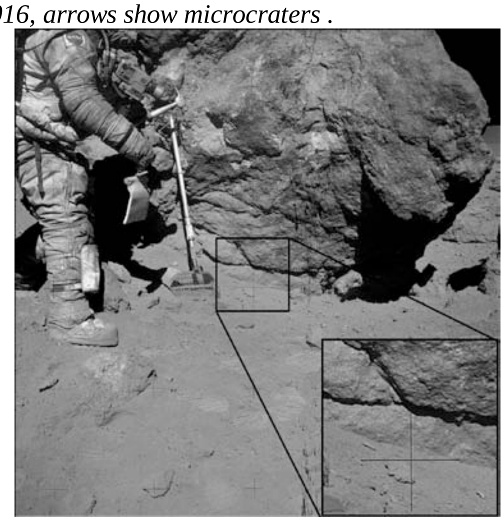

Figure 4. Part of the 5 m wide Outhouse Rock on the rim of 50 Ma-old North Ray crater, Apollo 16.

It is seen in Figures 2 and 3 that the 20 cm-rock shows no (or minor) fine fracturing and Figure 4 shows that the meter-sized rock shows no filets at their bases. The exposure ages of these rocks are ~ 50 Ma, that is ~3 to 7.5 x 10^8 thermal cycles - by 1.5-2 orders magnitude larger than the Delbo et al. estimates of the lifetime of the decimeter-sized rocks. So if their estimates were applicable to the lunar rocks, we should not see the 20-cm rock considered – they should be destroyed many times over, and the observed meter-sized Outhouse Rock should be surrounded by very prominent filets, which we do not see. So, on the basis of these observations, we conclude that the role of meteorite impacts in rock destruction is dominant while that of thermal cycling is secondary.

Calculations of meteorite flux, impact velocities and rock survival times on different airless bodies. Based on numerical modeling of orbital parameters taken from the complete catalog of 393,347 Main Belt, Trojans, and inner minor planets (as of November, 2014) considered as a proxy for the distribution of potential impactors, it was possible to estimate the meteorite flux and impact velocities for a number of airless bodies, including Phobos, Deimos, asteroids Itokawa, Eros, Vesta, Ceres, an average of the first 150 discovered Trojans and the planet Mercury. From these calculations, we deduced the survival times of meter-sized rock boulders on the surface of these bodies (see table below).

It is seen from the table that the mean survival times of meter-sized rock boulders on the atmospereless bodies considered differ by about three orders of magnitude. On the surfaces Phobos, Deimos and Itokawa they are close to those estimated for the lunar surface. On the surface of Mercury such rocks should survive for twice longer time. On the surface of Eros the mean survival time is estimated to be ~0.3 and on the surfaces of Vesta and Ceres ~0.03 from lunar values. On Trojans the mean life time is an order of magnitude longer than that on the Moon. These are estimates considering meteorite impacts as the major process of rock destruction. It is probably true for all considered bodies except Mercury, on which thermal cycling may also be important.

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References: [1] Basilevsky A.N. et al. (2013) *Planet. Space Sci. 89* 118–126. [2] Horz F. et al. (1975) *The Moon 13*, 235–238. [3] Delbo et al. (2014) *Nature 508*, 233-236.

Survival times of meter-sized rock boulders on the surface of considered atmosphereless bodies

Body	Meteorite flux			Impact velocity, m/s			Survival time		
	LH.	TH	Average	LH	TH	Average	LH	TH	Average
the Moon			1	15414	13458	14469			**1**
Mercury			0.12			29010			**~2**
Phobos	3.80	3.61		11651	7528		~0.4	~1	**~0.8**
Deimos	3.60	3.49		10890	8283		~0.5	~0.9	**~0.7**
Itokawa			4.31			7000			**~1**
Eros			13.52			7000			**~0.3**
Vesta			313			4659			**~0.03**
Ceres			320			4912			**~0.03**
Trojans			1.29			3602			**~12.5**

LH = Leading hemisphere, TH = Trailing hemisphere.