EVIDENCE FOR THERMAL FATIGUE ON MARS FROM ROCKFALL PATTERNS ON IMPACT CRATER SLOPES. P-A Tesson[1,2], S.J. Conway[2], N. Mangold[2], J. Ciazela[1], S. Lewis[3], and D. Mège[1]. [1]Space Research Centre, Polish Academy of Sciences, ul. Bartycka 18A, 00-716 Warsaw, Poland (pt@cbk.pan.wroc.pl), [2]Laboratoire de Planétologie et Géodynamique UMR 6112, CNRS, Nantes, France, [3]School of Physical Sciences, The Open University, Walton Hall, Milton Keynes MK7 6AA, United Kingdom.

Introduction: Individual block falls are one of the currently active surface processes on Mars. Similarly to Earth, clasts detach from upslope outcrops roll or bounce downslope, leaving a track on the substratum (Fig. 1). The trails show that the rockfalls are recent, as aeolian processes would infill topographic lows over time. Using rover-track erasure rates, these tracks are likely <100 ka.

On Earth, slope instability is usually caused by phase changes of H_2O [1]. However, solar-induced thermal stress could also play a key-role in rock breakdown leading to rockfalls [2]. Although liquid water is not stable at the surface of Mars today, sub-surface water ice is known to be present from mid- to high-latitudes [3]. Water ice and CO_2 seasonal frost on shadowed pole-facing slopes may exist at latitudes down to 30° [4] or less [5]. On the other hand, insolation-related thermal stress has been used to explain fracture orientation patterns in martian boulders observed by the Mars Exploration Rovers [6] and other studies suggest that it could cause rock breakdown on airless bodies [7]. Therefore, both phase transitions and solar-induced thermal stress are plausible mechanisms for rock breakdown and preconditioning slopes for rockfalls on modern Mars. In this study we analyze distribution of rockfalls on impact crater walls to assess whether one of these mechanisms could be involved in local rock breakdown.

Methods: We mapped the tracks left by rocks falling or bouncing from exposed outcrops in 45 impact craters in the equatorial to mid-latitude regions of Mars using Mars Reconnaissance Orbiter (MRO) High Resolution Image Science Experiment images (HiRISE) at 25-50 cm/pixel, Impact craters are widely distributed over the martian surface and can be used as sample sites to test the different factors controlling rockfall. Conveniently, they are circular and therefore allow an assessment of the influence of slope-orientation with respect to the sun. Here, we focus on relatively small (<10 km) and fresh impact craters (Fig. 1A) to reduce the influence of slope-inheritance from other long-term processes. To exclude that the observed trends are simply a function of asymmetries in slope steepness, we compared our rockfall distribution to slope angle for a subsample of 11 craters with 24 m/px Digital Terrain Model (DTM) derived from MRO Context camera (CTX) stereo-pairs using Ames Stereo Pipeline [8].

Figure 1. **Left**: A terrestrial rockfall example, Italy, 2014. (Credits: Markus Hell) **Right**: Rockfall example with a well-preserved track and 10 m wide clast. HiRISE image ESP_037190_1765. Credits NASA/JPL/UoA.

Results and Discussion: Mid-latitude craters have more numerous rockfalls on equator-facing slopes compared to pole-facing slopes and other orientations. At equatorial latitudes there are more rockfalls on N-S oriented slopes compared to E-W ones (Fig. 2). Comparison from rockfall patterns and slope angle analysis from our DTMs sub-sample indicates there is no systematic variation in slope angle with orientation that could explain the trends in Fig. 2.

Rockfall linked to phase changes should occur where water ice is expected to condense and/or be preserved from previous ice ages (i.e. on pole-facing slopes in the mid to high-latitudes and nowhere at the equator). Therefore, phase transitions of H_2O or CO_2 do not seem to play a role in present-day rockfall activity on Mars at these latitudes. Instead, the distribution of our rockfalls may be related to insolation (Fig. 2,3). To check this assessment we have computed direct solar flux over a HiRISE stereo-pair derived DTM resampled to 10 m/px available for Zumba crater (Fig. 3). Method for computation is derived from Earth solar geometry [9] adapted to Mars [10]. Thermal stress depends on temperature contrasts, and weathering rate is expected to be higher with higher solar flux. The stronger the daily solar flux is, the higher should be energy received by the material and its peak temperature. Our results reveal a correlation between potential daily temperature contrast (Fig.3A) in average and higher rockfall activity at mid-latitude (Fig.1). Yearly maximum of diurnal contrasts are also higher for equator-facing slopes at these latitudes (Fig. 3B). At the equator, our model predicts a more balanced

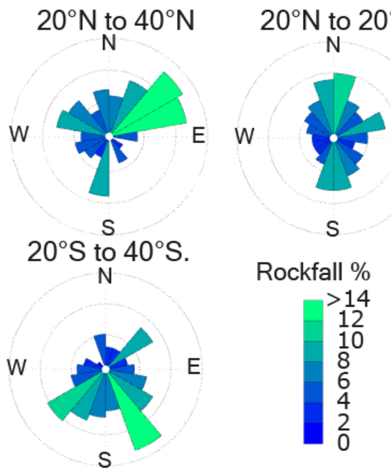

Figure 2. Standardized distribution of rockfall orientation in fresh impact craters for different latitude ranges (each bin is the mean percentage of rockfalls for a given orientation). This method tends to enhance craters with a low population of block.

value of average solar flux in every direction (Fig. 3A) which indicates no correlation between high block fall frequency and potential mean diurnal temperature contrast. However, the maximum mean solar flux is the highest on the south-facing slopes (Fig. 3B) which correlates to the strong rockfall activity recorded by our measurements (Fig. 2).

The lifespan of rockfall tracks is in the range of 50-100 ka, hence at a relevant timescale for changes in orbital parameters. While obliquity and eccentricity have varied relatively little over the last 100 ka [11], the precession cycle, which lasts ~50 ka [11] should be considered. At the opposite position of perihelion 25 ka, the north-facing slopes at the equator received maximum insolation during northern summer, as opposed to today. The precession cycles can therefore explain why, at the equator, we observe numerous rockfalls with tracks on both south and north-facing slopes (Fig. 2).

Conclusion: Our results indicate a latitude-dependence of recent rockfall frequency with respect to the orientation (Fig. 2). Topographic analysis of a sub-sample of craters shows no direct correlation between steep slopes in the source area and rockfall frequency. Thus, these trends are likely linked to the weathering mechanism responsible for rock breakdown prior to rockfall. The patterns we observe show that phase changes of H_2O or CO_2 do not play an important role in preconditioning slopes for rockfalls. Instead, our insolation model shows a good correlation between maximum insolation experienced by slopes and high rockfall activity. In order to explain the observed track distribution close to the equator the influence of precession cycles on insolation needs to be included (Fig. 2). Therefore, we advocate that thermal fatigue plays a key-role in rock breakdown and associated rockfalls.

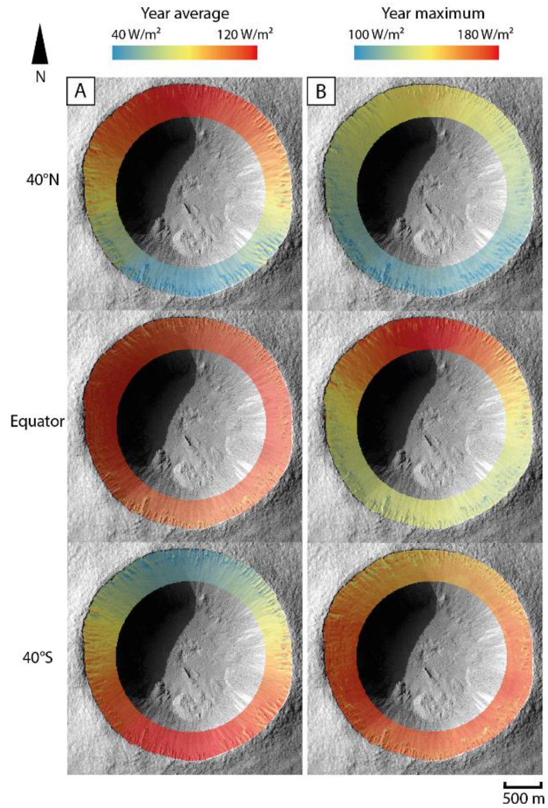

Figure 3. Results from insolation model over a HiRISE stereo-pair derived Digital Elevation Model of Zumba Crater reduced to 10m/px, at virtually different latitude. The model runs for specific sols at given solar longitudes for a whole martian year. **A**: Year average of the daily mean direct insolation in W/m². Equator-facing slopes display higher mean insolation at mid-latitude compared to pole-facing ones. At the equator, the mean insolation is balanced in every direction. **B**: Year maximum of the daily mean direct insolation in W/m². Equator-facing slopes display higher maximum insolation at mid-latitude compared to pole-facing ones. South-facing slopes experience a stronger peak of insolation compared to other part of the crater at the equator.

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References: [1] Prick, A. (2003) *8th International Conference on Permafrost*, Volume 2. [2] Do Amaral Vargas, E. et al. (2013) *Rock mechanics and rock engineering 46*(1). [3] Feldman, W. C. et al. (2004) JGR, 109(E9). [4] Schorghofer, N. and Edgett, K. S. (2006) *Icarus*. 180(2), 321–334. [5] Piqueux S. et al. *JGR 121*(7) 1174-1189. [6] Eppes, M.-C et al. (2015). *Nat. Comms. 6*, 6712. [7] Molaro, J. L. et al. (2017) Icarus, 294. [8] Broxton, M. J. and Edwards, L. J. (2008) *LPSC 41, #2364* [9] Fu, P., and P. M. Rich. (2002) *Computers and Electronics in Agriculture* 37:25–35. [10] Appelbaum, J. and Flood, D.J. (1990) *Solar Energy*, 45(6) 353-363. [11] Laskar, J. et al. (2004) *Icarus* 170(2) 343-364.