**Crater Formation and Shock Melt Production for the 17th March 2013 Lunar Impact Flash Event.** R. Luther¹, N. C. Prieur², K. Wünne mann¹ and S. C. Werner³, ¹Museum für Naturkunde Berlin, Leibniz Institute for Evolution and Biodiversity Science (Invalidenstraße 43, 10115 Berlin, Germany, robert.luther@mfn-berlin.de), ²Centre for Earth Evolution and Dynamics, University of Oslo, Norway.

**Introduction:** The small bodies flux in the size range of 10-50 m in the Earth-Moon System is suggested to be higher by one order of magnitude than predicted by current estimates based e.g. on the lunar crater record [1]. Thus, further observations are necessary for constraining the small body population. The method of ground based lunar impact flash observation covers a large detection area on the Moon with only one instrument. The size of an impactor is estimated by the intensity of the flash, which is related to its kinetic energy. However, the correlation of flash energy and duration with the impact process and impact energy is poorly understood. We use the unique example of the only detected impact crater that is assumed to correspond to an impact flash (March 17, 2013) [2] to study the vapor and melt production and to constrain the impactor energy based on the crater, including target properties.

![Figure 1: Measured and modelled crater profile. The best fit (bold line) corresponds to a projectile with a diameter of 0.575 m and a (vertical) impact velocity of 8.5 km/s. The other two lines correspond to a diameter of 0.525 and 0.65 m. Note, that depth counts from the top of the rim.](image1)

We assume a coefficient of friction $\mu = 0.40$. Due to the high crater efficiency (i.e. final crater diameter much bigger than the projectile size), a resolution of 10 cells per projectile radius (CPPR) was chosen. In a first series, the models were stopped when the transient crater was reached. The model that reproduced the observed depth and diameter best was used as a constraint for the kinetic energy of the projectile. In a second step, we re-ran models with the same kinetic energy but different impact velocities at higher resolution of 40 CPPR to study the peak shock pressure distribution. By correlating the shock pressure volume with the ejection flow, we determine the amount of melt that is ejected from the crater. The shock pressure required for melting of porous basalt is estimated to be 26.9 GPa or larger. Radiation originating from shreds of molten ejecta may also contribute to the observed bright impact flash [8] that is usually associated with vaporized projectile and target material.

**Methods:** We compare different recent LRO-NAC images and measure the rim diameter of the crater. From photoclinometry, we determine a crater profile and estimate the crater depth from the rim height. Based on these observational constraints, we model the crater formation with the iSALE 2D code [3,4,5] for various projectile masses and an impact velocity of 8.5 km/s to constrain the kinetic energy of the impact (Fig. 1). We assume a smaller velocity to minimize the CPU time required to run the models until a late stage of crater formation. The projectile material as well as the target are simulated with an ANEOS for basalt [6]. We assume a granular behaviour for the regolith target that we describe with a Drucker-Prager strength model with the strength $Y = \min (Y_0 + \mu \, p; \, Y_m)$, where $Y_0$ is the cohesion at zero pressure, $\mu$ is the coefficient of internal friction, $p$ is the pressure and $Y_m$ is the limiting strength at high pressure. According to literature values for lunar soil, we choose a coefficient of friction ($\mu=1.0$) [7]. The cohesion is set to zero, a typical estimate for sand-like material. Regolith porosity in shallow depth can be very high and we assume an average porosity of ~40%. Due to the high crater efficiency (i.e. final crater diameter much bigger than the projectile size), a resolution of 10 cells per projectile radius (CPPR) was chosen. In a first series, the models were stopped when the transient crater was reached. The model that reproduced the observed depth and diameter best was used as a constraint for the kinetic energy of the projectile. In a second step, we re-ran models with the same kinetic energy but different impact velocities at higher resolution of 40 CPPR to study the peak shock pressure distribution. By correlating the shock pressure volume with the ejection flow, we determine the amount of melt that is ejected from the crater. The shock pressure required for melting of porous basalt is estimated to be 26.9 GPa or larger. Radiation originating from shreds of molten ejecta may also contribute to the observed bright impact flash [8] that is usually associated with vaporized projectile and target material.

**Results:** The rim diameter of the crater is on average of $18.6 \pm 0.2$ m (1σ). From photoclinometry, we determine the maximum rim-to-floor crater depth of...
4.6 ± 0.6 m. The radial crater profile defined by 6 points between crater center and crater rim suggest a parabolic shape. A parabola fit gives: \( d(r) = 4.7r^2 - 4.4 \) with depth \( d \) and radius \( r \) \((R^2=0.94)\). We find a good agreement with our models in terms of rim diameter \((18.4 \text{ m})\) and depth \((4.4 \text{ m})\) for a projectile with a mass of \(285.9 \text{ kg}\) and a kinetic energy of \(1.03 \times 10^{10} \text{ J} \). For impact velocities of \(12 \text{ km/s}, 17 \text{ km/s}\) and \(21.2 \text{ km/s}\) (and consequently smaller projectiles) we find a volume of shock molten material of \(~0.39 \text{ m}^3\), \(~0.40 \text{ m}^3\) and \(~0.36 \text{ m}^3\), respectively, that equals about 0.3% of the crater volume (Fig. 2). A fraction of this molten material is ejected (Fig. 3). For lower velocities of about \(8.5 \text{ km/s}\) it is about 20% of the total melt, for all higher velocities (and smaller projectiles) it is about 30%.

**Figure 3:** Relative ejected melt volume to total melt volume for different impact velocities but constant kinetic energy (according to best fit model in Fig.1).

**Discussion:** Measuring the crater dimensions is limited by the resolution of the LROC-NAC images \((\sim1.2 \text{ m})\). However, measuring the diameter on several images by best fit circles improve our observational results even at sub-pixel resolution and we report the results with standard deviations for our measurements. The diameter measurement agrees within this standard deviation with the results from [3]. Our value of depth deviates from previous estimates by 1.6-2.6 m, possibly due to limited data resolution. The projectile characteristics we determined in the impact simulations agree with the previous mass and energy interval. Further studies including different target friction and the generation and expansion of a vapor plume are ongoing. We aim at further specifying characteristics of the impact plume (as e.g. amount of melt, or temperature of vapour) for several impact scenarios. A further important aspect that we plan to study is obliquity. The amount of molten material that is ejected might be different from our scenario of a vertical impact.

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