CRATER COUNTING ON SMALL BODIES – THE INFLUENCE OF TOPOGRAPHY-RELATED DISTORTIONS

T. Kneissl[1], N. Schmedemann[1], A. Neesemann[1], C.A. Raymond[2], C.T. Russell[3], [1]Freie Universität Berlin (Malteserstr. 74-100, 12249 Berlin, Germany, thomas.kneissl@fu-berlin.de), [2]Jet Propulsion Laboratory, Caltech, Pasadena, CA, USA, [3]University of California, Los Angeles, CA, USA.

Introduction: The investigation of crater size-frequency distributions (CSFDs) is a widely used and well accepted method to determine relative stratigraphic relationships and absolute surface ages of geological units on planetary bodies (e.g., [1], [2], [3]). On large planetary bodies precise measurements of crater diameters and measurement area sizes can usually be done in Geographic Information Systems (GIS) using, e.g., the CraterTools software extension for ESRI's ArcGIS [4]. The CraterTools software helps to avoid errors of crater diameters and measurement area sizes related to map-projection induced distortions.

Smaller bodies, like Vesta and Lutetia, the former recently visited by the Dawn spacecraft [5], are often characterized by proportionally large deviations of the actual surface from the reference body used for the map projection (see Figure 1). The deviations cause additional distortions in the projected image data independently of the used map projection. In order to measure precise CSFDs in GIS environments, the resulting distortions need to be considered and corrected before meaningful surface ages can be derived.

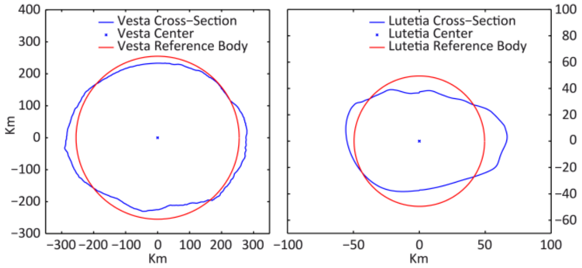

Figure 1: Global cross sections (blue lines) of Vesta (left) and Lutetia (right) in comparison with their reference bodies (red circles). Deviations range from -43 to +38 km on Vesta and -14 to +17 km on Lutetia.

Topography-Related Distortions: Crater diameters and measurement areas appear distorted in projected image data as a function of their elevation, i.e., the deviations of the actual surface from the reference body. Undistorted crater diameters can be calculated using:

$$D_u = \frac{D_d}{r} \times (r + E_c)$$

where D_u is the undistorted crater diameter, D_d the distorted diameter, r the radius of the reference body, and E_c the elevation of the crater rim above the reference body. In case of Vesta (reference sphere with a radius of 255 km) the distortion of crater diameters can amount to ~17%, whereas crater distortion on the much smaller asteroid Lutetia can amount to ~35% (see Figure 2).

Area distortion is the square of the length distortion. Consequently, true measurement areas can be calculated using:

$$A_u = \left(\frac{\sqrt{A_d}}{r} \times (r + E_a) \right)^2$$

where A_u is the undistorted area size, A_d the distorted area size, and E_a the elevation of the area above the reference body. Areas on Vesta can be distorted by up to ~32%, whereas area distortion on Lutetia can be as great as ~80%.

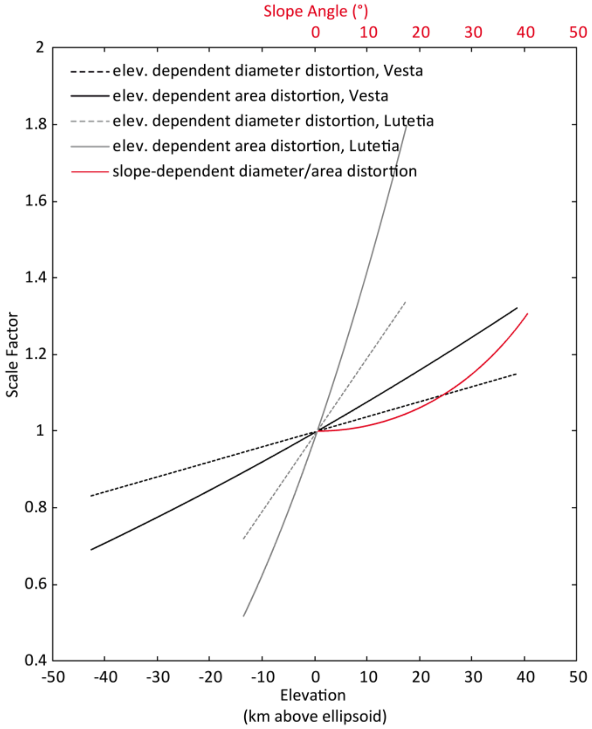

Figure 2: Topography related distortions of crater diameters and area sizes on Vesta and Lutetia. Scale factors as a function of elevation are shown in black (Vesta) and grey (Lutetia). Only the respective observed ranges of elevation are shown in the diagram. The scale factor as a function of slope is shown in red and is independent of reference body size.

In addition to the elevation-dependent distortion, the inclination of a measurement area relative to the reference body surface also influences the apparent dimensions of a measured feature. However, features are only distorted in the direction of the slope. Lengths/diameters perpendicular to the slope remain undistorted. Consequently, the scale factor for inclined areas equals the scale factor of the distorted axis of the craters and can be calculated using:

$$s = 1/\sqrt{\sin(90-\beta)^2}$$

where s is the slope-dependent scaling factor for the area and/or the distorted crater axis and β is the slope angle of the measurement area. Slopes on Vesta can reach up to ~40° [6] leading to an area/length distortion of up to ~30%.

Effect on Surface Ages: The influence of the distortions on the resulting surface ages depend, e.g., on the shape of the Production Function (PF) in the respective diameter range, the shape of Chronology Function (CF) in the specific age-range, or the binning of the crater data into diameter classes. Furthermore, the fitting-range for the PF, which is chosen by visual judgment, might also differ as a result of a varying shape of the CSFD-curves. As a consequence, the influence of the length/area scale errors on the resulting surface ages cannot be quantified in a general way and needs to be determined for each measurement separately.

Case Study: In order to demonstrate the influence of the elevation-related distortions on the derived surface ages we selected a measurement area located on Vestalia Terra, which represents a high-elevation plateau in the equatorial region of Vesta [6].

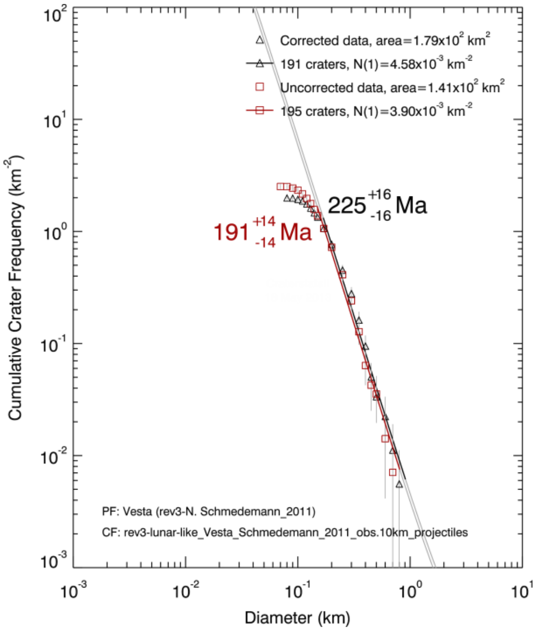

Figure 3: Cumulative CSFD plot of the corrected (black triangles) and uncorrected (red squares) crater data measured in the sample area on Vesta. The topography correction shifted the CSF curve down- and rightward.

The area has an average elevation of ~32.2 km above the reference body of Vesta. The topography-corrected and uncorrected CSFDs are shown in Figure 3. The location of the measurement area above the reference body led to a reduction of the measured area in the projected data. Thus, the corrected CSF curve (black triangles) is shifted slightly downwards in the logarithmic CSF plot because the crater density decreased with the increased area. The correction of the crater diameters, however, led to a shift of the data points to the right, finally increasing the derived surface age. The age difference in this specific case amounts to ~15%.

Correction in the CraterTools Software: CraterTools optionally corrects the distortions using the formulas given above. Besides the area and crater shapes, the software needs a georeferenced digital terrain model (DTM) giving the elevations in relation to the same reference body as used for the map projection. The software internally determines the mean elevation values of the measurement areas and crater rims and corrects the measured values for each feature separately.

Area distortions induced by slopes are corrected using the mean slope value of the area. In order to exclude the influence of the crater walls and other small-scale surface features with steep slopes, the software internally applies a low-pass filter on the automatically calculated slope map.

The CraterTools software is not designed to correct slope dependent distortions of crater diameters automatically. We recommend measuring the diameters of the craters manually perpendicular to the slope as this crater axis is undistorted and probably much less affected by gravity-driven mass wasting processes than the downslope axis.

In this respect it should be emphasized that age determinations on steep slopes have to be handled with care because mass-wasting processes can modify existing CSFDs and complicate a reliable determination of surface ages.

References: [1] Öpik E. J. (1960) *Mon. Not. R. Astron. Soc., 120,* 404-411. [2] Shoemaker E. M. et al. (1962) *Adv. Astron. Sci., 8,* 70-89. [3] Baldwin R. B. (1964) *Astron. J., 69,* 377-392. [4] Kneissl T. et al. (2012) *Planet. Space Sci., 59,* 1243-1254. [5] Russell C. T. et al. (2011) *Space Sci. Rev., 163*, 3-23. [6] Jaumann et al. (2012) *Science, 336,* 687-690.

Acknowledgements: The authors acknowledge the support of the Dawn Science, Instrument and Operations Teams. This research has made use of the USGS Integrated Software for Imagers and Spectrometers (ISIS). This work was partly supported by the German Space Agency (DLR), grant 50 OW 1101.