THE SIMPLE-TO-COMPLEX TRANSITION OF LUNAR CRATERS: NEW PRECISE DEPTH/DIAMETER MEASUREMENTS OF MARE AND HIGHLAND CRATERS.

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Introduction: New lunar high-resolution global morphologic and elevation maps are now available to examine the moon in great detail. The majority of remote sensing investigations of lunar craters still rely on old data sets [e.g., 1, 2]. The goal of this work is to revisit some of these older investigations and to improve the measurements if possible. We are building a new morphometric database for mare and highland craters. This study is focused on the simple-to-complex transition diameter of lunar craters. The simple-to-complex transition diameter primarily depends on gravity and secondly on the strength of the involved target rocks. It is a fundamental measurement for each planetary body. To derive equations for depth/diameter ratios and to precisely constrain the simple-to-complex transition diameter a large dataset covering craters over a wide range of sizes is required. The transition diameter from simple to complex craters has been studied since the 1980 and numerous diameters for this transition have been proposed for the Moon. Several threshold diameters were published by Pike; 17.5 km [1], 16.0 km for Maria [3], 21.0 km for Highlands [3] and 18.7 km [4]. A transition diameter of 15.0 km was proposed by [5, 6]. [7] proposed a transition diameter of 18.7 km and [8] of 19.0 km. Our ongoing work currently includes 540 lunar simple and complex impact craters of Mare and Highland areas.

Data: The remote sensing datasets have been processed with ISIS 3 (Integrated Software for Imagers and Spectrometers). For further analysis we used the ESRI ArcGIS 10.1 software package. Remote sensing resources for this study are the LRO (Lunar Reconnaissance Orbiter) WAC (Wide Angle Camera) Global Morphologic Map data with a resolution of 100m/pixel [9]. For the digital elevation maps we used the Global Lunar DTM 100 m (GLD100), which is derived from WAC stereo images. The resolution is 100 m/pixel with an elevation accuracy of about 10 to 20 m [10, 11].

Methods: The surface of the Moon was subdivided into eight subareas, which represent the original WAC Global Morphologic Map tiles. The investigated craters are further separated by their location into Mare and Highland craters, to include the different properties of the surface (Fig.1). On each tile at least 50 craters are selected, to ensure a homogenous distribution. We used mostly young craters to minimize the influence of crater degradation and erosion of the crater rim.

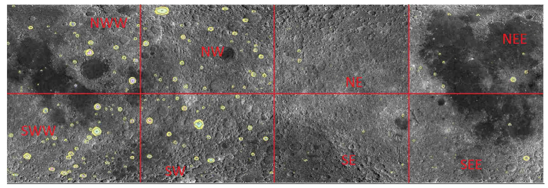

Fig.1: The subdivision of the eight WAC Global Morphologic Map tiles. The crater rims of the investigated craters are shown in yellow. The four tiles in the middle show the lunar farside and the outer four tiles show the lunar nearside.

Analysis and calculation: For the calculation of the crater depth (h_C) we used the mean value of all DTM points for the crater floor. The final crater diameter (D_F) was obtained from a circle fitted visually to the crater crest line. Furthermore we determined the diameter of the central peak (D_{CP}) and their height (h_{CP}). The depth and diameter data are plotted and linear and/or power law regressions were fitted to the datasets.

Results and Interpretation: Figures 2 and 3 display all depth-diameter data, including Mare and Highland craters. The simple-to-complex transition diameter can be determined by the intersection of two linear regression lines [12]. Our least square fits are:

(i) simple craters: $h_C = 0.130\ D_F + 0.434$
(ii) complex craters: $h_C = 0.008\ D_F + 2.917$

The coefficient of determination R^2 is 0.8 and 0.5 for the simple and complex crater population, respectively. The simple-to-complex transition diameter of all craters using this method is at 15.4 km (Fig. 2). The coefficient of determinations is not satisfying. Alternatively both crater types, simple and complex, can be described by power laws:

(iii) simple craters: $h_C = 0.1202\ D_F^{1.1243}$
(iv) complex craters: $h_C = 1.3043\ D_F^{0.2325}$.

Table 1 gives a summary of our results of the simple-to-complex transition diameter measurements and list previously published data.

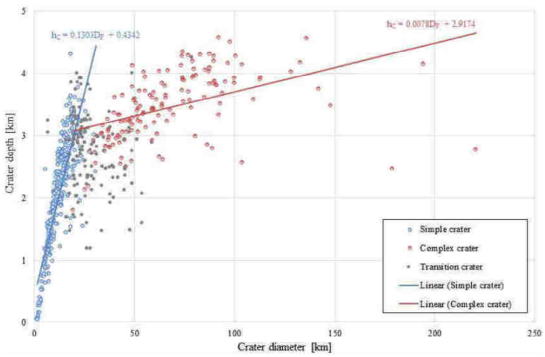

Fig.2: The measured simple-to-complex transition diameter for all craters. The intersection of the trendlines gives the transition diameter of 20.3 km. The complex craters are not well characterized by a linear trend. The coefficient of determination R^2 for simple crater is 0.8 and for complex craters 0.5.

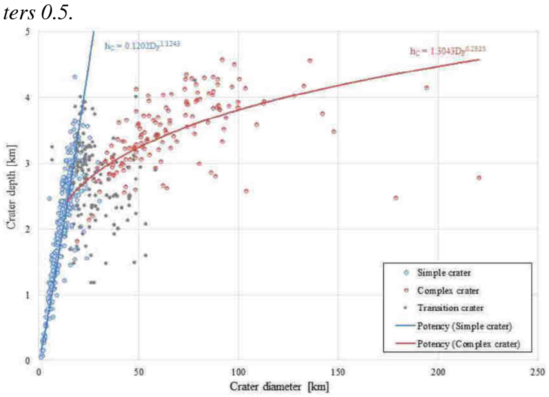

Fig.3: The transition diameter for all craters, with the complex craters following a power law. The black dashed line corresponds to the standard deviation. The intersection of the power law trendline with the standard deviation gives the transition diameter of 15.0 km. The coefficient of determination R^2 for simple crater is 0.8 and for complex craters 0.5.

	Simple-to-complex transition	Highland	Mare
Pike 1980 [3]	19 km	21.0 km	16.0 km
Croft 1985 [5]	15 km	-	-
Stöffler 2006 [7]	18.7 km	-	-
Measurements (linear)	20.3 km	21.1 km	14.1 km
Measurements (power law)	15.0 km	17.0 km	9.6 km

Table.1: Simple-to-complex transition diameters, from literature and our measurements. Where data is available the Simple-to-complex transition diameters are divided for Highland and Mare areas.

Discussion: The transition from simple to complex lunar craters is no well-defined. Between 20 km to 30 km most craters are in a transitional state between simple and complex morphologies. They do not show central peaks and terracing but crater wall slumping and crater floor uplift leads to a clear flattening of the crater cavity which is expressed in a reduced depth/diameter ratio. Remarkable is that the trend of simple morphologies seems to overshoot beyond the point of intersection with the regression line for complex craters. That means that a kinetic blocking exists before intense crater modification can start. This effect can be observed by Highland and Mare crater (Fig.4).

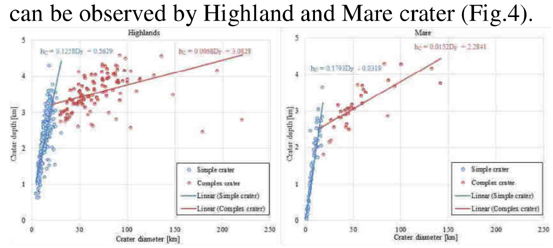

Fig.4: The measured simple-to-complex transition diameter for all craters divided after Highland and Mare units. The coefficient of determination R^2 for simple crater is 0.7 (Highlands), 0.9 (Mare) for complex craters 0.4 (Highlands) and 0.6 (Mare).

Conclusion: Our data set slightly refines former data of the simple-to-complex transition of lunar craters. A linear fit to the simple crater population seems appropriate, but the depth/diameter ratios for complex crater are better described by a power law trendline. Further work is needed to include more craters into the depth/diameter relationship. This will improve the results and helps to better constrain the regression lines of depth-diameter ratios and of the simple-to-complex transition diameter.

References: [1] Pike R. J. (1977) *Proc. Lunar Sci. Conf. 8th, 3,* 3427-3436. [2] Melosh H. J. (1989) *Oxford Monographs on Geology and Geophysics No. 11 - Impact Cratering A Geologic Process.* [3] Pike R. J. (1980) *Proc. Lunar Sci. Conf. 11th, 3,* 2159-2189. [4] Pike R. J. (1988) *Mercury. University of Arizona Press,* 165-273. [5] Croft S. K. (1985) *JGR, 90,* 828-842. [6] Melosh H. J. and Ivanov B. A. (1999) *Annu. Rev. Earth Planet. Sci., 27,* 385-415. [7] Stöffler D. et al. (2006) *Rev. in Mineralogy & Geochemistry, 60,* 519-596. [8] Grieve R. A. F. (1981) *Nature, 291,* 16. [9] Robinson M. S. et al. (2010) *Space Science Reviews, 150,* 81-124. [10] Scholten F. et al. (2012) *JGR, 117.* [11] Smith D. E. et al. (2010) *Space Science Reviews, 150,* 209-241.