AUTOMATIC AGE MAP CONSTRUCTION FOR THE FLOOR OF LUNAR CRATER TSIOLKOVSKY.

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Introduction: For the exploration of planets and other celestial bodies, the reconstruction of the surface history is of high scientific interest. A well-established method to determine absolute ages of surface features is the statistical analysis of the impact crater size-frequency distribution (CSFD) [1, 2, 3, 4]. This classical approach is generally based on manually determined crater statistics, which is time-consuming for very large surface areas and/or high image resolution.

Thus, in this study we present a surface age map of the complete floor of the lunar crater Tsiolkovsky constructed based on automatic image-based crater detection. Our method consists of two subsequent stages, a template matching stage described in [5] which provides crater candidates, followed by a fusion process for multiple detections at the same location, and a second stage that infers an absolute model age from the CSFD according to the method described in [1, 2, 3, 4, 6].

Methodology: From six generic 3D crater models, gray value images of craters are created and compared to parts of the image by means of cross-correlation [5]. Based on a 100 km² calibration area on the floor of the lunar farside crater Tsiolkovsky for which manual impact crater counts and size estimates are available (this area is similar to the region examined in [7]), the optimal detection threshold was chosen by minimizing the absolute difference between the age values obtained by manual and automatic crater counting, respectively. The derived age of the calibration region amounts to 3.21 ± 0.13 Ga, which is nearly identical to the average age value of $3.19^{+0.08}_{-0.12}$ Ga given in [7]. This age is lower than other published ages, such as $3.32^{+0.09}_{-0.20}$ Ga [8], 3.51 ± 0.1 Ga [9] and 3.8 Ga [10].

With the cross-correlation threshold of 0.6568 obtained by this calibration procedure, the template matching method was applied to a 7.4 m per pixel resolution Kaguya Terrain Camera (TC) [11] image covering crater Tsiolkovsky completely. Manually and automatically counted craters are shown for a part of the calibration area in Fig. 2. The estimated crater diameters are always close to the manually determined ones. The automatically detected craters show slight unsystematic positional random deviations with respect to the manually determined centres. However, the age estimation is not affected by these positional errors as it relies only on the diameters.

The obtained CSFD was then used to estimate the surface age of overlapping quadratic areas on the mare-like crater floor, with an area size of 600 by 600 pixels and a step width of 10 pixels. Our age estimation routine was implemented in Matlab according to the description of the method given in [1, 2, 3, 4, 6]. Only the range of crater diameters of 128-1000 m was evaluated, since for smaller diameters the empirical cumulative size-frequency distribution showed an artificial "roll-off" apparently due to incomplete detection of smaller craters. This localised age estimation procedure resulted in the map of the surface age shown in Fig. 3, covering the complete crater floor.

Results and Discussion: The surface age map of the flat mare-like dark floor of Tsiolkovsky shown in Fig. 3 reveals surface ages of approximately 2.9-3.6 Ga, where the majority of ages is centred around approximately 3.3 Ga. The age map does not comprise the central peak and other parts of the crater not covered by mare material. These regions are characterised by steep slopes and are older than the dark floor.

A comparison of the surface age map in Fig. 3 with the Clementine UV/VIS colour ratio image [12] of Tsiolkovsky in Fig. 4 shows that four localised surface age anomalies in the eastern part of the crater floor (identified by the letters A, B, C and D) correspond to small spectrally discernible regions in colour ratio image. Regions A, C and D have lower ages than the surrounding surface (about 2.9-3.1 Ga) while region B has a higher age (about 3.5 Ga). These small regions are also spectrally different from the surrounding surface, indicating differences in composition of the mare basalts. It is shown in [13] that for a 100 km² surface region with a uniform age of 4.0 Ga, age estimates for 4 km² subregions may deviate by several hundred Ma from the average value despite the absence of real age variations, while 10 km² subregions yield accurate and reliable ages [13]. Hence, the comparably large size of the overlapping surface areas used in this study (19.7 km²) and the correlations between age map and spectral data suggest that the age differences may be real and that the mare basalts on the floor of Tsiolkovsky may have been emplaced over a period of several hundred Ma with changing composition of the erupted material.

Conclusion: In this study we have applied a template-based automatic crater detection algorithm to a high-resolution orbital image of the lunar crater Tsiolkovsky. The obtained crater detection results were used for CSFD-based surface age estimation, where the calibration of the detection threshold was performed based on a region for which manual crater counts are available. The resulting age map indicates that this method is able to distinguish different geological units in terms of their relative ages. We found correlations between small regions exhibiting local surface age anomalies and local variations of spectral properties in Clementine UV/VIS colour ratio data, indicating that the emplacement of the floor material of Tsiolkovsky may have occurred in different phases over a period of several hundred Ma.

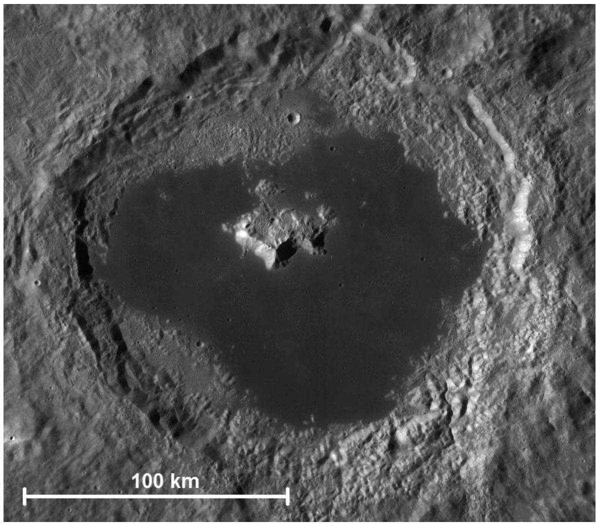

Figure 1: Crater Tsiolkovsky on the lunar farside, extracted from the Lunar Reconaissance Orbiter Wide Angle Camera global mosaic [14].

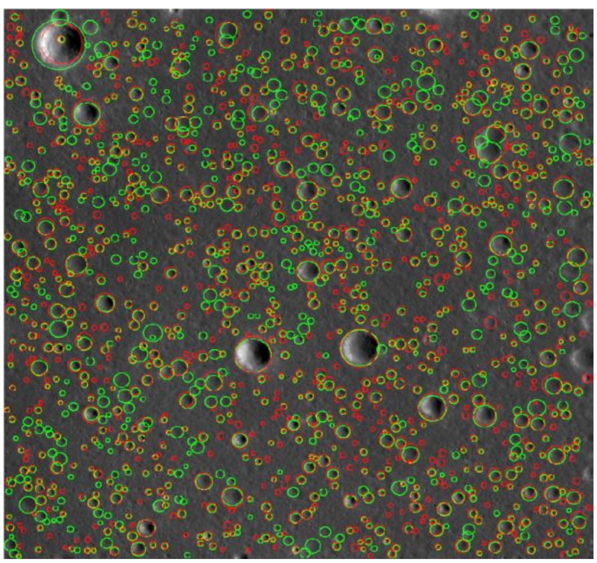

Figure 2: Manually (green) and automatically (red) counted craters for a part of the calibration area. Image data: Kaguya TC [11].

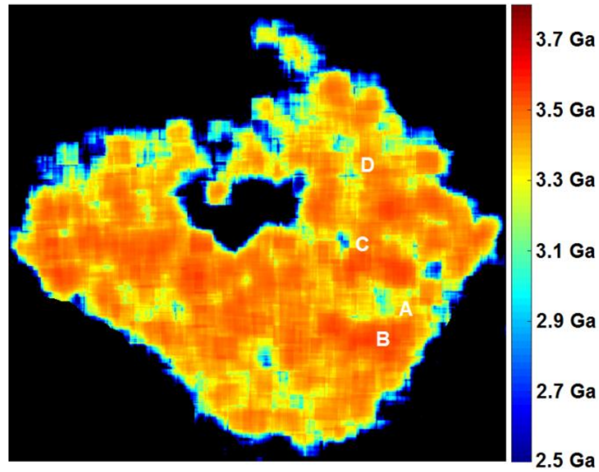

Figure 3: Map of the estimated surface age of the floor of Tsiolkovsky. The mare-like floor region has been segmented manually. Black: no data.

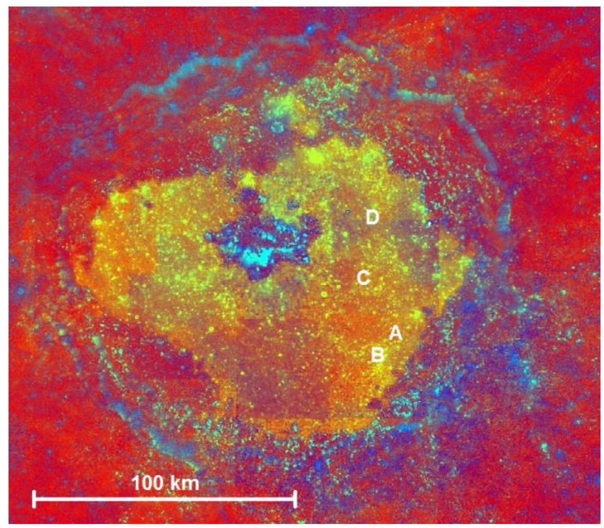

Figure 4: Clementine UV/VIS colour ratio image of crater Tsiolkovsky (image data obtained from [12]).

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