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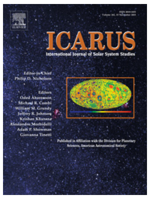

# Treatment of non-sparse cratering in planetary surface dating

T. Kneissl*, G.G. Michael, N. Schmedemann

*Institute of Geological Sciences, Planetary Sciences and Remote Sensing, Freie Universität Berlin, Malteserstr. 74-100, 12249 Berlin, Germany*

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ABSTRACT

We here propose a new technique to derive crater size-frequency distributions (CSFDs) from non-sparsely cratered surfaces, by accounting for the loss of craters due to subsequent crater/ejecta coverage. This approach, which we refer to as the buffered non-sparseness correction (BNSC), relates each crater to a measurement area found by excluding regions in the study area that have been resurfaced by larger craters and their ejecta blankets. The approach includes the well-known buffered crater counting (BCC) technique in order to consider the potential identification of craters whose centers are located outside the counting area. We demonstrate the new approach at two test sites on the Moon, one on the ancient lunar highlands outside the South Pole Aitken basin and the other on the much younger surface of lunar Mare Serenitatis. As expected, the correction has a much stronger effect on ancient, densely cratered surfaces than on younger, sparsely cratered surfaces. Furthermore, these first results indicate that the shapes of CSFDs on ancient terrains are actually very similar to the shapes of CSFDs on younger terrains.

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## 1. Introduction

The use of crater size-frequency distributions (CSFDs) for determination of relative and absolute surface ages is a well-established and frequently applied method in the planetary community (e.g., Öpik, 1960; Baldwin, 1964; Neukum, 1983).

The area occupied by craters and their ejecta on a counting area has customarily been considered negligible when considering crater densities. The assumption holds well when the densities are low. As they increase, it generally continues to hold for craters at the large end of the size–frequency distribution, but begins to break down for craters at smaller sizes: their measured spatial densities are relatively diminished because a fraction of the accumulated population has been obliterated by superposed larger craters. In this paper we consider an approach to studying crater populations which does not require this assumption.

We refer to the situation using the term *non-sparseness* because it is relevant whenever the area occupied by craters and their ejecta becomes non-negligible. Although this is unquestionably the case for densely cratered surfaces, it should be noted that the onset of non-sparseness occurs well before what might normally be considered as dense cratering.

If a surface becomes non-sparsely cratered, the ejecta blankets of impact craters act like new geologic units that superpose the older, preexisting crater population. Including their areas and crater statistics is comparable to including other geologic units into the counting area (Warner et al., 2015). This contradicts the requirement for a crater count to be based on the use of homogeneous geological units (e.g., Wilhelms et al., 1987). Craters superposed on the ejecta blankets of larger craters only carry information about the formation age of the respective crater they superpose, not about the age of the larger geologic unit. Consequently, craters superposed on ejecta blankets can only be used for age determinations of the ejecta blanket itself.

As a consequence, age determinations on non-sparsely cratered units become problematic because the “loss” of small craters from the original cratering record complicates the interpretation of the CSFD. To remove this effect, we propose a new approach for deriving CSFDs from crater measurements on a non-sparsely cratered geologic unit.

## 2. Correcting non-sparse crater distributions

The derivation of a CSFD requires the number of impact craters to be normalized to a measurement area (Arvidson, 1979). In the traditional crater-counting approach this includes all impact craters whose centers are located inside a defined area, which should represent a homogeneous geologic unit. Here, the area assigned to each crater is identical, i.e.:

$$A_T = A_U$$

where $A_T$ is the reference area assigned to a crater in the traditional crater counting approach and $A_U$ is the area of the geologic unit of interest (Fig. 1A).

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* Corresponding author. Tel.: +49 30 838 70567; fax: +49 30 838 70723.
*E-mail address:* Thomas.Kneissl@fu-berlin.de (T. Kneissl).

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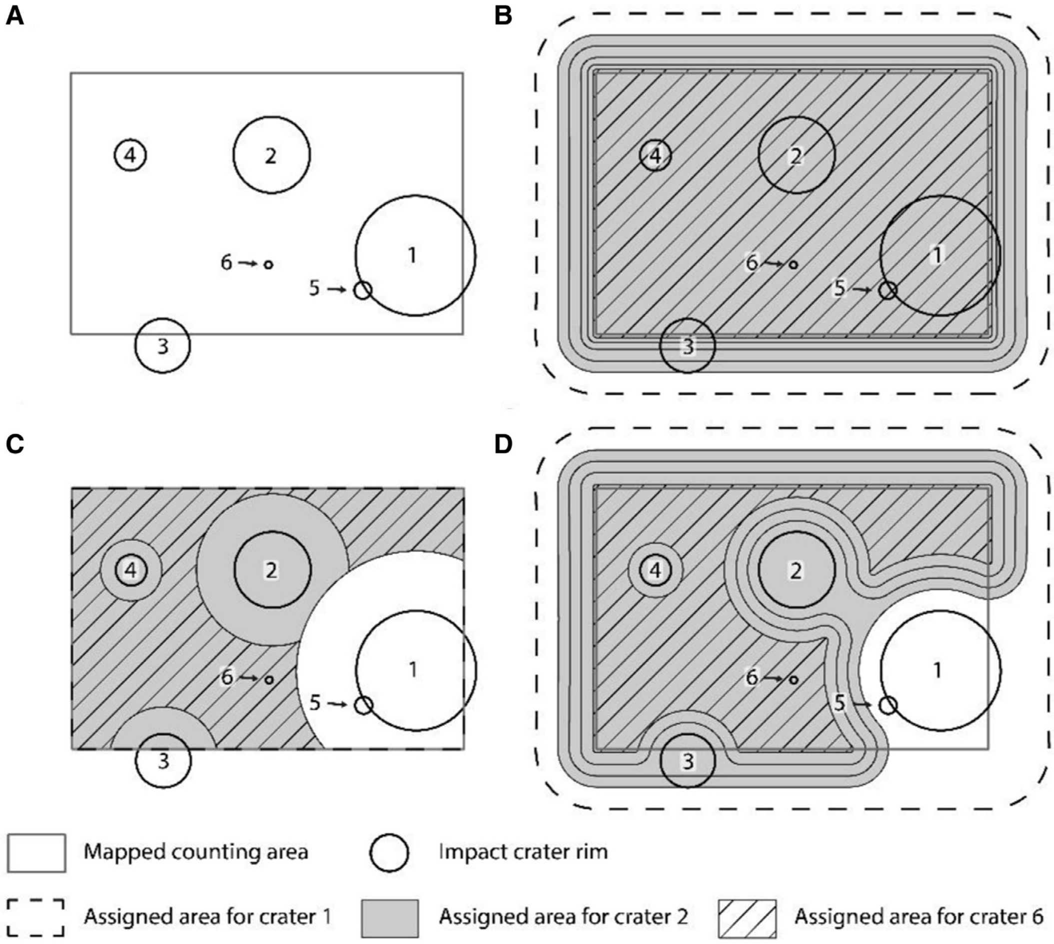

**Fig. 1.** Assignment of reference areas to individual craters. (A) Traditional crater counting approach. All craters use the same measurement area (grey outline). Crater 3 is excluded from the measurement because its crater center is located outside the counting area. (B) Buffered crater counting (BCC) approach. All craters are used for the analysis. The assigned measurement areas for each crater correspond to the original counting area plus a surrounding buffer of 1 crater radius. (C) Non-sparseness correction (NSC). Removal of "resurfaced" areas (craters plus ejecta blankets) from the counting area assigned to each respective crater. The area assigned to crater 1 (dashed outline) corresponds to the original counting area. For the second largest crater, crater 2, the assigned area is reduced by the area of crater 1 plus its ejecta blanket (1 radius). The measurement area assigned to crater 6 (striped area) excludes the crater and ejecta areas of all larger craters. Crater 5 is excluded from this measurement because it is located in the area resurfaced by crater 1. Crater 3 is excluded from the measurement too because its crater center is located outside the counting area. (D) Buffered non-sparseness correction (BNSC). Combination of B and C. In a first step, the resurfaced areas (craters plus ejecta blankets) are excluded from the counting areas assigned to each respective crater. Subsequently, we apply a buffer with the width of 1 crater radius. Crater 5 is excluded from this measurement because it is located in the area resurfaced by crater 1. Crater 3 however is included because its crater rim intersects the counting area.

Using the buffered crater counting (BCC) approach (for details see Tanaka, 1982; Fassett and Head, 2008; Hoke and Hynek, 2009; Kneissl et al., 2015), the statistics of a CSFD measurement can be improved by also including the craters whose centers are located outside the counting area, but whose crater rims or ejecta blankets still cut the boundary of the area (Fig. 1B). In the BCC technique, every crater gets assigned an individual reference area, $A_i$, which consists of the area of the geologic unit, $A_U$, plus a specific buffer area, $B_i$, with the width of at least one crater radius around the geologic unit:

$$A_i = A_U + B_i$$

For details on different buffer widths depending on the usage of ejecta blankets see Kneissl et al. (2015).

On heavily cratered surfaces pre-existing craters are often erased or covered by subsequent impacts. This is due to the impact event itself, the emplacement of a continuous ejecta blanket, and potentially the seismic shaking (e.g., Titley, 1966; Schultz and Gault, 1975; Richardson et al., 2005; Thomas and Robinson, 2005). As mentioned above, this eliminates a portion of the accumulated smaller craters in the measured CSFD of the surface. For larger crater sizes this effect is reduced, because it is less likely that these craters are completely obliterated by subsequent smaller craters. Due to the size-dependent effect of this process, we expect a change of the shape of the resulting CSFDs, typically a flattening of the CSFD curve (in a cumulative plot), complicating the interpretation and age extraction.

Here, we account for the influence of obliteration by subsequent impacts by removing the surface area covered by all craters larger than the crater currently under consideration. This also includes their corresponding continuous ejecta blankets, which have to be excluded from the assigned counting area, too (Fig. 1C). In principle, one could remove the areas of all impact craters, smaller and larger, within the counting area and use the remaining area as measurement area. However, due to the fact that smaller craters cannot normally obliterate larger craters, only the areas of larger impact craters must be excluded. We note that this procedure could also diminish the effects of so-called auto-secondary cratering (see e.g., Zanetti et al., 2015). In the proposed technique, hereafter called non-sparseness correction (NSC), the assigned

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