The Lunar Chronology: A Status Report. H. Hiesinger[1], C. H. van der Bogert[1], W. Iqbal[1], T. Gebbing[1]. [1]Institut für Planetologie, Westfälische Wilhelms-Universität, Wilhelm-Klemm-Str. 10, 48149 Münster, Germany (hiesinger@uni-muenster.de).

Introduction: In planetary sciences, the Moon is fundamentally important in calibrating the impact record of the inner Solar System with absolute ages derived from the returned samples. Between 1969 and 1972, astronauts carefully selected almost 400 kg of lunar samples and characterized in detail their geologic context. The Soviet Luna missions also robotically collected samples. These materials allow us to ground-truth remote-sensing data of the landing sites (e.g., crater size-frequency distributions (CSFDs), crater degradation, mineralogy, composition) [e.g., 1,2]. As a result, the lunar chronology function (CF) could be derived that links the CSFD at a certain reference diameter with the radiometric and exposure ages of lunar samples [e.g., 3-10]. This lunar chronology function and its extrapolation to other planetary bodies is key for the understanding the history and evolution of the Solar System because it enables us to not only study the geology of unsampled regions on the Moon but also to derive absolute model ages (AMAs) of surfaces on other planetary bodies. Although it could be shown that SNC meteorites come from Mars and that HED meteorites very likely originated from asteroid Vesta, we do not know specifically from where those meteorites originated on their parent bodies. Hence, it is impossible to link their radiometric ages with CSFDs, i.e., to directly derive chronology functions for other planetary objects.

Accurately understanding the lunar impact chronology is a prerequisite for dating any planetary surface. However, because several assumptions (e.g., importance of secondary craters, target properties, count area size, etc.) have to be made, several lunar chronology functions have been proposed over the last 50 years since the Apollo and Luna samples have been brought to Earth [e.g., 5,6,8,10]. Some of these chronologies are drastically different from the most widely used chronology of [5,6]. In particular, there are large discrepancies among the chronologies in the time period between about 1 and 3.2 Ga, resulting in drastically different model ages for the same crater frequency (Fig. 1). Unfortunately, some aspects of the chronology of [5,6] are not sufficiently documented in the literature. For example, the count areas of some of the CSFD measurements that were originally linked with the sample ages are missing for certain landing sites. In addition, our knowledge about the samples, their geologic context, and their ages has significantly grown and evolved since the derivation of the lunar chronology of [5,6]. For these reasons, we are independently and objectively evaluating the proposed chronologies.

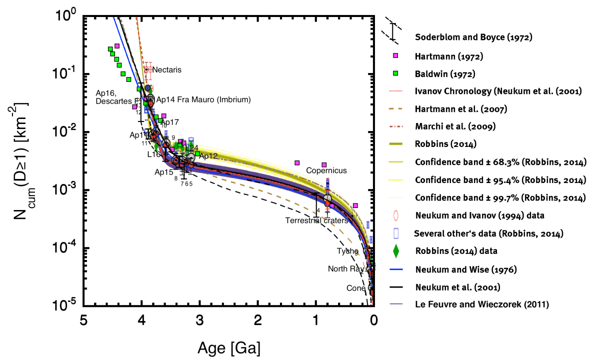

Fig. 1 Proposed lunar chronologies fit the Apollo and Luna samples in a variety of ways.

Results: Here, we report on our work evaluating some of the proposed lunar chronologies. We produced new geologic maps, performed new CSFD measurements, and reviewed the status of sample ages found in the literature. We re-mapped the landing sites in an effort to newly define homogeneous geologic units, which could be dated with our new CSFDs. This also allowed us to more accurately attribute samples to a specific geologic unit and to correlate their laboratory-derived ages with our new CSFDs. Were available, we also re-counted the count areas of [5,6] in order to gauge the quality of the original counts with modern high-resolution imaging data and to investigate possible differences with our newly defined count areas. As of now, we have re-investigated the data points for Copernicus, Tycho, North Ray [11], and Cone craters [12], as well as the Apollo 11, 12, 14, 16, and 17 landing sites [13-18], with Apollo 15 currently being underway.

Cone Crater: Our CSFD measurements on LROC images yielded older AMAs than previously determined [e.g., 19]. However, our results are closer to the older CSFDs than to those of [20] and are just within the error bars of [21]. Our derived $N(1)$ of 3.26 x 10^{-5} km^{-2} is similar to the N (1) of 3.36 x 10^{-5} km^{-2} of [10].

North Ray Crater: Two independent CSFD measurements for North Ray crater yielded an $N(1)$ of 3.94x10^{-5} km^{-2} and 3.90x10^{-5} km^{-2}, respectively for count areas defined by [5,6]. In a companion abstract [22], we report on CSFD measurements for slightly adjusted count areas, which resulted in an $N(1)$ of 4.26x10^{-5} km^{-2}, hence slightly older.

South Ray Crater: Our new CSFD measurements for South Ray crater yield somewhat younger $N(1)$ values than previously reported. On the basis of our CSFD measurement, we derived an $N(1)$ of 8.95x10^{-7} km^{-2}.

Tycho Crater: Hiesinger et al. [11] determined an $N(1)$ of 7.12x10^{-5} km^{-2} for several count areas on the ejecta blanket of Tycho and an $N(1)$ of 2.72x10^{-5} km^{-2} for several melt pools.

Copernicus Crater: Utilizing Lunar Reconnaissance Wide Angle (WAC) and Narrow Angle Camera (NAC) images, [11] found $N(1)$ values of 66.8x10^{-5} km^{-2} and 65.3x10^{-5} km^{-2}, respectively. Kaguya Terrain Camera images yielded a slightly lower $N(1)$ of 56.8x10^{-5} km^{-2}. In [5,6], the data point of Copernicus showed an $N(1)$ that was significantly higher than one would expect from the lunar chronology. This is most likely due to the inclusion of secondary craters in the work of [5,6]. Consequently, in [11] we adjusted the count area location carefully. As a result, the newly derived $N(1)$ fits the chronology much better.

Apollo 11: Iqbal et al. [13] re-investigated the CSFD at the Apollo 11 landing site. On the basis of WAC images, they determined an $N(1)$ of 6.47x10^{-3} km^{-2} for the original count area of [5,6]. However, they also found that the original count area is affected by the deposition of ray material. Taking this into account for the new definition of more appropriate count areas yielded $N(1)$ values of 6.42x10^{-3} km^{-2} (NAC) and 6.88x10^{-3} km^{-2} (WAC). On the basis of NAC CSFD measurements, [13] also determined a $N(1)$ of 5.74x10^{-3} km^{-2}.

Apollo 12: Recent CSFD measurements of [14] yielded an $N(1)$ of 2.81x10^{-3} km^{-2} for the mare unit containing the Apollo 12 landing site and an $N(1)$ of 6.67x10^{-4} km^{-2} for the Copernicus ray material. The $N(1)$ values published by [5,6] for this landing site are 3.61x10^{-3} km^{-2} and 1.3x10^{-3} km^{-2}, respectively. [10] determined an $N(1)$ of 5.68x10^{-3} km^{-2}.

Apollo 14: We performed new CSFD measurements for the Apollo 14 landing site on the basis of WAC and NAC images. For the count area of [5,6], we determined an $N(1)$ of 4.31x10^{-2} km^{-2}, thus, being slightly older than the $N(1)$ of 3.7x10^{-2} km^{-2} of [5,6]. We also adjusted our WAC count area to better conform to the new geological map and derived an $N(1)$ of 4.5x10^{-2} km^{-2}. Our NAC counts, combining several smaller count areas show an $N(1)$ of 5.39x10^{-2} km^{-2}. All our $N(1)$ values are significantly older than the $N(1)$ of [8], i.e., 2.595-2.672x10^{-2} km^{-2}.

Apollo 15: Our new CSFD measurements for Apollo 15 are described in a companion abstract [15]. These new CSFD measurements for count areas defined by [5,6] indicate $N(1)$ values of 2.99x10^{-3} km^{-2} and 2.98x10^{-3} km^{-2} for the count areas A and B of [5,6]. The $N(1)$ value given by [5,6] is 3.2±1.1x10^{-3} km$^{-2.}$ However, we also found that count area C consists of several geologic units and, thus, is heterogeneous. After adjustment of the count area, we determined an $N(1)$ of 1.72x10^{-3} km^{-2}. Count area E exhibits two $N(1)$ values of 3.55x10^{-3} km^{-2} and 7.88x10^{-3} km^{-2}, representing two mare units.

Apollo 16: The previously determined $N(1)$ values for the three count areas of [5,6] were 3.4±0.7×10^{-2} km^{-2} [5] and 2.490×10^{-2} km^{-2} to 2.509×10^{-2} km^{-2} [8]. We re-counted these areas and obtained an $N(1)$ of 1.84x10^{-2} km^{-2}. However, re-inspecting these count areas with modern LROC WAC data it became obvious that the count areas are heterogeneous, which resulted in the definition of new count areas. Preliminary CSFD measurements indicate that the adjusted count areas yield an $N(1)$ of 1.84x10^{-2} km^{-2}. NAC CSFD measurements of several smaller count areas within the WAC count areas show $N(1)$ values of 5.35×10^{-3} km^{-2} to 1.66×10^{-2} km^{-2} [16].

Apollo 17: The light mantle material at the Apollo 17 landing site was recently dated by [18] to show an $N(1)$ of 7.04x10^{-5} km^{-2}. The mare unit and pyroclastics around the landing site have an $N(1)$ of 1.06x10^{-2} km^{-2}, which is similar to the $N(1)$ values of [17,18].

Conclusions: On the basis of our newly performed CSFD measurements on carefully characterized count areas at the Apollo landing sites and at some additional anchor points we do not find large discrepancies with the lunar chronology of [5,6]. For the first time, all count areas and measured CSFDs are documented in the literature, which has not been the case for some measurements in the publications of [5,6]. On the basis of our CSFDs, we do not see the necessity to substantially change the lunar chronology function.

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