THE SYSTEM OF LUNAR CRATERS, REVISED*

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Abstract. A new catalogue of lunar crater diameters, depths and morphologies based on Orbiter photography is described. Preliminary shadow length reductions indicate that previous depths determined by ACIC and Baldwin are systematically about 500 m too shallow.

1. Introduction

The System of Lunar Craters (Arthur *et al.*, 1963, 1964, 1965, 1966), a catalog of positions, diameters, and morphological data for 17200 craters was completed in 1966, before the flight of Orbiter 1. That catalog was based entirely on Earth-based photographs and thus suffered from the uneven quality of the photographs and the unavoidable compression of detail near the limb. Yet the *System* provided a comprehensive set of data which has been statistically analyzed by Hartmann (1964), Ronca (1968), Wood (1968), Ronca and Green (1968, 1969), Titulaer (1969), and others. The catalog and maps have become the standard reference for crater positions, designations, and diameters. The nomenclature was adopted *in toto* by the International Astronomical Union (Hamburg, 1964 and Prague, 1967), and hence is used in the ACIC series of LAC and other charts, and the *Orbiter Gazetteer of Lunar Features* (in press).

The uniformly high resolution and large scale of the Orbiter 4 records allow an updating of the earlier catalog and the determination of crater depths. With the aid of Orbiter and Apollo photographs the cataloging can be extended to the averted lunar hemisphere, thus providing uniform, high precision statistical data for an entire planetary body. The Lunar and Planetary Laboratory is currently carrying out this work under the day to day supervision of the author and general guidance from D. W. G. Arthur (U.S. Geological Survey, in Flagstaff, Arizona), and E. A. Whitaker and R. G. Strom of LPL.

2. The Catalog

To organize the cataloging and to break it down into publication-size fragments the lunar sphere is represented by a circumscribed cube with its axes parallel to the axes of the $\xi\eta\zeta$ system. Each face of the cube is subdivided into four quadrants defined by the signs of ξ, η, ζ, so that each crater has a catalog number indicating its location on the lunar globe (Arthur, 1971).

The catalog includes the following information for each crater:

Position: For most of the earthward hemisphere, positions are measured from the

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Orthographic Atlas of the Moon (Arthur and Whitaker, 1961). Near the limb and on the averted hemisphere crater positions are being measured on the ACIC Lunar Planning Charts and Lunar Polar Chart. Positions taken from these charts differ from those measured by Arthur (1971) by a maximum of one-third degree, corresponding to an error in depth of 40 m.

Nomenclature: Some craters which were conspicuous at certain solar elevations on Earth-based photographs appear as ambiguous depressions adjacent to bright hills on Orbiter records. Previous designations of such features have either been cancelled or moved to a nearby crater suitable as a landmark. Some irregular depressions near the limb that are lettered in *The System* have for similar reasons been deleted and new lettered designations will be given to prominent limb craters. Thousands of craters will be lettered in conjunction with recently named craters on the averted lunar hemisphere following the precepts discussed in Arthur *et al.* (1963). It is hoped that the IAU will accept these letter designations.

Diameter: The diameters given in *The System* are altered only when obviously incorrect. Diameters of craters added to the earthward hemisphere catalog and all of the averted hemisphere craters are measured from scaled Orbiter photographs.

The System of Lunar Craters required four years' work by three-to-four assistants to catalog all detectable craters greater than 3.5 km on the earthward hemisphere. It would require an excessive amount of time to catalog the entire Moon to such small crater diameters. We have, thus, set a lower limit of 7 km, except for designated craters, for this cataloging project. As a result, 28% of the craters on the earthward face of the Moon cube that were measured in *The System* are too small for inclusion.

Depth: Shadow lengths, carefully measured on the large-scale Orbiter 4 high resolution prints and rigorously reduced by mathematics provided by Arthur (to be published in detail with the first section of the catalog) provide accurate depths for about 60% of the craters cataloged. The remaining craters have shadows which do not fall on their floors, or their rims are too irregular for any depth to be meaningful. The crater depths are discussed below.

Classification: Various statistical analyses of the data in *The System* have shown that the classification scheme of crater sharpness apparently represents an age sequence. We have continued this useful crater classification, supplementing the Orbiter information with both low and high sun elevation photographs from the *Consolidated Lunar Atlas* (Kuiper *et al.*, 1967).

Central Peak Information: Central peaks are easily detectable on Orbiter photographs and an improvement in statistics given by Wood (1968) is expected.

Ratio: The ratio of the floor diameter to the rim diameter of a crater is easily measured and provides a quantitative method to distinguish morphologically different craters.

Type: Pohn and Offield (1969) suggested that there are three basic types of craters and subdivided these into seven age classes. This was a start in the neglected field of crater comparison, but there are more than three types of lunar craters. In cataloging the earthward face of the Moon about 50 types thus far have been isolated excluding ruins and secondary craters. This is an excessive number of types: some are only slightly different from others and a few are unique. Yet it is better to over-differentiate and later recognize the essential similarities of two or more types, than to over-simplify and lump together craters with significantly different characteristics.

3. Crater Depths

The large scale of the Orbiter photographs permits much-improved accuracy in shadow measurements compared to all previous height determinations based on earth-based photographs. Thus far, approximately 600 crater depths have been determined from Orbiter shadow measurements.

Different LPL observers seldom differ by more than $\frac{1}{200}$th of an inch in measuring the shadow length. This corresponds to about 30 m change in depth. The coordinates of the shadow-casting point are measured to ± 0.0005 on the *Orthographic Atlas of the Moon*. False coordinates were supplied to test the sensitivity of the depth calculation to positional accuracy. An error of 0.005 in both ξ and η of the shadow casting point lead to a maximum error of 40 m in depth.

To test the reliability of the calculated depths, nine craters which appear in the overlap zones of adjacent Orbiter frames were measured on two to four different frames; the average probable error is 97 m. Six of the craters had an average standard deviation of about half that value.

Comparison of these depths with values given on the ACIC LAC series shows that the Orbiter values are systematically 500–600 m deeper for all crater diameters. Measurement of shadow lengths on prints from the *Consolidated Lunar Atlas* (Kuiper *et al.*, 1967) for 20 craters where the ACIC-LPL difference was approximately 1 km showed that the LPL values are correct. This prompted a closer look at the ACIC depths. Of 25 craters whose depths differed on LAC charts and the more recent Ranger Lunar Chart RLC 6 (ACIC, 1966), 21 craters show an average depth increase of 340 m on RLC 6. Each of 11 craters whose depth differs on the 1964 edition of LAC 58 compared to the 1961 edition of the same chart is substantially deeper. The average increase in depth is 665 m. The comparison of ACIC and LPL depths was made on LAC charts of various publication dates (including the 1961 edition of LAC 58), rather than the RLC series which covers a small area. The craters where ACIC and LPL depths are in agreement generally are flat floored, rather than bowl-shaped; thus it is easier to detect whether the shadow is on the floor on Earth-based photographs. All of the shadows measured on Orbiter photographs are unequivocally on the crater floor. It appears that the ACIC depths are incorrect.

E.A. Whitaker (personal communication) suggests the ACIC error has two causes: (a) Atmospheric seeing produces an image on a negative in which well-exposed areas (crater walls) extend into unexposed areas (shadows). This diminution of the shadow occurs at both ends, doubling the effect. This may explain why ACIC depths, for all crater diameters, differ by a constant 500–600 m from LPL depths. This effect would be minimized for flat-floored craters where the contrast between shadow and floor is far less than for bowl-shaped craters where the shadow is adjacent to a bright wall. (b) The second source of error is conjectural but undoubtedly occurred at least occasionally. On small scale photographs such as ACIC used to determine depths it is frequently impossible to decide if the shadow reaches the floor for small craters.

Comparison of the forty-one craters which appear in both the LPL and Baldwin (1963) lists again shows the LPL craters to be systematically deeper. Baldwin measured his crater depths in a similar fashion to ACIC, and thus made the same type of errors. Yet, Baldwin's depths are systematically less than those calculated by ACIC for the forty-one craters sampled.

To determine with certainty whether the crater depths of Baldwin, ACIC, or LPL are approximately true it is necessary to know irrefutably the depths of a few lunar craters. It is hoped that the Apollo 15 metric camera data will provide this information. If the depths reported in the LPL crater catalog are correct, Baldwin's depth-diameter relationships must be re-examined. Using the floor-to-rim ratio and depth-to-diameter ratio, it will be possible to compare quantitatively the various types and ages of craters on the Moon, Earth and Mars.

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