

Description of the Lunar Boulder Data PDS Archive

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Purpose: Created as part of a project funded by NASA'S Lunar Data Analysis Program (LDAP), the purpose of this dataset is to provide locations and diameters of boulders around small, young impact craters on the Moon. These boulder counts were conducted as part of a study aimed at determining regolith production rates and assessing landing site hazards, as discussed in the associated publications. Researchers are encouraged to read the publications and data description document to understand how the data was acquired and used.

1. Dataset Overview

This database contains boulder distributions around small (< 1 km), young (< 200 Ma) lunar impact craters located near spacecraft landing sites. The most up-to-date database contains boulder diameters and coordinates for counts around Surveyor (Apollo 12), Cone (Apollo 14), North Ray (Apollo 16), South Ray (Apollo 16), Camelot (Apollo 17), and Zi Wei (Chang'e-3) craters.

Boulders were manually identified and measured on Lunar Reconnaissance Orbiter Camera (LROC) Narrow Angle Camera (NAC) images (Robinson et al., 2010) at scales of ~ 0.5 -2 m/pixel. LROC NAC images allow for boulders ~ 1 -2m in size and larger to be identified and measured. The tools for measuring boulders were CraterTools (Kneissl et al., 2011) and Crater Helper Tools (Nava, 2011), both developed for the ArcMap GIS platform.

These boulder distributions are being used to understand boulder degradation rates on the lunar surface, and to assess landing site hazards for future surface missions to the Moon. This dataset is being archived in the Planetary Data System (PDS) for use in future boulder distribution and landing hazard studies. Future boulder counts and any refinements to existing measurements will be uploaded into subsequent versions of this dataset.

Tools required for viewing data:

CSV file reader

GIS Application (ArcMap is preferred) for viewing shapefiles

USGS's Integrated Software for Imagers and Spectrometers (ISIS3) – for processing and map-projecting NAC images - <https://isis.astrogeology.usgs.gov/>

Tools required for conducting boulder counts:

CraterTools (records circular diameters only)

<https://www.geo.fu-berlin.de/en/geol/fachrichtungen/planet/software/cratertools.html>

and/or

Crater Helper Tools (measures ellipses)

https://astrogeology.usgs.gov/search/map/Software/GISTools/CraterHelper_0526101019p_Package

2. Data Collection

In NAC images, boulders are positive relief features and appear as bright, sun-facing pixels adjacent to dark, commonly elongated shadows. The best NAC images for boulder counting are those with medium-to-low sun angles, which allow the boulder shadow to be visible and elongated. With the exception of Cone crater, the NAC images for the count sites in this archive were all ~60-70°.

NAC images were downloaded in raw (.IMG) format and processed using the USGS's Integrated Software for Images and Spectrometers (ISIS) software (Anderson et al., 2004). Images were processed and map projected into .cub format at native resolution to ensure that the smallest boulders possible could be identified. Resolutions ranged from 0.48-1.1 m/pixel for the images used for boulder counts in this dataset. The link to each NAC image on the PDS is provided within the CSV file for each count site.

We located and counted boulders on NAC images using the CraterTools and Crater Helper Tools programs developed for ArcGIS. For images with a 0.5 m/pixel resolution, the smallest boulders that could be identified with confidence were ~1 m (>3 pixels, including the shadows). The earlier counts were done using CraterTools, which records boulders in terms of a circular diameter (capturing the longest dimension) and the latitude and longitude of each boulder. Crater Helper Tools is slightly better suited for measuring boulders and was utilized for the later counts. Crater Helper Tools captures the long and short dimension of each boulder, as well as its latitude and longitude coordinates. The data in the CSV files within this database report the major axis of each boulder, as measuring the longest dimension allows us to a) compare data taken using both methods, and b) take a conservative approach to evaluating boulders as potential landing hazards.

The distance of each boulder from the center of the crater was calculated using the haversine formula:

$$d = 2r \sin^{-1} \left(\sqrt{\sin^2 \left(\frac{\varphi_2 - \varphi_1}{2} \right) + \cos \varphi_1 \cos \varphi_2 \sin^2 \left(\frac{\lambda_2 - \lambda_1}{2} \right)} \right)$$

where d is the distance between the two points, r is the radius of the Moon, φ_1 and λ_1 are the latitude and longitude, respectively, of the center of the crater, and φ_2 and λ_2 are the latitude and longitude of the center of the boulder.

3. Data Product Structure

Each boulder count site in this archive consists of a CSV file and a folder of associated shapefiles.

a. CSV files:

The CSV files contain information regarding the study site, as well as the boulder measurements and locations. Each file contains the following information:

NAC images = PDS URL for each NAC image used for the count. These images are raw and should be processed and map-projected before ingesting into ArcMap.

Total_area = total count area, in km². Note that this is not the total area of the NAC image; rather it encompasses the area in which boulders were counted and measured.

Crater center = latitude and longitude of the center of the study crater. Planetocentric values in decimal degrees, eastward and northern locations are denoted by positive values.

The boulder measurements and locations are provided in 6 columns:

- **BOULDER_DIAM_km** – boulder diameter (major axis) in kilometers.
- **BOULDER_DIAM_m** – boulder diameter (major axis) in meters.
- **LON** – Longitude coordinates of the boulder center. Planetocentric values in decimal degrees, eastward longitudes are denoted by positive values.
- **LAT** - Latitude coordinates of the boulder center. Planetocentric values in decimal degrees, southern locations are denoted by negative values.
- **DISTANCE_m** – distance of the boulder from the center of the crater in meters, calculated using the haversine formula (ref). See associated publications by Watkins et al. for more details.
- **CRATER_RADII** – distance of the boulder from the center of the crater, in units of crater radii.

Note: *Surveyor and Camelot craters are both located in the vicinity of other fresh craters that have their own boulder populations. Because of this, we use CraterTools and Crater Helper Tools to flag boulders that we deemed to originate from somewhere other than the crater of interest (see Data Product Structure). The boulder data reported in the CSV files are only the boulders from the crater of interest; the shapefiles still retain the flagged boulders.*

b. Shapefiles

Each count site contains a folder of GIS shapefiles that can be easily ingested into a GIS platform such as ArcMap. Every folder contains:

- **Area_Xradii** = circular areas showing increasing units of crater radii (“X”) from the crater rim. X varies for each count site.
- **Area_rim** = outline of the crater rim

For counts conducted using **CraterTools**, the shapefiles containing boulder data appear as:

- **CRATER_<filename>** - shapefile containing:
 - Diam_km – the boulder diameter (km),
 - x_coord – longitude coordinate of the boulder center
 - y_coord – latitude coordinate of the boulder center

For counts conducted using **Crater Helper Tools**, the shapefiles containing boulder data appear as:

- **<filename>_point** = point shapefile, where each point marks the center latitude and longitude of the boulder. This shapefile contains:
 - **MINOR_AXIS** – boulder minor axis, in km
 - **RIM_DIA** – boulder diameter (major axis), in km
 - **LAT** – latitude coordinate of the boulder center
 - **LON** – longitude coordinate of the boulder center
- **<filename>_line** = line shapefile containing the outline of the boulder, as determined using a 6-point ellipse.

Notes:

- *For the Surveyor crater count (completed with CraterTools), the shapefile identifies boulders as “marked” or “standard”. The “marked” boulders are those attributed to originating from Surveyor crater, the ones marked “standard” are those that likely originated from other nearby craters.*
- *The Camelot count contains boulders from the nearby Central Cluster. The shapefile folder for Camelot contains one set of point and line shapefiles for boulders from Camelot only, and another set for boulders from both Camelot and the Central Cluster.*

Additional notes on the boulder counting database

- This database will be updated when new boulder counts are conducted. All future counts will be conducted using Crater Helper Tools, as boulders on the lunar surface tend to be elliptical in shape.
- The data in the CSV files are the data used for calculating boulder size-range, size-frequency, and range-frequency distributions, as discussed in the associated publications.
- Measurements of boulder heights were conducted using shadow-lengths and knowledge of illumination conditions. Details can be found in the associated publications by Watkins et al. For these measurements, NAC Digital Terrain Models (DTMs) are necessary. NAC DTMs are available publicly on the PDS and the Lunar Reconnaissance Orbiter Camera website - http://wms.lroc.asu.edu/lroc/rdr_product_select

- The NAC images used for these counts had suitable lighting conditions and resolutions for conducting boulder counts. There are currently many additional LROC NAC images of these sites, and more are being obtained as the mission continues. The authors do not currently plan to re-count the sites listed in this database, but welcome contributions from others who wish to utilize new or existing imagery to reassess these counts.
- Please don't hesitate to email the authors with questions, updates, corrections, or to discuss potential collaborations for future lunar boulder counting projects. Please send all correspondence to Ryan Watkins at rclegg-watkins@psi.edu

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