# LUNAR CRATER MATURITY ANALYSIS IN PYTHON: DEVELOPING A TOOLKIT FOR EJECTA ANALYSIS.

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**Introduction:** The lunar surface is covered by impact craters, which were formed throughout solar system history. The expression of craters can change with age and affect what is seen in remote sensing data. Examining a variety of impact craters can provide information about how the ejecta of these craters evolves with exposure to the space environment. Ultimately, the goal of this research is to be able to better understand the evolution of the lunar surface by understanding the evolution of impact ejecta. Here, we describe a toolkit developed for the purpose of being able to evaluate the ejecta of young craters on the Moon.

**Background:**

*Maturity of lunar soils*. Maturity in this context refers to a qualitative estimate of the length of time a specific region of interest has experienced surface exposure. By looking at the maturity of craters and their ejecta, important questions such as when these impacts occurred, and what the surface around the crater is like, can be answered. Changes in the physical properties of lunar soil with age are usually quantified in terms of specific indices (e.g., Optical Maturity (OMAT) [1]). Evaluating maturity indices at different wavelengths [e.g., 1-8] provides a more complete understanding of how ejecta degrade on the lunar surface. Crater ejecta can reveal a lot of information about how a given crater formed, and can more broadly tell us more about the composition of the Moon and how the surface evolves with time.

*Methods of evaluating maturity*. Current available tools that are used to evaluate crater maturity include, for example, ISIS, MATLAB, and IDL. To varying degrees, these tools have been utilized with a wide variety of datasets to examine maturity of lunar soils (e.g., LROC WAC [2], Diviner [3], $M^3$ [4], Mini-RF [5,6], and OMAT [1]). As a result, the workflow involved with conducting this type of analysis can be complex, requiring significant manual intervention. The goal of the Lunalyze toolkit is to streamline workflow for this type of analysis, primarily through the automation of tasks.

**Method:** The Lunalyze toolkit uses Python to allow users to be able to open and run select scripts. Right now, current drawbacks to crater analysis software include having packages that can be difficult to install and set up. Python was chosen because of its versatility as a computing language, the fact that it is open source, and that it is relatively easy to access and learn how to use. Lunalyze builds off of existing Python packages [e.g., 9], but includes new features in Jupyter Notebooks, which allow the user to get real time feedback on which segments of the scripts are working and which ones are not. Currently, Lunalyze can read in a variety of image file types and convert them to other file types as needed. The image conversion is done using a graphical user interface (GUI) that removes the step of having someone go and edit the source code (Figure 1).


Welcome to the Image conversion user interface!
please enter the absolute file path
if you would like to convert a single mat file and view the image, please enter the filename here
if you would like to convert a single cub file and view the image, please enter the filename here
if you would like to view a .img file and convert it to tiff, please enter the filename here
please enter the number of lines in the image
please enter the number of line samples in the image
please enter the name of the file you would like to view
if you would like to convert a fits file to tiff, please enter the filename here

**Figure 1:** An image of the GUI for image conversion. A variety of different data types can be converted as needed, including standard PDS formats, image cubes and MATLAB files.

Current development efforts for Lunalyze analysis capabilities include crater detection, rim and floor detection, and shape file generation. This work builds on the open-source Python package Craterpy [9]. The Lunalyze interface allows a user to look at regions of interest based on specified coordinates and perform analysis for a given dataset. This analysis includes options for looking at the crater floor, rim, and ejecta individually. Ongoing development will facilitate the analysis of craters (and their ejecta) across a variety of data sets.

The current use-case for Lunalyze is to provide a user-friendly and efficient means of evaluating the maturity of Copernican crater ejecta. Our objectives are twofold: 1. To evaluate whether maturity indices at different wavelengths can be correlated, and 2. To provide a new, open-source toolkit to the community that can be used to study lunar craters across a variety of data sets. Stickle et al. [5] showed that the maturity of ejecta blankets for young lunar craters could be tracked across wavelengths for craters of varying ages. That initial work used radial profiles that were placed and calculated manually to evaluate maturity indices in LRO and Kaguya data. To increase the time and efficiency of conducting such analyses, Lunalyze provides a user-friendly interface that includes automation options.

**Discussion and Future Work:** The development of Lunalyze is ongoing and is currently focused on options related to detecting crater rims and extracting radial profiles from selected regions of crater ejecta blankets. This capability is being tested on select lunar craters. An example is the crater Dufay B (Figure 2). Dufay B was chosen as a stressing case due to its irregular rim and non-circular shape (Figure 2A). These factors can pose a significant challenge for an automated tool. The option to manually draw the crater rim is in development (Figure 2B). However, automated options that can address this case are being considered and evaluated. For example, a simple test-case attempt at fitting the crater rim with a circular mask is shown in Figure 2C. In this test-case, the rim is approximated incorrectly and its center location is not properly determined.

Lunalyze has been designed to accommodate analysis across multiple relevant datasets (e.g., Diviner, LOLA, and Mini-RF). Current tested capability for viewing and analyzing craters is restricted to image data (e.g., Figure 2). Multi-band datasets pose a challenge for integration in our analysis framework and are another focus of current development.

**Summary:** Using a GUI, we hope to remedy current analysis challenges and allow the user a greater range of autonomy and analysis capabilities. Additionally, the benefits of Lunalyze allow for more time for scientists to study the lunar surface with less time spent on formatting data and generating common analysis tools. It will also provide a repeatable method of analysis that can be used by members throughout the community.

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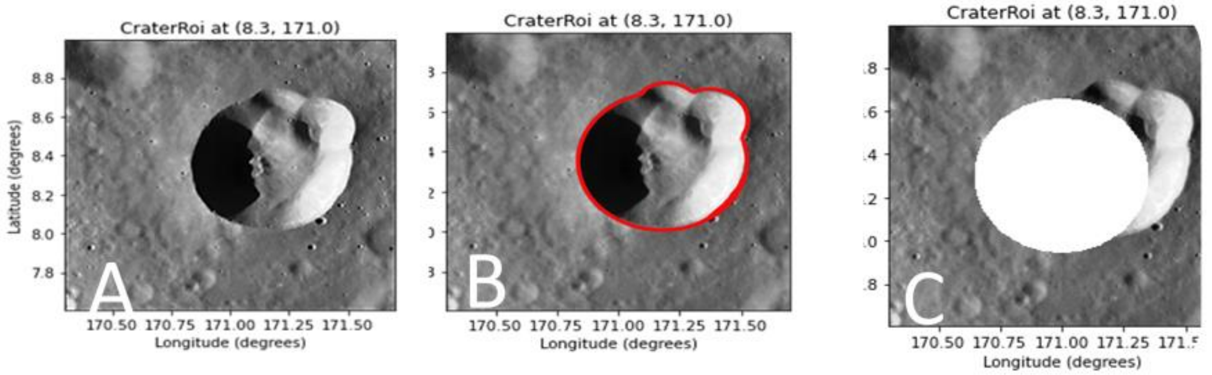

**Figure 2**. A) A LROC WAC image of the highlands crater Dufay B, one of the craters of interest in this study. Dufay B (19.8 km, 8.3°N, 171°E) is categorized as "intermediate" in age [2]. B) Dufay B with the crater rim superposed. The rim was manually identified and marked using the updated tool Lunalyze. C) Dufay B with a circle estimating the crater overlain. The white circle represents the automated determination of the crater planform in Lunalyze, showcasing still-needed adjustments.