IDENTIFICATION (AND MISIDENTIFICATION) OF DARK-HALO CRATERS WITHIN THE TAURUS-LITTROW REGION OF THE MOON FROM MOONZOO DATA.
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Introduction: MoonZoo is an online citizen science project, one of several of the Zooniverse Citizen Science Alliance. MoonZoo uses high spatial resolution images from the NASA Lunar Recognizance Orbiter (LRO) (Fig 1) [1], Narrow Angle Camera (LROC NAC) instrument [2].

Figure 1: Lunar Recognizance Orbiter (NASA).

Through the MoonZoo interface, citizen scientists are presented with NAC images of the surface of the Moon and they are asked to identify and annotate a wide range of geologic features. These features include crater sizing (the main research target) and counting, identifying rills and boulder tracks. MoonZoo has access to subsets of NAC images from three different zoom levels, representing the lunar surface at a scale from metres to kilometres (Fig 2).

Figure 2: The MoonZoo website and graphical interface for crater identification and measurement tasks [3].

No scale bars are provided on each image to prevent bias. Craters are identified down to a size of 20 pixels, which equates to a crater size of about 10 m in diameter in the highest resolution images (Fig 3).

Region of study: The Taurus-Littrow region, a steep-sided flat-floored valley, which is linked to the formation of the Serenitatis basin. Before the Apollo missions, the dark surface areas were thought to represent pyroclastic materials originating from cinder cones [5]. Many of these presumed volcanic edifices have now been recognised as DHCs. One of the better known is Shorty crater, also in the region, where several patches of pyroclastic orange and black glass beads were found around the rim of the crater.

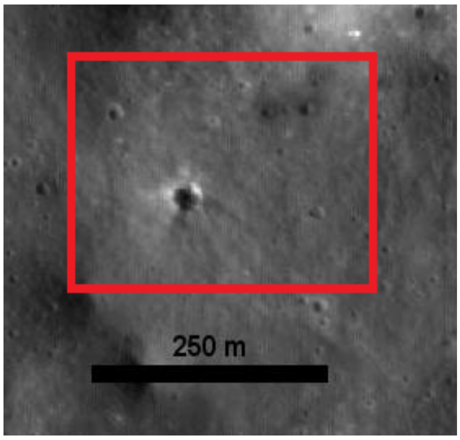

Figure 3: DRC identified by MoonZoo user.

Dark Halo Craters: This work focuses on Dark Halo Craters (DHC) and Dark Ray Craters (DRC), found within the Taurus-Littrow valley region, site of the Apollo 17 mission. The results show that, out of a total of 1018 possible identifications of DHCs by MoonZoo users, only 23 DHCs were correctly identified, and of these, only 4 were found to be unique, the others consisting of repeated identifications.

Consequently, this study suggests that a data validating routine should be implemented to scrutinise the output from MoonZoo; this could involve data assessment by experts, although this would be time consuming. Therefore more in-depth tutorials might improve detection skills of the citizen scientists.

In principle, by mapping dark-halo craters, it should be possible to estimate the thickness of the regolith. Small DHC may sample the top of the cryptomare, while larger ones would potentially sample materials below this layer, exhuming lighter coloured materials. To test this hypothesis a wide range of crater sizes from the same area is needed. The difference in excavation depths between these extremes can give an estimate of the cryptomare thickness [4]. The identification of DHCs can also provide information on the extent and volume of the cryptomare, a key aspect in the understanding of early volcanism on the Moon. If cryptomare were found to be a common occurrence on the Moon, then our estimates of surface igneous distribution would need to be re-assessed. This would challenge aspects of the present understanding of the thermal history and evolution of the Moon, allowing for more prolonged periods of early volcanism than presently reckoned [4].

Method: The initial MoonZoo data coordinates were entered into the data handling program JMARS (Java Mission-Planning and Analysis for Remote sensing), a GIS developed by Arizona State University Mars Space Flight Facility to provide a free data analytical tool for NASA and the general public.

JMARS projects the MoonZoo crater coordinates on a generic Clementine map of the region (Fig 4).

Once the general location is established, the appropriate NAC stamp is identified and rendered. This stamp is then enlarged to evaluate DHC-DRC entries.

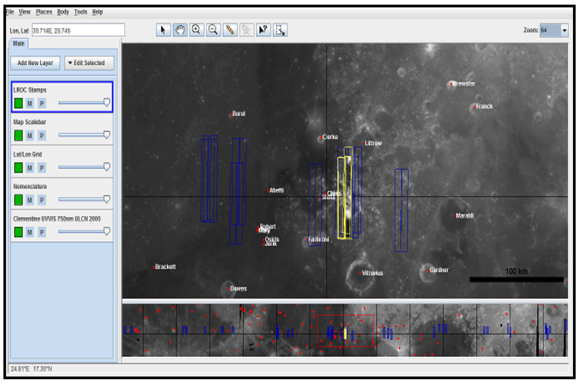

Figure 4: JMARS window showing Taurus-Littrow area and stamp boxes, yellow boxes indicate stamp rendered.

The depth of each crater was trigonomically derived using the shadow length on the crater floor cast by the crater rim against the illumination angle of incidence. The shadow length was obtained by the measuring tool supplied by JMAR.

Results: The results show that out of a total of 1018 possible identifications of DHC made by MoonZoo users, only 23 craters were correctly identified, and of these only 4 were found to be unique, the others representing repeated identifications. The average thickness of the regolith within the Taurus-Littrow valley is approximately 14 m, as indicated by Apollo 17 field studies [6]. The DRCs observed so far fall into this approximate depth when uncertainties are considered (Table 1). Their excavation depths (i.e. one tenth of the crater diameter) are also compared in (Table 2) Only 2 out of the 4 identified DRC`s were suitable for depth calculations. A much larger pool of DHCs-DRCs are needed to provide a clearer picture of the depth of the regolith along the Taurus-Littrow Valley.

Table 1: Mean depth and uncertainty values for two DRC`s.

DRC Location	*Mean Depth (m)*	*Crater Diameter (m)*	*Uncertainty*
30.515E 21.136N	11	26	± 4
30.499E 20.994N	23	79	± 10
*30.536E 20.970N	0	30	0
* 30.905E 20.759N	0	11	0

* Insufficient data to produce mean depth.

Table 2: Comparison between mean and excavation depths.

DRC Location	*Mean Depth (m)*	*Crater Diameter (m)*	*Excavation depth (m)*
30.515E, 21.136N	11	26	3
30.499E, 20.994N	23	79	2

Conclusion: Our main objective is to identify DHCs within the Taurus-Littrow region by examining the data provided by citizen scientists through MoonZoo and validate their contributions. The indication so far is that a very large proportion of the DHC`s-DRC`s are misidentifications. The majority of highlighted craters are standard impact craters, which quite often show strong shadowing inside the crater and/or around the rim. The wrong interpretation of shadows for dark ejecta could be the main source of mistakes. More in-depth tutorials might improve detection skills by giving the observer a better understanding of what to look for.

To confirm the depths of the regolith within the Taurus-Littrow valley a much larger database of DHCs-DRCs is required covering a larger geographical area. Further, a wider investigation into DHCs-DRCs would allow for a better understanding of the extent of buried cryptomare.

Bibliography: [1] Chin, G.G. et al. 2007. *Space Science Revs* 129 391-419 [2] Robinson, M.S. et al. 2010. *in Lunar and planetary Science* XLI Abstr.no.1874. [3] Joy, et al. 2011. *A&G*, vol. 52, 2.11-2.12. [4] Antonenko, I. et al. 1995 *Earth, Moon and Planets* 69, 141-172 [5] Scott, D.H. 1972. *U.S. geol. Surv*. Map 1-1695. [6] Muenhlberger, W.R. 1992 *Lunar and Planetary Institute Technical Report* 92-09, part 1. 36-37.