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Geomorphology of Lowell crater region on the Moon

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ABSTRACT

Surface topography, surface morphology and crater chronology studies have been carried out for the Lowell crater region (occupying ~198 × 198 km^2 in the northwestern quadrant of the Orientale basin) using Kaguya TC-DTM, LRO-WAC data, and Chandrayaan-1 M^3-750 nm image, to characterize and date Lowell impact event and to identify and assess the geological importance of the Lowell crater and effect of pre-existing geological conditions on the present day appearance of Lowell crater. The Lowell crater has been found to be polygonal in shape with an average diameter of 69.03 km. Its average rim height and depth from pre-existing surface are 1.02 km and 2.82 km respectively. A prominent central peak with average height of 1.77 km above the crater floor is present, which could have exposed undifferentiated mantle rocks. The peak exhibits a pronounced "V" shaped slumped zone on the eastern side and a distinct "V" shaped depression in the adjacent region on the crater floor. Several other peculiarities noticed and mapped here include W–E asymmetry in the degree of slumping of the walls and height of the topographic rim, N–S asymmetry in the proximal ejecta distribution with most of the material lying in the northern direction, concentration of exterior melt pools in the northeastern direction only, presence of several cross cutting pre-existing lineaments on the crater walls, presence of a superposed rayed crater on the eastern wall, and a geologically interesting resurfaced unit, which could be an outcome of recent volcanic activity in the region. It has been inferred that the Lowell crater formed due to impact of a ~5.7 km diameter bolide in the Montes Rook region. The impact occurred at an angle of ~30–45° from the S–SW direction. The age of the Lowell crater has been estimated as 374 ± 28 Ma, therefore it is a Younger Copernican crater consistent with the possibility expressed by McEwen et al. (McEwen, A.S., et al. [1993]. J. Geophys. Res. 98(E9), 17207–17231). Pre-existing topography and morphology has played a key role in shaping up the present day Lowell crater.

1. Introduction

The surface of the Moon is full of impact craters of varying shapes and dimensions. Among them, the spectacular ones are the large sized (>~15 km diameter) complex impact craters that characteristically possess central peaks, terraced crater walls and flat floors (Melosh, 1989; Melosh and Ivanov, 1999). At a sufficiently large size i.e., at diameter >~140 km, the morphology of the central peak takes the form of a peak-ring structure resulting in peak-ringed craters (Hale and Head, 1980; Melosh, 1982). The even larger ones (>300 km in diameter), which possess 3 (or more) concentric ring structures are termed as multi-ring basins (e.g. Wood, 1978; Melosh and Mckinnon, 1978; Spudis, 1993). Impact cratering is the principal geological process that has carved and modified the Moon's surface since its formation; therefore, the resulting craters and basins serve as important chrono-stratigraphic units (e.g. Shoemaker, 1962; Shoemaker and Hackmann, 1962; Stöffler et al., 2006). Further, impact structures expose subsurface rock formations and deep-seated structures; therefore, they provide an opportunity to study subsurface geology of an area through manned/robotic efforts or through remote sensing studies (e.g. Senft and Stewart, 2007). Recent availability of global high resolution remote sensing data from the Moon has provided an opportunity to carry out detailed geomorphological investigations of impact structures on the Moon.

In this study, remote sensing data from recent missions Kaguya of JAXA, Lunar Reconnaissance Orbiter (LRO) of NASA, and Chandrayaan-1 of Indian Space Research Organization (Haruyama et al., 2008; Robinson et al., 2010; Goswami and Annadurai, 2009; Green et al., 2011) have been used to investigate surface topography and surface morphology of a part of the Orientale basin on the far side of the Moon, enclosing ~66 km diameter Lowell crater (Scott et al., 1977) centered at (~13.0°S; 103.4°W) (Fig. 1). The region is geologically important since it is located inside Orientale basin, the proto-type multi-ring basin on the Moon. In addition to that, a distinct fresh resurfacing has been reported in the region (Srivastava et al., 2011), whose origin is been debated (Srivastava

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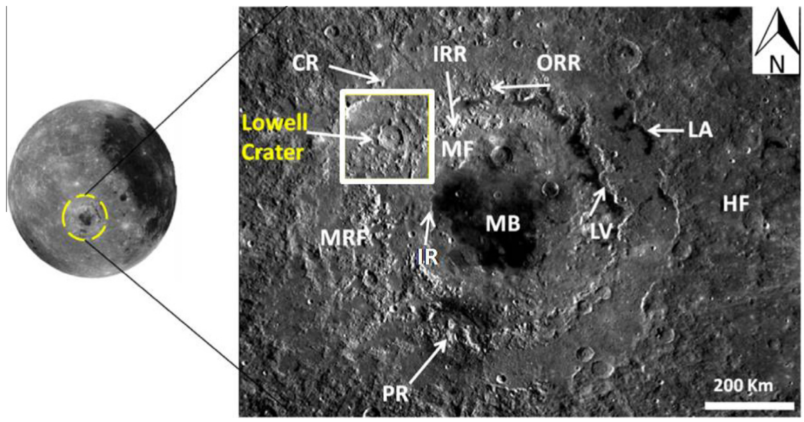

Fig. 1. A part of the LROC-WAC image mosaic of the Orientale basin from wms.lroc.asu.edu showing the study area i.e. the extent of the Lowell crater region (enclosed within rectangle) inside the Orientale basin. The Lowell crater is centered at ~(13°S, 103.4°W). The various geological units of the Orientale basin are marked. Here, HF: Hevelius Formation; MRF: Montes Rook Formation; MF: Maunder Formation; MB: Mare Basalt; LA: Lacus Autumni; LV: Lacus Veris; PR: the pyroclastic ring deposits; CR: Cordillera Ring; ORR: Outer Rook Ring; IRR: Inner Rook Ring, and IR: Inner Ring.

et al., 2013; Wöhler et al., 2014; Plescia and Spudis, 2014; Gupta et al., 2014). Surface topography and morphology of the Lowell crater region and age-dating of Lowell crater have been the main aspects of the study. The results have been synthesized to understand nature and characteristics of the Lowell impact event.

2. The study area

2.1. Location and extent

The study area defined here as Lowell crater region covers an area of ~198 × 198 km^2 in the NW quadrant of the Orientale basin on the far side, just beyond the western limb of the Moon (Fig. 1). In order to understand physiography and geological setting of the Lowell crater region and to realize geological importance of this area, it is essential to comprehend the location and geology of its host mega impact structure – the Orientale basin. Centered at ~(20°S, 95°W), the Orientale basin is a ~930 km diameter impact basin on the western limb of the Moon (Hartmann and Kuiper, 1962; Hartmann, 1964; Spudis, 1993; Potter et al., 2013). It is the youngest and the most well preserved multi-ring basin on the Moon and is a host to several prominent complex impact craters such as Lowell (diameter ~66 km), Maunder (diameter ~55 km), and Kopff (diameter ~41 km). The formation of Orientale basin defines the beginning of the upper Imbrian period in the lunar stratigraphic system (Wilhelms, 1987).

The Orientale basin possesses four prominent topographic rings that include Cordillera Ring (CR), Outer Rook Ring (ORR), Inner Rook Ring (IRR) and Inner Ring (IR) (Fig. 1), with diameters of ~930 km, ~620 km, ~480 km and ~320 km respectively (Head, 1974; Whitten et al., 2011; Potter et al., 2013; Nahm et al., 2013). According to the popularly accepted Megaterrace model for the formation of multi-ring basins (Hartmann and Kuiper, 1962; Hartmann and Yale, 1968; Hartmann and Wood, 1971; Head, 1974), the CR and the ORR are comprised of large scale normal faults. Topographically and morphologically, the CR show resemblance to final rim of complex craters (Head, 1974; Nahm et al., 2013). The ORR is composed of largely continuous massifs with steep slope toward the basin interior. It may present the edge of the Orientale transient cavity (e.g., Head, 1974; Scott et al., 1977; Fassett et al., 2011). However, Potter et al. (2013) and Nahm et al. (2013) have proposed that the diameter of the transient cavity could be much smaller than the ORR. It could be either ~320–480 km (Potter et al., 2013) or ~500–550 km (Nahm et al., 2013). Unlike the CR and the ORR, the IRR is composed of discontinuous isolated massifs. The IRR is considered to be plausible equivalent of peak ring based on its morphology, topography and composition (e.g., Head, 1974; Whitten et al., 2011; Nahm et al., 2013). The innermost ring IR represents structural terrace and is also discontinuous. It outlines the deeper part of the initially formed cavity where mare volcanism plausibly initiated in the Orientale basin and smooth facies of Orientale impact melts are present (Scott et al., 1977; Vaughan et al., 2013). At around the IR, ~175 km away from the center of the Orientale basin, there is an abrupt rise in topography of ~1.75 km along a chain of marginal faults, leading to clast rich Orientale impact melts forming corrugated facies (Vaughan et al., 2013). There are three principal geological formations in the Orientale basin. These are the Maunder Formation, the Montes Rook Formation and the Hevelius Formation. In addition to these, there are several volcanic units that formed in the basin during different times. The formations and volcanic units are briefly described as follows:

2.1.1. The Maunder Formation

The Maunder Formation (MF) represents impact melt sheet created by large scale melting of crustal and possibly mantle rocks during the Orientale basin forming impact event. The formation mostly lies within the IRR; however, at several places it extends beyond IRR into the Montes Rook Formation (Scott et al., 1977; Nahm et al., 2013; Spudis et al., 2014). The melt sheet is a mature iron-poor highland unit. Its spectral signature corresponds to a feldspathic upper crustal rock type, such as anorthositic norite or noritic anorthosite (e.g. Spudis et al., 1984; Hawke et al., 1991; Bussey and Spudis, 1997, 2000). Based upon the models of impact melt production and LOLA (Lunar Orbiter LASER Altimeter) derived topography, the depth of the impact melt sea has been estimated to be ~15 km (Vaughan et al., 2013). Further, Vaughan et al. (2013) have postulated that slow equilibrium crystallization in the homogenized impact melt sea would have resulted in a differentiated rock – sequence [comprising of norite (8 km)–dunite (2 km)–pyroxenite (4 km)] below the anorthositic fall back and the rapidly frozen crust. However, based on revised lesser anticipated thickness of melt sheet and detailed compositional analysis of the Maunder crater and other small superposed craters on the MF, Spudis et al. (2014) have concluded that the melt sheet has not differentiated.

2.1.2. The Hevelius Formation

The Hevelius Formation (HF) refers to the radially lineated, hummocky and swirly textured Orientale ejecta blanket that