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LROC: Nine Years Exploring the Moon

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Abstract

The Lunar Reconnaissance Orbiter Camera (LROC) acquired its first image of the Moon on 30 June 2009 and has since acquired over 1.6 million Narrow Angle Camera (NAC) images and over 600 thousand Wide Angle Camera (WAC) images (WAC nominal mapping began 1 January 2010). LRO was originally intended to support a human return to the Moon by providing technical data for mission planning acquired over a one year period. After successfully meeting those exploration goals the spacecraft was given a new two year science focused mission. Subsequently three extended science missions were funded and valuable science data is still being returned (3rd extended mission). Thus far the LROC team members have contributed to at least 100 peer-reviewed LROC-observation based publications.

1. Introduction

The NAC has provided globally distributed coverage (>90% of the surface) at the meter scale and high science value targets have been observed under a broad range of temporal, lighting and viewing conditions allowing 2 to 5 meter scale topography, landform analysis, and albedo characterization. Major NAC based discoveries are broadly grouped into the fields of tectonism, volcanism, and impact cratering. The WAC has acquired over 100 nearly global 7-color datasets, each with unique lighting and viewing geometry providing the most comprehensive non-terrestrial global photometric dataset ever collected. Orbit-to-orbit overlap provides parallax measurements from which a global topographic model was derived for characterizing large-scale landforms and allowing pixel-by-pixel viewing and lighting angles.

1.1 Small Sampling of NAC Discoveries

LROC images have revealed globally distributed small-scale contractional tectonic landforms (>3500 lobate scarps) that were largely undetected prior to LRO. The pristine condition, crosscutting relations with small-diameter impact craters, and crater size frequency distribution dating all indicate a young age for the small lobate thrust fault scarps (<50 my). These young thrust faults provide a window into the recent stress state of the Moon and offer insights into the origin of global lunar stresses. The global distribution of the faults is evidence of a "shrinking Moon" from cooling of a still hot interior, and the pattern of the fault scarps is consistent with stresses from global contraction and superimposed tidal stresses. The young age of the fault scarps raises the possibility that coseismic slip events on the developing faults were recorded by the Apollo Seismic Network. Modelling of the current lunar stress state indicates that peak stresses are reached at apogee, and many of the recorded shallow moonquakes in proximity to scarps occurred when the Moon was near apogee. The emerging conclusion from is that the Moon is still tectonically active. The search for evidence of very recent change on young tectonic landforms using temporal pairs of LROC NAC images may provide the best case for current tectonic activity.

The longevity of the LRO spacecraft enables temporal observations used to discover changes to the surface. Temporal image pairs consist of "before" and "after" images acquired under nearly identical lighting and viewing geometries. Systematic scanning of over 24,000 temporal pairs revealed over 400 newly formed impact craters. Before/after ratio images reveal previously unknown proximal and distal reflectance zones around the impact sites that provide insight into the crater formation process. In some cases, the distal reflectance zones affect areas 100s of crater diameters away from the new crater. We infer that these broad surface disturbances are caused by vapour and melt that was jetted from the impact site soon after the bolide contacted the surface. Additionally, the temporal pairs revealed over 120,000 other surface changes termed "splotches". While some of the splotches may be small primary impact craters, clusters of splotches identified around newly formed craters suggest that many splotches are the result of secondary impacts. Continued collection and analysis of temporal observations during the

Cornerstone Mission will help refine the current impact rate and provide more insight into the cratering process and churning of the upper regolith caused by secondary impacts.

Prior to LRO, the Compton-Belkovich Volcanic Complex (CBVC) was known only as an isolated, enigmatic, Th-rich anomaly, located on the northern farside. Narrow Angle Camera (NAC) images revealed the volcanic character of the anomaly and, coupled with data from Diviner, showed the CBVC to be rich in silica, making it an example of rare high-Si volcanism on the Moon. The CBVC occupies an area of roughly 25 x 35 km, centered at 61.1°N, 99.5°E. The complex is characterized by high reflectance and elevated topography, including domes and cone, some with steep slopes and abundant boulders. These volcanic features formed from viscous lava and occur around a central, irregular depression, likely a collapsed caldera associated with silicic pyroclastic activity. Moon Mineralogy Mapper spectra suggest this volcanic activity involved release of indigenous H_2O-rich volatiles. CSFD analysis constrains the volcanism to have occurred 3.5 billion years ago. The CBVC is unique among silicic volcanic localities on the Moon in its well-preserved morphologies and apparent H_2O-rich, silicic pyroclastic activity.

High resolution Apollo 15 photography revealed the presence of an enigmatic landform, known as Ina, thought to have formed through volcanic processes. Due to its small size (<3 km width) and inadequate observations, a definitive formation mechanism was elusive, and possibilities included effusive and explosive eruptions over a broad range of ages. LROC provided high resolution imaging with a variety of lighting conditions, and stereo-based topography allowing a reinvestigation of Ina. A significant finding from LROC was the discovery of similar deposits occurring in over 50 locations spanning from eastern Mare Tranquillitatis across a broad arc (2500 km) to the Gruithuisen Domes. Crater size–frequency distributions (CSFD, diameters ≥10 m) from Ina (and other similar deposits) were interpreted as indicating an eruption age of <100 My.

1.2 Small Sampling of WAC Discoveries

The origin of lunar light plains has long been debated, particularly since the return of Apollo 16 impact breccias. Conflicting relative age estimates and geologic context suggest all light plains are ejecta from the Orientale and Imbrium basins, many impact events, or even volcanic eruptions. In order to distinguish between the various origins of light plains deposits both at the local and global scale, a consistent global map of light plains was produced using WAC observations (morphology, albedo, topography). Results from the farside highlands suggest that the bulk of the light plains within 4 radii of the Orientale rim formed as a result of the Orientale basin-forming impact. It appears that the Imbrium basin displays a similar, though less pronounced, trend. Further, flow features identified among light plains deposits during the creation of the global map preserve a record of the emplacement dynamics of light plains deposits and may provide critical insight into the physical properties of light plains and, therefore, the basin formation process.

Enigmatic albedo patterns known as swirls occur in many locations on the Moon but are not known to exist on any other Solar System body. The WAC ultraviolet bands provided the means to better map their distribution and extent. Swirls were distinguished as low 321/415 nm ratio coupled with moderate to high reflectance, with high optical maturity (OMAT) values, stronger 1-μm bands, and shallower normalized continuum slopes than their surroundings. This new comparison showed the swirls to be significantly more extensive than previously known and likely the result of diminished space weathering rates from magnetic shielding.

The extensive photometric coverage provided by the WAC observations allowed the derivation of the first resolved map (30 km scale) of Hapke parameters for any body in the Solar System. Surprisingly the Hapke maps demonstrate decreased backscattering in the maria relative to the highlands (except 321 nm band), probably due to the higher content of both SMFe (submicron iron) and ilmenite in the interiors of back scattering agglutinates in the maria.

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