Pyroclastic Deposits and Source Vents on the Moon: The J. Herschel Crater Example

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Abstract

J. Herschel is a crater that is located in the northern part of the Moon (62°N, 42°W) on the margin of Mare Frigoris. J. Herschel crater is 165 km in diameter and hosts a major volcanic deposit that is located on the eastern floor. The deposit appears to have a rille system associated with it and covers an area of 60 km by 35 km. Four craters appear to be major sources for the pyroclastic material spread on the eastern floor. Spectral data shows that the deposit material is composed 30% pyroxene and 70% olivine (McCord et al., 1981). There is an interest in the mineral olivine because it is thought to come from deep within the moon and reflects conditions within the lunar interior. Studies of the origin and distribution of olivine-rich deposits will help us to understand how volcanism has influenced the surface of the Moon and may help us understand where we may want to land for future human missions to the Moon. My research will focus on the J. Herschel deposits and will address several major questions. How much of this material was erupted and is this material associated with any lava flows? How many deposits and vents are found at J. Herschel? Are these deposits located at higher or lower areas of the crater? Are the deposits related to volcanic deposits in nearby Mare Frigoris? Recently acquired remote sensing data for the Moon will be used in this research to address these questions. All data is available through NASA Planetary Data System archives.

1. Introduction

1.1 Pyroclastic Deposits on the Moon
Nearly 100 individual pyroclastic deposits are known to exist on the Moon, and more are being found with recent data (e.g., Gaddis et al., 2003; Gustafson et al., 2012 in press). These deposits are believed to have been emplaced on the surface by explosive volcanic means (e.g., Head and Wilson, 1979). Characteristics of these deposits include low albedo, smooth surface, and the presence of volcanic glass and crystallized spheres (Head, 1974; Gaddis et al. 1985, 2003).

Pyroclastic deposits can be described as regional or localized. Regional deposits have an areal extent of several 1000 km$^2$ and are usually found in lunar highlands next to major maria. They are thought to be the result of a strombolian style of volcanic explosion (Hawke et al. 1989). Strombolian eruptions occur from bubbles forming and disrupting parts of the magma surface. These explosions shoot particles of different sizes at different ranges. Particles larger than a few mm will land fairly close to the vent (~100m) and particles that are smaller than a mm can be shot out as far as tens or hundreds of km (Head & Wilson 1979).

Localized deposits have a small areal extent and are usually found in the floors of large impact craters which often have floor fractures and are often concentrated around the perimeters of major maria (lava-filled basins). The presence of one source vent leads to deposits of less than 100 km$^2$. The presence of several source vents leads to overlapping of deposits for an areal extent of less than 1000 km$^2$ with most falling between 250-550 km$^2$. These deposits are thought to be the result of a vulcanian style of eruption (Hawke et al. 1989). Vulcanian eruptions are the result of a plug formed by cooled magma being burst out by gases building pressure. Particles larger than a cm are shot to a few km while smaller particles can be shot to a few tens of km (Head & Wilson 1979).
1.2 J. Herschel Crater

The specific area that I will be working on is the J. Herschel crater. J. Herschel is located in the northern part of the Moon (62°N, 42°W) and has a diameter of 165 km. A major localized pyroclastic deposit is located on the eastern floor of the crater and is associated with a local linear rille system (Figures 1, 2, 3). The rilles appear to be composed of coalesced craters of endogenic origin. It appears that four of these craters are major sources for the pyroclastic material spread over the eastern floor of the crater. The diameters of these source vents range from 4-8 km and the pyroclastic material covers an area of about 60 km by 35 km (Hawke et al., 1989).

Earth-based telescopic spectra for J. Herschel shows the most likely composition of the deposit is a mixture of 30% pyroxene and 70% olivine (McCord et al., 1981). Plug rock could be responsible for some of the olivine content present, but to explain the high amount of olivine present, another source is required. A good amount of this olivine was emplaced with the juvenile (pristine or primitive) material during the J. Herschel eruption. Spectral data shows the surrounding area is dominated by pyroxene. It is likely that the pyroxene was a component of wall rock and was eroded and then emplaced by the eruption (Hawke et al., 1989). The J. Herschel site thus may preserve samples of olivine derived from the lunar interior.
2. Data

Data from several recent remote sensing lunar missions will be used for this analysis.

2.1 LROC NAC

Images from the NASA Lunar Reconnaissance Orbiter Camera (LROC) Narrow Angle Camera (NAC) have a resolution of ~0.5 m/pixel. The images are panchromatic meaning they are a realistic image of what the human eye would see. The NACs can detect craters with diameters down to 2.5 m and blocks down to 1m in width and 0.5 m height (Robinson et al., 2010).
2.2 LROC WAC

The LROC Wide Angle Camera (WAC) provides images at a resolution of 100 m/pixel. It can offer monochromatic and multispectral images. The camera uses a 1000 by 1000 pixel CCD that has seven narrow-band interference filters. Two of these filters are in the ultraviolet and the other five are in the visible range (Robinson et al. 2010).

2.3 Kaguya Terrain Camera

2.4 Kaguya Multiband Imager

The Japanese SELENE “Kaguya” Multiband Imager (MI) is a high resolution camera that consists of visible and near-infrared sensors which have 5 visible and 4 near-infrared bands. From a 100 km orbit, the resolution of the visible bands is 20 m/pixel and the resolution of the near-infrared bands is 62 m/pixel (Ohtake et al. 2008). The MI data can be used to study the compositions of lunar volcanic deposits as well as highland soils.

3. Methods

3.1 ISIS

Images from LROC NAC and WAC along with Kaguya Multiband Imager will be used for this research. Images are processed using Integrated Software for Imaging Spectrometers (ISIS) developed at USGS by the Astrogeology Science Center. ISIS is used to process planetary image data that is distributed in raw form and to create cartographically accurate image products such as maps and mosaics that can be used for scientific analyses (e.g., Gaddis et al., 1997).

3.2 ArcGIS

After the images are processed, they are imported into ArcGIS software for display and
analysis. Programs used in the ArcGIS software are ArcMap and ArcCatalog. Mosaicked data from the Kaguya Terrain Camera are used as base map for an ArcMap project. ArcCatalog is used to match the coordinate system of the newer imported data to that of the base map. Once this is done, the data can then be imported into ArcMap. The images are then manually georeferenced to the base map; assuming that the coordinate systems of the base map and imported data match reasonably well, this manual process involves creating tie points that move the images a few tens of meters on the lunar surface. This allows for a more accurate view of surface features to study their properties.

3.3 Crater Measurements

Once the images have been georeferenced, small craters are counted and measurements of their diameters are made. There are two purposes for making these measurements: (1) Small crater population density is used to help identify the locations of pyroclastic deposits because of the superposition of their loose, friable materials on lunar soil, and (2) The depths of excavation of small craters helps to identify and constrain the thickness of pyroclastic and other layers in lunar soil. Previous experiments of impacts into a uniform target and a target having a weak surface layer (a “regolith”) showed that uniform targets produce round, bowl-shaped craters, but impacts into a layered regolith have a different morphology. These morphologies are abundant in small (~50 m diameter) lunar craters. This experimental work was used to correlate the morphology of experimental craters to the depth of regolith in which they formed. It was found that the ratio of the apparent diameter of the crater (D_A) to the diameter (D_F) of the interior feature (flat floor, mound, or concentric ring) was a function of the ratio of the apparent crater diameter to the regolith thickness. It was found that the thickness was given by:
thickness = \( (k - D_F/D_A)D_A \tan(\alpha)/2 \)

where \( k \) is 0.86 (empirically determined constant) and \( \alpha \) is the angle of repose of the material (31°) (Bart et al. 2011). In this research, both small crater density and “regolith thickness” in and near pyroclastic deposits will be used to study their distribution and thickness, and to estimate their volumes.

### 3.4 Volcanic Modeling

This research will use volcanic modeling as a means to determining a likely scenario for the emplacement of pyroclastic deposits. In particular, we will test whether a vulcanian eruption model works for the small pyroclastic deposits at J. Herschel crater. A vulcanian eruption is one in which a plug bursts when the pressure of gases beneath the plug build. In addition the eruption is also intermittent. The Woods model (1995) was developed for such explosive volcanoes on Earth. Because of the lack of atmosphere and lower gravity on the Moon, parameters such as particle size, type and amount of volatiles (gases) must be changed to fit conditions seen on the Moon. The Woods model takes into account wall friction, the geometry of the conduit (cone), changing diameter of vent over time due to wall erosion, thermal disequilibrium between solids and gases, the amount of material being ejected, and the velocity at which the material is being ejected (Woods 1995). Essentially, the model predicts the spatial extent of materials thrown from a volcanic vent. By working backwards from the observed distributions of the deposits at J. Herschel, we will be able to study whether water was needed for these pyroclastic deposits, what the ejection velocities must have been, and how much material was needed to form the observed deposits.

Another model that could be utilized is the model developed by Mastin. This model is...
more complex than the one developed by Woods. In addition to being more complex, the Mastin model is used for strombolian eruptions. A strombolian eruption is one in which bubbles form and disrupt the magma. The eruption does not behave intermittently like a vulcanian one does. It can be a single explosive eruption or continuous. Mastin takes into account the geometry of the conduit (cylindrical), friction created by the walls, the density of the magma, and the properties of individual materials (Mastin 2002). The Mastin model can be used through the program Conflow (see http://vulcan.wr.usgs.gov/Projects/Mastin/Publications/OFR00-209/conflow.htm). A user can specify the composition of the magma with SiO$_2$, Al$_2$O$_3$, Fe$_2$O$_3$, FeO, MgO, CaO, TiO$_2$, Na$_2$O, K$_2$O, MnO, P$_2$O$_5$, and water. As well as magma composition, temperature, pressure, and the major mineralogy present during an eruption can be varied, with olivine and pyroxene being important ones for lunar eruptions. Again, using this model and the observed properties of the pyroclastic deposit at J. Herschel, we will be able to study both the composition of the melt needed to form the deposits and the major type of gases involved in the eruption. Results will help us to understand whether water was necessary to form these deposits, and especially to bring important minerals such as olivine up from deep within the Moon.

4. Research Plan

For this research project, I will be studying the area of J. Herschel with the goal of answering questions about lunar pyroclastic deposits in general and specifics about the deposits located in the floor of the J. Herschel crater.

4.1 General Questions to be Addressed

Lunar pyroclastic deposits have been identified by their smooth surface, low albedo, and the presence of volcanic glass and crystallized spheres (e.g., Adams, 1974; Coombs et al., 1989).
The deposits vary in brightness and ones with materials such as olivine would be brighter than other dark deposits. Since the relative darkness or low albedo of these deposits is used to identify them, there is a possibility that we have not recognized all of them. Also, a question is whether these materials really come from deep inside the Moon and how they erupted onto the surface. Knowing how much material was erupted, the size of the deposit, and the likely means of eruption gives us information about the type of volcanic activity that occurred and how it relates to interior materials and processes. Finally, it is believed that small and large deposits were emplaced through different styles of eruption. We want to understand whether this is true, or whether a continuum of eruption styles and materials are observed.

Questions to be addressed about lunar pyroclastic deposits in general:

1. What are the deposits like? Are they all smooth, and are they all dark?
2. Do the recent data confirm the presence of materials such as olivine in these deposits? If so, what does the presence and spatial distribution tell us about how materials from deep within the Moon are brought to the surface?
3. How big are the small deposits, how much material is erupted at one time, and what are the source vents like?
4. Are small deposits erupted onto the surface by different means than larger deposits as has previously been thought?

4.2 J. Herschel Deposits

The small pyroclastic deposits at J. Herschel have been previously studied, but not with such high-resolution imaging data. We will use the new data to understand how many deposits and associated vents are in the floor of J. Herschel crater, how far the material has been
distributed, what the materials in these deposits are like (were they blocky, or fine-grained and smooth?). We will search other areas near floor fractures and we will use small crater density to search for additional deposits. We will also search for any evidence of lava flows or other types of eruption; this will help us to understand whether these deposits were really erupted by a vulcanian style of eruption or whether another style was more likely. Finally, we will search for evidence of association between the pyroclastic materials and the nearby basalts of Mare Frigoris to determine whether their origins may have been related (e.g., Hiesinger et al., 2002). For example, we will examine the topography of J. Herschel and the spatial and compositional relationships between these volcanic deposits and those of Mare Frigoris.

Specific questions to be addressed about the pyroclastic deposits at J. Herschel include:

6. How many deposits and source vents are likely there?
7. Are these vents and deposits only associated with the fractures on the crater floor?
8. Are there any lava flows or ponded material associated with these deposits? These deposits would be evidence for effusive volcanism, which has not previously been observed with explosively emplaced deposits on the Moon.
9. What is the topography like around the crater and within the crater floor?
10. Are the deposits located in a higher or lower area of the floor?
11. Are the deposits similar in composition to the nearby volcanic deposits in Mare Frigoris?

References


Coombs, C. R. et al., 1990, The Alphonsus region: a geologic and remote-sensing perspective, 


Robinson, M. S. et al., 2010, Lunar reconnaissance orbiter camera (LROC) instrument overview, 

*Space Science Reviews*, v. 150, p. 81-124.