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Features

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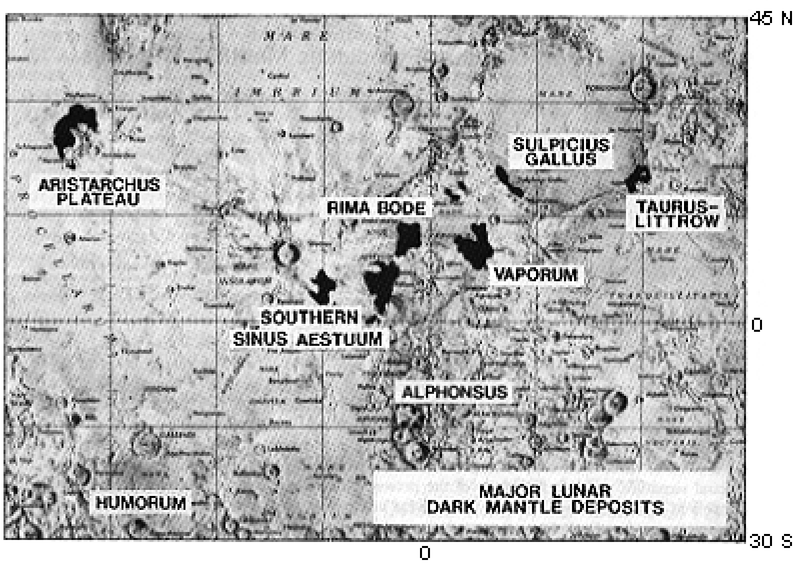
Explosive Volcanic Eruptions on the Moon

Written by Catherine M. Weitz
Department of Geological Sciences, Brown University
Recipient of the 1996 Dwornik Student Paper Award.

If you look up at the Moon in the sky you'll see the bright highlands and the dark mare. The mare are composed of lavas that erupted billions of years ago and filled in basins created by large impacts. In addition to the mare, there are also several dark areas that have diffuse boundaries and appear more unconsolidated than the mare. These nonmare deposits are called **D**ark **M**antle **D**eposits (DMDs) and they were produced from relatively explosive volcanic eruptions that hurled magma above the lunar surface.

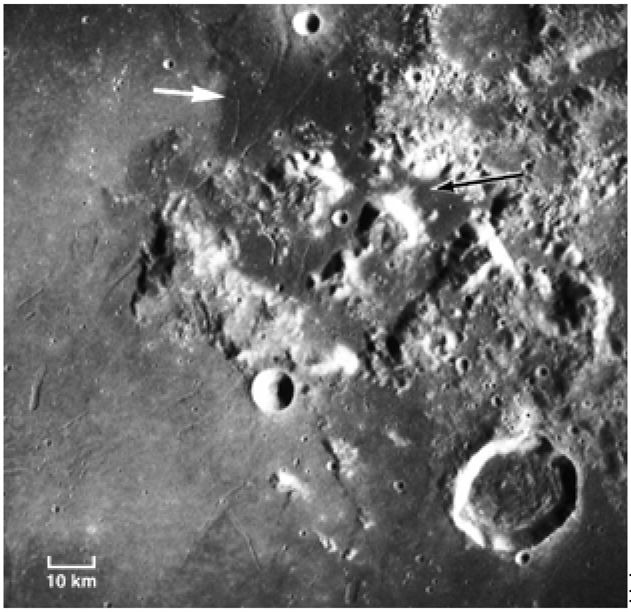


(Map from J. W. Head, 1974, Lunar Dark Mantle Deposits: Possible Clues to the Distribution of Early Mare Deposits, Proc. LPSC 5th, p. 207-222.)

For my doctoral dissertation, I am studying samples of the dark mantle deposit from the Apollo 17 landing site and images taken by the Clementine Ultraviolet-Visible (UVVIS) camera of several of the larger, regional DMDs on the Moon (see map above). My goal is to understand how the DMDs formed and model the volcanic eruptions that emplaced them.

The Apollo 17 Landing Site

Dark **M**antle **D**eposits were originally thought to represent some of the youngest volcanic eruptions on the Moon. The assumption used to determine the relative ages for areas on the Moon is that the more impact craters an area has, the older it must be. Compared to other areas on the Moon, the DMDs have fewer impact craters and therefore were thought to be younger.



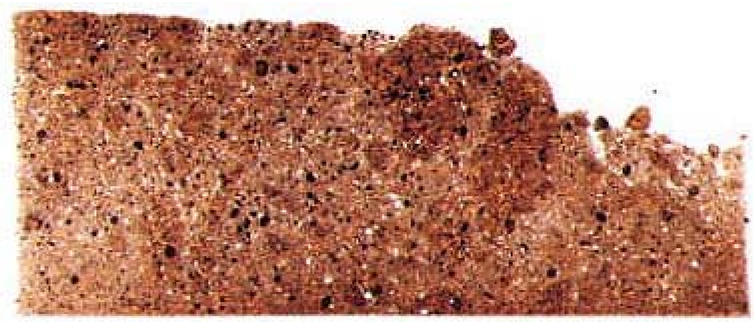
(NASA photo,
Apollo 17
frame M-5000

The Apollo 17 landing site (black arrow) in the Taurus-Littrow DMD was originally selected as a landing site because Apollo 15 astronaut Al Worden thought he saw cinder cones in the DMD and because the unit was thought to be younger in age (i.e. it had fewer small impact craters) than any of the other landing sites. Even though geologists not involved in the Apollo mission noticed that the DMD was covered over by mare lava flows (white arrow) that filled in the Serenitatis basin and therefore was older than the flows, the paucity of impact craters seemed to support a young age for the DMD.

Only after the Apollo 17 mission when the absolute age of the samples could be measured was it realized that the DMD was not as young as previously thought. It turns out the DMDs are composed of very fine-grained volcanic beads and the unconsolidated nature of the deposit allows small impact craters to degrade very rapidly. This is why older DMDs can have fewer craters than other geologic units that are younger.

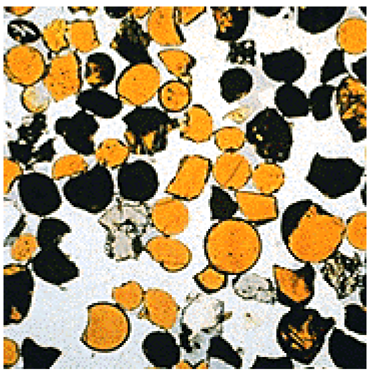
Samples from the Dark Mantle Deposits

The Apollo 17 astronauts took several soil samples from the Taurus-Littrow DMD. One of the most scientifically valuable samples was a 68-cm deep drill core taken on the rim of the impact crater Shorty. The core is composed of submillimeter orange glasses and their crystallized equivalents (black beads). As the cooling rate decreases, beads that would have quenched to form a glass now have time to crystallize minerals like olivine and ilmenite. Near the top of the core, most of the beads are orange glasses (see figure below) while near the bottom, most are crystallized black beads. Because the core represents the inverted stratigraphy at depth, the eruption that produced the beads must have begun with rapid cooling in the volcanic plume to form the orange glasses. Then the cooling rate decreased progressively, allowing crystals in the black beads to form. Similar glass beads called Pele tears are also found in Hawaiian eruptions but they are considerably larger in size, generally about 1 cm in size compared to less than 1 mm for the lunar beads.



(Thin section photo by Catherine Weitz, Brown University.)

The photo above shows a 2.5-cm-long thin section taken from the top of the Shorty core. The thin section has an orange color because the orange glass beads dominate over the crystallized black beads. Further down the core, the black beads dominate. Orange and black beads average about 0.04 millimeters in diameter.



Here is a thin slice of some Apollo 17 orange glass beads as viewed through a microscope. Crystallized black beads are the opaque mineral ilmenite. The view is only about one millimeter across. (Photograph courtesy of Graham Ryder, Lunar and Planetary Institute.)

How Do Explosive Eruptions Occur?

Eruptions that formed the DMDs on the Moon are thought to resemble fire fountains seen in Hawaii. This photograph shows a September, 1985 eruption of Pu'u 'O'o on the Big Island of Hawaii.

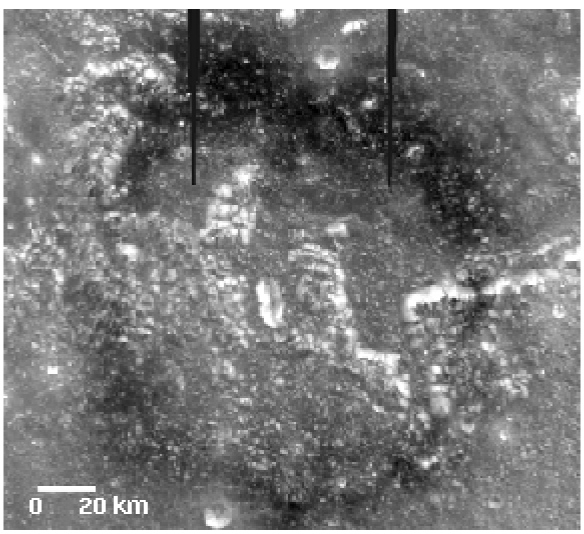
(Photo used with permission from Kenai Helicopters Hawaii.)

Gases dissolved in a magma at depth come out of solution as the magma approaches the surface and the pressure decreases. This causes bubble formation and growth which eventually leads to an explosive eruption at the surface. If you've ever shaken up a Coke bottle and then opened it, you are producing an explosive eruption because the carbon dioxide gas in the Coke came out of solution when you shook the bottle and then erupted explosively once you opened the top and allowed the gas to escape.

On the Moon, smaller amounts of volatiles are required to cause an explosive eruption and eject fragments for great distances compared to the Earth. This is because gravity is only 1/6 that on the Earth so the fragments can travel further and there is no atmosphere to slow down the beads during their flight above the surface. So on the Moon, gas bubbles that are only a few microns across will burst in the magma once they reach the surface and produce the volcanic beads that compose the DMDs.

A New Dark Mantle Deposit on the Farside

Now that we have Clementine images of the farside of the Moon, new discoveries are constantly being made. One new DMD (see figure below) located in southwestern Orientale basin is unlike any of those seen on the nearside beacuse of its annular shape. Using the Clementine data, we have been able to determine that the deposit is located at an average radius of 77 km from a central vent. Simple ballistic calculations indicate that the volcanic plume that emplaced the deposit may have been 40 km in height and resembled the umbrella-shaped plumes on Io rather than the fire fountains in Hawaii. The Clementine multispectral data also indicate that the DMD is composed of volcanic glasses rather than crystallized beads, indicating that the beads cooled very quickly in the volcanic plume.



(Clementine mosaic made by Catherine Weitz.)

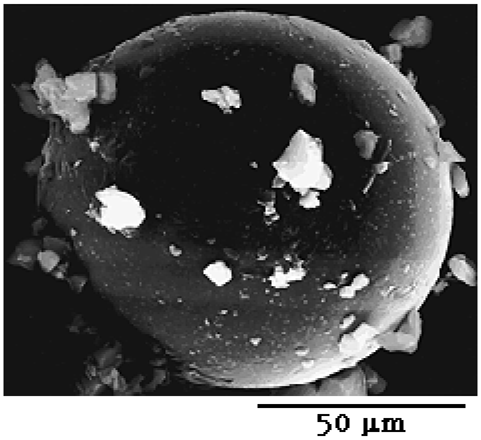
The dark ring in this Clementine mosaic of the southwestern Orientale basin on the Moon is a DMD. The two black spikes at the top of the mosaic are simply areas of no data.

DMDs as Future Sites for Lunar Bases

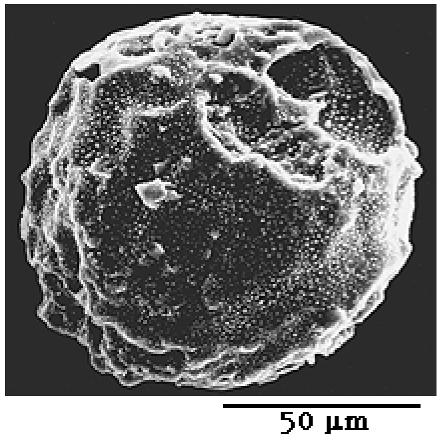
Dark Mantle Deposits would be ideal locations for future human colonies on the Moon. They could supply oxygen for life support and fuel, and provide unconsolidated material for use as shielding from cosmic rays and solar flares. A source of oxygen is especially important for future lunar development.

Although water may be present in permanently-dark areas near the south pole of the Moon (see "Ice on a Bone

Dry Moon" Dec. 1996), a base may not be placed there, depending on many factors. Experiments by Carl Allen (Lockheed Martin Aerospace Corporation) and his colleagues at the Johnson Space Center have shown that oxygen can be efficiently removed from pyroclastic glass beads by reacting the glasses at a high temperature with hydrogen gas.



Before reaction with hydrogen



After reaction with hydrogen

The image on the left, above is an electron microscope image of a glass bead (collected at the Apollo 17 landing site) before being reacted with hydrogen. Its surface is smooth, ignoring the small grains adhering to it. The image on the right shows a similar glass bead after reaction with hydrogen at 1100 ^{o}C for 3 hours. This glass bead is decorated with numerous small blebs of iron metal. The hydrogen reacted with iron oxide in the glass, producing iron metal and water vapor. The water vapor could be collected for use, or separated again into hydrogen and oxygen for life support or use as rocket fuel. The heating also caused formation of minerals in the glass, which have smaller volumes than the original glass, leading to the distortion of the original smooth surface of the little sphere.

An artist's conception of an advanced mining and production facility on the Moon.

(NASA artwork by Pat Rawlings/SAIC.)

An advanced industrial operation on the Moon might someday be manufacturing assorted products for use in space travel, such as oxygen from DMDs, or even products for use on Earth, such as helium for nuclear fusion reactors. Perhaps within 10-20 years people will return to the Moon and set up a colony in a Dark Mantle Deposit.

Additional Resources

Weitz, C. M., and J. W. Head, 1996, Eruption and Emplacement of Lunar Pyroclastic Glasses as Inferred

From the 74001/2 Section, in *Proc. LPSC XXVII*, p. 1411-1412.

Spudis, Paul D., 1996, *The Once and Future Moon*, Smithsonian Institution Press, 308 p.

Gaddis, L., C. Pieters and B. R. Hawke, 1985, Remote Sensing of Lunar Pyroclastic Mantling Deposits, *Icarus* 61, p. 461-489.

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psrd@higp.hawaii.edu
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