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Our New Moon and its Water

Y.J. Pendleton
Solar System Exploration Research Virtual Institute, NASA Ames Research Center, Moffett Field, CA. 94035
(yvonne.pendleton@nasa.gov)

Abstract

After years of thinking the Moon is dry, we now know there are at least three ways in which water appears on the Moon today:

1) The hypothesized buried deposits of volatiles at the lunar poles were found by the LCROSS mission at Cabeus crater (Colaprete et al., 2010).

2) Widespread, thinly- distributed, surficial OH (or H2O) has been mapped across many types of lunar terrain by several missions, including the Chandrayan mission using the Moon Mineralogy mapper instrument (Pieters et al., 2009).

3) The amount of water present when the Moon formed is now documented in lunar materials from Apollo samples (preserved in the lunar mantle material found in volcanic glass beads) which have recently been analysed using modern day technology (Saal et el., 2008).

Here I present a summary, of the work done by many others, to elucidate our current understanding of the sources and processes affecting water on the Moon. Several of the key researchers in these discoveries have been associated with the former NASA Lunar Science Institute (NLSI) and some are current members of the newly created Solar System Exploration Research Virtual Institute (SSERVI). Having served as the Director of the NLSI, and now of SSERVI, it is an honor to highlight the significance of some the lunar research that has created new knowledge about our nearest neighbor.

1. Introduction

Two early missions, Clementine (1994) and Lunar Prospector (1999) gave us preliminary evidence that there may be deposits of water ice at the lunar poles. In recent years, the NASA Lunar Reconnaissance Orbiter (LRO), The Lunar Crater Observation and Sensing Satellite (LCROSS) and the Gravity Recovery and Interior Laboratory (GRAIL) missions, the Indian Space Research Organization Chandrayan mission (with the NASA Moon Mineralogy Mapper instrument), the European Space Agency Smart-1 mission, and the Japanese Aerospace Exploration Agency Kaguya mission have added great depth to our knowledge of the composition and formation of the Moon, in addition to confirming the presence of water. We now have detailed maps of the Moon that identify surficial OH across several types of lunar terrain, and we better understand the role of the solar wind in the implantation process of hydrogen. Furthermore, modern technology has allowed more in-depth analyses of lunar samples, providing insights into the quantity or water within the Apollo samples of lunar glass. Dynamicists and meteoriticists have worked together to puzzle out the early history of the Moon and its relationship to Earth. Taken together, a picture of the Moon has emerged that would have been considered science fiction only a few years ago.

2. LCROSS and Water in Cabeus

The Lunar Crater Observation and Sensing Satellite (LCROSS) mission, impacted the Cabeus crater near the lunar South Pole on 9 October 2009 and created an impact plume that was observed by the LCROSS Shepherding Spacecraft.
The Sun never rises more than a few degrees above the polar horizon, causing some crater floors, such as Cabeus, to be in permanent shadow. The crater floor temperatures are very low < -200° C (-328° F), so water molecules move very slowly and are trapped for billions of years. There are questions about the origin of such volatiles (i.e., in-falling comets & meteorites, migrating surficial OH/H_2O, and accumulated release from the interior), but there is no doubt water is there (see Heldmann et al., 2015, for a recent analysis using data from the ultraviolet–visible spectrometer and visible context camera to constrain a numerical model to understand the physical evolution of the resultant plume).

3. Surficial OH

The Indian lunar mission, Chandrayan, carried aboard eleven instruments, two which were supplied by NASA, including the Moon Mineralogy Mapper (M3) instrument (Carle Pieters, PI). M3 revealed astonishing maps of the Moon's mineralogy and the identification of OH located across many parts of the moon's surface. The consensus is that this OH is derived from solar wind H linked to O from the surface silicate rocks. Although pervasive, we don't know how quickly it forms, nor how mobile it is. Analysis of absorption features near 3 micrometers in the lunar reflectance spectrum, observed by the orbiting M^3 spectrometer has been interpreted as being due to OH and/or H_2O. The dependence of the absorptions on lunar physical properties, including composition, illumination, latitude, and temperature continue to be investigated. Solar wind proton-induced hydroxylation is proposed as the creation process, and its products could be a source for other reported types of hydrogen-rich material and water. The irregular and damaged fine-grained lunar soil seems especially adapted for trapping solar wind protons and forming OH owing to abundant dangling oxygen bonds (McCord et al., 2011).

4. Water in Volcanic Glass

In recent years, NASA-funded researchers used modern-day technology to study samples of lunar material brought back to Earth in 1972 by astronauts on NASA's Apollo 17 mission. Within a sample of orange soil, beads of volcanic glass, they identified melt inclusions, small amounts of lunar magma encased within solid crystals. The crystalline shells prevented outgassing of water from the encased magma during its eruption approximately 3.7 billion years ago. Results of this analysis found water contents ranging from 615 to 1,410 parts per million, some 100 times higher than previous studies had suggested. These readings were comparable to concentrations measured in primitive terrestrial mid-ocean ridge basalts sampling the Earth's upper mantle (Hauri et al, 2015).

5. Conclusions

The work discussed here was conducted by many individuals and mission teams, too numerous to mention. Their hard work in obtaining the data, as well as their insight and careful analyses, have lead to our current understanding of water on the Moon. Many of the researchers involved in the NASA Lunar Science Institute and the Solar System Exploration Research Virtual Institute took part in several of the international and NASA missions and analyses that have advanced the state of knowledge on this subject. There are many references that deserve credit in this summary, but I list here only a few very recent references and encourage interested readers to explore these topics further through the reference lists within these and other relevant papers.

References

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