Abstract #1815

Simulating Lunar Ice

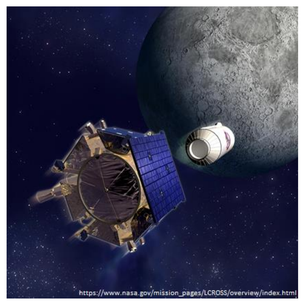
Formerly: A Comparison of Volatile Release Rates During a Simulated Extraction from Lunar Ice Mixed with Highland or Mare Regolith

Off Planet Research, LLC

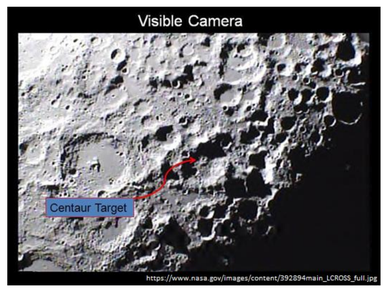
Vincent Roux, Melissa Roth, and Steven Miller

Background

In-situ extraction of volatiles from lunar ices for the production of rocket fuel and other critical materials is instrumental in a sustainable return to the Moon. It is imperative that some exploratory experiments are conducted to characterize any potential interactions of lunar ices with differing host regolith during the extraction process.



This experiment was intended to identify potential differences in the physical progress of volatile extractions from lunar ice caused by the presence of Highland or Mare regolith in the samples. However, what we actually learned was the difficulty in simulating lunar ice and that there are notable physical differences between ices in Highland and Mare regolith.



It is important to remember that this is information from a single location on the Moon and that the ices in other locations may have differing chemical compositions and physical characteristics.

LCROSS Data

Table 1 from Colaprete, A. et al [1]. Summary of the total water vapor and ice and ejecta dust in the NIR instrument FOV.

	Water mass (kg)			
Time (s)	Gas	Ice	Dust mass (kg)	Total water %
0–23	82.4 ± 25	58.5 ± 8.2	3148 ± 787	4.5 ± 1.4
23–30	24.5 ± 8.1	131 ± 8.3	2434 ± 609	6.4 ± 1.7
123–180	52.5 ± 2.6	15.8 ± 2.2	942.5 ± 236	7.2 ± 1.9
Average	53 ± 15	68 ± 10	2175 ± 544	5.6 ± 2.9

Compound	Molecules cm^{-2}	% Relative to H_2O(g)
H_2O	5.1(1.4)E19	100.00%
H_2S	8.5(0.9)E18	16.75%
NH_3	3.1(1.5)E18	6.03%
SO_2	1.6(0.4)E18	3.19%
C_2H_4	1.6(1.7)E18	3.12%
CO_2	1.1(1.0)E18	2.17%
CH_3OH	7.8(42)E17	1.55%
CH_4	3.3(3.0)E17	0.65%
OH	1.7(0.4)E16	0.03%

Table 2 from Colaprete, A. et al [1]. Relative abundances of ice constituents. The uncertainty in each derived abundance is shown in parenthesis.

Simulants Used

Lunar regolith simulants:

- OPRH1N (Off Planet Research Highland Group 1 Non-Agglutinate)
- OPRL1N (Off Planet Research Mare Group 1 Non-Agglutinate)

Lunar ice simulant created:

- OPRFLCROSS1 based on the data gathered from the LCROSS impact
- Note: SO_2 and OH components were not included in the simulated lunar ice for safety reasons.

The specifications for these simulants can be found at Offplanetresearch.com.

Sample Preparation

Samples of Highland and Mare simulants of equal dry mass were placed into stainless steel containers. Liquid nitrogen was used to cool the regolith simulants and equipment and to freeze the components of the simulated lunar ice as they were mixed into the regolith simulants.

Simulated lunar ice made by OPR in Feb 2018. The image shows mixed Highland regolith and ice simulant.

The simulated lunar ice/regolith mixtures were produced using LCROSS impact data (Tables 1 & 2). The ice and regolith were mixed as described by PI Anthony Colaprete: “it is likely water ice is interspersed between dirt particles on the lunar surface” [2].

Enough OPRFLCROSS1 was made for 10 trials of both Highland and Mare mixtures.

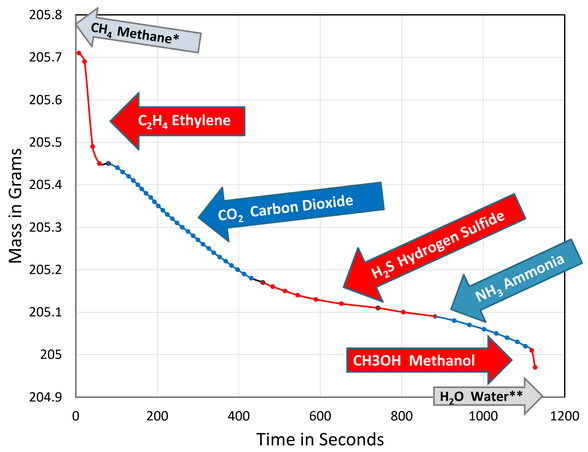
A 125 mL sample was placed into a vacuum chamber and warmed. The mass was recorded as the components sublimated off.

Simulated lunar ice made by OPR in Feb 2018. The images show the frozen gas components in Highland (left) and Mare (right) regolith simulants before the addition of water and methanol.

Results

The vacuum chamber suffered a structural failure approx. 23 minutes into the first Highland trial.

Volatilization of Ice Components Indicated by Loss of Mass Over Time



The above placement of ice components (arrows) is an approximation based off the changing slope of the line and the estimated masses seen in the table below.

* Due to the precision of the scale, methane volatilization was not recorded.
** Due to the failure of equipment, methanol volatilization was partially recorded and water volatilization was not recorded.

Order of Volatility	Component		Measured Mass (g)	Theoretical Mass (g)	Vaporization Point at 1 ATM (^{O}C)
1	CH_4	Methane	Unknown	0.002	-258.68
2	C_2H_4	Ethylene	0.26	0.30	-103.7
3	CO_2	Carbon Dioxide	0.28	0.33	-78.5
4	H_2S	Hydrogen Sulfide	0.08	1.88	-60
5	NH_3	Ammonia	0.08	0.35	-33.34
6	CH_3OH	Methanol	Unknown	0.17	64.7
7	H_2O	Water	Unknown	6.22	100

Future Studies/Recommendations

Lessons Learned:

- Notable differences between ices formed in Highland and Mare regolith
- Changes in the geotechnical characteristics of super-cooled regolith
- Making lunar ice is difficult
- Volatiles seem to come off in stages

Simulated lunar ice made by OPR in Feb 2018. The image shows mixed Highland regolith and ice simulant.

Simulated lunar ice made by OPR in Feb 2018. The image shows the gas components added to Mare regolith simulant.

Next Steps:

- Physical nature of volatile species (e.g. pure concentrations, inter-granular, globular)
- More consistent distribution of volatiles in each trial
- Geotechnical and mechanical testing
- Material handling characteristics
- Catalogue differences between Highland and Mare ice regolith mixtures
- Develop methods for ice storage

Resources Needed:

- NIR sensors (Ask us about our SBIR proposal!)
- Measurement equipment
- Long-term ice storage
- Improved thermal vacuum capabilities

Contact Information

Melissa and Vince

This is a placeholder for our business cards. Feel free to take one from our large poster! Our contact information can also be found below.

If you are interested in learning more:
Find us on Facebook @OffPlanetResearch
Website: www.offplanetresearch.com
Email: contact@offplanetresearch.com

Haiku

Out of the loop left
To talk haikus required
Present we cannot

References

[1] Colaprete, A. et al. (2010) *Detection of Water in the LCROSS Ejecta Plume. Science* 330, 463, DOI:10.1126/science.1186986.

[2] Thompson, A. (2009) *Significant Amount of Water Found on Moon. Space.com* Accessed Jan 6, 2017 from https://www.space.com/7530-significant-amount-water-moon.html