

THE MOON IS A HARSH CHROMATOGRAM: THE MOST STRATEGIC KNOWLEDGE GAP (SKG) AT THE LUNAR SURFACE E. Patrick, R. Blase, M. Libardoni, Southwest Research Institute[®], 6220 Culebra Rd., San Antonio, TX 78238 (epatrick@swri.edu)

Introduction: Data from analytical instruments deployed during multiple lunar missions, combined with laboratory results[1], suggest the regolith surface of the Moon traps more volatiles in gas-surface interactions than is currently understood. We assert that the lunar surface behaves as a giant 3-D surface chromatogram, separating gas molecules by species as each wafts across the regolith according to its mobility and adsorption characteristics before eventually becoming trapped. Herein we present supporting evidence for this claim.

In gas chromatography (GC), components of a sample are separated within a column according to their individual partitioning coefficients and by such physical characteristics as molecular weight, boiling point, polarity, size, or retention (adsorption) by the solid “stationary phase” used for chromatographic separation. At the surface of the Moon, as a gas mixture expands from its origin at a mission landing site or impactor ejecta plume, the gas density rapidly plummets as the mean free path of particles within the expanding plume undergo fewer and fewer collisions until their motion becomes dominated almost entirely by ballistic motion within the lunar gravitational field.

The Fundamental Issue: Volatile Trapping at the Lunar Surface: There are both endogenic (internal) and exogenic (external) gas sources at the lunar surface. The former consists of radiogenic gases such as ^{40}Ar inherent in rock and formed from the decay of ^{40}K ($\tau_{1/2} = 1.25 \times 10^9$ yr). The latter is due primarily to solar wind ions (H^+ , He^{+2} , Ne^{+10} , etc.) and materials delivered by the occasional impacting comet or asteroid, but in recent cosmic history has also been punctuated from time-to-time by artificial sources such as combustion byproducts from spacecraft engine plumes[1], outgassing from landed spacecraft and equipment[2], or water coma from cooling units in astronaut backpacks[3].

Evidence from Apollo 11 (A11) Sample 10086: In the temperature programmed desorption (TPD) experiments of Gibson & Johnson[4], returned A11 lunar “soil” sample 10086 taken from near the landed Lunar Module (LM) produced a gas evolution peak for N_2 not observed in similarly-treated sample 12023 taken from over 150 meters away from the A12 LM. Furthermore, the characteristic mass 28 peak for N_2 in the scan of the quadrupole mass spectrometer (QMS) occurred immediately upon heating above room temperature[4]. Henderson et al.[5], seeking to identify organic compounds in lunar samples, also observed mass 28 in 10086 using

a gas chromatograph mass spectrometer (GCMS) and revealed 97% of the composition in that mass channel to be N_2 . Henderson et al.[5] also identified amino acids which were attributed to contamination, but results from recent more sensitive LCMS and GCMS experiments by Elsila et al.[1] found some amino acid and other organic signatures to be extraterrestrial in origin. While these and other investigations suggest contamination from the Apollo spacecraft as a likely source for a number of observed signatures[1,2,4,5], what is not explained is the nature of the trapping mechanism for the N_2 feature in 10086, and demonstrates gas retention from a gas that, under most circumstances, exhibits no retention at temperatures around 300 K[3].

Evidence from Apollo 12, 14 & 15 Cold Cathode Gauge Experiments (CCGE): The CCGE, deployed to the lunar surface during Apollos 12, 14 & 15, was the first instrument to measure pressure of the tenuous lunar ambient atmosphere[2]. The A12 CCGE failed to saturate during venting of the atmosphere from the LM cabin, but saturated for over 6 minutes as astronaut Pete Conrad walked away from it – a pressure signature likely due to his backpack sublimator beaming H_2O into the ion source inlet of the gauge as we have previously reported[3].

Evidence from Apollo 15 & 16 Lunar Orbiter Mass Spectrometer Experiment (LOMSE): Analytical chemistry of the lunar exosphere from orbiting spacecraft began with the Lunar Atmospheric Mass Spectrometer Experiment (LOMSE) aboard A15[6] & A16[7] Command Modules. Data included measurements of Ne, CO_2 & H_2O , but no mention is made of gas signatures detected above the LM beneath every orbit.

The Evidence: Apollo 17 Lunar Atmospheric Composition Experiment (LACE): We will present results obtained by LACE relevant to the trapping and transport of volatiles and contamination at the lunar surface.[8]

The Evidence: Lunar Crater Observation and Sensing Satellite (LCROSS): We will present LCROSS results relevant to the trapping and transport of volatiles and contamination at the lunar surface.[9]

The Evidence: NASA’s Lunar Atmosphere Dust Environment Explorer (LADEE) and China’s Chang’e-3 Mission: The LADEE Neutral Mass Spectrometer (NMS) measured the presence of a number of atomic species (He, Ne, Ar)[10]. In December 2013, the Chinese Chang’e-3 lunar spacecraft landed and deployed its Yutu rover while NMS was operating

aboard LADEE. A lack of detection by the LADEE NMS of any gas signature from Chang'e-3 not only suggested that closer scrutiny of earlier Apollo-era gas detection at and above the lunar surface was warranted, but also suggested the possibility that molecular gases transported across the lunar surface may experience significant interaction and trapping at the highly-reactive surfaces of regolith grains.

Laboratory Results: Previously, we presented pressure profiles resulting from exposure of JSC-1A lunar soil simulant to multiple gases, including CO₂[3,11]. Here we report observations of CO and N₂ gas dosing of JSC-1A, along with that of the curated lunar sample 10084 for comparison (Fig. 1).

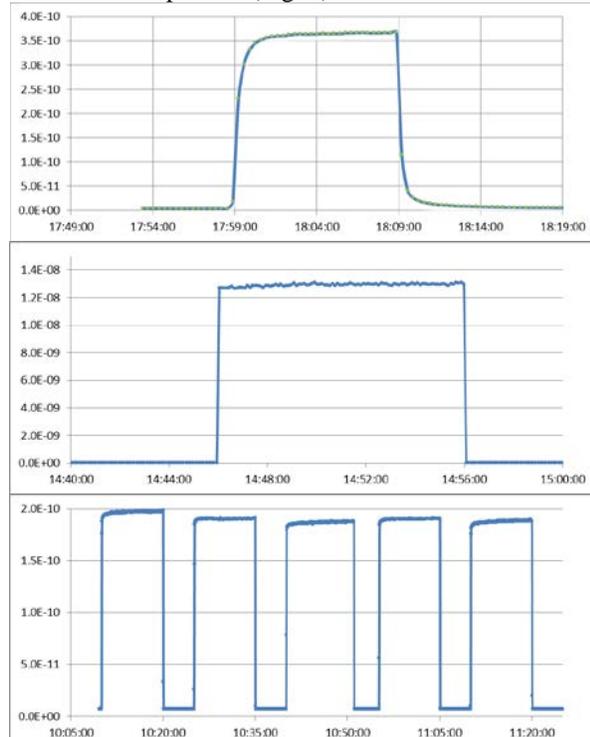


Fig. 1. CO & N₂ share nearly the same molecular weight (28), but the more polar CO shows retention (delayed rise & decay) against the surface of lunar simulant JSC-1A (top), whereas N₂ does not (middle). N₂ repeatedly exposed to Apollo 11 sample 10084 (bottom) also shows no evidence of retention at room temperature.

We have found no evidence of retention of N₂ in JSC-1A lunar soil simulant in numerous laboratory experiments[11], nor have we produced evidence of N₂ trapping in 10084. Here we also report results for volatile exposure to Apollo 11 sample 10084 including those for N₂.

Discussion & Conclusions: Questions concerning how regolith functions to trap gases from both above and below the lunar surface motivated our experiments, and the gases used included those expected to represent

contamination byproducts from spacecraft (exhaust, outgassing, etc.), those delivered to the lunar surface by impactors (comets, meteoroids), and those escaping from the lunar interior (radiogenic Ar). Contamination from artificial sources at each Apollo site during missions was significant and included engine exhaust products, outgassing spacecraft components and surfaces, deployed instrumentation, multiple cabin atmosphere depressurizations, and water “coma” from astronaut backpacks. We summarize these and what their impact means for future missions to the lunar surface.

Suggestions for Future Missions: Our recommendations for future investigations of the lunar surface with implications for both studies of *in situ* resource utilization (ISRU) and the paleocosmic record of lunar volatiles include:

1. **Regolith Contamination Control:** Contamination factors for regolith surfaces need to be identified and then eliminated, or at least controlled.

2. **Previous Landing and Impact Sites:** Investigations of past landing sites (Surveyor 1), or impact sites (A17 LM ascent stage), could reveal secrets of volatile retention with implications for the contamination of the paleocosmic record by artificial sources.

3. **Artificial Impactor Lesson from LCROSS:** Impacts by known masses and materials (e.g., Cu) would produce ejecta plumes revealing the composition and concentration of entrapped lunar volatiles, and aid in the modeling of impactors.

4. **Return Mass Spectrometry to the Lunar Surface:** The A17 Lunar Atmospheric Composition Experiment (LACE) remains the only mass spectrometer[8] ever deployed at the lunar surface. High-resolution mass spectrometry (MS) can separate interfering peaks of atoms and molecules in the lunar exosphere to reveal sputtered atomic species such as Al, Si, S & Ca or interfering fragment ion peaks from such common species as CH₄ (16), NH₃ (17) & H₂O (18).

References:[1]Elsila, et al., *Geochim. Cosmochim. Acta* 2, (Suppl. 4), 2241-2248. [2]Johnson F.S. et al. (1970) *A12 PSR*, 93-97. [3]Patrick et al., *LPSC* 47, 2649 (2016). [4]Gibson E. K. and Johnson S. M., *LPS II*, 1351-1364 (1971). [5]Henderson W. et al., *LPS II*, 1901-1912 (1971). [6]Hoffman J.H. et al. (1972) *A15 PSR* 19-1. [7]Hodges R.R. et al. (1972) *A16 PSR*, 21-1. [8]Hoffman J.H. et al. (1973) *A17 PSR*, 17-1. [9]Gladstone, G. R. et al., *Science* 330, 472 (2010). [10] Benna, M. et al., *GRL* 42, 3723 (2015). [11] Patrick et al. *Icarus* 255, 30-43 (2015).

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