AUGMENTING THE MOJAVE MARS SIMULANT TO MORE CLOSELY MATCH THE VOLATILE CONTENT OF GLOBAL MARTIAN SOILS BASED ON MARS SCIENCE LABORATORY RESULTS.
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Introduction: We have developed a modified version of the Mojave Mars Simulant to more closely match the volatile release profile of the Rocknest sample measured by the Sample Analysis at Mars (SAM) instrument on the Mars Science Laboratory (MSL) rover. This new simulant was developed to support In Situ Resource Utilization (ISRU) testing, primarily for water recovery from regolith, on a material representative of average Mars soil. The new simulant uses results from the SAM instrument on MSL, which was the first to characterize the volatiles released from an average martian soil heated up to ~835 °C.

The MSL rover scooped material from an aeolian sand shadow named Rocknest and processed it through the Sample Acquisition/Sample Processing and Handling (SA/SPaH) system, where 90% of the sample passed through a 150 µm sieve [1]. The major volatiles released when the Rocknest sample was heated to ~835 °C are listed in Table 1 (For more detail on SAM operations see [2] or [3]). Because we are primarily focused on the volatile content of the sample for ISRU purposes, our primary consideration is matching the major volatile content of the sample determined by SAM.

Table 1 - Abundances of major volatiles released from the Rocknest sample (values are averages over four runs) [1].

Species	Weight % (with 2σ error)
H_2O	2.0 ± 1.3
SO_3	2.0 ± 2.2
CO_2	0.9 ± 0.2
Cl_2O_7*	0.4 ± 0.2

*Cl_2O_7 is based on O_2 released and is a proxy for oxychlorine species such as perchlorate or chlorate

In total, the sample loses 5.3 ± 2.6% of its mass when heated to 835 °C, with just under half of that being from water. There are also minor releases of compounds such as HCl, H_2S, and NO from the sample [1].

Previous Simulants: JSC Mars-1 has been the most used martian soil simulant over the past few decades. JSC Mars-1 is the <1mm component of weathered volcanic ash from a cinder cone on the Island of Hawaii [4]. While JSC Mars-1 is a good spectral and geochemical match to average Mars soil, it has a few limitations for ISRU work. First, JSC Mars-1 is the B horizon of a soil and contains abundant organic material. Second, JSC Mars-1 has undergone some chemical alteration and is relatively volatile rich, losing up to 20% of its mass when heated to 1000 °C.

The Mojave Mars Simulant (MMS), described by Peters et al. [5], is a crushed basalt that is a good geochemical match for the globally similar martian regolith encountered by martian landers. It has been separated by JPL into multiple size fractions. To match Rocknest's particle size distribution, we mixed a sample consisting of 35% of the <2 mm size fraction and 65% of the "dust" size fraction so that ~90% of the material was <150 µm, determined by laser particle size analysis. When heated, the sample only loses ~0.5 wt% water <400 °C and 2.5 wt% total below 950 °C, substantially lower than the Rocknest sample and, therefore, not ideal for ISRU applications involving water recovery.

Augmenting the Mojave Mars Simulant: We have added minerals to make the MMS simulant more Rocknest-like for ISRU applications involving water recovery. The minerals added and the rationale for adding each are listed in Table 2. Overall, the primary goals of adding minerals are to better match the Rocknest water release profile as well as include other minerals that release gases that could impact ISRU systems. For example, perchlorates release HCl and sulfates release SO_2 upon decomposition. Inlcuding these minerals allows us to test the robustness of ISRU hardware under more realistic conditions.

Table 2 – Minerals added to make MMS more Rocknest-like.

Mineral added	Rationale
Epsomite ($MgSO_4•7H_2O$)	Releases low temperature water and high temperature SO_2.
Melanterite ($FeSO_4•7H_2O$)	Releases low temperature water and intermediate temperature SO_2.
Sodium Perchlorate ($NaClO_4$)	Releases some water, large O_2 release, and HCl in the presence of water.
Illite (IMt-2, Clay minerals society standard)	Releases H_2O at high temperature which causes HCl release from NaCl (the decomposition product of $NaClO_4$).
Ferrihydrite (synthetic)	X-ray amorphous, water bearing, broadens out low temperature water peak

Minerals have been added in amounts to match Rocknest geochemistry, broadly speaking, but the exact amounts added are still being refined. Hyrdated sulfates were added to give more low temperature water and to release SO_2 at higher temperatures. Sodium perchlorate was selected as the oxychlorine species, not because it is the most likely to be present in the Rocknest sample, but because the O_2 release is similar enough and $NaClO_4$ is not as deliquescent as Mg or Ca-perchlorate (which turn into liquid droplets under ambient conditions), simplifying sample handling and eliminating the need for the sample to be kept in a very low humidity environment (e.g. an N_2 purged container/glove box) or under vacuum to prevent deliquescence. Illite was added to the sample despite no phyllosilicates being detected in Rocknest materials because we have demonstrated that the release of water at high temperature is a possible mechanism for the HCl release seen in Rocknest [6]. Ferrihydrite was added as an iron-rich X-ray amorphous material.

Results: The addition of these minerals makes the simulant more Rocknest-like in terms of the volatile release profile and total mass loss. Total mass loss from the augmented simulant is ~7% at 900 °C (within the uncertainty of Rocknest mass loss). The evolved gas analysis profiles from SAM and an analog lab instrument are shown in Figure 1. The release pattern for water is similar but narrower in the simulant, potentially a function of Rocknest water being adsorbed to the higher percentage of amorphous material present in the sample (duplicating that would increase the overall water in the sample). The SO_2 release is similar but is still offset from the large 700 °C peak in Rocknest. CO_2 is much broader in the simulant, likely reflecting the decomposition of organics at low temperature and carbonate at higher temperatures. The O_2 and HCl peaks match very well between the two samples.

Conclusions: We have produced a Mars soil simulant based on the JPL Mojave Mars Simulant that more closely matches the Rocknest volatile composition as measured by the SAM instrument on MSL. The water release profile, in particular, is more Mars-like than previous simulants (i.e. JSC Mars-1 or unmodified MMS), making it more appropriate for use in ISRU applications involved with water recovery.

There will never be a single simulant that will meet all needs because Mars is a geochemically, mineralogically, and geotechnically diverse planet. Consideration must be made for how the properties of a simulant align with the goals of any work and a simulant must be selected accordingly.

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References: [1] Archer, P. D. Jr., et al. (2014) *JGR*, doi:10.1002/2013je004493. [2] Mahaffy, P. R. (2012) *Space Science Reviews*, doi:10.1007/s11214-012-9879-z. [3] Leshin, L. A. et al. (2013) *Science*, doi:10.1126/science.1238937. [4] Allen, C. C. et al. (1998), *LPS XXIX*, Abstract #1690. [5] Peters, G. H. et al. (2008), *Icarus*, doi:10.1016/j.icarus.2008.05.004. [6] Hogancamp, J. V. et al., (2017) *AGU Fall Meeting*, Abstract P51H-09.

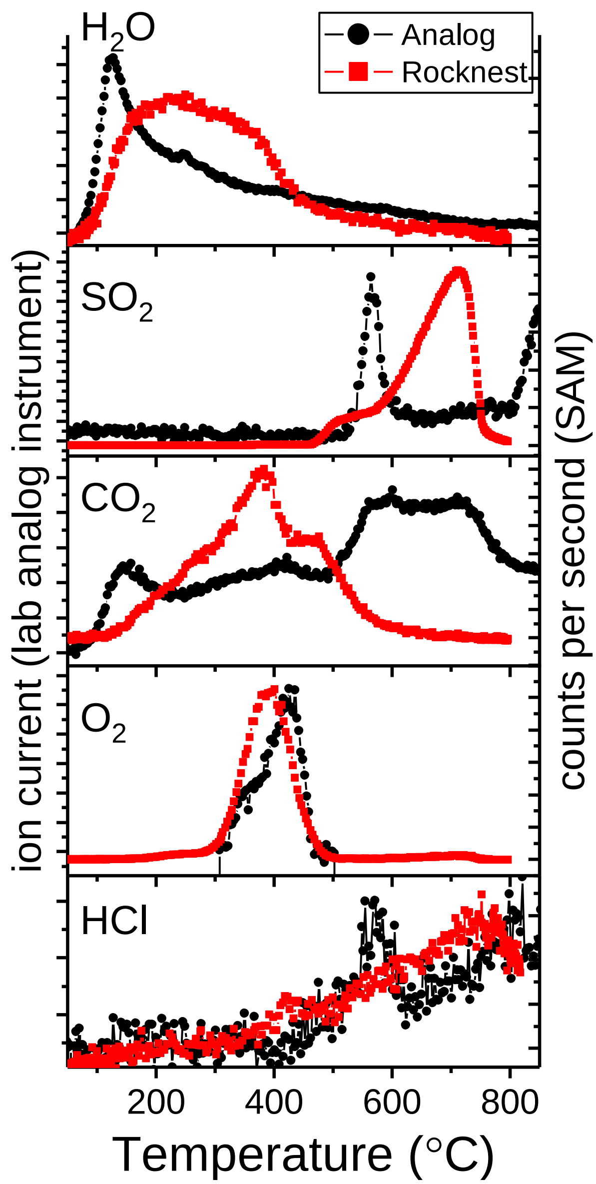

Figure 1 – Evolved gas analysis traces for the major volatile species released from the Rocknest sample in Gale Crater, Mars and an augmented Mojave Mars Simulant created for ISRU applications. Note that the vertical axes are not on the same scale between plots or instrument, but are scaled for easier comparison.