

April 2, 2018

**To: Christopher M. McHugh, Esq.**

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From: Tom Tague, Ph.D.

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Re: Lunar sample analysis

Dear Chris,

Per your request, I have expanded the analysis of the sample provided by Mr. Chris Cicco. As before, the chemical composition of moon soil has been well described in the literature and will be referenced in this report. X-ray fluorescence (XRF) spectroscopy and x-ray diffraction (XRD) spectroscopy have been utilized in the testing of the sample. XRF spectroscopy is a well-established tool for determining the elemental content of materials and XRD spectroscopy allows the geological content to be more specifically identified. It should also be noted that a research XRF instrument (M4 Tornado) was used to confirm the previous handheld XRF measurements. A research D8 Advance research system was utilized for the XRD measurements.

Validating the scientific instruments

XRF – The established NIST traceable standard 2710a was run to verify the instrument performance of the utilized M4 Tornado research XRF instrument (Bruker Corporation, Billerica, MA).

XRD – The D8 Advance research system instrument response and alignment were verified using a NIST SRM 1976 (Al₂O₃) (corundum) standard.

Experimental Parameters

XRD – The sample was measured on a D8 Advance with a rotation stage and Lynxeye XE-T detector under the following conditions:

Source: Cu (40kV, 40mA)
Divergence slit: 0.6mm
Soller slits: 2.5deg
Scan range: 5-70deg 2theta
Step size: 0.02deg
Time/step: 1 sec
Total time: 1 hour

XRF – 60 second acquisitions for three data collects were performed to ensure reproducibility. An acquisition time of 60 seconds for each was performed.

Results

XRD - The mineralogy is consistent with the known composition of lunar regolith. The absence of olivine, presence of quartz, and high plagioclase content suggest a felsic composition, so likely from the anorthositic highlands and not from the basaltic lunar mare (mafic). There is also a considerable amount of amorphous content (~30%), also consistent with lunar regolith. From an XRD perspective, there is no evidence to rule out a lunar origin. This assessment is based upon careful comparison with the following references:

<https://curator.jsc.nasa.gov/lunar/lsc/74220.pdf>

<https://curator.jsc.nasa.gov/lunar/lsc/74241.pdf>

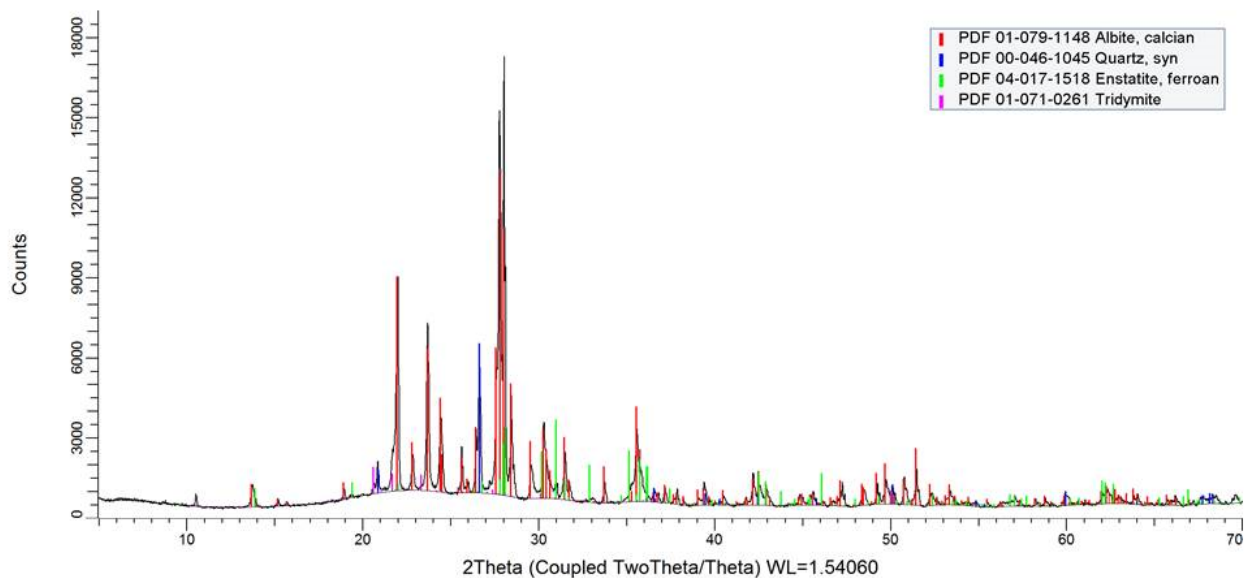
<https://curator.jsc.nasa.gov/lunar/lsc/72431.pdf>

Lunar soil catalog information from NASA

https://curator.jsc.nasa.gov/lunar/catalogs/other/lunar_soils_catalog.pdf

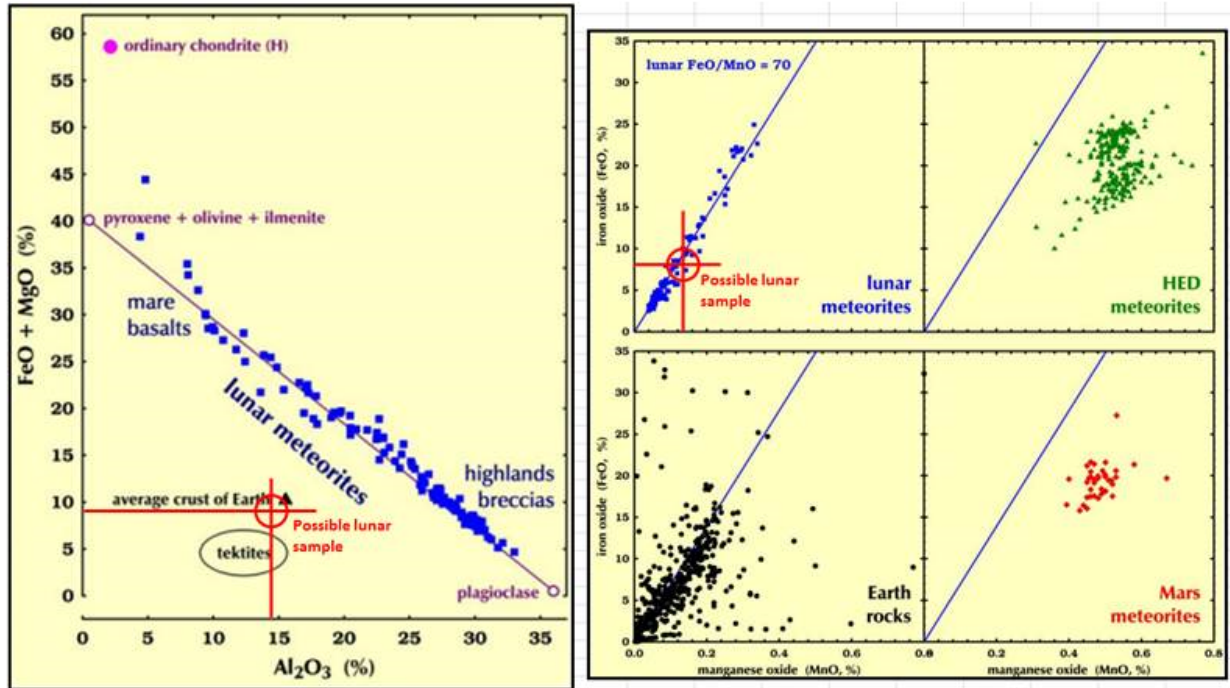
(handbook of lunar soils)

Figure 1: Composite XRD spectrum of moon dust sample



XRF - Bulk XRF analysis had a different result. Plotting FeO + MgO vs Al₂O₃ revealed a composition similar to “average crust of Earth” as shown below and does not follow the lunar meteorite trend. This is in agreement with the previously reported results. FeO vs. MnO does follow the lunar trend, but Earth and lunar systems are not considerably different. We conclude that the chemical composition of the sample is not consistent with lunar regolith. A more conclusive result could likely be obtained by investigating the chemistry of individual pyroxene grains ([Papike et al., 2003](#)).

Figure 2 – Scatter plots of FeO + MgO vs Al₂O₃ and FeO vs MnO with the reported results shown by the applied cross target.



Conclusions:

The XRF data collected in this investigation yielded results very similar to those previously reported. The XRD results would seem to indicate that this sample may have originated from lunar regolith. At this point, it would be difficult to rule out lunar origin. I am speculating, but it may be possible that some dust from the earth became mingled with this likely lunar sample. If there are any questions or concerns, please do not hesitate to contact me.

Sincerely yours,

Tom