Mineral Abundances in Moon Dirt

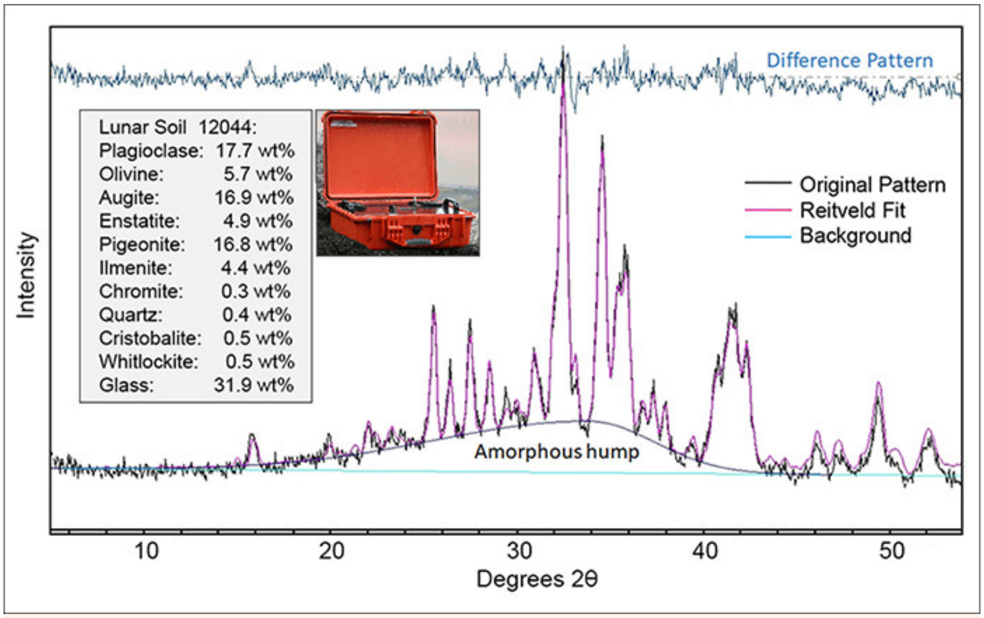
Regolith (soil) samples from the Moon have been studied for 50 years, but the abundances of minerals in the lunar soil have not been thoroughly documented. Many of us lunar **petrologists** examined moon soil samples in detail but did not determine the overall abundances of minerals. Instead, we determined the abundances of mineral fragments, rock fragments, and impact products such as **agglutinates** (kind of ugly yet beautiful glassy particles containing rock and mineral fragments).

Apollo 12 mission photograph of the collection location of soil sample 12044. NASA photo AS12-48-7082. Click for more information about this sample.

The first study to focus on bulk abundances (the total amount) of minerals and glass (the major component of agglutinates) was done by Larry Taylor and his collaborators at the University of Tennessee, Knoxville and Brown University. They used an electron microprobe equipped with an **energy-dispersive** detector to make digital images of element abundances to determine the compositions of moon dirt grains at thousands of locations in polished mounts of lunar soil. (Polished mounts consist of dispersed grains of soil mounted in epoxy on a glass slide, then polished.) Larry Taylor and collaborators were able to obtain bulk mineral and glass abundances from elemental abundances, although that has significant ambiguities. Because of the time-consuming nature of the work, they analyzed only 19 lunar soil samples. More data were needed, and it would be nice to have a data set that identified minerals by their fundamental crystallographic properties, not just by composition. We needed another technique.

The technique arrived one day when Dave Blake (NASA Ames Research Center and affiliate faculty member in our Hawai'i Institute of Geophysics and Planetology) walked into my office. Dave was Principle Investigator of the CheMin instrument on the Curiosity rover that was going to Mars. He arrived bearing an orange briefcase-sized Pelican case containing a portable X-Ray Diffraction (XRD) instrument. The case contained an XRD system called Terra, a terrestrial commercial spinoff of the CheMin instrument. We ran a couple of lunar soil samples in the instrument, demonstrating to us that it would be useful for quantifying abundances of minerals in lunar soils. My office-suite mate Paul Lucey was so captivated by the instrument that he almost immediately wrote a proposal to NASA to purchase such an instrument and to measure mineral abundances in selected lunar samples. Paul is a ***remote sensing*** specialist and recognized the need for ground truthing remote observations.

Lucey's proposal was funded, meaning that we were going to get our own orange case packed with X-Ray mineralogic-determination gear. To pay for personnel time to run the orange marvel, we needed funding to pay people. That came via a grant from the LASER program, a NASA fundamental research program whose full name was Lunar Advanced Science and Exploration Research. Result: we determined the mineral and glass abundance of the <150μm size fraction of 118 lunar soil samples (doing duplicates of each) from all landed Apollo missions. Here's the cool part: Linda Martel (the other half of PSRD) and I made all the measurements during the next few years. The results are reported in a paper published in a special volume of *Geochemica et Cosmochemica Acta* dedicated to Larry Taylor (***link to special volume***).



XRD spectrum for a ***mare*** soil 12044 from Apollo 12 obtained at the University of Hawai'i with the portable XRD instrument. We used the technique of Rietveld whole-pattern fitting to calculate abundances of minerals in the soil sample. The fit to the raw data is excellent. The small, insert photograph shows Terra at a terrestrial field site. From Taylor *et al.* (2019).

Oh, what did we discover? Well, mineralogy is tricky. Read the paper. The important point is that the database is available in its full glory at the ***Open Data Repository: Lunar-regolith XRD***.

See Reference:

· Taylor, G.J., Martel, L. M. V., Lucey, P. G., Gillis-Davis, J. J., Blake, D. F., and Sarrazin, P. (2019) Modal Analyses of Lunar Soils by Quantitative X-ray Diffraction Analysis, *Geochimica et Cosmochimica Acta,* v. 266, p. 17-28, doi: 10.1016/j.gca.2019.07.046. [***article***]

See Database links:

· ***Lunar Soil Characterization Consortium Data*** from the University of Tennessee, Knoxville.
· ***Open Data Repository: Lunar-regolith XRD***

See also:
Terra portable XRD analyzer from Olympus.

Rietveld, H. M. (1969) A Profile Refinement Method for Nuclear and Magnetic Structures, *Journal of Applied Crystallography,* v. 2, p. 65-71, doi: 10.1107/S0021889869006558. [***open access article***]

Taylor, L. A., Patchen, A., Taylor, D.-H. S., Chambers, J. G., and McKay, D. S. (1996) X-ray Digital Imaging Petrography of Lunar Mare Soils: Modal Analyses of Minerals and Glasses, *Icarus,* v. 124(2) , p. 500-512, doi: 10.1006/icar.1996.0226. [***article***]

Taylor L. A., Pieters C., Patchen A., Taylor D.-H. S., Morris R. V., Keller L. P. and McKay D. S. (2010) Mineralogical and Chemical Characterization of Lunar Highland Soils: Insights into the Space Weathering of Soils on Airless Bodies, *Journal of Geophysical Research: Planets,* v. 115, E02002, doi: 10.1029/2009JE003427. [***open access article***]

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