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Quantitative Compositional Wavelength-Dispersive Mapping of Particles from the Moon.

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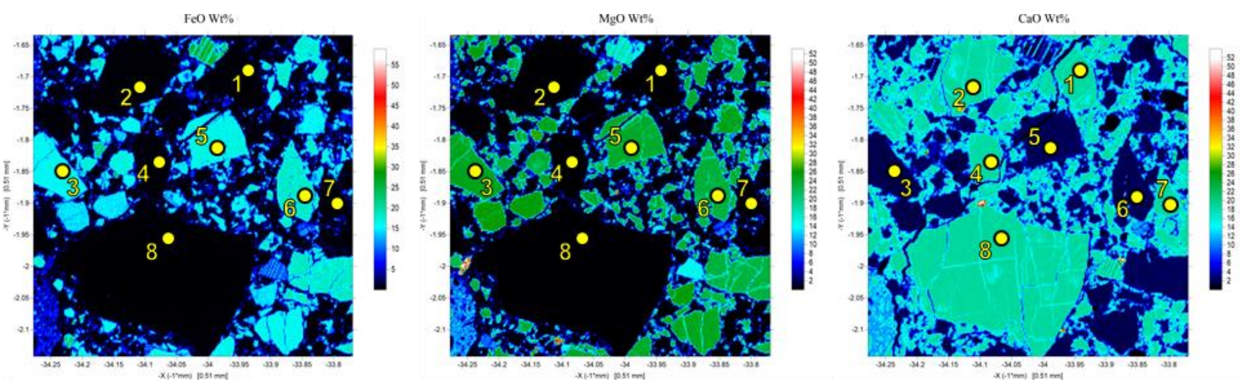
The Apollo Program was a human spaceflight mission that sent astronauts to the Moon between 1968 and 1972. In total, the Apollo program brought back 842 pounds (382 kg) of rock and soil from the Moon for scientists to study in laboratories on Earth [e.g. 1,2]. These rocks were invaluable in shaping our understanding of how the Moon formed, and how processes such as volcanism and impacts have affected the lunar surface [e.g. 3, 4]. Not all of the returned samples were immediately studied however; a subset of material from the Apollo 17 mission was set aside in special storage (either frozen, or stored under vacuum/inert gas), to await advances in technology and the development of new methods to study them. Now, almost 50 years after their return, these samples have been opened.

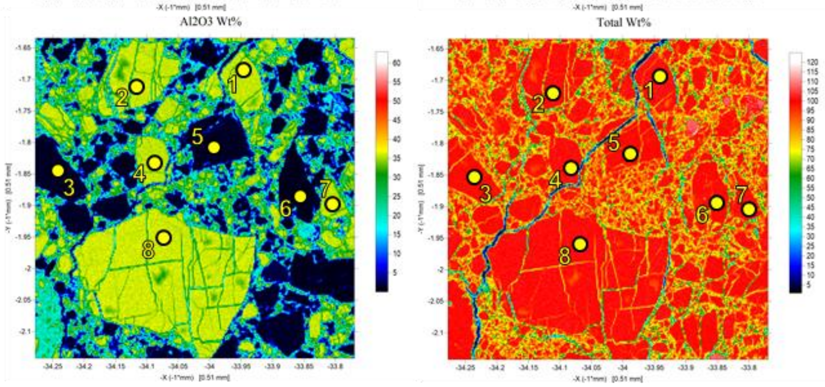
The Apollo Next Generation Sample Analysis Program (ANGSA) brings together over 50 scientists from across the United States to study these pristine lunar materials. Because of the extremely valuable nature of these materials, it is imperative that as much scientific information be obtained from each sample as possible. The ANGSA Consortium aims to perform non-destructive characterization of selected particles, before any destructive analyses take place.

In this work, we performed quantitative electron microscopy on fifteen samples, in order to determine their texture, mineralogy and petrology. The samples will subsequently undergo destructive analysis in order to determine their noble gas composition. The samples are taken from the upper section of a drill core (73002) that was collected and sealed on the lunar surface, and which has remained unopened at the Johnson Space Center since it’s return. The mass of the samples studied here ranges from 2-16mg, and the fragments were recovered from different depths throughout the drill core. This core samples material that was collected from a lunar landslide event in the Taurus Littrow Valley landing site of Apollo 17.

Each particle was split, with one half of the particle mounted in a 1” round epoxy puck, and then polished to a smooth, flat finish. The samples were carbon coated, and analyzed using JEOL 8530F electron microprobes (EPMA) at the Carnegie Institution for Science, and the Smithsonian Institution. Both EPMA instruments are equipped with 5 wavelength dispersive spectrometers, and were operated using the Probe for EPMA software package. Fourteen elements were analyzed, requiring three passes, and the Mean Atomic Number method [5] was used for background subtraction. The operating conditions were 15kV and 30nA, a dwell time of 100-300msec, a step size of 1-2μm, a slightly defocused beam of 1-2μm, and a map size of up to 575×530 pixels. The maps were then processed using the Surfer program to produce quantified elemental or oxide maps, along with detection limit and analytical total maps for each pixel (Figure 1). In addition to these maps, back-scatter electron images were collected, and single-point quantitative analyses were performed in order to test the accuracy of the quantitative maps (major elements only are shown in Table 1). The total analysis time for each fragment, including data processing, ranged from 15-30 hours.

The maps reveal that the majority of the fifteen fragments are breccias (angular fragments of rock and mineral that have been cemented together). This is perhaps unsurprising, given the long history of impacts that have affected the lunar surface. Also present are fragments of basaltic material, formed when lava welled up onto the surface of the moon, and norite (an intrusive igneous rock). The collection of quantified maps allows a comprehensive examination of each fragment, and a quantitative exploration of the mineral compositions and relationships within each fragment. The colour scale bar to the right of each element map in Figure 1 can be compared with the point analysis values given in Table 1, and the Totals map indicates that for large anhydrous silicates, 100% totals were achieved. The use of the MAN background subtraction routine speeds up data collection significantly, as only on-peak maps need to be collected. The collection of individual point analyses with considerably longer dwell times shows that the quantitative mapping routine is producing reliable results.





Point #	SiO2	FeO	MgO	CaO	Al2O3	Total
1	44.77	0.20	0.06	18.35	35.68	100.11
2	44.47	0.14	0.08	18.46	35.72	99.81
3	53.28	15.65	24.92	1.81	1.01	97.97
4	44.67	0.25	0.08	18.38	35.59	100.03
5	53.54	16.24	23.93	2.29	1.03	98.25
6	53.25	17.80	23.18	1.89	0.75	98.29
7	45.14	0.19	0.07	18.24	35.42	100.17
8	44.65	0.13	0.09	18.68	35.97	100.36

Fig. 1 Quantified maps
Table 1. Point analysis results (not all elements analysed are included here).

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