Geochemical characterization of potential melt clasts from lunar meteorite PCA 02007,53

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Background and motivation

- As our nearest neighbor, the Moon is an excellent proxy for understanding the early history of the Earth because it has not been tectonically and biologically resurfaced like our own planet.
- Relics of ancient meteorite impacts can be found in the lunar soil (regolith) in the form of impact melt clasts - rocks that were melted and recrystallized from the energy of a meteorite impact. This melting and recrystallization resets the isotopic clock of the clasts, thus dating the time of impact.
- Lunar meteorites sample the lunar regolith, allowing us to date impact melt clasts using ^{40}Ar-^{39}Ar geochronology.
- The controversial theory of a Late Heavy Bombardment of the moon and inner solar system has been put forward to explain an apparent concentration of large meteorite impact ages around 3.9 billion years ago. However, this apparent spike in impacts could merely be a byproduct of sampling bias or the nearly complete resurfacing of the moon by a large impact which would have destroyed evidence of earlier events (Norman 2009).
- Determining whether or not there was a Late Heavy Bombardment will not only help us to better understand early Solar System dynamics, but it also could help to explain the timing of the appearance of life on Earth 3.85 billion years ago (Norman 2009).

Objectives

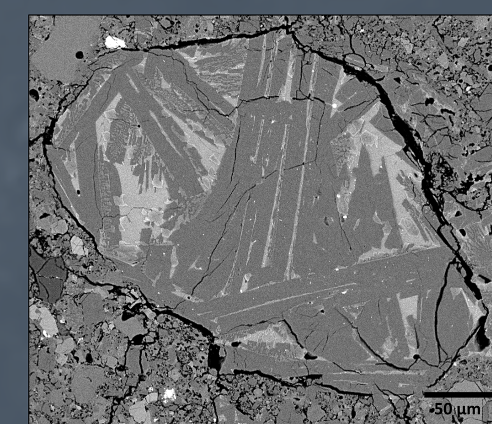
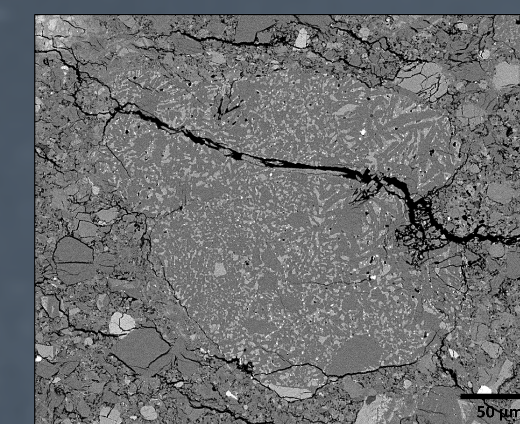
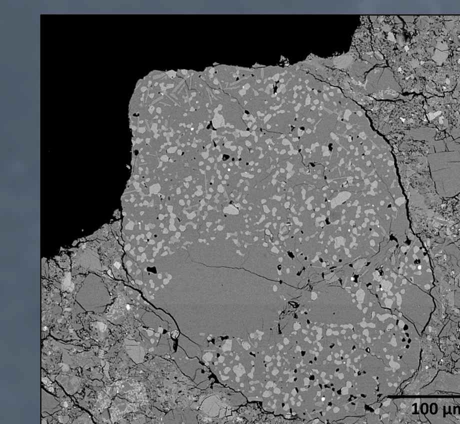
- Identify potential melt clasts for ^{40}Ar-^{39}Ar dating and determine their bulk composition
- Compare bulk clast chemical analyses using two different analytical techniques

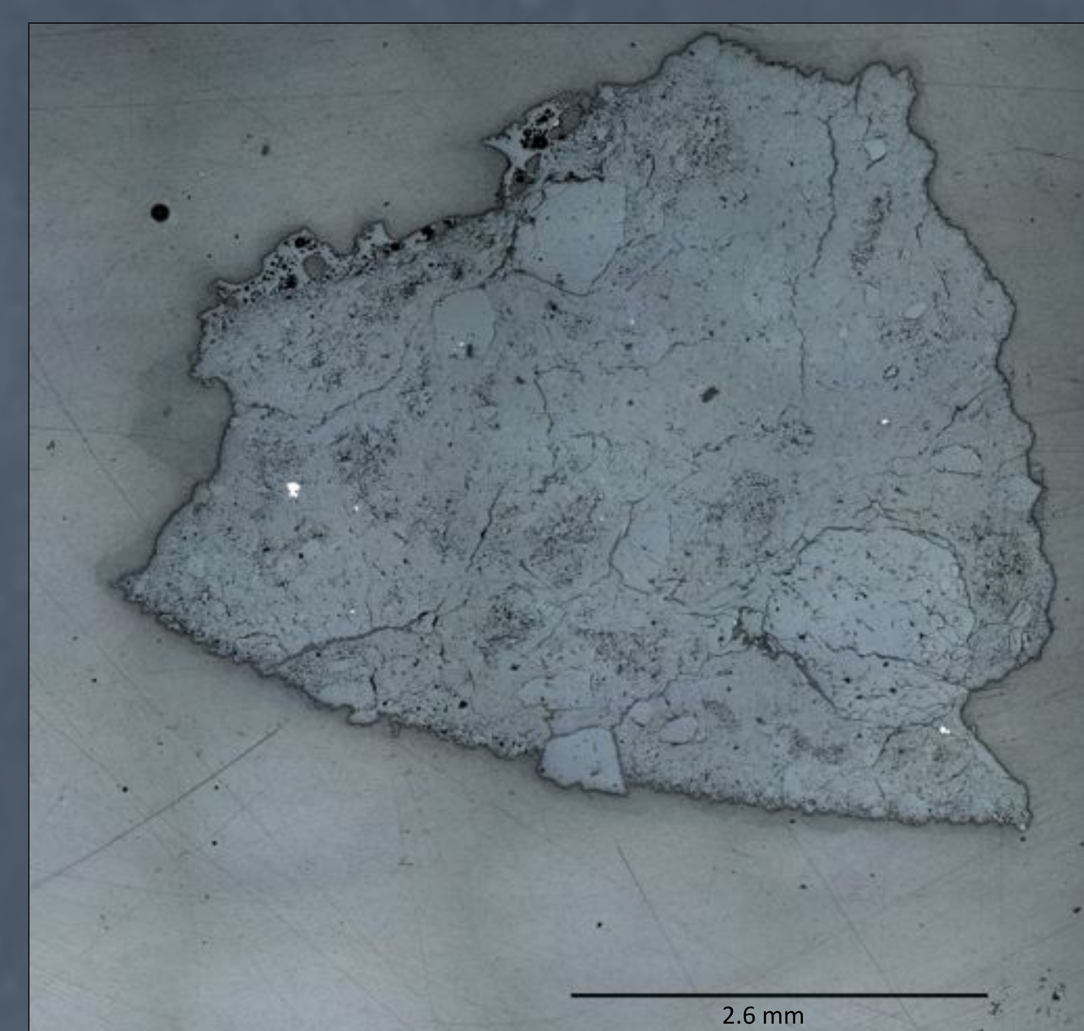
My sample

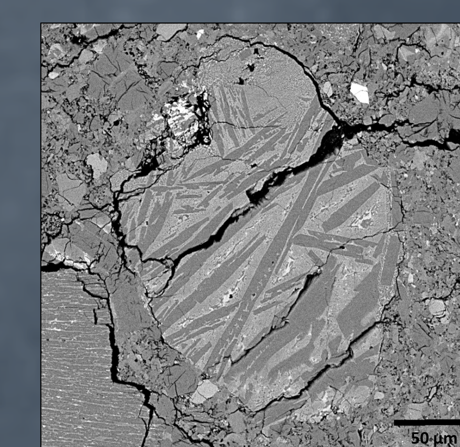
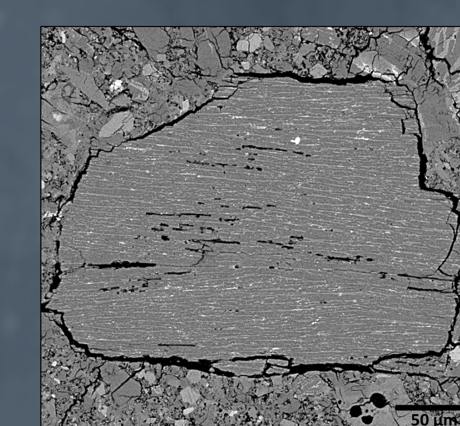
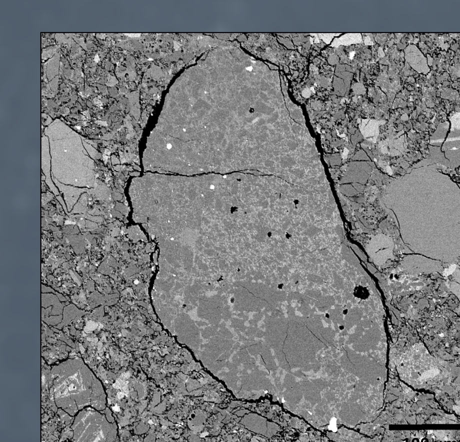
This is a photograph of PCA 02007 (cube is 1 cm) http://curator.jsc.nasa.gov/antmet/lmc/lmc.cfm

Pecora Escaprtment (PCA) 02007 is a Lunar meteorite that was collected during the 2002-2003 field season as part of the Antarctic Search for Meteorites (ANSMET) Program. It is an anorthositic regolith breccia, meaning that it is mainly composed of broken rock fragments, glass, and other debris found in the lunar highlands. The lunar highlands make up about 83% of the Moon's surface and are predominantly composed of the mineral anorthite ($CaAl_2Si_2O_8$). We therefore expect the clasts in the regolith to reflect this same composition with some slight contamination by lunar basalts and chondritic material brought in by impacting meteorites.

Data and Results

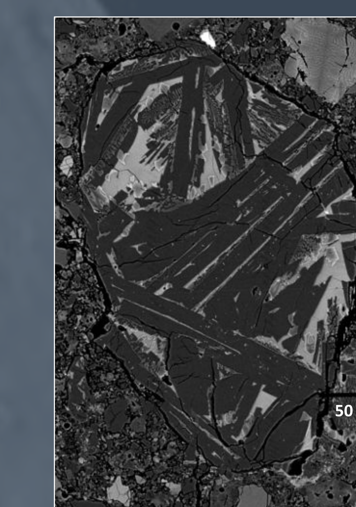


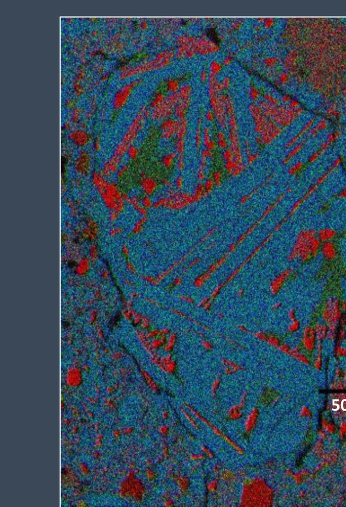




The center image is a photo of the entire PCA 02007,53 thick section taken in reflected light at 5x magnification. The other images are backscatter (BSE) photos of the six clasts we analyzed.

Clast 6 chemical data

On the left is a BSE image of clast 6 and on the right is an element map of the same clast. Red represents the element magnesium, while blue represents aluminum and green represents calcium. There are large plagioclase phenocrysts (dark grey crystals) within a mixed composition glassy matrix (brighter patchy material).



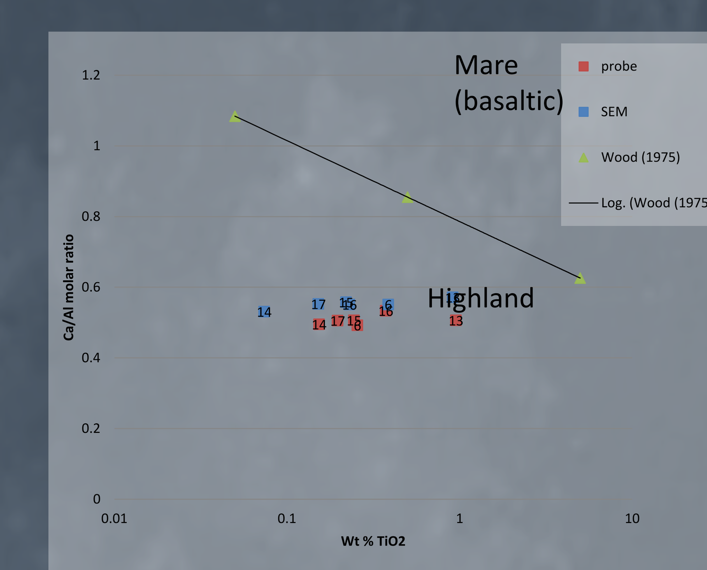


Bulk chemical composition of clast 6

	SiO2	CaO	Na2O	MgO	TiO2	FeO	Al2O3	K2O	MnO	Cr2O3	NiO	P2O5	SO2	Total
SEM	43.50	16.47	0.4757	5.866	0.3707	5.386	27.24	0.1648	0.0722	0.1366	0.0499	0.1936	0.086	100.01
EMP	41.47	15.29	0.3996	6.630	0.2558	5.286	28.23	0.0272	0.0765	0.1201	-0.0007	0.0234	unavailable	97.81
Difference (SEM-EMP)	2.026	1.183	0.0761	-0.7646	0.1149	0.0997	-0.99	0.1376	-0.0044	0.0165	0.0507	0.1702		
Whole meteorite*	44.6	15.3	0.33	6.7	0.28	6.26	26.4	0.02	0.09	0.11	N/A	0.03	unavailable	100.09

The table above is a comparison of SEM and EMP determination of the bulk chemical composition of clast 6. The whole meteorite composition is included as a rough estimate of what the clast composition should be.
*As obtained by Instrumental Neutron Activation Analysis (INAA) by Zeigler et al. (2004)

Ca/Al molar ratio v. wt % TiO2



The graph to the left shows that these six clasts are of highland origin. The empirically determined Wood (1975) line demarcates the boundary between a highland and a basaltic composition.

Methods

Using the Energy Dispersive X-Ray spectrometer (EDX) of the FEI NovaNanoSEM in the Mineral Sciences department, we were able to gather chemical data on six clasts from a polished and carbon coated thick section of lunar meteorite PCA 02007. Using Noran System Six, we were able to extract the bulk composition of each clast. When extracting the chemical data, we consistently analyzed for Na, K, Mg, Ca, Ti, Fe, Si, and Al. Trace amounts of Cr, S, and P were also detected.

We collected the same data for each of the six clasts using the JEOL JXA-8900R electron microprobe (EMP) to compare the precision of these two methods. We used a 30 micron beam at 15 kV and 20 nA to collect the bulk chemical composition of the clasts while we used a 1 micron beam to determine the composition of individual mineral phases within the clasts. Because focused beams (and to a lesser extent defocused beams) will volatilize K and Na, we did not choose spots across the entire clast, in case future bulk chemical studies are to be conducted on this sample. However, this decision introduced a significant amount of human error into the analysis, as it was our job to pick representative spots from only half of the clast. For our microprobe work we standardized and analyzed for Si, Ti, Al, Cr, Ni, Fe, Mn, Mg, Ca, Na, K, and P.

Discussion

In identifying impact melts, we looked for clasts that exhibited igneous textures. Unfortunately, there are four types of igneous rock found in the lunar regolith: melt clasts, basaltic clasts, pristine highland rocks, and chondrules. In order to determine that these are not basaltic clasts, we compared the Ca/Al ratio to wt % TiO2 of all the clasts to an equation empirically derived by Wood (1975) to distinguish between highland and mare (lunar basaltic) samples. According to both data sets (EMP and SEM), our clasts are unambiguously of highland origin, and therefore not a product of lunar volcanism. Although it is possible to distinguish melt clasts from pristine lunar crust and chondrules, I was unable to do so this summer. However, these clasts are texturally similar to previously identified melt clasts (Cohen 2005) and the chances of finding unaltered lunar crust or chondritic material in the regolith are so slim that it is reasonable to assume that the clasts we have identified are impact melt derived.

In comparing the chemical data collected from the SEM to that collected by the EMP, the SEM generally measured 10 times the amount of potassium that the EMP detected. Considering that these are melt clasts, they should roughly sample the regolith from which they were derived. To this end, the EMP analysis appears to be more accurate because it more closely matches the bulk composition of the meteorite as determined by Zeigler et al. (2004). Still, more comparisons are needed, with particular attention paid to how easily potassium is volatilized by a defocused beam.

Conclusions and future work

- These clasts are all chemically characteristic of lunar melt clasts, and therefore will be age dated by Barbara Cohen at the NASA Marshall Space Flight Center in Huntsville, Alabama, to bolster our sample size of lunar melt clasts.
- In the future, melt clasts in ordinary chondrites can also be age-dated to determine the origin of the Late Heavy Bombardment impactors (if indeed there was a Late Heavy Bombardment)
- This research has shown that there are significant discrepancies between bulk rock analyses using the SEM and EMP defocused beam techniques, particularly for the more volatile elements like sodium and potassium.
- Future comparisons of these techniques should be done with SEM analyses that are first calibrated with standards to get a more quantitative result.
- Another good comparative study would be to use both the SEM and the EMP to extract a bulk chemical composition for a known standard.

Acknowledgments

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