Lunar Meteorites
Lunar Meteorites

The first recognized lunar meteorite (1981).

Note fusion crust, brecciated nature, and presence of significant anorthite.
Lunar Meteorites

Fast Facts

>170 individual stones

~16% of mass returned by Apollo and Luna missions.

Somewhere between ~50-90 impact events?

How Do We Know They Are Lunar?

~98% of lunar rocks are composed of just a few minerals: olivine, pyroxene, plagioclase, and ilmenite

Can compare chemistry of a found meteorite directly to chemistry of Apollo samples!

Textural attributes and ages.
Lunar Meteorites

Histogram showing the number of meteorites by mass (grams):

- 8192-16384 grams
- 4096-8192 grams
- 2048-4096 grams
- 1024-2048 grams
- 512-1024 grams
- 256-512 grams
- 128-256 grams
- 64-128 grams
- 32-64 grams
- 16-32 grams
- 8-16 grams
- 4-8 grams
- 2-4 grams
- 1-2 grams
- 0.5-1 gram

Pie chart showing the distribution of meteorites:

- Northern Africa: 68%
- Antarctica: 6%
- Oman: 12%
- Botswana: 16%

[Note: Kalahari 008/009]
Kalahari 009 is the largest single stone (13.5 kg). It is a basaltic breccia with no anorthositic clasts.

Kalahari 008 is paired with 009 (found 50 m apart) and is 598 g. It is an anorthositic breccia with little evidence for basaltic clasts.

Similar exposure ages...only ~230 years!
Lunar Isotopes

Moon and Earth fall on same line....or do they?
Lunar Isotopes

Slight difference in O isotopes between Moon and Earth.

Can use this to model type of impactor that formed Moon and mixing between Earth and Theia material.

Fig. 2. $\Delta^{17}O$ composition for terrestrial and lunar samples. A slope of 0.5305 and zero intercept (VSMOW) is used to calculate $\Delta^{17}O$ (19, 20). Error bars are 1$\sigma$ SEM. Solid vertical lines denote mean values for the BSE and the Moon. Gray shaded areas represent 1$\sigma$ SEM, and dotted lines represent 2$\sigma$ SEM.

[Herwartz et al., 2014]
Moon is depleted in Na

**Figure 3.** Na (afu) vs. $X_{Fe}$ for pyroxene grains from the four different planetary bodies.

[Karner et al., 2006]
Lunar Meteorites

Moon is enriched in Cr

**Figure 5.** Cr vs. $X_{\text{Fe}}$ for pyroxene grains from the Earth, Moon, Mars, and Vesta.

[Karner et al., 2006]
Moon has higher Fe/Mn values

**Figure 6.** Mn vs. Fe\(^{2+}\) in atoms per 6-oxygen formula unit (afu) for pyroxene analyses from the Earth, Moon, Mars and Vesta. Best-fit trend lines are indicated and their equations are given.
Fe and Mn are in 2+ oxidation state on Moon, thus they do not fractionate during geochemical processes on the Moon like they do on Earth.

[WUSTL meteorite site]
Feldspathic meteorites suggest magnesian (not ferroan) anorthosite is a major component of highland crust. Only Luna 20 & 24 sampled areas outside of Imbrium ejecta, and they are dominated by magnesian anorthosite.

[Gross et al., 2012]
Magma Ocean or Not?

KREEP, Mg-suite, and ferroan anorthosite rocks reflect processes localized to Imbrium? Serial magmatism to form variety of layered intrusions that are then spread over planet by SPA basin-forming process?

[Fig. 2]

[Image]

KREEP, consistent with the Th distribution on the lunar farside. Magnesian anorthosites and noritic meteorites suggest that most feldspathic highlands meteorites should be primarily derived from mid- and deep crustal materials, except where covered by younger deposits (basin ejecta). This alone suggests that a hallmark of KREEP, is not globally distributed. The lunar feldspathic material over most of the Moon. Only 1/3 of the feldspathic highlands meteorites should consist mostly of Imbrium ejecta.

References:

27. Petro and Science Grant NNX08AH78G to AHT and an NLSI/CLSE subcontract to J.Gross.
Lunar meteorites exhibit different trace element patterns compared to Apollo and Luna samples: heterogeneous mantle sources? Note the range in Eu depletion....varying degrees of plag. xtlzn?

[Fig. 3: Apollo and Luna samples: heterogeneous mantle sources?

[REE in selected lunar basalts]

Sample/Cl chondrite (volatile free)

[La, Ce, Pr, Nd, Sm, Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb, Lu]

LAP 02 205,19
Y-793169
Apollo 15 (15119,19)
Asuka 881757
NEA 003-A

[Note the range in Eu depletion....varying degrees of plag. xtlzn?]

[Gross et al., 2012]
Lunar Meteorites

3: Timing of impact events as recorded by argon isotopes in Apollo 16 (black curve) and 17 (blue curve) and lunar meteorites (red curve). (a) Full y-axis scale and (b) limited y-axis scale showing details of the lunar meteorite dataset. To calculate these curves, the age and error were combined in bins of 0.5 Gyr (500 Myr), which is representative of the average error in $^{40}\text{Ar}/^{39}\text{Ar}$ age determination for the Apollo 16 samples. The normalized Gaussian curve calculated for each age bin (age column) was obtained by taking into consideration the width of the Gaussian curve calculated and the measured uncertainties. Each column was added and the result normalized to the total of all analyses per sample. Argon plateau data for Apollo 16 and 17 samples from supplementary dataset of Shuster et al. (2010) (see details for S2 and references therein) with additional data from Borchardt et al. (1986). Individual impact melt clasts and bulk rock (MacAlpine Hills 88105, Dar al Gani 400, Dar al Gani 262, Queen Alexandra Range 93069, Dhofar 026, 280 and 303) impact melt lunar meteorites taken from data compiled by Fernandes et al. (2013) with additional argon data from Yamato-86032 (Nyquist et al. 2006), Sayh al Uhaymir 169 (Gnos et al. 2004), North West Africa 482 (Daubar et al. 2002) and Dhofar 489 (Takeda et al. 2006).

[Joy & Arai, 2013]