RECENT LUNAR MAGNETISM.

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Introduction: It is currently unknown whether the Moon is a fully differentiated object with a metallic core. Magnetization in lunar rocks may provide evidence for an ancient dynamo and, by implication, a core [1, 2, 3]. An alternative explanation is that lunar paleomagnetic fields were generated by plasmas from meteoroid impacts. In fact, some young samples (<~1.5 Ga) are apparently magnetized [4] even though a dynamo is unlikely to have persisted for >3 Ga [5]. This has led to skepticism of the dynamo hypothesis for all lunar paleomagnetism. Here we describe paleomagnetic studies of what is likely the youngest lunar magnetization yet identified. The goal of these studies was to determine the origin of the magnetizing field.

Sample: We analyzed Apollo sample 12017, which consists of a 3.2 Ga mare basalt covered with melt glass [6, 7]. The basalt is thought to have been splattered by the glass following a nearby impact at just ~4-20 ka (Fig. 1) [6, 7]. We analyzed 5 mutually oriented subsamples of the basalt and glass lithologies (Fig. 2).

Fig. 1. Lunar sample 12017. Photograph is ~11 cm across.

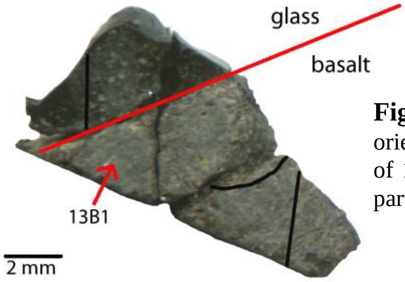

Fig. 2. Mutually oriented subsamples of 12017 measured as part of this study

Paleomagnetic Measurements: Alternating field (AF) demagnetization removed a low coercivity (LC) component in glass subsamples from 1.5 to 18 mT and an LC component in the basalt subsamples by 7 mT. Demagnetization to 60 mT, despite noisy data, revealed high coercivity (HC) components in both basalt and glass subsamples (Fig. 3). Unidirectional magnetization in the basalt was also observed by Strangway [8]. The HC component of the glass is 118° away from the HC component of the basalt (Fig. 3). Additionally, basalt sample 13B1 (see Fig. 2) has a medium coercivity (MC) component in the same orientation as the HC component of the glass (Fig. 4).

Using the anhysteretic remanent magnetization (ARM) and isothermal remanent magnetization (IRM) methods [1], we calculated the paleointensity of the field that produced the HC components, ~40 μT for the basalt and ~1 μT for the glass. We then gave the samples an ARM in various dc bias fields to determine their magnetic recording fidelity. We found that using our AF-based paleointensity methods, we are unable to accurately recover paleointensities for these samples below ~50 μT and ~7 μT for the basalt and glass, respectively. These values are therefore upper limits on the strength of the paleofields that magnetized the basalt and glass.

Discussion of Measurements: The magnetization in the basalt was likely acquired on the Moon at 3.2 Ga. The basalt was cooled too slowly for the magnetization to be explained by impact. The unidirectional magnetization in the glass is very surprising: is it extremely unlikely that there was a lunar core dynamo at 20 ka when the glass formed. We estimate that the cooling time for the glass from the Curie point to ambient surface temperatures is between ~4-10 s. The crater that formed this glass was likely within a few crater radii of the 12017 basalt (e.g., [9]). Following [10], we estimate that for an impact to produce a magnetic field lasting at least 4 s within 2 crater radii of the impact point, the crater must be at least ~1 km in radius. There are no fresh craters this large in the vicinity of the Apollo 12 site, indicating that it is highly unlikely the glass could have been magnetized by an impact-generated field. However, there are meter sized craters capable of producing the glass [11, 12].

Also intriguing is the MC component of basalt sample 13B1, which is directionally similar to the HC component of the glass. This subsample has a thick glass coating. When the glass was emplaced, the underlying basalt was likely heated and partially remagnetized. The similarity of the orientation of the MC component of this sample with the HC component of the glass implies that the magnetic field that magnetized the glass was also responsible for partially remagnetizing the basalt (Fig. 3).

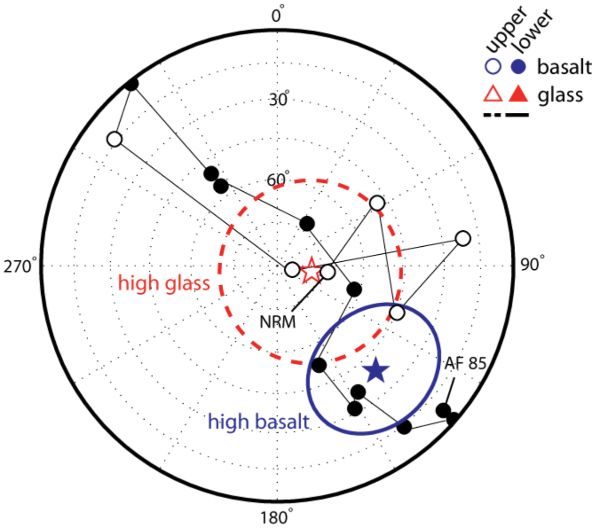

Fig. 3. Equal area projection showing AF demagnetization of sample 13B1 (refer to Fig. 2). The MC component is at first oriented like the HC glass component but after 50 mT it is oriented like the HC basalt component. Sample 13B1 was apparently baked and partially remagnetized by the emplacement of the hot glass.

Model: Magnetic fields of 36 nT were measured by the Apollo 12 surface magnetometer 75 cm above the surface of the moon [13]. This field is generally considered to be too weak to magnetize rocks. It is possible that fields measured immediately above magnetized samples would be significantly stronger. Magnetization of rocks cooled within these interaction fields may be possible and may explain low paleointensity and unidirectional magnetization of young (and old) samples. In particular, a possible explanation for the magnetization of the glass is that it formed in the large scale magnetostatic field of the underlying 12017 basalt.

To test this hypothesis, we developed software following the magnetic field modeling procedure described by Barnett [14]. Prior to subsampling of the hand sample at the Lunar Receiving Laboratory at NASA Johnson Space Center, a cast of the whole rock was made. We used the cast of the hand sample to create a digital version of the whole rock (Fig. 4). Using our measured direction of the magnetization of the basalt, we calculated the strength and direction of the basalt's field in the vicinity of our glass samples.

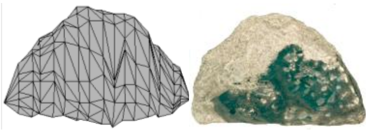

Fig. 4. Comparison between digital rock and actual rock

Model Results: We determined that at the location of our glass samples, the strength of the field from the basalt was ~240 nT. This is consistent with our upper limit on the paleointensity of the glass. Furthermore, the measured HC direction of the glass is within error of the predicted basalt field direction (Fig. 5).

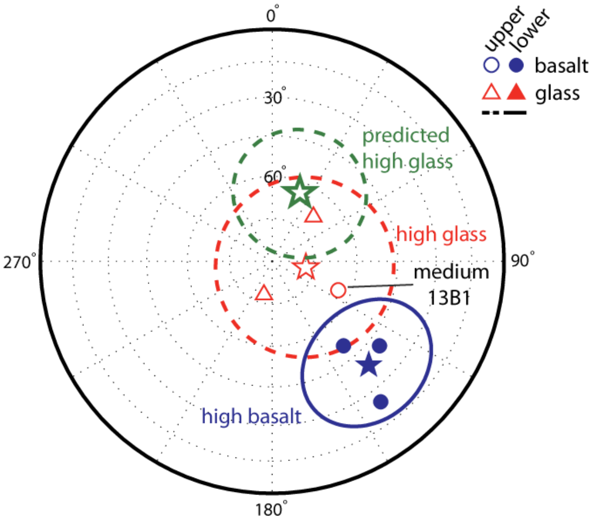

Fig. 5. Equal area projection showing the magnetization components identified this study and the predicted field direction from the underlying basalt at the glass location.

Conclusions: The magnetization in the ~4-20 ka 12017 glass is likely produced by magnetostatic interaction fields from the underlying 3.2 Ga basalt. Many of the young magnetized lunar samples are also glass splatters or glassy breccias, for which the glass is in close proximity to much older surrounding rocks. The magnetization of these samples might also be explained in the same way as the 12017 glass. Interaction fields from the magnetized rocks on the surface of the Moon are a possible explanation for the magnetization of young rocks. This would remove a key argument against an ancient lunar core dynamo.

References: [1] Garrick-Bethell et al. (2009) *Science, 323*, 356-359. [2] Shea et al. (2010) *LPSC XLI*, Abstract #2204. [3] Mitchell et al. (2008) *Icarus, 194, 2*, 401-409. [4] Wiezcorek et al. (2006) *Rev. Min. Geochem., 60*, 221- 364. [5] Dwyer and Stevenson (2005) *AGU, Abstract #GP42A-06* [6] Morgan et al. (1971) *Science, 172*, 556-558. [7] Fleischer et al. (1971) *LPS 2, 3*, 2559-2568. [8] Strangway (1971) *EPSL, 13*, 43-52. [9] Heiken et al. (1991) *Lunar Sourcebook: A Users Guide to the Moon, CUP Archive* [10] Crawford and Schultz (1999) *Int'l Jour. Impact Engineering, 23*, 169-180 [11] Apollo 12 Preliminary Science Report (1970) *NASA Manned Spacecraft Center* [12] Neukum et al. (1975) *The Moon, 12*, 201-229 [13] Dyal and Parkin, *LPSC II, 3*, 2391-2413 [14] C.T. Barnett (1976) *Geophysics, 41*, 1353-1364