ANCIENT LUNAR DYNAMO: ABSENCE OF EVIDENCE IS NOT THE EVIDENCE OF ABSENCE.

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"There's another way to phrase that and that is that the absence of evidence is not the evidence of absence. It is basically saying the same thing in a different way. Simply because you do not have evidence that something does exist does not mean that you have evidence that it doesn't exist." –Donald Rumsfeld

Introduction: Nearly four decades after the Apollo era, the source of lunar crustal magnetization remains a matter of debate. The two leading hypotheses for paleofield generation are the presence of an ancient lunar dynamo [1] and transient (< 1 day in duration) fields produced by impact-generated plasmas [2].

A study of the unshocked lunar troctolite 76535 suggests the presence of a stable, ≥ 1 microtesla (μT) lunar paleofield 4.2 billion years ago (Ga) [3]. A more recent paleomagnetic analysis of the 3.7 Ga ilmenite basalt 10020 also contains a stable magnetization (see accompanying abstract [4]). Petrographic analyses reveal that these samples cooled slowly, making it unlikely that short-lived impact-generated fields could be the source of the magnetization. These data therefore favor the dynamo hypothesis.

However, samples such as 76535 and 10020 appear to be the exception, rather than the rule, among lunar rocks. The vast majority of lunar rocks subjected to paleomagnetic scrutiny appear to be poor magnetic recorders. Magnetic moments of many samples often exhibit zigzag behavior or 'pinning' upon AF demagnetization, with high scatter in magnitude and direction [5]. The lack of a stable remanence in these samples is sometimes cited as evidence against the existence of an ancient lunar dynamo. Our findings indicate that this need not be so.

Here we present a comprehensive paleomagnetic analysis of mare basalts 15556 and 12017. Our results reveal that 15556, and to a lesser extent, 12017 are poor magnetic recorders, incapable of being stably magnetized by paleofields with intensities under 20-30 μT (approximately half the strength of the Earth's resent field). Therefore, we propose that many lunar samples may be intrinsically unable to preserve weak magnetic fields. Therefore, their NRM behavior does not preclude the existence of an ancient lunar dynamo.

Mare basalt 15556: 15556 is a fine-grained, highly vesicular, olivine-normative basalt [6], with an $^{40}Ar/^{39}Ar$ age of ~3.4 Ga [7]. Our petrographic analyses (not shown) indicate that 15556 appears to be unshocked (peak pressures < 5 GPa). Based on this assessment, 15556 initially appeared to be an excellent sample for paleomagnetic analysis.

Mare basalt 12017: 12017 is a medium-grained apparently unshocked (< 5 GPa) pigeonite basalt [9,10] with an $^{40}Ar/^{39}Ar$ age of approximately 3.2 Ga [11].

Measurements: We have conducted numerous experiments on multiple subsamples of both 15556 and 12017. These studies include alternating field (AF) demagnetization, paleointensity, anisotropy, and various other rock magnetic procedures. During AF demagnetization, magnetization was measured following AF exposure in the three orthogonal directions. This is done to reduce spurious remanence from anhysteretic remanence magnetization (ARM) and gyroremanent magnetization (GRM) (after [3]). The final NRM values were computed as the average of all measurements for each AF level [8].

Results:

NRM behavior: We have subjected four mutually oriented subsamples of 15556 to identical AF demagnetization routines spanning 1.5 to 290 mT. While there are two linear components in the early stages of demagnetization in most samples (blocked between NRM to ~7 mT and ~7 mT to 20 mT), at higher fields, most 15556 subsamples devolved into exhibiting zig

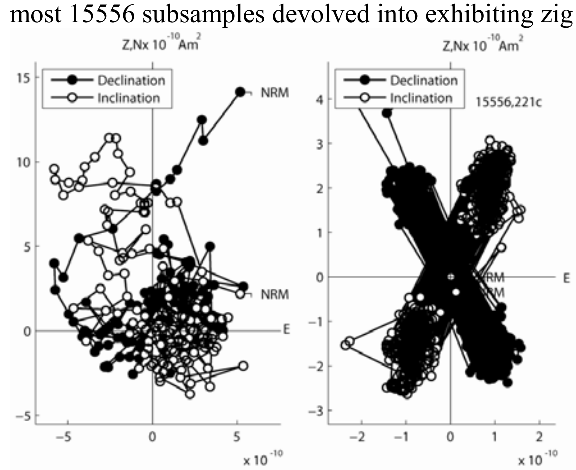

Fig. 1. Demagnetization 15556,221a (left), and 15556,221c (right). Shown in the projection of the NRM vector on two orthogonal planes (N-E and Z-E) during AF demagnetization. The NRM of sample 221c exhibits highly regular zigzagging between two nearly antipodal directions even at low AF fields.

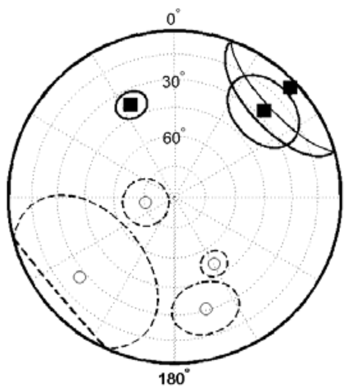

Fig. 2. Equal area plot of least squares fits to 15556 magnetic components from various samples. Closed (open) symbols = lower (upper hemisphere). Squares = components blocked from 0 to 7 mT. Circles = components blocked from 7 to 20 mT.

zag behavior and seemingly random demagnetization patterns (Fig. 1). The two low coercivity components are very roughly unidirectional throughout the sample (Fig. 2).

AF demagnetization of one subsample of 12017 revealed two components. The first component was removed at 6.5 mT and the second component remained roughly stable until 77 mT.

Magnetic recording capacity: A key question is whether the observed poor stability of the NRM and scatter in directions is an indicator of very weak magnetic paleofields or poor magnetic recording properties. To distinguish between these hypotheses, we gave our samples a laboratory-induced magnetization. We then analyzed this magnetization using the same AF demagnetization and paleointensity analyses as that conducted on the NRM. The artificial magnetization was an ARM, which is an analog for the natural thermoremanence expected in igneous rocks [12]. ARM was applied at different bias field levels ranging from 3 to 200 μT (analogous to natural paleofields of ~2 to 150 μT recorded as thermoremanence).

If the retrieved paleointensity values are similar to the laboratory field, then they effectively are of high accuracy. If the the simulated paleointensity values have low uncertainties as measured by scatter around linear regressions in paleointensity plots (e.g., Fig. S3 of [3]), then they effectively have high precision.

Our results (Fig. 3) show that 15556 and 12017 are both capable of robustly recording applied fields down to ~20-30 microteslas. Below that threshold, any magnetization is overpowered by spurious noise introduced during AF demagnetization despite our large of our large number of repeat measurements and GRM-correction procedures (see above).

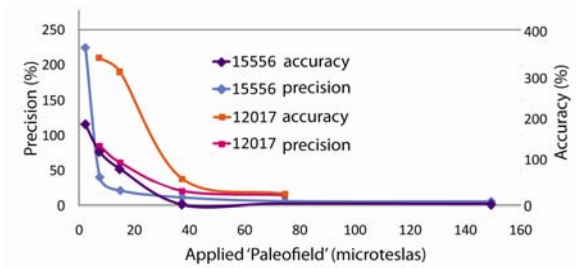

Fig. 3. Loss of measurement precision and accuracy at low paleofields. Shown is the percentage difference between the retrieved and actual paleointensity (accuracy) and nominal uncertainty on retrieved paleointensity values (precision) for representative subsamples of 15556 and 12017.

Discussion: At first glance, the magnetic behavior exhibited by 15556 appears to be incompatible with the existence of a lunar dynamo field at 3.3 Ga. While that is certainly a possible explanation, another could lie in 15556's inability to acquire weak magnetization. Given that many lunar paleointensities are below 20 μT [1] and that the surface magnetic field of Mercury (a body substantially larger than the Moon) today is only in the range of hundreds of nanoteslas, it seems quite plausible that the intensity of an ancient lunar magnetic field would fall well below the recording threshold for 15556 and 12017. Therefore, the lack of evidence of for a lunar dynamo in many Apollo samples is not evidence for the absence of a dynamo.

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