PERSISTENCE OF THE LUNAR DYNAMO UNTIL 3.6 BILLION YEARS AGO. C. Suavet[1], B. P. Weiss[1], M. D. Fuller[2], J. Gattacceca[3], T. L. Grove[1], D. L. Shuster[4], [1]Dept. of Earth, Atmospheric, and Planetary Sciences, Massachusetts Institute of Technology, Cambridge, MA, USA (csuavet@mit.edu), [2]Hawaii Institute of Geophysics and Planetology, University of Hawaii at Manoa, Honolulu, HI, 96822, [3]CEREGE CNRS/AixMarseille Université, BP 80, 13545, Aix en Provence, Cedex 4, France, [4]Berkeley Geochronology Center, 2455 Ridge Road, Berkeley, CA 94709, USA.

Introduction: The existence of a global magnetic field on a planetary body implies that there is an advecting liquid core. Although the Moon today does not have a global field, lunar crustal magnetism and paleomagnetism in returned samples have been interpreted as evidence of an ancient lunar dynamo [1, 2]. However, an alternative explaination is that this magnetization was produced by impact-generated fields [3].

New analytical methods and an advances in our understanding of rock magnetism have enabled recent paleomagnetic studies to confidently demonstrate that the Moon had a core dynamo at 4.2 billion years (Ga) [4] and 3.7 Ga [5] ago. However, it currently remains unclear when the lunar dynamo finally decayed. To constrain the lifetime of the lunar core dynamo and better characterize its magnetic field intensity, we carried out a paleomagnetic study of 3.6 Ga old mare basalt 10017.

Sample: This Apollo 11 fine-grained vesicular high-K (petrologic type A) ilmenite basalt has a crystallization age of 3.6 Ga [6]. Following its collection, the paleomagnetic record of this sample was studied [7], and a highly stable natural remanent magnetization (NRM) was identified. However, mutually oriented samples were not measured, samples were not fully demagnetized and other tests were not conducted that could conclusively establish the origin of the primary NRM as a thermoremanence (TRM) acquired on the Moon at 3.6 Ga.

Nevertheless, this rock is highly promising for paleomagnetic studies. A cooling rate of ~1.5 °C/hour is inferred from the maximum plagioclase width method [8], indicating that it is unlikely to have recorded transient magnetic associated with impacts. Our electron microprobe analyes indicate that metal grains are nearly pure iron (Ni content is below detection limit) and therefore are unlikely to have a thermochemical remanence from phase transformations below the Curie point. Furthermore, our petrologic analyses indicate that 10017 shows no evidence of shock >5 GPa (plagioclase does not show mechanical twinning, fracturing, or alteration to maskelynite). Nevertheless, our hysteresis data indicate that the metal grains are multidomain.

Methods: We cut nine mutually oriented subsamples with masses from 40-250 mg We carried out alternating field (AF) demagnetization up to 290 mT. To determine the origin of the magnetization of the rock, the demagnetization of the NRM was compared with that of laboratory-induced fields: anhysteretic remanent magnetization (ARM) as an analog of thermoremanent magnetization (TRM), pressure remanent magnetization (PRM) as an analog of shock remanent magnetization (SRM), and isothermal remanent magnetization (IRM) as an analog of stray fields in the spacecraft and during sample handling. Viscous remanent magnetization (VRM) experiments were carried out to estimate the effect of the residence in the Earth field since the samples were collected.

Paleomagnetic record: AF demagnetization identifed two NRM components (Fig. 1): a low coercivity (LC) component erased by 9-20 mT and a extraordinarily stable high coercivity (HC) component (directionally stable up to >290 mT and decaying to the origin until 120 mT).

The LC component is not consistent in direction be

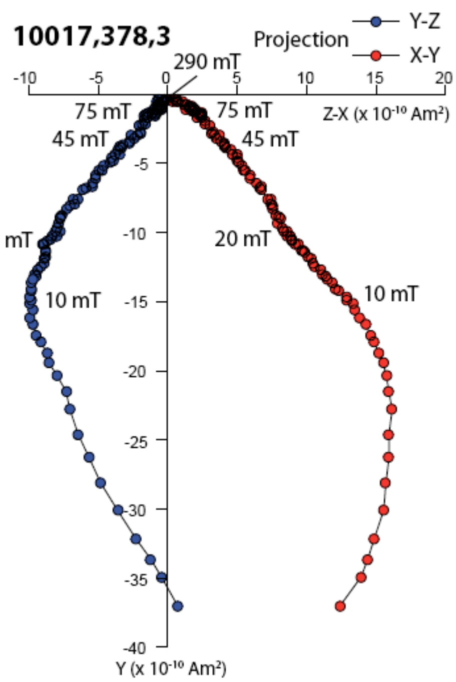

Fig. 1. NRM of mare basalt 10017. Two dimensional projection of the NRM vector of subsample 3 during AF demagnetization. Symbols represent end points of magnetization projected onto orthogonal (blue symbols: Y-Z, red symbols: X-Y) planes. Selected AF steps are labeled.

-tween subsamples (Fig. 2). Its NRM/IRM >0.08 and its decay rate is similar to that of an IRM during AF-demagnetization. These results indicate that the LC component is an overprint likely acquired in a strong artificial field during transportation [9] or sample handling.

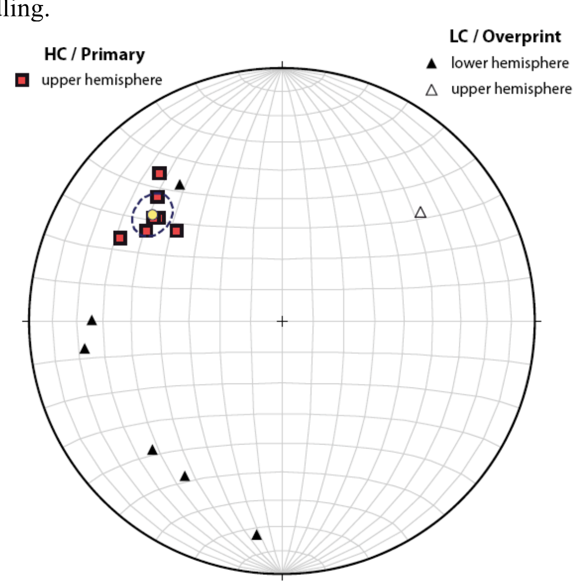

Fig. 2. Equal area stereographic projection of NRM component fits to 10017 subsamples. Squares denote HC directions (primary magnetization), triangles denote LC directions (overprint). Yellow circle = Fisher mean HC direction. Dashed circle = associated 95% confidence interval (not accounting for mutual 5-10º orientation errors).

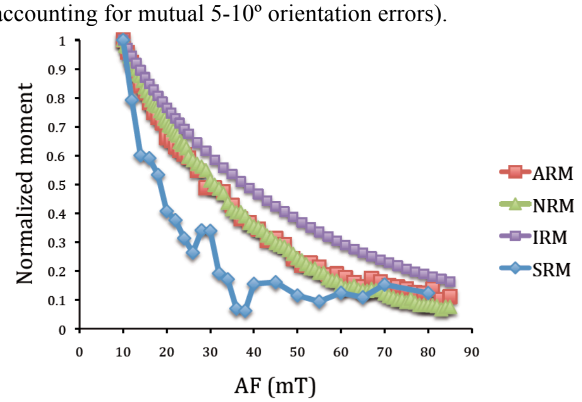

Fig. 3. AF demagnetization of the NRM, ARM (AC field 85 mT, DC field bias 0.1 mT), IRM (DC field 200 mT) and PRM (2 GPa) of subsample 3.

The AF demagnetization rate of the HC component closely resembles that of an ARM and is distinct from that of a PRM and IRM (Fig. 3). Our VRM experiments show that the HC component cannot be explained by residence in the Earth's field. Therefore, the HC component is likely a TRM acquired by cooling in a stable field on the Moon. The cooling time from the Curie temperature to ambient surface temperatures was >20 days. Because impact-generated fields are thought to persist for << 1 day [10, 11], this indicates that they cannot be a source for this magnetization. The magnetic field recorded by mare basalt 10017 was most likely generated by an ancient lunar core dynamo

Paleointensity: Both the ARM method and the REM' method [12] give paleointensities of ~70 µT, indicating a very conservative minimum of 14 µT (accounting for the ~3-5 factor of uncertainty on the calibration factor between TRM and ARM/IRM). This value is almost identical to that inferred at 3.7 Ga from 10020 [5].

Implications for the lunar core dynamo: This sample extends the lifetime of the lunar core dynamo by 100 million years: the Moon had an active dynamo at least between at least 4.2 and 3.6 Ga. It is becoming increasingly clear that this lifetime is not consistent with a thermal convection driven dynamo, as the minimum heat flux required to sustain thermal convection is unlikely to have lasted after 4.1 Ga [13]. These results support the idea of an unconventional power source for the lunar dynamo, such as a mechanical stirring [14] due to precession [15] or basin-forming impacts [16]. Given that there were almost certainly no basin-forming events within several thousand years of the formation of 10017, a precession-dynamo is the more likely source for its magnetization. However, given that mechanical dynamos are expected to produce surface fields ranging from ~0.2-15 µT [14, 16], the high paleointensities of 10017 and 10020 present a challenge to dynamo theory.

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