MAGNETIC FIELDS ON 4 VESTA AS RECORDED IN TWO EUCRITES. R. R. Fu[1], B. P. Weiss[1], L. Li[1], C. Suavet[1], J. Gattacceca[2], E. A. Lima[1]. [1]Dept. of Earth, Atmospheric, and Planetary Sciences, Massachusetts Institue of Technology, Cambridge, MA, USA (rogerfu@mit.edu) [2]CEREGE, BP80, 13545 Aix-en-Provence Cedex 4, France.

Introduction: The asteroid 4 Vesta is believed to be the largest surviving example of a class of differentiated planetesimal bodies that populated the early solar system [1]. Understanding its early evolution can therefore yield important clues regarding the origin of asteroids, meteorites, and the terrestrial planets. Measurements of the Vesta gravity field by the Dawn spacecraft suggest the presence of a metallic core about one-half the body's diameter [2]. This is consistent with geochemical constraints from meteorites of the howardite-eucrite-diogenite (HED) clan [3], which are believed to originate from Vesta [4]. The existence of a metallic core opens the possibility of a core dynamo-generated magnetic field in the past.

Analysis of the paleomagnetism of Vesta would provide important constraints on its evolution. The past presence of such a field would imply that Vesta's early core underwent vigorous advection. Because large scale melting likely occur only in cases of early formation, the past presence of a convecting core in 4 Vesta provides further evidence that it accreted within 1.5 Myr after solar system formation [e.g., 5]. Furthermore, inferring the intensity and duration of a dynamo-generated field would place experimental constraints on numerical models of asteroidal core dynamos as well as on models of the early thermal evolution of asteroids [e.g., 5, 6].

Finally, present-day surface magnetic fields affects the style and efficiency of ongoing space weathering [7, 8]; therefore, constraining the intensity of present-day surface fields holds implications for the interpretation of observable features on the surface of Vesta.

Due to the absence of a magnetometer onboard the Dawn spacecraft, laboratory analysis of HED meteorites is one of the only methods for constraining past and present surface magnetic fields on Vesta. Furthermore, the existence of HED meteorites with diverse thermal histories potentially allows direct sampling of surface magnetic fields recorded at different times during the history of Vesta.

Samples: We have been conducting paleomagnetic studies on two eucrites, Millbillillie and ALH 81001, which likely originate from the crust of Vesta.

Millbilllillie is a polymict eucrite fall formed from the impact mixing of fragments from at least two distinct basaltic sources. Since its assembly within 150 million years (Ma) of Vesta formation, Millbillillie has been subject to multiple metamorphic and impact episodes. Non-uniform heating due to impact events may have resulted in the acquisition of heterogeneous thermoremanent magnetization [9]. The most recent major thermal event, ^{40}Ar-^{39}Ar dated to 3.55 Ga, likely heated the meteorite to ~300-700˚C [10]. Therefore, any magnetization that exists below 300˚C must have been acquired at or after 3.55 Ga.

In constrast, ALH 81001, is an unbrecciated, apparently unshocked eucrite. Its very fine-grained texture suggests rapid cooling in a surface lava flow [11]. Although no radiometric ages are available for ALH81001, unbrecciated eucrites are typically found to have early ^{40}Ar-^{39}Ar dates of ~4.48 Ga [12]. Our ^{39}Ar-^{40}Ar dating of ALH 81001 is in progress.

Methods: Fifty-four mutually-oriented samples were taken from a large (~100 g) section of Millbillillie. Of these, 21 samples were subject to thermal demagnetization up to between 580˚C and 800˚C while the remainder underwent alternating field (AF) demagnetization. Anhysteretic remanent magnetization (ARM) and isothermal remanent magnetization (IRM) methods were used to obtain paleointensities for eight samples. Twelve mutually-oriented samples were obtained for ALH 81001. All were subject to AF demagnetization, with ARM and IRM paleointensities obtained for five samples.

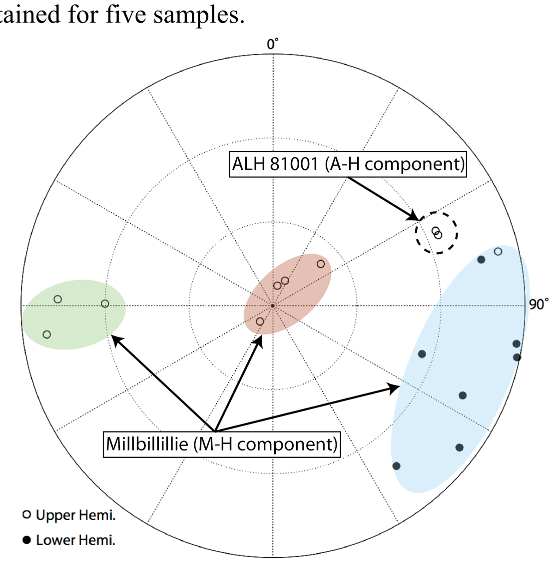

Fig. 1. Equal area plot showing directions of high coercivity and blocking temperature magnetization from samples of Millbillillie and ALH81001. Color coding indicates samples taken from adjacent regions of Millbillillie (up to 4 cm apart). Subsample from each meteorite are mutually oriented; however, the two meteorites are not mutually oriented to each other.

Samples of both meteorites taken near the fusion crust show systematic differences in the recorded field direction compared to those taken in the interior, suggesting that the samples have escaped significant contamination by hand magnets, weathering, or viscous remagnetization since their arrival on Earth.

Results: Interior samples of Millbillillie reveal three distinct components of magnetization in both AF and thermal demagnetization. We refer to these components as M-L, M-M, and M-H for low, medium, and high coercivity or blocking temperature. The low blocking temperature of the M-L and M-M components (75˚C and 135˚C, respectively, corresponding to 25 and 70 mT in AF demagnetization) and their uniform orientation throughout the meteorite suggest that they represent viscous remanent magnetization (VRM) acquired on Earth.

The M-H component is directionally stable between 135˚C and at least 540˚C (70 and 160 mT in AF). The magnetization decays to near zero during AF demagnetization at a rate most similar to that of an artificial ARM (and distinct from an IRM, VRM, and pressure remanent magnetization, PRM), suggesting that the M-H was acquired during cooling in the presence of a magnetic field. It is unidirectional on scales of up to 4 cm, which may suggest a heterogeneous impact heating origin. We infer a paleointensity between 5 and 10 μT for the magnetizing field.

Interior samples of ALH 81001 also carry three components of magnetization upon AF demagnetization blocked from 0 to 14 mT, 14 to 66 mT, and 66 to 290mT, respectively. We refer to these as the A-L, A-M, and A-H components. The magnetic softness of the A-L components suggest that it represents a weak hand magnet overprint. Meanwhile, the A-M component may represent a VRM, although further experiments are required to confirm this interpretation.

The A-H component decays to near zero during AF demagnetization and is one of the most stable magnetizations observed in any HED. It is unidirectional across all mutually oriented samples (~1 cm scale). Its demagnetization spectrum is more similar to that of a laboratory ARM compared to an IRM. Therefore, the A-H component was most likely acquired during cooling in a stable magnetic field. Inferred paleofield intensities are between 10 and 37 μT.

Discussion: The high coercivity components of magnetization in both Millbillillie and ALH 81001 were most likely acquired during cooling in the presence of a magnetic field on the surface of Vesta.

The late heating of Millbillillie implies that Vesta had a surface magnetic field at or after 3.55 Ga. No core dynamo is expected to have existed at such a late age [e.g., 5]. Instead, remanent crustal magnetization is the most likely source of the recorded field. The intensity of the surface field inferred from Millbillillie (5-10 μT) is a factor of 2-10 higher than the maximum inferred surface field strengths found near lunar magnetic anomalies of purported impact origin [7]. In contrast, crustal remanence on Mars due to past dynamo activity can generate surface fields up to 50 μT in strength [13]. The paleofields recorded in Millbillillie are therefore most consistent with crustal remanent fields caused by a core dynamo in the distant past.

Because of the their crustal remanent origin, magnetic fields of the intensity as inferred from Millbillillie may still be present on Vesta today and may be strong enough to affect space weathering patterns on the surface of Vesta [8].

The high coercivity component of magnetization in ALH 81001 yields significantly higher paleointensities than Millbillillie. If, like most unbrecciated eucrites, ALH 81001 has an ^{40}Ar-^{39}Ar age of ~4.48 Ga, it may have formed sufficiently early to have recorded directly a core dynamo-generated magnetic field. Indeed, the inferred paleointensities are consistent with those expected for a Vesta-sized body [6]. Alternatively, the magnetizing field may be due to remanent crustal fields. In that case, as with Millbillillie, the inferred strength of the the crustal fields is most consistent with the presence of a past core dynamo.

Conclusions: Both Millbillillie and ALH 81001 carry magnetization likely acquired on the surface of Vesta. The late age and moderate paleointensities of Millbillillie magnetization suggest that remanent crustal fields with intensities between 5 and 10 μT were present on the surface of Vesta at or after 3.55 Ga. Such fields are most consistent with magnetization of the Vesta crust by a early core dynamo. The stronger (10-37 μT) paleointensities from ALH 81001 are consistent with a direct recording of an early dynamo field or of crustal remanent fields due to an earlier core dynamo.

References: [1] Zuber, M. T. et al. (2010) Space Sci. Rev. 163, 77-93. [2] Raymond, C. A. et al. (2011) AGU, Abstract U21B-07. [3] Righter, K. and Drake, M. J. (1997) MPS 32, 929-944. [4] Binzel, R. P. and Xu, S. (1993) Science 260, 186-191. [5] Elkins-Tanton, L. T. et al. (2011) EPSL 305, 1-10. [6] Weiss, B. P. et al. (2010) Space Sci. Rev. 152, 341-390. [7] Hood, L. L. and Williams, C. R. (1989) Proc. 19th LPSC, 99-113. [8] Vernazza, P. et al. (2006) A&A 451, L43-L46. [9] Cassata, W. S. et al. (2010) GCA 74, 6900-6920. [10] Yamaguchi, A. (1994) Meteoritics 29, 237-245. [11] Mayne, R. G. et al. (2009) GCA 73, 794-819. [12] Bogard, D. D. and Garrison, D. H. (2003) MPS 38, 669-710. [13] Langlais, B. et al. (2004) JGR 109, E02008.