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Magnetic fields on asteroid 4 Vesta recorded by the Millbillillie eucrite

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Abstract

The existence and size of a metallic core in 4 Vesta place key constraints on the asteroid's differentiation and thermal history. Because convecting cores can generate magnetic fields, remanent magnetization in planetary rocks can be used to infer past dynamo activity and therefore core formation and convection. To search for records of such a dynamo, we performed a paleomagnetic study of the Millbillillie eucrite. Our data provide the first unambiguous evidence of remanent magnetism recorded on its parent body 4 Vesta. Mutually-oriented subsamples contain at least one stable, unidirectional component of magnetization. This remanence is likely a record of crustal fields on 4 Vesta before 3.55 Ga or a dynamo field during a period of global thermal metamorphism within the first 100 Myr of formation. The intensity and acquisition timing of this remanence constrain the strength and duration of a proposed early Vesta dynamo, and have important implications for detecting crustal magnetic fields using observations of possible space weathering features by the Dawn spacecraft.

1. Introduction

As the largest unambiguously differentiated asteroid, 4 Vesta is a model system for understanding early planetesimal differentiation and evolution. In particular, a key goal of the Dawn mission is to determine the existence and size of a metallic core on Vesta. Recent analyses of angrite meteorites coupled with theoretical considerations suggest that many Vesta-size planetesimals generated core dynamo magnetic fields up to ~100 Myr after solar system formation [6]. Constraints on the remanent magnetization on 4 Vesta could be used to infer the presence of an ancient dynamo and therefore a convecting metallic core. Although the Dawn mission does not have a magnetometer, this could be accomplished by paleomagnetic studies of achondrites from the howardite-eucrite-diogenite (HED) clan, which are thought to be samples of the asteroid.

Petrographic studies of HEDs have found evidence for an extended period (up to 100 Myr) of thermal metamorphism and multiple brecciation and heating events associated with impacts as recent as 3.55 Ga [7, 8]. Therefore, depending on the timing of the metamorphic and impact events, rocks on 4 Vesta may record the field of a primordial dynamo or the crustal remanent fields. Detection of crustal remanence would constrain the existence of a past dynamo and provide clues to its strength and time of duration. These constraints are closely tied to the formation age of Vesta, the size of its metal core, and its accretionary history [6]. Significant crustal magnetization in the present day deflect solar wind ions, possibly producing high-albedo anomalies [5] detectable with the Dawn framing camera and mapping spectrometer [4]. Interpretation of such features as magnetic in origin requires an estimate of the intensity of crustal magnetization.

Past paleomagnetic studies of HED meteorites have observed non-unidirectional and unstable magnetization of uncertain origin [1, 2]. Furthermore, most HED studies did not conduct tests to rule the effects of atmospheric entry, weathering, and hand magnets on Earth. As a result, there has been no unambiguous determination of extraterrestrial magnetization in HED meteorites.

A possible exception to this is the Millbillillie eucrite. A previous study of this meteorite [3] identified unidirectional magnetization in mutually oriented samples seemingly acquired in a paleofield of 6–37 μT. Given that the 3.55 Ga $^{40}Ar/^{39}Ar$ age of this sample is well after the lifetime of a putative early dynamo on Vesta, this seems to suggest the presence of strong crustal remanent magnetic fields. However, this study lacked a number of tests essential for determining the age and origin of the remanence. Furthermore, we have now found that the samples analyzed by this study apparently contained fusion crust from atmospheric passage and were therefore contaminated by magnetization produced on Earth. To resolve these ambiguities, we are conducting a new paleomagnetic study of the Millbillillie eucrite.

2. Experimental Results

We studied the natural remanent magnetization (NRM) of nine mutually oriented subsamples of the Millbillillie eucrite. We found that subsamples taken from within 2.0 mm of the fusion crust have an uniform, intense magnetization acquired during atmospheric passage in the Earth's field, while interior subsamples have specific magnetizations ~1000 times weaker and oriented >80˚ degrees away from exterior samples. These contrasts in magnetization direction and intensity show that the NRM in the interior of Millbillillie is pre-terrestrial in origin.

We applied alternating field (AF) demagnetization to interior samples to progressively remove distinct components of the magnetization. At AF fields above 65 mT, interior samples converge to a single direction (Fig. 1). The high coercivity and unidirectionality of this component rules out contamination by hand magnets and likely by shock remanent magnetization acquired at low temperatures. Because Millbillillie was subjected to brecciation, similar unidirectionality tests with other subsamples, petrographic studies, and other rock magnetic data are necessary to confirm this interpretation. These analyses are ongoing

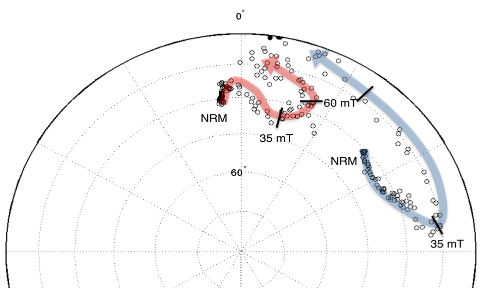

Figure 1. AF demagnetization up to 85mT of two Millbillillie sub-samples plotted on an equal area stereonet. Note convergence of the two directions at high alternating fields. Open (closed) symbols represent the upper (lower) hemisphere

3. Summary and Implications

We have presented the first unambiguous detection of a remanent magnetization from Vesta from a paleomagnetic study of the Millbillillie eucrite. Our study addressed the shortcomings of previous studies of HED meteorites by performing unidirectionality and fusion crust tests to verify the extraterrestrial nature of the remanence [3].

Given the complex thermal history of Millbillillie, it is not yet clear whether its NRM was acquired during heating within the first 100 Myr of Vesta's history or during a late impact event before 3.55 Ga. We are currently studying additional subsamples to distinguish between these possibilities and to determine the paleointensity of the magnetizing field. In the former case, paleointensity experiments would constrain the strength and duration of a core dynamo, while in the latter case, they would constrain remanent crustal magnetic fields.

Acknowledgements

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