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Magnetic Field On Early Protoplanet Vesta

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Introduction

The early Solar System is characterized by populations of protoplanets, which grew through accretion processes. Protoplanets of sufficient mass were fueled by short-lived radionuclides like ^{26}Al, which caused widespread melting and led to chemical differentiation. Asteroid 4 Vesta is one of the best-preserved and studied examples of such a differentiated protoplanet from the early Solar System. Paleomagnetic analyses of HED (**H**owardite, **E**ucrite, **D**iogenite) meteorites - thought to be crustal samples from Vesta - reveal natural remanent magnetization, which implies the presence of an ancient internal magnetic field (Weiss et al. 2010; Fu et al. 2012). This magnetic field might have been powered by an internal core dynamo, driven by thermal convection within a liquid, electrically-conductive metallic core. Since NASA's Dawn mission did not carry a magnetometer, we rely on a combination of numerical thermal evolution modeling and meteorite analysis to constrain Vesta's magnetic history.

Research question and methodology

This study investigates the potential for an ancient, thermally driven core dynamo on the protoplanet Vesta to explain the natural remanent magnetization observed in HED meteorites. Because there are no direct measurements of Vesta's magnetic field, the study performs investigations on modeled 1-dimensional radial temperature profiles, which represent the physical properties of the body's interior. The datasets represent Vesta as a radially non-homogeneous, spherically symmetric body, and span a time interval of up to 4.5 Ga following the formation of Calcium-Aluminum-rich Inclusions (CAIs), which represent the earliest dated solids in the Solar System and are therefore commonly used as the reference time for Solar System formation. The profiles are generated following the modeling framework of Neumann et al. (2014), applying numerical solutions of coupled partial differential equations governing heat transfer and mass transport. The configurations vary based on the differentiation scenario - comparing a global magma ocean against a shallow magma ocean case - and the timing of the accretion, investigating an early accretion time (at the time of CAIs) against a late accretion time (1.5 Ma after CAIs). Furthermore, MAC (**M**agnetic, **A**rchimedean and **C**oriolis forces) scaling laws are applied to estimate the magnetic Reynolds number and the resulting magnetic field strength inside the core and on the surface for each scenario. The results are compared to the remanent magnetization recorded in the HED meteorites.

Results

Our findings reveal that all four configurations meet the conditions for a thermally driven core

dynamo at some point during the first hundred Ma of the protoplanet's evolution. The onset, duration and intensity of the dynamo are dependent on the available heat budget from ^{26}Al. Consequently, early accretion scenarios produce more vigorous and long-lasting dynamos, whereas late accretion results in delayed or marginal magnetic activity. Notably, for all modeled configurations the core dynamo terminates before 500 Ma after CAIs. This is consistent with the HED meteorite record preserving crustal remanence from an earlier active dynamo rather than an actively generated field (Fu et al. 2012; Weiss et al. 2010). However, the modeled surface field strengths of 200–300 μT are higher than the 2–5 μT recorded in HED meteorites, which is attributed to the known tendency of MAC scaling laws to overestimate field strengths in small convecting bodies (Christensen 2009; Formisano et al. 2016). The models of timing and occurrence of the dynamo are the more robust outcomes of this study and provide new quantitative support for an ancient core dynamo on Vesta consistent with the paleomagnetic evidence.

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