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Long-lived magnetism from inner core solidification on small planetary bodies

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Paleomagnetic measurements of meteorites suggest that many asteroids generated their own magnetic activity during the early solar system, with the majority of measured meteorite classes appearing to have recorded dynamo fields. Despite this apparent near ubiquity of magnetic activity among small planetary bodies, many of the most fundamental aspects of this activity remain enigmatic. Crucially, both the temporal evolution and the processes capable of generating small body magnetic activity are yet to be gleaned from paleomagnetic measurements. This information has been central in understanding the dynamic and thermochemical evolution of our planet, and equivalent information from asteroids could help illuminate the evolution of matter in our solar system. Here, we present time-resolved records of the magnetic activity generated on the main-group pallasite parent body inferred from X-ray photoemission electron microscopy (XPEEM) images of the metal matrix within the Imilac, Esquel, Brenham and Marjalahti pallasite meteorites. This metal cooled at <10 K/Myr, which permitted a unique nanostructure known as the cloudy zone (CZ) to form. The CZ is an excellent paleomagnetic recorder, and formed over a distance of $\sim$10 μm over tens of millions of years. By spatially resolving the magnetism of this nanostructure using XPEEM, we infer both the direction and intensity of the field experienced by the CZ of these meteorites. All four meteorites recorded unidirectional fields. The Brenham and Marjalahti meteorites recorded relatively weak fields with intensities of >20 μT over a period of $\sim$4 - 10 Myr. The Imilac meteorite recorded a stronger field between 120 - 130 μT over a period of <10 Myr. The Esquel meteorite initially recorded a field of $\sim$80 μT, which then weakened over time down to a plateau at $\sim$30 μT, before decreasing further down to $\sim$0 μT. By comparing experimental cooling rates to those predicted from planetary cooling models, the Brenham and Marjalahti meteorites are expected to have recorded the magnetic activity shortly before core solidification, and the Imilac and Esquel meteorites are expected to have recorded the magnetic activity associated with the early and later stages of this process, respectively. Dynamo field intensities predicted from empirical scaling relationships suggest that the Imilac meteorite experienced a dipolar dynamo field generated by compositional convection associated with the early stages of bottom-up core solidification. The Esquel meteorite appears to have experienced a dipolar-multipolar transition (intensity decrease), multipolar regime (plateau at $\sim$30 μT), and the cessation of dynamo activity associated with the near-completion of core solidification (decrease down to $\sim$0 μT). The weak fields experienced by the Brenham and Marjalahti are consistent with a period of dynamo activity quiescence prior to inner core growth. Solidification-driven convection is yet to be associated with small bodies, but given its efficiency, likely lead to convection across the majority of bottom-up solidifying cores in these bodies, implying a widespread, intense and long-lived epoch of magnetic activity among small bodies during the early solar system.