**PARTIAL DIFFERENTIATION AND MAGNETIC HISTORY OF THE IIE IRON METEORITE PARENT BODY.** C. Maurel[1], J. F.J. Bryson[2], B. P. Weiss[1], R. J. Lyons[3], M. R. Ball[2], R. V. Chopdekar[4] and A. Scholl[4], [1]Department of Earth, Atmospheric, and Planetary Sciences, Massachusetts Institute of Technology, Cambridge, MA, USA, [2]Department of Earth Sciences, University of Cambridge, Cambridge, UK, [3]Department of the Geophysical Sciences, The University of Chicago, Chicago, IL, USA, [4]Advanced Light Source, Lawrence Berkeley National Laboratory, Berkeley, CA, USA

**Introduction:** Meteorites are divided into two principal classes: chondrites (unmelted accretional aggregates) and achondrites (products of planetary melting processes) [1]. The existence of iron meteorites and other achondrites demonstrates that some planetesimals underwent igneous differentiation. However, the extent of internal melting and differentiation among planetesimals remains debated. Some planetesimals may have only partially differentiated (i.e., formed a metallic core and silicate achondritic interior, but retained a chondritic crust) [2]. The existence of such partially-differentiated planetesimals would imply that some chondrites and achondrites could share a common parent body and indicate that accretion of some planetesimals was likely protracted over >0.1 million years (My) [2].

The silicate-bearing IIE iron meteorites contain a diversity of achondritic and chondritic silicate inclusions [3]. These inclusions likely formed on a single parent body given their similar O-isotopic composition [4]. The varying extent of melting in the IIE silicates has been suggested as evidence for a partially-differentiated parent body, where silicates from the melted mantle and unmelted crust were mixed with endogenous or exogenous metal during a large impact [3]. The leading alternative explanation is that the IIEs formed in impact melt pools on a metal-rich undifferentiated body [5].

Recently, we have found that the IIE Colomera, which contains melted silicates, recorded a ~20 µT magnetic field generated by its parent body ~98 My after calcium-aluminum-rich inclusion (CAI) formation [6]. Using a quantitative cooling rate indicator based on the size of CZ islands [7], we also estimated that Colomera cooled through ~350°C at 2.5 ± 1.4 °C My$^{-1}$. Given this timing, Colomera's slow cooling rate, and the intensity of the paleofield, this record is most compatible with a dynamo-generated magnetic field powered by core crystallization, providing evidence that the IIE parent body formed a metallic core.

To further test this hypothesis, we carried out a paleomagnetic study of the IIE iron Techado, which contains unmelted silicates. Using numerical simulations, we also investigated the hypothesis of mixing metal with silicates during large impacts.

**Experimental method:** We studied the Fe-Ni matrix of Techado using X-ray photoemission electron microscopy (XPEEM) [8]. We measured the remanence carried by two cloudy zones—nanoscale intergrowths of Ni-rich, ferromagnetic tetrataenite islands embedded in a Ni-poor paramagnetic matrix [9]. It has been shown that cloudy zone islands record the intensity and direction of the ambient magnetic field they experienced as they cooled through the tetrataenite formation temperature (320°C) [10–12].

**Paleomagnetic results and implications:** The relative paleodirections obtained for the two CZs analyzed in Techado (Fig. 1A) are within 95% of each other, meaning that we cannot reject the hypothesis that both CZs recorded the same magnetic field. We will be able to estimate the paleointensity (see Fig. 1C for Colomera) after we measure the size of the CZ islands. The Ar-Ar age of Techado (orthopyroxene) corresponds approximately to the time when the meteorite cooled between 700 and 600°C, assuming a cooling rate of 10 °C My$^{-1}$ [13]. Although the low-temperature cooling rate of Techado will be more precisely determined once the CZ island size is measured [7], this means that Techado recorded its parent's field approximately ~120 My after CAI [14].

We now have paleomagnetic evidence from two IIE meteorites (Colomera with melted silicates, and Techado with unmelted silicate) that their parent body generated a magnetic field at least at ~98 and ~120 My after CAI. This supports the conclusion that the IIE parent body had a large (tens of km radius) metallic core. Combined with the presence of chondritic and achondritic silicate inclusions, this bolsters the partial differentiation hypothesis for this planetesimal. This time record of the magnetic field is also promising to better constrain the size of the parent body.

**Simulations of the IIE parent body:** How can chondritic and achondritic material mix with metal to form the IIEs while preserving a core capable of powering a dynamo at least at ~98 My after CAI, and allowing Colomera to cool at ~2.5 °C My$^{-1}$ during that period? We numerically investigated three possible formation scenarios involving a partially-differentiated target body: (1) a hot iron-rich impactor injected metal into the mantle; (2) a cold iron impactor injecting metal into the mantle; (3) a chondritic

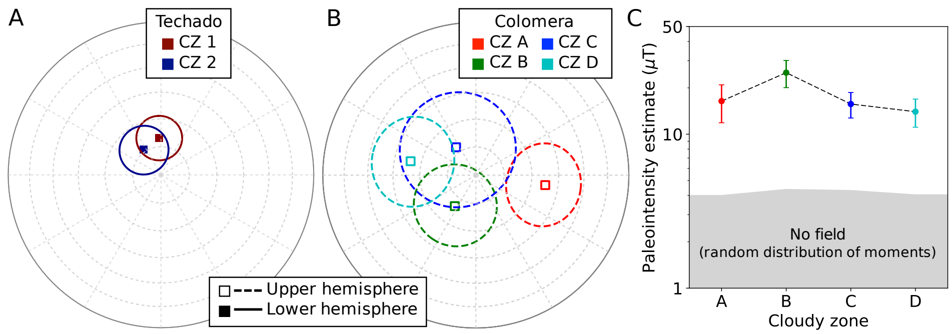


**Fig. 1. A) Equal area projection showing the relative paleofield directions recovered from the two CZ (1 and 2) in Techado. Ellipses represent the 95% confidence interval accounting for the scatter in the recovered directions. Open (closed) symbols denote upper (lower) hemisphere. B) Relative paleofield directions recovered from the four CZ (A, B, C and D) in Colomera. C) Paleofield intensities for each CZ with total uncertainty including XPEEM measurement uncertainty, island size measurement uncertainty and statistical uncertainty.**

impactor excavating metal from the core of the target body. Colomera's cooling rate is too slow for it to have formed in metal pools at the bottom of impact craters, even if they are covered by insulating regolith.

The impact simulations were carried out using the iSALE-2D shock physics code [15–17]. We modeled a partially-differentiated IIE parent body with a radius of 170 km impacted vertically at 10 and 30 My after cessation of radiogenic heating with a 30-km radius projectile and at different impact speeds. The initial temperature profile of the parent was obtained using the 1D thermal model mentioned above. We followed the cooling of the impacted planetesimal using a two dimensional conductive cooling model [18].

We found that scenario (3) is unlikely to occur while the core is still liquid (i.e., even at 30 My) because any uplifted iron will readily rejoin the core. In comparison, scenarios (1) and (2) can occur given specific impact conditions. At 30 My and 1 km $s^{-1}$ impact speed, both cold and hot iron impactors can be implanted into the mantle without subsequently merging with the core (Fig. 2). Although it is not resolved in our simulations,

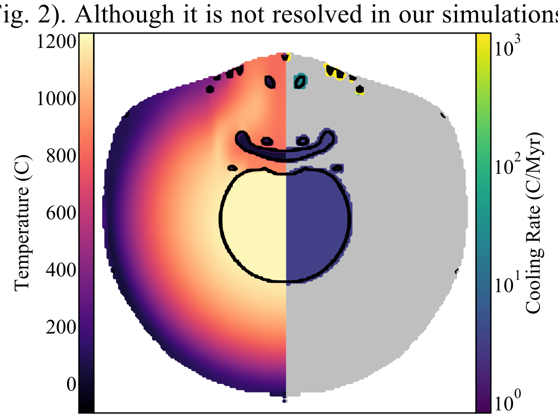


**Fig. 2. Temperature profile of the 170-km radius parent body post-impact (left) and cooling rate at 350°C of the metal parts (right). This results from an impact at 1 km $s^{-1}$ with a 30 km radius cold iron projectile, occurring 30 My after cessation of radiogenic heating.**

mixing with silicates from the crust and mantle is expected. In all cases, the exogenous iron thermally equilibrates with the surrounding mantle. The time of cooling through 320°C of the mixed IIE region would therefore mainly depend on the burial depth of the impactor. As shown by this first suite of simulations, if the impactor is implanted too deeply, it will be reheated to core temperatures and cool at core's rate (Fig. 2), such that it will not cool through 320°C while the core is still partially liquid.

**Conclusion:** We have more evidence that the IIE parent powered a long-lived dynamo, which further support the idea of a partially-differentiated body. This identification of a second iron meteorite parent body with dynamo activity is relevant for the NASA mission Psyche, which will search for past dynamo activity on the metallic asteroid (16) Psyche. Our next step is to assess the likelihood of IIE formation by impact on a partially-differentiated body by adding new simulations and CZ island size measurements on Techado to the present results.

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