A TIME RESOLVED PALEOMAGNETIC RECORD FOR THE PALLASITE PARENT BODY. C. I. O. Nichols[1], J. F. J. Bryson[2], B. P. Weiss[1], J. Herrero-Albillos[3,4], F. Kronast[5] and R. J. Harrison[2], [1]cion2@mit.edu, Department of Earth, Atmospheric and Planetary Sciences, Massachusetts Institute of Technology, 54-814, 77 Massachusetts Avenue, Cambridge, MA 02139, USA, [2]Department of Earth Sciences, University of Cambridge, Downing Street, Cambridge, CB2 3EQ, UK, [3]Centro Universitario de la Defensa, Zaragoza 50090, Spain, [4]Instituto de Ciencia de Materiales de Aragon-Departamento de Fisca de la Materia Condensada, Universidad de Zaragoza, Zaragoza 50009, Spain, [5]Helmholtz Zentrum Berlin, Elektronenspeicherring BESSY II, Albert-Einstein-Strasse 15, Berlin 12489, Germany.

Introduction: The pallasites are composed of olivine crystals surrounded by a metallic FeNi matrix. The first paleointensity measurements on pallasites were conducted on pristine olivine crystals hosting magnetic inclusions from the Imilac and Esquel pallasites [1]. These results were interpreted as evidence for the presence of a core dynamo and motivated a model whereby the pallasite metal was sourced from the impact of a differentiated planetesimal [1]. When etched, the metal reveals the Widmanstätten pattern; an intergrowth of taenite and kamacite lamellae. Between these lamellae, a range of microstructures develop including the cloudy zone, a region of tetrataenite islands in an Fe-rich matrix that forms by spinodal decomposition [2]. The tetrataenite islands are of the order of 100 nm in diameter, and their size, structure and composition make them extremely reliable paleomagnetic recorders [3].

Here we present previously published paleointensity results for meteoritic metal from four pallasites: Imilac, Esquel, Brenham and Marjalahti [4,5] alongside new results for the Springwater pallasite. We compare paleomagnetic studies of meteoritic metal with measurements of magnetic inclusions in olivine crystals from the Springwater, Imilac and Esquel pallasites [1,6]. We also present new results for olivine inclusions from the Springwater and Imilac pallasites.

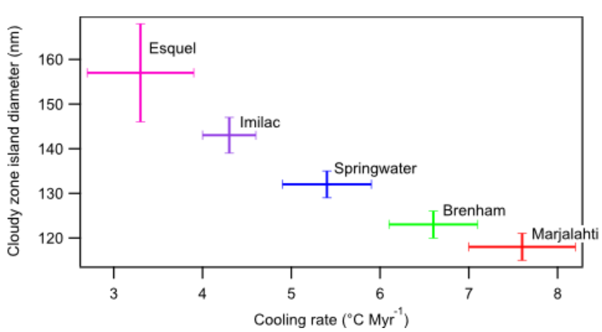

Figure 1 The cooling rates and remanence acquisition times for the five pallasites investigated in this study [7].

The five pallasites presented here have cooling rates ranging from 3-8 °C Myr^{-1} [7]. They therefore recorded a paleointensity at different times during the thermal evolution of the pallasite parent body (Figure 1). Our results provide the most complete time-resolved record of dynamo evolution on a planetesimal to date.

Methods: The direction of magnetisation in the cloudy zone was imaged using X-ray Photoemission Electron Microscopy (X-PEEM). The distribution of magnetisation directions provides information about the strength of the magnetic field the cloudy zone experienced during its formation [4,5,9]. All X-PEEM data were collected at the BESSY II synchrotron facility, Berlin. New results for Springwater incorporate a three-rotation method, providing a much more robust estimate for the distribution of magnetization in the cloudy zone.

Rock magnetic and paleomagnetic analysis of olivine inclusions from the Springwater and Imilac pallasites were conducted using alternating-field (AF) and thermal demagnetisation experiments at the MIT Paleomagnetism Laboratory. Measurements were conducted on a 2G Enterprises SQUID magnetometer. Heating was carried out using a thermal demagnetizing oven, in a controlled H_2-CO_2 atmosphere, and 2-hour heating times [10]. AF demagnetization experiments were also conducted for natural remanent magnetisations (NRMs). Fidelity tests were conducted using established methods by comparing NRMs to known laboratory-applied anhysteretic remanent magnetisations and isothermal remanent magnetisations [11,12].

Results: Relative paleointensities were calculated from the distribution of magnetization directions in the cloudy zone, normalized by the radius of the largest tetrataenite islands in the cloudy zone (Figure 2). Our record begins ~ 100 Myr after accretion, where no magnetic field is recorded. Paleointensity estimates then increase between ~ 120 – 200 Myr before a decline back to a weak magnetic field ~ 240 Myr after accretion.

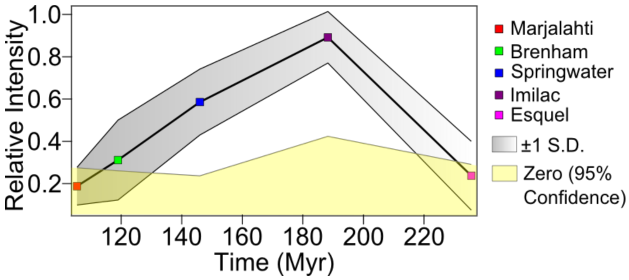

Figure 2 A time-resolved record of relative paleointensity on the pallasite parent body from X-PEEM measurements of matrix metal from the Marjalahti, Brenham, Springwater, Imilac, and Esquel meteorites [4,5].

An attempt was made to calibrate relative paleointensities using a complimentary study of olivine inclusions from the Springwater and Imilac pallasites. Fidelity tests suggest that we cannot reliably infer a paleointensity of < 75 µT from the olivines using alternating field (i.e., non-heating) methods. Because all results lie below this value, no accurate paleointensity estimate can be constrained (Figure 3).

Furthermore, we found that olivines from Springwater and Imilac experienced unstable demagnetization and thermochemical alteration during heating in a controlled oxygen fugacity atmosphere using very long heating times, meaning that paleointensities could not be retrieved by Thellier-Thellier-based (i.e., heating) methods.

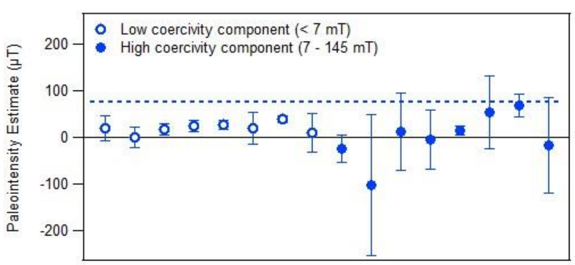

Figure 3 Paleointensity estimates from alternating field experiments on olivine inclusions from the Springwater pallasite. The vertical dashed line is the minimum field that can be reliably recorded based on fidelity test results. High and low coercivities are calculated using principal component analysis of the Zijderveld plots [11].

Discussion: We interpret our paleointensity results as evidence for a late-stage dynamo driven by core solidification on the pallasite parent body [1,4,11]. Our record captures a negligible magnetic field prior to the onset of core solidification [5] and a decline in intensities as core solidification reaches completion.

Only relative paleointensities are presented here due to uncertainty in the size of the tetrataenite islands in the cloudy zone at the time of remanence acquisition. This issue is currently being addressed by numerical modelling of spinodal decomposition [2].

Silicate paleointensities were only calculated from alternating field demagnetization experiments. We were unable to retrieve any new reliable paleointensities from thermal demagnetization experiments due to problems with alteration. Results from olivine inclusions in the Springwater pallasite suggest it experienced a field of < 75 µT. Our relative paleointensities suggest Springwater experienced a slightly weaker field than Imilac. This is supported by our paleointensity estimate from the silicates in Springwater, since a previous study reports a paleointensity of 73.6 ± 8.1 µT for Imilac [1].

Time-resolved records of paleointensity on planetesimals are providing new insight into the mechanisms and longevity of planetary dynamos. These experimental constraints are likely to be essential for the improvement and refinement of numerical models to predict the response of the geodynamo to inner core nucleation on Earth.

References:

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