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Size of the Group IVA Iron Meteorite Parent Body

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The group IVA fractionally crystallized iron meteorites display a diverse range of metallographic cooling rates, ranging from 100 - 6600 K/Myr [1]. These have been attributed to their formation in a metallic core, ∼150 km in radius that cooled to crystallization without any appreciable insulating mantle. Such an exposed core may have resulted from a hit-and-run collision [2] between two large (∼ 10^3 km) protoplanetary bodies. Here we build upon this formation scenario by incorporating several new constraints. These include (i) a recent U-Pb radiometric closure age of 4565.3 Mya (<2.5 Myr after CAIs) for the group IVA iron Muonionalusta [3], (ii) new measurements and modeling of highly siderophile element compositions for a suite of IVAs, and (iii) consideration of the thermal effects of heating by the decay of the short-lived radionuclide ^{60}Fe.

Fractional Crystallization Model: We model the fractional crystallization sequence of the IVA system using an approach similar to [4]. With initial S, P, Re and Os compositions of 3%, 0.1%, 295 ppb and 3250 ppb respectively we find that compositions similar to Muonionalusta are produced after ∼60% fractional crystallization. For an inwardly crystallizing core [5] this suggests formation at 70% the radius, R, of the body. The results of our fraction crystallization model are presented in Figure 1.

Thermal Conduction Model: To match the wide range of IVA cooling rates we follow [1] by assuming an exposed core that cools without any insulating silicate mantle. We solve the 1D thermal conduction equation [6] for cores with variable amounts of live ^{60}Fe, ranging from zero [7] up to a plausible maximum of ^{60}Fe/^{56}Fe = 4 x 10-7 [8]. With core size and ^{60}Fe abundance as the primary variables in this model, we fit both the range of IVA cooling rates and the crystallization of Muonionalusta at 4565.3 Myr at a radius of 0.7R.

Results: Our calculations suggest that the IVA core was 50-110 km in radius after the hit-and-run collision (Fig. 2). This range is primarily due to uncertainties in the initial abundance of live ^{60}Fe incorporated into the IVA core. This emphasizes the need to better constrain initial ^{60}Fe abundances for the IVAs and other iron meteorites that may have crystallized in mantle-free parent bodies within a few half-lives of ^{60}Fe after CAI formation ($\tau_{1/2}$=2.62 Myr). Candidates for such early crystallization include the IIAB, IIIAB and IVB groups. Lastly, our models define a relationship between cooling rate and closure age. For example, IVAs with the fastest cooling rates (>1000 K/Myr) may have absolute ages separated by as little as a few times 10^5 years after CAI formation. The details of this relationship can be firmly established if old U-Pb ages are confirmed/measured for Muonionalusta and other IVAs. This would have important implications for understanding the chronology of the earliest planetary bodies in the Solar System.

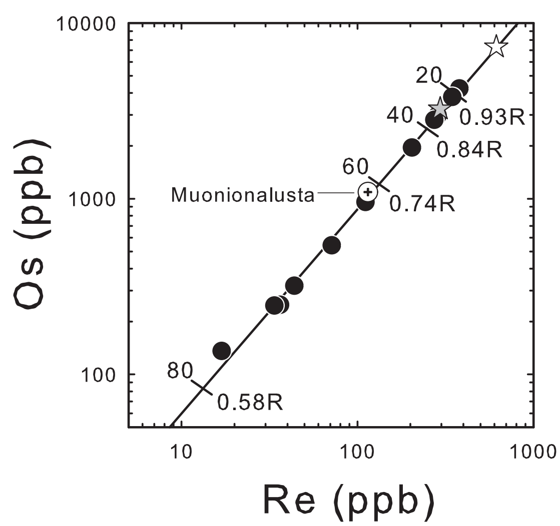

Figure 1: Plot of Re versus Os for 14 group IVA iron meteorites. The solid line is the fractional crystallization trend for 50:50 mixes of equilibrium solids and liquids. Tick marks indicate 20 through 80% extents of fractional crystallization (0.58-0.93R in an inwardly crystallizing core). The grey star represents the assumed initial liquid composition; the open star denotes the composition of the first solid to form from this liquid.

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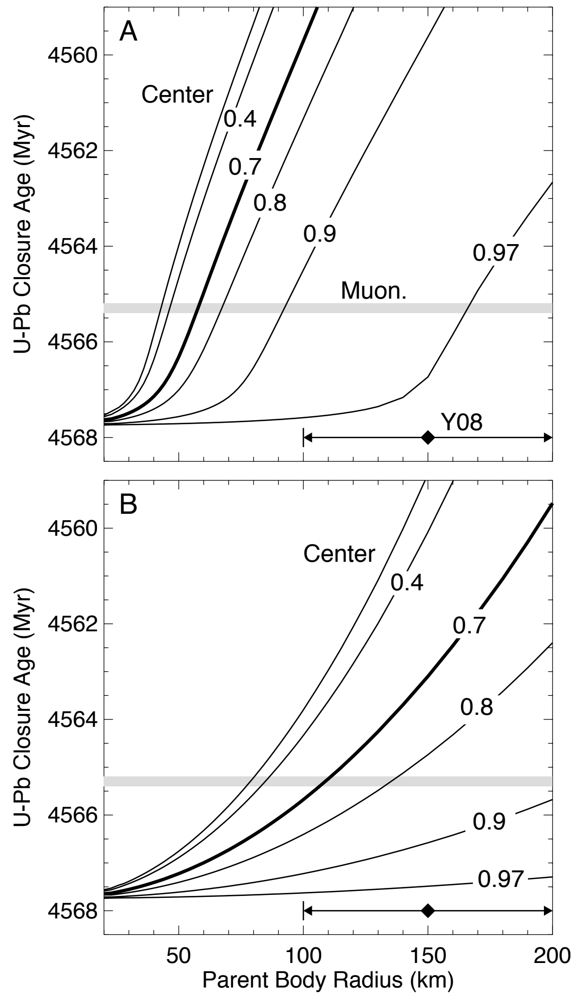

Figure 2: U-Pb closure ages at different depths for a range of parent body sizes with initial ^{60}Fe/^{56}Fe=4×10^{-7} (A) and ^{60}Fe/^{56}Fe=0 (B). The thick curve (0.7R) represents the expected radius of Muonionalusta's origin. The grey region denotes Muonionalusta's closure age of 4565.3$\pm$0.1 Ma. The size estimate for the IVA parent body from [1] is shown at the bottom right. The closure age at the formation radius of Muonionalusta is reproduced for core radii between 50 (panel A) and 110 km (panel B), depending upon the initial abundance of ^{60}Fe.