CHRONOLOGICAL EVIDENCE FOR MESOSIDERITE FORMATION ON VESTA BY A HIT-AND-RUN COLLISION.

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Introduction: Mesosiderites are a type of stony-iron meteorites that formed by mixing of differentiated crust and molten core materials [1]. These meteorites provide insights into the catastrophic break-up of differentiated asteroids. The petrology and chemical compositions of mesosiderite silicates are similar to howardite-eucrite-diogenite (HED) meteorites [2], which are believed to originate from the asteroid Vesta based on the agreement of their laboratory and astronomically observed infra-red spectra [3]. In addition, the O, Cr, and Ti isotope compositions of mesosiderite silicates are excellently consistent with those of HED meteorites [4–6], indicating that mesosiderites also came from Vesta or that their parent bodies formed in the neighbouring region in the solar nebula. If the parent body of mesosiderite silicates is Vesta, the large-scale disruption that formed mesosiderites should have left a chronological mark on both mesosiderites and HED meteorites. In this study, we focus on the zircons in mesosiderites and report the first comprehensive high-precision U-Pb dataset to determine the precise timing of the metal-silicate mixing event and propose a formation model.

Samples and Methods: Zircons were hand-picked from five mesosiderite samples (Vaca Muerta, NWA 1242, NWA 8402, Estherville, NWA 8741) after dissolving the metal parts in concentrated HCl and the silicate parts in concentrated HNO_3-HF mixtures. Samples for U-Pb dating were spiked with 3–5 mg of EARTHTIME ^{202}Pb-^{205}Pb-^{233}U-^{235}U tracer solution and dissolved in concentrated HF using Parr® bombs. Uranium and Pb isotopes were separated using a HCl-based column chemistry and were then measured using a TRITON Plus TIMS at ETH Zurich [7].

Results and Discussion: The ^{207}Pb-^{206}Pb dates of analyzed zircons show two distinct populations with a weighted mean of 4,525.39 ± 0.85 Myr and 4,558.5 ± 2.1 Myr (2σ). The older zircons are likely magmatic relict zircons that formed before the metal-silicate mixing event. Intriguingly, the younger zircons are characterized by unusually low U and Th concentrations (<1 ppm), which are best explained by growth after secondary phosphate minerals during the metal-silicate mixing [8]. Therefore, the younger zircon dates correspond to the timing of the metal-silicate mixing. The ages of the two populations are in good agreement with the timing of crustal formation (4,550–4,560 Myr [9]) and large-scale reheating (~4,530 Myr) on the eucrite parent body, i.e. Vesta. This chronological coincidence corroborates that Vesta is the parent body of mesosiderite silicates.

Since the mesosiderite metal was molten at the time of mixing [1], the parent body size can roughly be estimated to ≥530 km in diameter based on comparison to numerical calculations of Vesta's thermo-chemical evolution [10]. If the mesosiderite metal was derived from the core of another different asteroid [1], the direct collision between such large protoplanets likely would have led to a wholescale disruption of Vesta. As an alternative, a hit-and-run collision with a smaller planetesimal (mass ratio 0.1) only disrupts one hemisphere of Vesta. It produces significant ejecta consisting mainly of crust and mantle materials, but also small amounts of core [11]. In such a case, the collisional debris re-accretes opposite of the collision site and mixes with the underlying crust in the early stage, whereas subsequently pure ejecta debris accumulates in the upper layer. Considering the extremely slow cooling rate of mesosiderites at temperature below 500°C (~0.4°C/Myr) [12] and their low olivine contents, they presumably formed in the lower part consisting of a mixture of collisional debris and underlying crust. Long after the hit-and-run collision, mesosiderites and possibly HED meteorites were ejected from the south pole basin, Rheasilvia, whose initial depth corresponds to 20–80 km [14]. If correct, the hit-and-run collision must have occurred in the northern hemisphere of Vesta, thickening the original crust in the southern hemisphere, which resulted in the two different estimates for crustal thickness reported from HED meteorites (30–60 km) [15,16] and the Dawn mission (>80 km) [14].

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