

INSIGHTS FROM SIDEROPHILE ELEMENTS INTO THE IMPACT ORIGIN OF MESOSIDERITES. J.K. Dhaliwal¹, M.F. Horan², R.D. Ash³, E.S. Bullock² and R.W. Carlson^{2,1} Earth & Planetary Sciences, UC Santa Cruz, 1156 High Street, Santa Cruz, CA 95064, ²Earth & Planets Laboratory, Carnegie Institution for Science, 5241 Broad Branch Road, NW, Washington, DC 20015, ³Department of Geology, University of Maryland, 8000 Regents Dr., College Park, MA 20742

Introduction: The highly siderophile elements (HSE: Re, Os, Ir, Ru, Pt, Rh, Pd and Au) are important tracers of core-formation, partitioning between solid metal-liquid metal and metal-silicate, and impact addition on planetary bodies in the solar system. We focus on bulk measurements of HSE abundances and Os isotopic ratios in metal and silicate phases of mesosiderites. We additionally measure a suite of trace elements, including several HSE, in kamacite and taenite using *in situ* techniques. The objective of this work is to determine if the metal represents core material and if the silicate phases might preserve primary HSE signatures.

Mesosiderites, which consist of approximately equal amounts of metal and silicate, have been proposed as possible specimens of the Psyche asteroid based on density measurements [1], although differences in silicate compositions do not support this [2]. The origins of the metal and silicate phases in mesosiderites are therefore important for understanding planetary bodies in the solar system. In particular, we seek to determine if the metal and silicate in these meteorites reflect differentiation processes on a single parent body, or if these phases originated on different parent bodies and were mixed during an impact event.

During core formation and fractional crystallization, trace elements partition between liquid metal and solid metal; for example, Ir and Os strongly partition into solid metal [3]. Relative abundances of trace elements in metal that derives from a planetary core and has undergone fractional crystallization will therefore exhibit inter-element fractionation patterns when normalized to chondritic abundances. Conversely, metal that has not completely segregated to a core and experienced fractional crystallization, or has been remelted, will have relative trace element abundances more similar to precursor material (e.g., chondrites).

In the case of silicate phases, primary signatures of metal-silicate differentiation are expected to have low but measurable abundances of HSE, as these elements largely partition into metal. The metal-silicate partitioning behavior is variable among the HSE, leading to observable inter-element fractionation and non-chondritic patterns in primary silicate phases. Impact addition of chondrites is expected to result in elevated HSE abundances that would overprint primary signatures of metal-silicate differentiation; for mesosiderites, contamination from nearby metal phases

is also possible. Finally, undisturbed Re-Os systematics in metal and silicate phases can be used for age-dating, as well as tracers of fractional crystallization and metal-silicate differentiation, respectively.

Samples & Methods: The mesosiderite samples in this study consist of Elephant Moraine 87500 (Type B), Lewis Cliff 87006 (Type A), Queen Alexandra Range 93001, Reckling Peak A79015 (Anomalous) and Vaca Muerta (Type A1). These samples were chosen because they were previously measured for siderophile elements allowing for comparisons among studies [e.g, 4, 5, 6].

The bulk analyses were performed at the Carnegie Institution of Science Earth & Planets Laboratory (EPL). Whole rock chips of these samples were separated into their metal and silicate portions under a binocular microscope. The silicate samples were crushed and then isolated from any remaining metal using magnetic separation, which was performed at each crush and sieve stage (120 μm , 45 μm), as well as after final powdering in an agate mortar and pestle. The purpose of this separation technique was to prepare silicate aliquots that were as metal-free as possible. Aliquots of metal and silicate from each specimen were separately digested using Carius tubes in a mixture of HCl and HNO₃, with Os extraction through CCl₄ and HBr, and column chemistry to isolate Re, Ir, Ru, Pt, Pd. The Os isotopic compositions were measured on a Thermo Triton Thermal Ionization Mass Spectrometer (TIMS) in negative ion mode, and the remaining HSE abundances were measured on an inductively coupled mass spectrometer (ICP-MS), both housed at EPL.

The *in situ* analyses were performed on the following polished mounts of the samples listed above: EET 87500 (54), LEW 87006 (30), RKPA 79015 (63 and 22), QUE 93001 (26) and Vaca Muerta (USNM Unk55). The samples were characterized and measured for major element abundances using the electron microprobe at Carnegie's EPL. The mounts were then measured for trace element abundances using a laser-ablation ICP-MS housed at the Department of Geology, University of Maryland.

Results: Bulk analyses of metal aliquots yield HSE abundances $\sim 10 \times$ CI chondrite with relatively unfractionated patterns. Measurements of silicate aliquots yield significantly lower absolute HSE abundances, between 0.01 and 0.1 \times CI chondrite, with approximately chondritic relative abundances (Fig. 1). *In situ* measurements of trace elements in kamacite and

taenite yield $\sim 10 \times$ CI chondrite abundances, with relative depletions and variability of Cu and Ga in kamacite, and depletions of Co, Ga, and Ge as well as enrichments of Pd and Au in taenite (Fig. 2). Re-Os systematics are given in Fig. 3.

Fig 1. CI-chondrite normalized HSE abundances in metal and silicate aliquots of mesosiderites (CI-normalization data from 9).

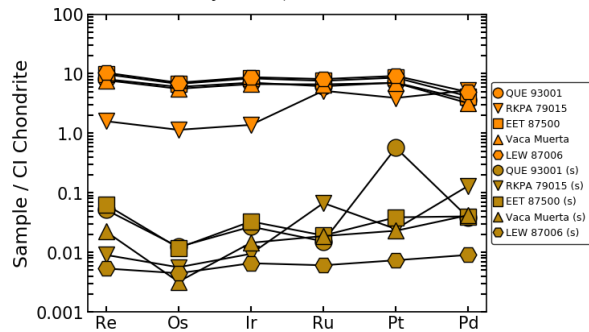
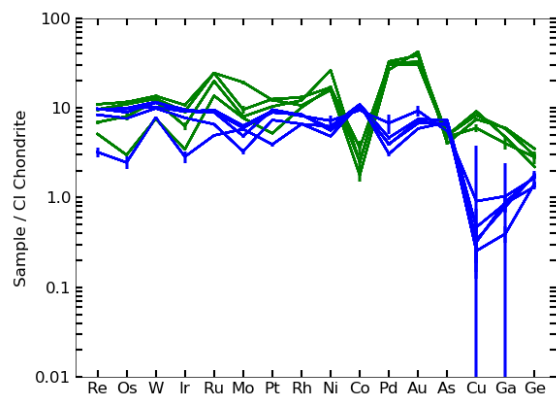


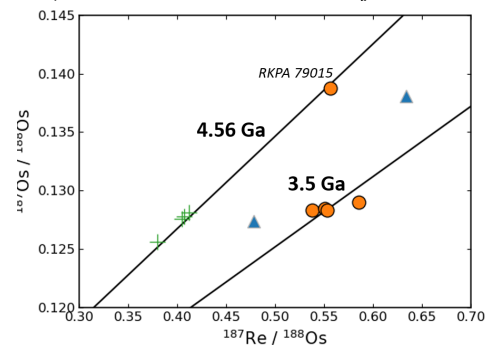
Fig 2. In order of volatility, trace element abundances in mesosiderite kamacite (blue) and taenite grains (green) normalized to CI-chondrite [9, 10]



Discussion: The data reported in this study show limited fractionation of the HSE in metal aliquots, with the exception of “anomalous” mesosiderite, RKPA 79015. These generally chondritic HSE patterns are consistent with earlier work [4,5]. The HSE abundances are similar to those expected from core formation in a body originally having chondritic HSE abundances prior to differentiation. These mesosiderite data have been interpreted to reflect molten metal prior to and at the time of impact, and not the accretion of unique portions of a core that had previously experienced fractional crystallization [4, 7, 8]. The HSE abundances measured in RKPA 79015 in this study may reflect fractional crystallization on a different parent body, as suggested by [4]. The HSE contents of the silicate fractions are elevated, relative to those expected from metal-silicate fractionation. These abundances and their generally chondritic abundances likely reflect minor contamination from incomplete separation of metal

from silicate aliquots during sample preparation. The HSE measurements of silicate fractions are hence difficult to interpret for primary metal-silicate segregation signatures.

Fig 3. Re-Os systematics of metal (orange circles), silicate (blue triangles) aliquots of mesosiderites, and data from [7] of mesosiderite metal fractions (green crosses), with 4.56 Ga and 3.5 Ga reference lines [11].



The compositions of all mesosiderite metal fractions from this study plot along a 3.5 Ga reference line, except for RKPA 79015, which plots along the 4.56 Ga reference line (Fig. 3). Previous measurements of mesosiderites (Crab Orchard, Emery, Estherville, Mt. Padbury) lie slightly above the 4.56 Ga reference line [7] with slightly lower $^{187}\text{Re}/^{188}\text{Os}$ compositions, and were interpreted to reflect uniform disturbance to those samples. With the exception of RKPA 79015, the metal samples analyzed in this study may reflect a separate disturbance in Re-Os systematics, resulting in higher $^{187}\text{Re}/^{188}\text{Os}$ ratios. Silicate fractions, some of which appear in Fig. 3, show varying extents of late disturbance of their Re-Os isotope systematics, possibly as a result of post-crystallization impact. Finally, *in situ* trace element compositions of kamacite and taenite reflect partitioning between these two phases [e.g., 12].

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References: [1] Viikinkoski et al. (2018) *A&A*, 619, L3. [2] Elkins-Tanton et al. (2020) *JGR Planets*, 125, e2019JE006296. [3] Chabot et al. (2017) *Meteoritics & Planet. Sci.*, 52, 1133-1145. [4] Hassanzadeh et al. (1990) *GCA*, 54 3197-3208. [5] Righter et al. (2008) *LPSC XXXIX*, #9719 [6] Chernozhkin et al. (2016) *GCA*, 186, 168 -188. [7] Shen et al. (1998) *GCA*, 62, 2715-2723. [8] Scott et al. (2001) *Meteoritics & Planetary Sci.*, 36, 369-881. [9] Horan et al. (2003) *Chemical Geology*, 196 5-20. [10] McDonough and Sun (1995) *Chemical Geology*, 120, 223-253. [11] Archer et al. (2014) *GCA*, 131, 402-414. [12] Corrigan et al. (2009) *GCA*, 73, 2674-2691.