

THE ORIGIN OF METAL GRAINS FROM ENSTATITE ACHONDRITES BASED ON IRON ISOTOPE COMPOSITIONS. S. Ray¹, M. Wadhwa¹, V. K. Rai¹, ¹Center for Meteorite Studies, School of Earth and Space Exploration, Arizona State University, 781 East Terrace Rd., Tempe, AZ 85287-6004 (Soumya.Ray@asu.edu).

Introduction: Enstatite achondrites or aubrites are highly-reduced, enstatite pyroxenites consisting of enstatite (75-98 vol%), almost FeO-free diopside and forsterite, variable amounts of plagioclase, troilite, metallic Fe-Ni and a variety of accessory minerals [1]. Given the highly reducing formation conditions of the aubrites, elements that are typically lithophile (such as Na, Ca, Ti, Cr, and Mn) behave as chalcophiles and are incorporated into sulfides while Si becomes partly siderophile and occurs in the Fe-Ni metallic phase.

Metal in aubrites occurs in a variety of textural settings, including as: small inclusions (with a maximum size of a few microns) within enstatite; submicron-sized blebs dispersed in the matrix; irregularly shaped grains of upto hundreds of microns; and large (~0.2 to ~1.5 cm) nodules [2]. As discussed by [2], there are several possibilities for the origin of these aubrite metals: 1) they may have formed by in situ reduction of FeO under reducing conditions; 2) they may be extraneous clasts admixed into the aubritic material (possibly by impacts); 3) they may represent fragments of a fractionally crystallized, impact-distrupted core of its parent body; or 4) they may represent globules that were segregated from a silicate-metal-sulfide magma during melting and inefficient core formation on the aubrite parent body.

It was suggested by [2] that the chondritic relative abundances of siderophile elements in the metal nodules in aubrites indicate that this metal could not have fractionally crystallized in a core; rather, it is likely that it is residual in nature, i.e., these metal nodules were trapped in the silicate magma during partial melting of the aubrite precursor material under reducing conditions. This explanation is also consistent with the relatively high abundances of Ni and Si found in these nodules.

We recently determined that the iron isotope composition of 6 metal nodules (ranging in size from ~1mm up to a few mm) from the Norton County aubrite were correlated with their Si contents and structural characteristics [3,4]. Based on these preliminary results, we suggested that the Si-poor metal nodules from Norton County have a different origin than the Si-rich nodules (which appear to have a residual origin and likely formed during igneous processes operating on the aubrite parent body).

As a follow-up to these preliminary investigations, we report here the iron isotope compositions of silicate fractions (dominated by enstatite) from Norton County

and Bishopville as well as metal nodules from several other aubrites, i.e., Bishopville, Cumberland Falls, Khor Temiki, Mayo Belwa, and Shallowater (which is suggested to have originated on a parent body distinct from the other aubrites [5]). In addition, we have also analyzed the Horse Creek iron meteorite, which is suggested to be part of the differentiated core of the aubrite parent body [6].

Methods: All sample preparation and chemical procedures were carried out under clean laboratory conditions in the Isotope Cosmochemistry and Geochronology Laboratory (ICGL) at Arizona State University (ASU). Interior chips from the Norton County and Bishopville aubrites (~375 and 350 mg, respectively) were crushed in an agate mortar and pestle, and ultrasonicated in Milli-Q water. Each silicate fraction was then sieved, clean enstatite grains were hand-picked under the microscope and then digested in a 3:1 HF:HNO₃ mix. Interior chips of the selected aubrites were crushed in a clean agate mortar and pestle and metal nodules (1 each from Bishopville, Cumberland Falls, Khor Temiki and Mayo Belwa, and 2 from Shallowater) were separated using a hand magnet. The aubrite metal nodules (~5 to ~49 mg; ranging in size from ~1 to 6 mm) and a piece of the Horse Creek iron meteorite (HC1, weighing ~78 mg) were cut in half; one half of each sample was mounted in epoxy, polished, and etched briefly in nital. Abundances of selected elements (Si, P, Fe, Co, and Ni) were measured via WDS with a JEOL JXA-8530F Hyperprobe in the LeRoy Eyring Center for Solid State Science at ASU. The other half of each aubrite metal nodule and the Horse Creek iron (HC1) was ultrasonicated in methanol, and then dissolved in concentrated HCl. A second piece of the Horse Creek iron meteorite (HC2, weighing ~23 mg) was ultrasonicated in Milli-Q water and dissolved in concentrated HCl. Iron was purified from each of these samples using anion exchange column chemistry procedures similar to those described by [7]. Iron isotope compositions were measured on a Thermo Neptune multicollector inductively coupled plasma mass spectrometer (MC-ICPMS) in medium-resolution mode. Instrumental mass bias was corrected using both Cu-doping and sample-standard bracketing (using IRMM-014 as the standard). The accuracy and precision of our analyses were assessed using repeated analyses of the terrestrial rock standards BCR-2 and BIR as well as an aliquot of homogenized powder of the Alende CV3 chondrite during each analytical session.

Results: While most of the metal nodules studied here have relatively high Si abundances (typically approaching ~1 wt.%), some were relatively Si-poor (in some cases below the detection limit of our electron microprobe analyses). Figure 1 shows the $^{56}\text{Fe}/^{54}\text{Fe}$ ratios (expressed as $\delta^{56}\text{Fe}$ values, which are deviations in the $^{56}\text{Fe}/^{54}\text{Fe}$ ratio relative to the IRMM-014 standard in parts per mil) in each metal nodule analyzed here from Bishopville (BSP3), Cumberland Falls (CF1), Khor Temiki (KT1), Mayo Belwa (MB1), and Shallowater (SW1 and SW3), silicate fractions from Norton County (NC-Sil) and Bishopville (BSP-Sil), and the two pieces of the Horse Creek iron (HC1 and HC2). Also shown for comparison are our recently reported data for the metal nodules from Norton County (NC1-6) [3], as well as the average value for the metal fraction from enstatite chondrites [8].

As is evident from Fig. 1., the iron isotope compositions of the Si-rich metal nodules from Bishopville, Mayo Belwa, Shallowater and Norton County define a narrow range, with an average $\delta^{56}\text{Fe}$ of 0.13 ± 0.04 (2SD) (horizontal black solid lines in Fig. 1). Also, the iron isotope compositions of the silicate fractions from Norton County (NC-Sil) and Bishopville (BSP-Sil) and the two Horse Creek iron samples (HC1 and HC2) measured here fall within this range of $\delta^{56}\text{Fe}$ values defined by the Si-rich aubrite metals (Fig. 1).

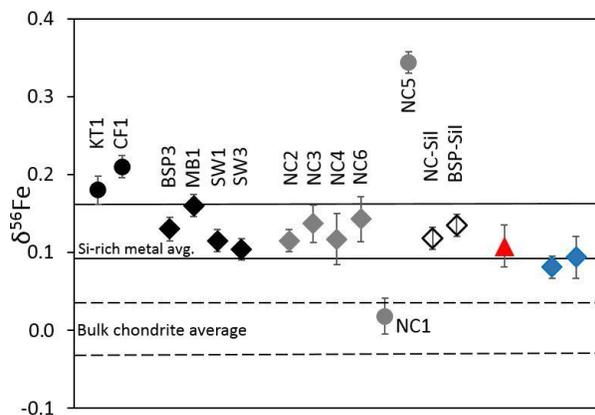


Figure 1: The $\delta^{56}\text{Fe}$ values (‰) for aubrite metal nodules (black symbols: this study; gray symbols: Norton County metal nodules [3]); circles represent Si-poor nodules and diamonds represent Si-rich nodules. The horizontal black solid lines show the average value for all Si-rich metal nodules. The $\delta^{56}\text{Fe}$ values for the silicate fractions from Norton County (NC-Sil) and Bishopville (BSP-Sil) are shown as open black diamonds (this study). The $\delta^{56}\text{Fe}$ values for two pieces of the Horse Creek iron meteorite, HC1 and HC2, are shown as blue diamonds (this study). The average value for the enstatite chondrite metal fraction (from [8]) is shown as a red triangle. The average bulk chondrite value (from [9]) is shown as the horizontal black dashed lines. BSP = Bishopville; CF = Cumberland Falls; KT = Khor Temiki; MB = Mayo Belwa; NC = Norton County; SW = Shallowater.

The Si-poor metal nodules from Khor Temiki and Cumberland Falls have systematically higher $\delta^{56}\text{Fe}$

values compared to Si-rich metal nodules as well as the Horse Creek iron (Fig. 1). As we reported previously [3], the two Si-poor metal nodules from Norton County, NC1 and NC5, also have $\delta^{56}\text{Fe}$ values distinct from those of the Si-rich metal nodules; while NC5 has a significantly higher $\delta^{56}\text{Fe}$ value, NC1 has a lower $\delta^{56}\text{Fe}$ value similar to bulk chondrites (Fig. 1).

Discussion: Planetary differentiation is one of the most significant physical and chemical processes transforming an undifferentiated body (with a near-chondritic bulk composition comprised of rocky and metal components) into a differentiated one. Several previous studies have reported the iron isotope compositions of a variety of meteorites, as well as experimental run products, to evaluate whether metal-silicate segregation (i.e., core formation) in planetesimals and planetary bodies resulted in iron isotope fractionation [10-15]. While some studies have attributed the observed mass dependent fractionation of iron isotopes in several achondritic meteorites and terrestrial basalts relative to bulk chondrites to core formation (e.g., [16]), others have argued against this (e.g., [17]).

The Horse Creek meteorite, an ungrouped iron with Si-bearing metal, has been suggested to represent the core of the aubrite parent body [6]. The similarity of the iron isotope composition of this iron meteorite to 1) those of Si-rich metal nodules from a variety of aubrites, 2) those of the silicate fractions from Norton County and Bishopville, and 3) that of the metal fraction of enstatite chondrites [8] suggests that the Si-rich aubrite metal nodules are residual in nature and that core formation on the aubrite parent body did not resolvable fractionate iron isotopes. The different iron isotope compositions of Si-poor nodules compared to those of the Si-rich nodules is indicative of distinct origins for these two types of aubrite metals. In particular, it seems possible that the Si-poor metal nodules may be exogenous.

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