PLANETARY GENEALOGY OF IRON METEORITES AND PALLASITES USING ε^{54}Cr-Δ^{17}O ISOTOPE SYSTEMATICS.

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Introduction: A large-scale isotopic dichotomy has emerged among Solar System materials in recent years based on correlated isotopic systematics of O, Cr, Ti, Mo, Ru, and W. With improved analytical precision, nucleosynthetic isotopic anomalies observed in meteorites have become a powerful tool for establishing genetic links between different classes of meteorites. One of the weakest links in planetary genealogy in the current literature is the disconnection between stony meteorites (characterized using Δ^{17}O-ε^{54}Cr-ε^{50}Ti isotopes) and iron meteorites (studied using siderophile elements such as Mo, Ru and W). While Mo and W isotopes differentiate iron meteorites into two major groups (CC vs. NC, ostensibly originated from the outer and inner Solar System, respectively) [1], it has been difficult to associate specific iron groups with particular stony meteorite counterparts (chondrites or achondrites), due to the lack of suitable phases to measure O, Cr, or Ti isotopes. We overcome this difficulty by searching for and extracting silicate and oxide phases from the major groups of iron meteorites and pallasites and measuring Cr and Ti isotopes (UC Davis) with complementary O isotopes (UNM) and comparing with the Mo, Ru, and W isotopes measured in the counterpart metallic phases (in collaboration with R. Walker group at UMD).

In this study, we use nucleosynthetic anomalies of ^{54}Cr combined with Δ^{17}O to explore 1) a possible genetic connection between the IAB irons and winonaites and test the impact origin of IAB irons [2,3]; 2) the IIE iron meteorites connection to H chondrites; and 3) to re-examine the Eagle Station pallasite. Eagle Station is a member of anomalous grouplet of pallasites, with an oxygen and Cr isotopic composition close to CK chondrites [4]. However, literature ^{54}Cr data for Eagle Station are inconsistent. One study showed that ε^{54}Cr is similar in olivine and chromite phases within Eagle Station [5], whereas, another study found them to be distinctly different [6]. Here we re-investigate the Cr isotopic composition of the silicate and oxide phases (olivine and chromite) in Eagle Station to elucidate if all the phases are derived from a common geochemical reservoir. The outcome has implications for potential impact origin of Eagle Station pallasite.

Analytical Methods: The silicates from the following meteorites have been investigated in this study – three IAB irons (Campo del Cielo, Caddo County, Maslyanino), two IIE irons (Netschaëvo, Watson 001), one H chondrite (Portales Valley), and the anomalous pallasite Eagle Station.

For Caddo County, diopside mineral separates were dissolved and analyzed, following the same procedure as described below. For all the other meteorites, the silicate inclusions were extracted manually. A subsample of the silicate inclusions from each IAB iron and olivine from the Eagle Station pallasite was sent to UNM for analyzing the triple oxygen isotopic composition using laser-assisted fluorination (modified after [7]) followed by isotope ratio mass spectrometry (Thermo *MAT 253Plus™*). The silicates were leached in 6N HCl for ~3 hours to remove any bound metal. After leaching, the silicate material of each sample was placed in individual Teflon vials and underwent preferential dissolution in a 1:3 mixture of concentrated HNO_3:HF heated at 160ºC for 72 hours. After the silicate dissolution, any residues, if present, were refractory chromites. The chromite residues were separated and transferred to individual Parr bombs and dissolved in concentrated HNO_3 heated at 190ºC for 96 hours.

After all the silicates and oxides were dissolved, Cr was separated from the matrix using a 3-column chemistry procedure described by [8]. The Cr isotopic composition was measured at UC Davis using a Thermo *Triton Plus* thermal ionization mass spectrometer. For each sample, Cr was loaded on four outgassed W filaments, with either 3 µg or 1 µg of Cr per filament, depending on the total Cr yield for each sample. Each sample measurement was bracketed with an equal amount of NIST SRM 979 Cr standard. All the reported ^{54}Cr/^{52}Cr ratios are expressed in ε-notation (parts per 10,000 deviations from the measured standard). To correct for spallation contribution of ^{54}Cr, Fe/Cr ratio was measured on an aliquot of the dissolved silicates and chromites of each sample using a Thermo *Element XR* HR-ICP-MS at UC Davis.

Results and Discussion:

IAB – Winonaite connection and impact origin of IAB irons: The silicate inclusions of the three IAB irons studied here represent three different lithologies out of five as described by [3]: Campo del Cielo – angular, chondritic silicate inclusions; Caddo County – basaltic, non-chondritic inclusions; Maslyanino – best corresponds to sulfide-rich inclusions based on the petrological description by [3,9]. Chromite from Maslyanino, exsolved from metal, plot within the bulk

winonaite field and overlap with chromite extracted from Northwest Africa (NWA) 725 (winonaite) we reported earlier [10]. All the IAB silicates plot together, and are distinct and well-resolved from the winonaites in $\varepsilon^{54}Cr$-$\Delta^{17}O$ space (Fig. 1). We have verified that no correction scheme (e.g. spallation) would move silicate and chromite together in the $\varepsilon^{54}Cr$-$\Delta^{17}O$ space. An inescapable conclusion arising from this observation is that the IAB metal and silicates represent impact mixing of two distinct reservoirs, where the iron metal originated from a winonaite-like reservoir, but the silicates in IAB represent a new, previously unknown chemical reservoir (Fig. 1).
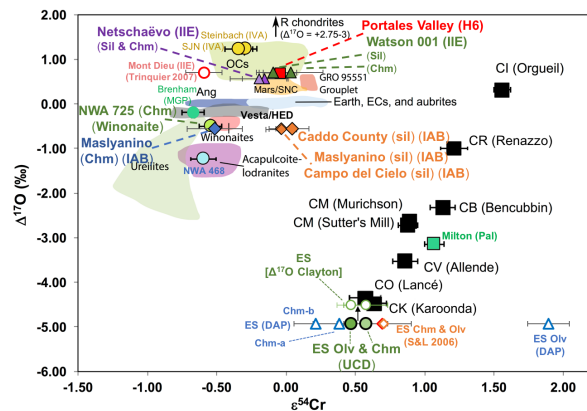
Fig. 1. $\varepsilon^{54}Cr$-$\Delta^{17}O$ diagram for irons and pallasites. (a) A genetic link of IABs with winonaites and an impact origin of IAB irons are evident; (b) It further shows a close IIE–H-chondrite association; (c) New UC Davis data for Eagle Station (ES) is plotted along with literature data (S&L 2006 [5], DAP [6]), with the upward shift using the $\Delta^{17}O$ value from [11] shown for reference. Figure adapted from [12].

Genetic link between the IIE irons and H chondrites: The Cr isotopic composition was investigated in silicates from the metal-rich H-chondrite Portales Valley, and both silicate inclusions and chromites extracted from two IIE irons, Netschaëvo and Watson 001. All samples showed unresolved $\varepsilon^{54}Cr$ within error. The corresponding $\Delta^{17}O$ values are referred from [13]. All the samples studied plot close to the H chondrite region in the OC field in $\varepsilon^{54}Cr$-$\Delta^{17}O$ space. Our $\varepsilon^{54}Cr$-$\Delta^{17}O$ results suggest a strong genetic link between the H chondrite reservoir and IIE irons (for both silicate and chromites). In other words, IIE irons represent differentiated metallic fraction from an H chondrite parent body.

Our results are inconsistent with the single measurement of chromites from the IIE Mont Dieu as reported by [14], showing a significant deficit in $\varepsilon^{54}Cr$ (Fig. 1). The reason for this discrepancy is unclear at this point. Mont Dieu is a primitive chondritic IIE like Netschaëvo [13], and also contains relict chondrules within silicate inclusions [15]. It is possible that H chondrites show a moderate variability in $\varepsilon^{54}Cr$ outside analytical error. Future work will focus on investigating Cr isotopic composition of IIEs with differentiated and evolved silicate inclusions, to verify if they originated from the same parent body as the IIEs with primitive chondritic inclusions.

Revisiting the Eagle Station pallasite: The oxygen isotopic composition was measured at UNM in a subsample of the same olivine that was analyzed for Cr isotopes at UC Davis. The measured values of $\Delta^{17}O'$ are = -4.930 and -4.934 (linearized, using TFL slope = 0.528). This is lower than the previously reported [11] value $\Delta^{17}O' = -4.508$ (re-calculated using TFL slope = 0.528 and linearized for consistency), and closer to the average $\Delta^{17}O = -5.22 \pm 0.05$ of the Eagle Station grouplet (including Itzawisis pallasite) [16]. The measured $\varepsilon^{54}Cr$ values have been corrected for minor spallogenic contribution (resulting in a -0.08ε correction for olivine and a negligible correction for chromite) using the measured Fe/Cr ratio of 170.17 (olivine) and 0.26 (chromite), and a reported CRE age of 43 ± 5 Myr [17]. Our measured $\varepsilon^{54}Cr$ values for both olivine and chromite in Eagle Station are identical within error, and also agree with "chromite-a" and "chromite-b" of [6] and chromite and olivine data of [5] (Fig. 1). The very high $\varepsilon^{54}Cr$ for "olivine" reported by [6] was not reproduced in this study. It might have been due to metal contamination. The Cr isotopic data suggests that both the silicate and oxide phases in Eagle Station sampled a common Cr reservoir, and rules out an impact origin with distinct Cr isotopic composition.

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