

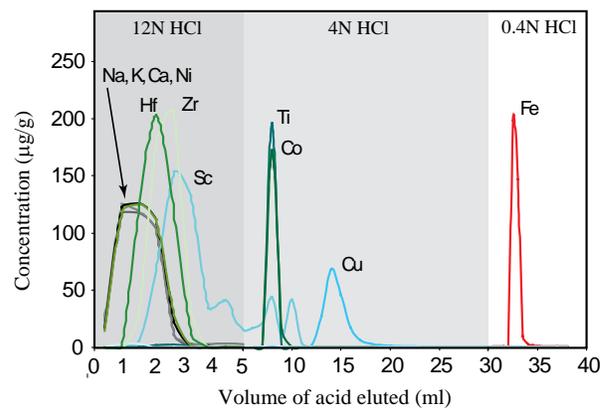
**HIGH PRECISION IRON ISOTOPIC ANALYZES OF METEORITES AND TERRESTRIAL ROCKS:  $^{60}\text{Fe}$  DISTRIBUTION AND MASS FRACTIONATION LAWS.** H. Tang<sup>1</sup>, N. Dauphas<sup>1,2</sup>, and P.R. Craddock<sup>1</sup>,  
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**Introduction:** High precision iron isotopic analyzes have proven useful for investigating the distribution of  $^{60}\text{Fe}$  in the protoplanetary disk ( $^{60}\text{Fe}$  is a short-lived isotope that decays into  $^{60}\text{Ni}$  with  $t_{1/2}=1.49$  My) [1]. This stems from the fact that  $^{58}\text{Fe}$ , the most neutron-rich stable isotope of iron is produced together with  $^{60}\text{Fe}$  in AGB-stars and supernovae by neutron capture reactions. The lighter isotopes,  $^{54}\text{Fe}$ ,  $^{56}\text{Fe}$ , and  $^{57}\text{Fe}$  are produced by other processes. For instance, in core-collapse supernovae, they are synthesized in more internal regions by nuclear statistical equilibrium. Heterogeneous distribution or late injection of  $^{60}\text{Fe}$  would therefore be accompanied by isotopic anomalies at  $^{58}\text{Fe}$  in bulk chondrites. Because of its very low abundance in nature (0.282 %), very few measurements of  $^{58}\text{Fe}$  have been published thus far [1-4]. Völkening and Papanastassiou [2] demonstrated that large  $^{58}\text{Fe}$  excesses, up to +290  $\epsilon$ , were present in FUN inclusions. More recently, Dauphas et al. [1] reported high precision measurements of  $^{58}\text{Fe}$  ( $\pm 0.3$   $\epsilon$ ) in several groups of meteorites and found isotopic compositions identical to terrestrial. Here, we extend the database of high precision  $^{58}\text{Fe}$  measurements to more meteorites and terrestrial samples.

High precision measurements can also be useful to investigate the slope of mass fractionation laws, which could convey clues on the mechanism responsible for such fractionation. Young et al. [5] showed that resolvable differences in slopes could be measured for Mg isotopes. We have also tested whether such differences could be measured for Fe by analyzing samples showing significant degrees of mass-dependent fractionations but formed in very different conditions (e.g., a granite and a banded-iron formation).

**Separation of Fe for isotopic analysis:** The method that is routinely used at the University of Chicago has been described in a recent publication [6]. It however does not separate Fe from Cu and we have developed a more selective method that efficiently purifies Fe. It relies on a 10.5 cm long Teflon column ( $\varnothing=0.62$  cm) filled with 3 mL of AG1-X8 resin. Iron is fixed on the column in  $>8$  M HCl. The elutant containing Ni is saved for future isotopic analysis. Approximately 8 resin volumes (25 mL) of 4 M HCl is then passed through the column to eliminate Cu. Iron is finally eluted with 8 mL of 0.4 M HCl. The column separation procedure is repeated 3 times. Elution

curves are shown in Fig. 1. Several geostandards as well as pure IRMM-014 were passed through this sequence of anion exchange chromatography and the measured iron isotopic compositions are indistinguishable from those reported in the literature [7]. This shows that no isotopic fractionation is introduced on the column and it also confirms that previous measurements carried out with a more rapid chemistry are accurate. Isotopic analyses were performed on a Neptune MC-ICPMS in high resolution mode to separate argide interferences from Fe isotopes. On some samples, the level of  $^{58}\text{Ni}$  interference on  $^{58}\text{Fe}$  was significant (up to 170  $\epsilon$ ) but this can be very accurately corrected for by analyzing standards doped with Ni to correct for the fact that  $\beta_{\text{Ni}} \neq \beta_{\text{Fe}}$ . The measurements were replicated 20 times by standard bracketing and the uncertainties correspond to the 95 % confidence interval of the average.



*Fig. 1. Elution curves for separation of matrix and Fe (AG1-X8, 200-400 mesh, chloride form resin). Iron is separated from matrix elements by eluting in 12N and 4N HCl progressively. Iron is eluted from the resin in 0.4N HCl.*

**Results:** The precisions obtained represent a factor of 10 improvement relative to [2,3] but are comparable to values obtained previously in our lab [1]. Error bars of  $\pm 0.5$  on  $\epsilon^{58}\text{Fe}$  allow us to probe the distribution of  $^{60}\text{Fe}$  in the protoplanetary disk down to  $\pm 10$  % dispersion in the  $^{60}\text{Fe}/^{56}\text{Fe}$  ratio at any given time. In the following, the  $\delta'$  notation is used to refer to the degree of mass fractionation relative to IRMM-014 [8] and  $\epsilon$  is used to denote isotopic compositions after internal normalization to a fixed  $^{57}\text{Fe}/^{54}\text{Fe}$  ratio [e.g., 1].

As shown in Fig. 2, all terrestrial samples (IRMM-014 passed through the column, geostandards BHVO-1, AC-E, and IF-G, and G05-32 a 3.7 Ga mafic rock from Isua) have normal (terrestrial) compositions for both  $^{56}\text{Fe}$  and  $^{58}\text{Fe}$  within uncertainties. Two Allende samples were also analyzed. One was digested using a Parr bomb and the other was decomposed by flux fusion using lithium metaborate followed by acid dissolution. Both have  $\epsilon^{58}\text{Fe}$  equal to zero within uncertainties ( $0.112 \pm 0.934$  and  $0.062 \pm 0.302$  for flux and bomb digestions, respectively). Both bomb and flux digestions of Allende show departure from terrestrial composition for  $\epsilon^{56}\text{Fe}$  ( $-0.097 \pm 0.058$  and  $-0.110 \pm 0.050$ , respectively). While it is too early to rule out analytical artifacts as the cause for this departure, the fact that the two samples digested using different methods give consistent values suggests that the departure is not the result of random fluctuations. Further work is currently under progress to ascertain whether these effects are real.

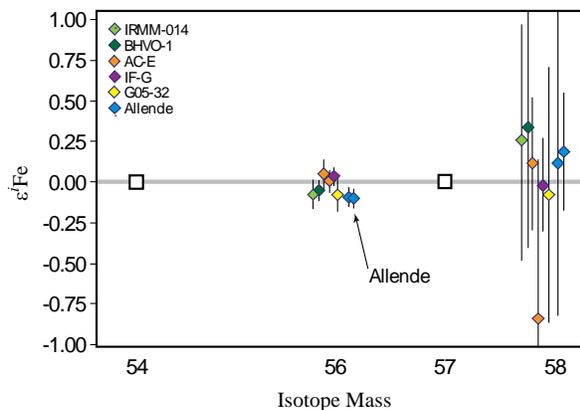


Fig. 2. Iron isotope compositions in bulk meteorites (Allende) and in terrestrial rocks. Data ( $^{58}\text{Fe}/^{56}\text{Fe}$ ) are normalized to  $^{58}\text{Fe}/^{56}\text{Fe} = 0.36255$  to correct for mass fractionation. Bulk terrestrial samples and meteorites do not show any  $^{58}\text{Fe}$  anomalies.

**Discussion and conclusion:** The results presented here (Fig. 2) confirm the conclusion of [1] that no  $^{58}\text{Fe}$  anomalies are present in meteorites, which limits the maximum dispersion in the  $^{60}\text{Fe}/^{56}\text{Fe}$  ratio to less than  $\pm 10\%$  around the average. By the time of the conference, we plan to analyze more meteorite groups in which Ni will also be studied to search for the possible presence of nucleosynthetic anomalies [e.g., 1,9].

We have also measured different terrestrial rocks that show significant isotopic fractionation to test whether one could trace different processes based on the slopes of the mass fractionation laws [5]. Taking all samples together, the slope of the  $\delta^{57}\text{Fe}$ - $\delta^{56}\text{Fe}$  correlation is  $1.4957 \pm 0.0192$  (Fig. 3). This is slightly

higher than the slope of  $1.4663 \pm 0.0150$  derived by [8] for sedimentary samples. We cannot resolve any difference in slope between AC-E, a granite geostandard with  $\delta^{56}\text{Fe} = +0.330 \pm 0.033$  and IF-G, a 3.7 Ga BIF from Isua with  $\delta^{56}\text{Fe} = +0.629 \pm 0.033$ . These preliminary results suggest that very different processes such as magmatic differentiation and ferrous iron oxidation in aqueous systems may be controlled by similar mass fractionation laws.

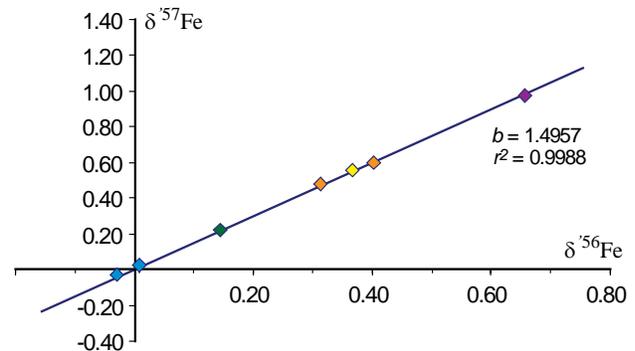


Fig. 3. Three-isotope plot of  $\delta$ -values [8] measured in terrestrial and meteoritic samples. Data are corrected for mass fractionation using standard-sample bracketing with geostandard IRMM-014. Terrestrial samples plot on a  $^{57}\text{Fe}$  vs.  $^{56}\text{Fe}$  mass fractionation line with slope of  $1.4957 \pm 0.0192$ . Within analytical uncertainties, samples appear follow the same mass fractionation law, despite formation under a wide range of geochemical processes and conditions.

**References:** [1] Dauphas N. et al. (2008) *ApJ* 686, 560-569. [2] Völkening J. & Papanastassiou D.A. (1989) *ApJ* 347, L43-L46. [3] Kehm K. et al. (2003) *Geochim. Cosmochim. Acta* 67, 2879-2891. [4] Dauphas N. et al. (2004) *Anal. Chem.* 76, 5855-5863. [5] Young E.D. et al. (2002) *Geochim. Cosmochim. Acta* 66, 1095-1104. [6] Dauphas N. et al. (2009) *Chem. Geol.*, in press. [7] Dauphas N. & Rouxel O. (2006) *Mass Spectrom. Rev.* 25, 515-550. Erratum 25, 831-832. [8] Malinovsky D. et al. (2003) *J. Anal. At. Spectrom.* 18, 687-695. [9] Regelous M. et al. (2008) *Earth Planet. Sci. Lett.* 272, 330-338.