THE IRON ISOTOPIC COMPOSITION OF THE SILICATE EARTH: CLUES FROM CHONDRITES, PERIDOTITES, AND EOARCHEAN MAGMAS.

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Introduction: Knowing the iron isotopic composition of the silicate Earth is critical to possibly identifying Earth's building blocks and establishing the conditions that prevailed during core-mantle differentiation. As an example of how isotopic studies can illuminate some of these problems, Georg et al. [1] took small differences between δ^{30}Si of chondrites and basalts from the Earth and the Moon as evidence that Si was one of the light elements in the Earth's core.

Using High-Resolution Multi-Collector Inductively Coupled Plasma Mass Spectrometers (HR-MC-ICPMS), the isotopic composition of Fe can now be measured accurately with precisions of better than 0.03 ‰ for δ^{56}Fe [2]. While it was initially thought that all igneous rocks had constant Fe isotopic compositions, improvements in precision in subsequent studies have shown that processes like mantle melting and metasomatism [3,4], magmatic differentiation [5,6], or fluid exsolution [7,8] could modify the Fe isotope composition of igneous rocks. Mid-ocean ridge and ocean island basalts (MORBs and OIBs) show a narrow range of δ^{56}Fe values, centered around +0.1 ‰. Weyer and Ionov [4] found a correlation between δ^{56}Fe and Mg#=Mg/(Mg+Fe$_{tot}$)$_{at}$ in mantle peridotites, from which they estimated δ^{56}Fe=0.02±0.03‰ for the fertile upper-mantle (Mg#=0.894). The geological record of mantle magmatism can be tracked back to >3.85 Ga in SW Greenland, a time in Earth's history when the geothermal gradient was steeper and the tectonic setting and conditions of mantle melting could have been different from the modern ones. Whether Eoarchean magmas had δ^{56}Fe similar to phanerozoic MORBs-OIBs is presently unknown. Dauphas et al. [9] suggested that Eoarchean magmas could have had δ^{56}Fe closer to chondritic but the precisions of the measurements were insufficient to reach a definitive conclusion.

Samples: In an effort to better characterize the Fe isotopic composition of the silicate Earth and understand how the composition of mantle magmas relates to their sources, we have analyzed the isotopic compositions of chondrites and of Eoarchean mantle peridotites, basalts, gabbros, and boninites. The chondrites that were studied are Murchison (CM2), Allende (CV3), Paragould (LL5), Saint-Séverin (LL6), Farmington (L5), Bielokrynitschie (H4), Ochansk (H4), Kernouvé (H6), Hvittis (EL6 breccia), Indarch (EH4), Saint-Sauveur (EH5), Blithfield (EL6 breccia). All meteorites were digested by prolonged acid dissolution in Parr bombs. Together with previous studies [9,10], 27 chondrites have now been measured at high precision.

Over 40 Eoarchean igneous rocks from SW Greenland were also analyzed. Several have already been studied and complete chemical characterizations are available in the literature. The most notable samples are basalts with island-arc affinities [12, 13], boninites (unpublished), and mantle peridotites [14]. Careful sample selection (e.g, avoiding specimens with veining) ensured that metasomatic alteration was minimal. Geochemical evidence points to a subduction/island arc setting for Eoarchean magmatism in SW Greenland [12, 13,15,16].

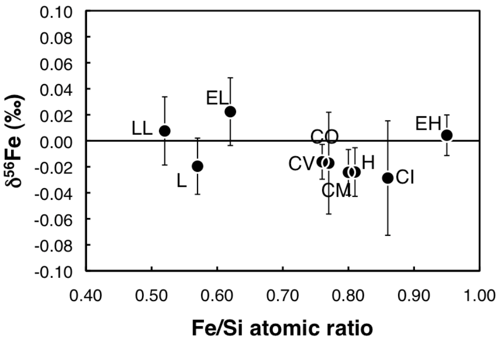

Fig. 1. Averages of δ^{56}Fe values (this study [10,11]) and Fe/Si ratios [18] of chondrites.

Results: Most chondrites have homogeneous δ^{56}Fe (Fig. 1, 2). The only exception in our data set is Blithfield (not shown), which has δ^{56}Fe=-0.140±0.030 ‰. Blithfield is a EL6 breccia showing extensive redistribution of Fe between sulfide, metal, and silicate [17], which is likely the cause for the low δ^{56}Fe value measured. Hvittis, another EL6 breccia, has normal δ^{56}Fe (+0.032±0.045 ‰). Iron abundance and oxidation state play important roles in the classification of chondrites but iron isotopes show no resolvable variation from one meteorite group to another (Fig. 1). The average of all chondrite measurements, excluding Blithfield, is -0.014±0.010 ‰ relative to IRMM-014.

Eoarchean mantle peridotites with Mg#>0.89 have iron isotopic compositions that range from +0.019 to +0.128. For many samples that we have analyzed, chemical compositions are not available and we have plotted all mantle peridotites. While this introduces more scatter, the distribution of δ^{56}Fe values peaks at around +0.02 ‰, close to modern peridotites and chondrites.

Eoarchean basalts, gabbros, and boninites show distributions of δ^{56}Fe values that overlap with modern MORBs and OIBs but are overall significantly lower. A noteworthy feature is that the 3 boninites analyzed so far have δ^{56}Fe values that are indistinguishable from chondrites and mantle peridotites (average δ^{56}Fe=0.014). Teng et al. [5] reported low δ^{56}Fe in Kilauea Iki picrites but these were the products of olivine crystal accumulation in the lava lake. This is the first time that near-chondritic δ^{56}Fe values are reported in non-cumulate mantle magmas. It supports the conclusion of [4] that the iron isotopic composition of the bulk silicate Earth is δ^{56}Fe=+0.02±0.03 ‰.

Discussion and conclusion: Chondrites have almost constant δ^{56}Fe values, close to IRMM-014 while pristine mantle magmas of basaltic compositions have variable iron isotopic compositions. IRMM-014 should therefore be used as the reference for δ^{56}Fe notation. Eoarchean mantle peridotites have iron isotopic compositions very similar to more recent fertile peridotites. This indicates that the iron isotopic composition of the mantle did not change over the past 3.8 Ga. This is consistent with the expectation that continental crust extraction should have had a negligible impact on the Fe isotopic composition of the depeleted mantle. All chondrite groups have identical δ^{56}Fe values within uncertainties and it is not possible to distinguish between different building blocks of the Earth based on iron isotopes. The fact that the bulk silicate Earth has chondritic δ^{56}Fe indicates that iron isotopic fractionation associated with core-mantle differentiation must have been small. If the fractionation factor between metal and silicate melts was known for Fe, a lower-limit on the temperature of equilibration could conceivably be derived. A major challenge at the present time is explaining why Eoarchean magmas have near chondritic iron isotopic compositions. Two parameters could potentially influence isotopic fractionation during magma genesis in the mantle: temperature and water content. Iron isotopes may thus provide useful constraints on the conditions of magma genesis on Earth and other planets through time.

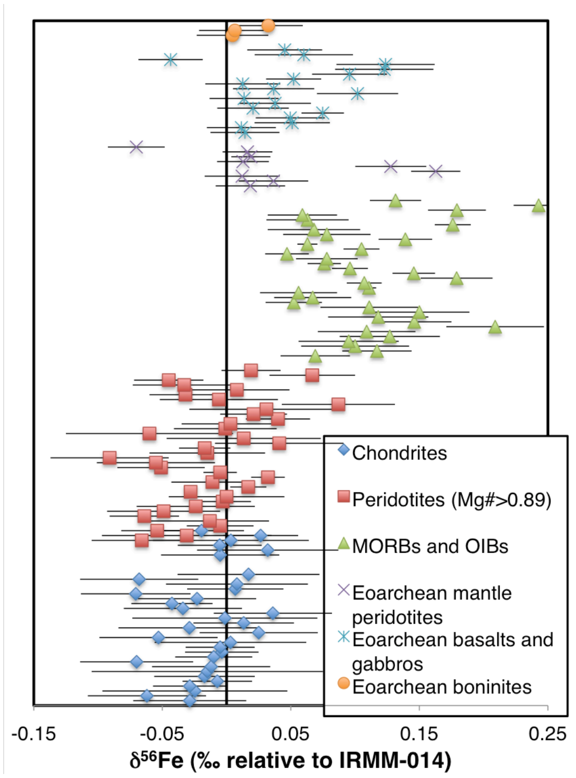

Fig. 2. Iron isotopic compositions of chondrites (this study, [9, 10]), modern peridotites [3-5,11], MORBs and OIBs [4,5,10,11,19], Eoarchean mantle peridotites, basalts, gabbros, and boninites (this study).

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