Abundances of Lithophile Trace Elements in Iron Meteorites

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Introduction: Magmatic iron meteorites are interpreted as fragments of asteroidal cores and their siderophile element composition records fractional crystallization of metal and progressive solidification of these cores [1, 2]. Non-magmatic iron might represent solidified metallic melts formed during impact events [3]. In irons, inclusion phases predominantly comprised of troilite and schreibersite reflect late eutectic crystallization and possibly exsolution and oxidation processes during cooling. Elemental abundances reflect metal silicate fractionation, solid metal - liquid metal fractionation and small scale metal-sulfide-phosphide partitioning superimposed on volatility controlled primary element inventories [4].

The abundances of nominally lithophile elements in iron meteorites such as alkaline metals and alkaline earth metals are little constrained. There is some data on K abundances from early attempts to date irons by K-Ar [5]. A few studies indicate that alkaline metals, and Ba occur as major constituents in rare minerals associated with troilite [6]. Another study reports Mg, Ca and Na as being significant in phosphate minerals [7].

Partitioning studies have focused on K and Na indicating generally very low solubilities in metal, but somewhat higher values in sulfides e.g. [8, 9, 10]. These data indicate an increasingly siderophile character of these and other lithophile elements with increasing temperature and pressure. Experimental work at high p and T indicates Al and Mg contents in the range of tens of ppm in metal coexisting with silicate melt [11].

Analytical Methods: The feasibility of multi-element analysis by ICP-MS as an effective method for iron meteorites could be demonstrated on siderophile and chalcophile element contents [12]. In natural samples a content of alkaline and earth alkaline elements in the sulfide phase as well as in the metal phase of a non magmatic iron meteorite in the range of tens of ppm was determined by ICP-MS analysis [13].

We have developed a technique for ICP-MS analysis of a spectrum of major and trace elements in metal, sulphide and phosphide from iron meteorites.

Several 5 mg to 200 mg size aliquots of samples from iron meteorites were cut from internal parts of lager chunks of iron meteorites using a brass bond diamond blade saw. Samples were cleaned with diluted HCl, nanopure water and ethanol in an ultrasonic bath. Cleaned samples were digested in aqua regia, converted into nitrate form in nitric acid and diluted 1:10000. A multi element mass spectrometric technique using the sector field ICP-MS Element XR applying a combination of external and internal standardization and matrix matched standard solutions was employed. Each sample solution has been analyzed repeatedly 3 to 5 times. Precisions for Fe and Ni are at the % level (1rsd). For most minor elements and trace elements down to the 10 ppm precisions are at the 10 % level. Precision for trace elements vary, depending on abundance and the type of element. Blank contributions are small, reflecting the fact that only small aliquots of the digestion were used for ICP-MS analysis. Prior to digestion, the mineralogy was determined by XRD and Rietveld refinement. Troilite and pyrrhotine are the main sulfide species, schreibersite is the common phosphide mineral.

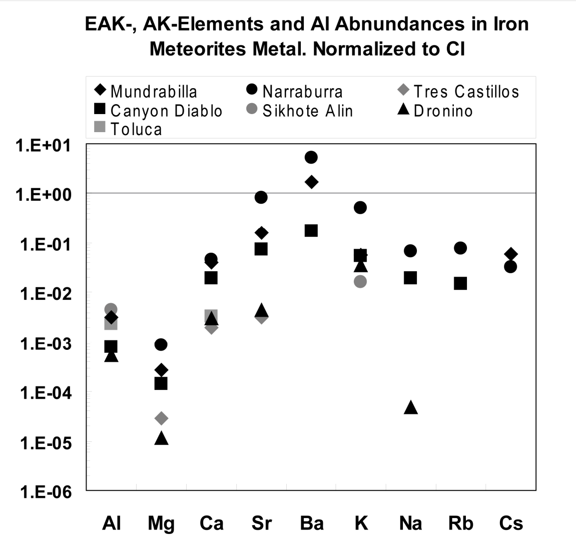

Figure 1. CI normed earth alkaline, alkaline element and Al concentrations for some magmatic and non magmatic iron meteorites (Arrangement according to 50 % condensation temperature, except Mg [14]).

Results: Metal and sulphidic or phosphidic inclusions from magmatic and non-magmatic iron meteorites were studied. We focus on lithophile and siderophile elements in the metallic phase, particularly of magmatic irons. Figure 1 shows CI normalized abundances of Al, alkaline and alkaline earth elements analyzed in the metallic phase.

Our data shows general features that can be explained by the effects of metal-silicate segregation, such as the low abundances of the lithophile elements. A conspicuous feature is the systematic increase in normalized abundance of the earth alkaline elements with increasing atomic number in all metals. CI normed contents for Mg are about 10^{-4}, with a spread of roughly two orders of magnitude. Values for Ca are about 10^{-2}, Sr reaches from 10^{-2} up to 1. For Ba, two samples exhibit a siderophile behaviour of Ba with normalized abundances >1. This trend is confirmed by the abundance of these elements in troilite and schreibersite inclusions of the same meteorites. With an abundance of as far as $^{1}/_{100}$ relative to CI for most samples, alkaline elements display similar partitioning into the metal phase, relative abundances exceed those of Mg, Ca and Al, but are lower than Ba. A trend is not discernable as it is not for the alkaline element content in metal compared to the inclusion phase.

Al abundances in metal are systematically higher than Mg abundances, giving a suprachondritic Al/Mg ratio. The particular Al/Mg ratio in metal and troilite, schreibersite differs by one order of magnitude.

Figure 2 compares the enrichment of some lithophile and siderophile elements in inclusions relative to FeNi metal from the same iron meteorite. While for some elements variations are limited to one order of magnitude (e.g., Al, Mo, Mg, Cu) others (Cr, Mn) display larger variation. Besides the clear chalcophile behaviour of Cr and Mn, even Al of some meteorites is slightly enriched in the inclusion. Mo and Ni are preferentially incorporated into the phosphide rich inclusion, whereas they display no distinct chalcophile character. Cu displays chalcophile behaviour, but does not partition into the phosphide. Unrelated to meteoritic grouping earth alkaline element distribution appears twofold, ratios are lying slightly above one and clearly beyond.

Discussion: The trends found for our data, such as the systematic increase of CI normalized abundances from Mg to Ba in metals, provide arguments in favor of a partitioning control rather than an arbitrary incorporation of silicates. Because of their refractory behaviour, it appears most likely that abundances of Al and the alkaline earth metals in iron meteorites were controlled by processes and conditions during metal-silicate segregation.

Concentrations of Mg in metal and in the inclusion phase of up to ten and even tens of ppm, and systematically higher abundance of Al may enable chronometric application of the short lived ^{26}Al decay system, regarding the discussed possibility of asteroidal core differentiation early in solar system history and isochronous to chondrite formation e.g. [15, 16, 17]. Differences in Al/Mg ratio between inclusion and FeNi alloy would permit isochrone construction.

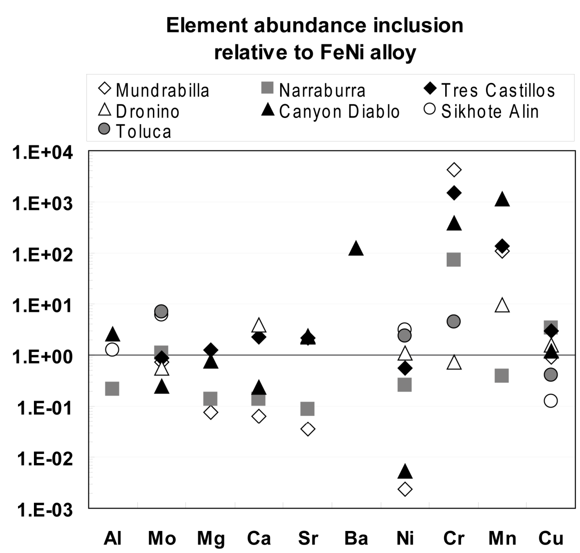

Figure 2. Enrichment of elements in the inclusion relative to the metal phase for seven magmatic and non-magmatic meteorites. The inclusions consist of sulphides, except for two samples which are dominated by phosphide minerals (plotted with open and filled circles).

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