FRACTIONATION OF REFRACTORY LITHOPHILE ELEMENTS IN BULK CHONDRITES AND CHONDRITE COMPONENTS. A. Pack, Georg-August-Universität, Geowissenschaftliches Zentrum, Abteilung Isotopengeologie, Goldschmidtstraße 1, D–37077 Göttingen, Germany (apack@uni-goettingen.de).

Introduction: The group of refractory lithophile elements (RLE) is defined by their high condensation temperatures under solar nebular conditions [1, 2]. The group includes elements such as Ca, Al, Sc, Ti, Y and rare earth elements (REE). These are enriched in refractory Ca- and Al-rich inclusions (CAI). REE abundances in chondrites were used to trace igneous and nebular processes on scale of bulk rock samples [3, 4].

Here, it is reported on combined results of REE+Y analyses of chondrite components and bulk chondrites [5]. A novel technique for high-precision bulk rock trace element analyses is presented.

Analytical procedure: 0.1 – 1.5 g chips of chondrites were ground to powder in an agate mortar. Samples of metal-rich chondrites were placed in a muffle furnace in order to oxidize the metal, which prevents preparation of a fine powder. 10 – 20 mg powder were placed in a small graphite crucible and briefly melted to a sphere by means of a 50 W CO_2 laser. The sphere was then placed on top of a levitating gas stream for CO_2 laser-assisted melting and chemical homogenization [5, 6]. Sample spheres were quenched by switching off the laser, embedded into resin and polished for EPMA (major elements) and LA-ICPMS. The latter analyses were conducted at the ANU Research School of Earth Sciences in Canberra. Bulk rock samples were analyzed for ~2 min in scanning mode with a 120 µm beam. Spot analyses of chondrules and CAI were performed with smaller spot diameters of ~50 µm [for more details, see 5].

Y/Ho: Y/Ho-data for bulk rock samples are shown in Fig. 1 [from 5]. The error of a single analysis is typically ±0.2% (Y/Ho-ratio, 1σ).

Carbonaceous chondrites (CC; $N = 5$) have a common Y/Ho-ratio of 25.94±0.04 ($N = 15$, 1σ). A slightly higher Y/Ho-ratio of 26.06±0.03 ($N = 4$, 1σ) is observed in LL-chondrites. L- and H-chondrites have, within error, an identical Y/Ho-ratio of 26.28±0.03 ($N = 12$, 1σ). The highest Y/Ho-ratio (27.25±0.07, $N = 4$, 1σ) is observed in two EL6 enstatite chondrites (EC). The variations in bulk chondrite Y/Ho-ratios span a range of ~6%.

Chondrules from CC and ordinary chondrites (OC) have a common Y/Ho-ratio of 26.2±0.2 ($N = 72$, 1σ). CAI from CV3 chondrites Allende and Vigarano show variable Y/Ho-ratios between 3.3 and 25.9. Fractionated Y/Ho-ratios are accompanied by volatility-controlled REE-fractionation. CAI with group-II REE patterns [7] have systematically low Y/Ho-ratios.

The Y/Ho-ratio of a terrestrial depleted mantle lherzolite is 25.65±0.07 ($N = 10$, 1σ). A slightly higher ratio of 26.30±0.04 ($N = 7$, 1σ) has been measured in USGS BCR-2G basaltic reference material.

REE: Bulk chondrite REE abundances were normalized to the respective intensities that were measured on the Orgueil (CI1, 432 mg aliquot, 4 spheres) samples. The relative REE abundances for Orgueil are, within error, identical to the data published by [1].

Most bulk CC, OC and EC show variable REE abundances and inter-REE fractionation relative to Orgueil (CI1).

CV3 chondrites Mokoia and one aliquot of Allende show distinct group-II REE patterns. Most OC and EC show heavy > light REE fractionation, often with indication of negative Tm and/or Yb anomalies. Such patterns are known from ultra refractory CAI [8].

Unusual patterns with distinct positive Ce- anomaly are observed in Karoonda (CK4) and Lake Labyrinth (LL6). Such patterns are not known from CAI.

OC and CC chondrules have either unfractionated REE patterns or show little REE fractionation that can be related to differences in REE volatility [7]. CAI from CV3 chondrites show variable REE fractionation from unfractionated to distinct group-II patterns [7].

Discussion: Within error, chondrules from different chondrites have identical Y/Ho-ratios. The ratio overlaps with the mean Y/Ho-ratio obtained for CC, including Orgueil (CI1, Fig. 1). From these data, a solar system Y/Ho-ratio of 25.94±0.04 (1σ) is suggested.

The Y/Ho-ratio of bulk chondrites increases from CC through OC to EC (Fig. 1). The sampled meteorites have not suffered any type of igneous process that could have led to Y/Ho-fractionation. Terrestrial alteration is excluded as cause for Y/Ho-variations since most of the analyzed meteorites, namely the two EL6 chondrites are observed falls.

Data from CAI give information about volatility-controlled Y/Ho-fractionation [see Fig. 6 in 5]. CAI with group-II REE patterns have low Y/Ho-ratios, whereas those with ultra refractory REE patterns have high Y/Ho-ratios [data from 9]. This indicates that Y is, indeed, more refractory than Ho [this was suggested by 10].

It is concluded that elevated Y/Ho-ratios in bulk OC and EC are related to differences in volatility, i.e. these chondrites have a deficit in material with sub-solar Y/Ho-ratio. CAI with group-II REE patterns have been identified to have sub-solar Y/Ho [5]. Enrichment of EC in a component with super-solar Y/Ho-ratios, such as ultra refractory CAI [5, 9] does not seem plausible since EC are notably depleted in refractory elements, such as Ca and Al [2].

The conclusion that EC have a deficit in a component with group-II REE pattern is supported by observed ultra refractory bulk rock REE patterns (Fig. 2). Such patterns are related to fractional condensation and a missing "group-II component" [8]. Slight variations in Y/Ho within CC may also be related to volatility. Mokoia (CV3) has slightly sub-solar Y/Ho-ratio (Fig. 1), which is accompanied by a distinct bulk-rock group-II REE pattern.

From the observed RLE fractionation in chondrites, it is suggested that elevated Re/Os-ratios in EC [11] as well as sub-chondritic Nb/Ta of the Earth [12] are also related to large-scale volatility-controlled refractory element fractionation in the solar nebula.

Conclusions: High-precision LA-ICPMS data show that bulk chondrites can exhibit volatility-controlled RLE-fractionation, respectively. Variations in REE and Y are related to incorporation of variable amounts of refractory components with volatility-controlled refractory lithophile element abundances. EC show a deficit in refractory material that chemically resembles CAI with group-II REE patterns. Some CV3 chondrites (Mokoia, Allende) may be enriched in a similar component. The coarse-grained nature of CV3 chondrites, however, requires analyses of possibly more representative samples. The new data show that volatility-related fractionation plays a role in establishing the refractory element budget of planetary bodies, presumably including Earth.

References:

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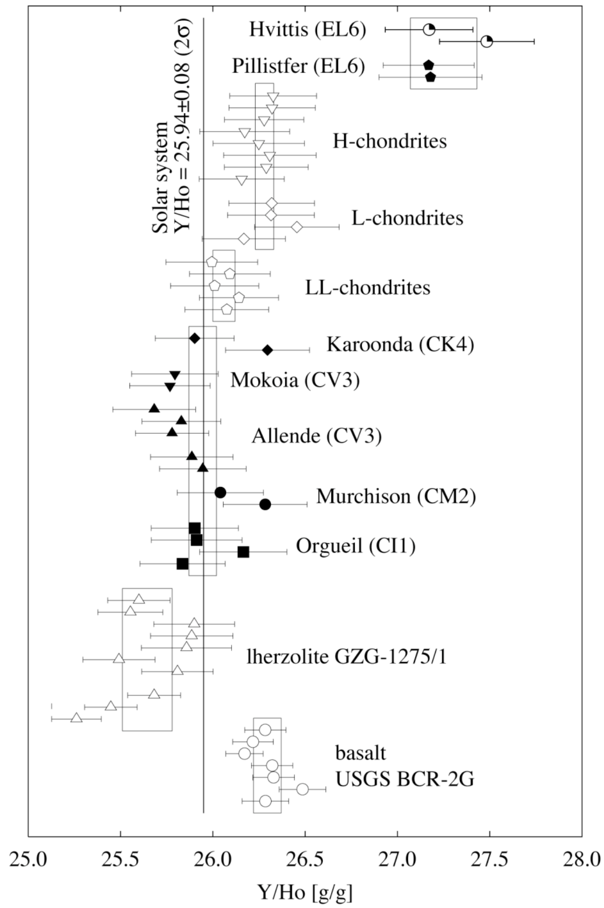

Fig. 1. Variation diagram showing the Y/Ho-ratios for different bulk chondrites. The error bars outline the 2σ uncertainty.

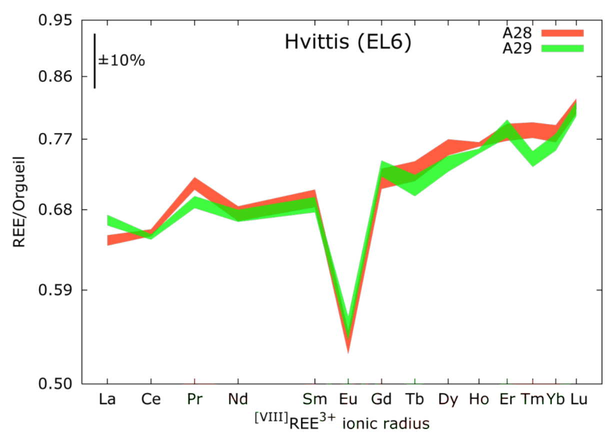

Fig. 2. Orgueil-normalized REE variation diagram of EL6 chondrite Hvittis (observed fall, 2σ error outlined).