Rare Earth Elements in CI1-chondrites and planetary samples. V. Bendel[1]*, A. Pack[1] and H. O'Neill[2], [1]Georg-August-Universität Göttingen, Geoscience Center, Department of Isotope Geology, Goldschmidtstrasse 1, D-37077 Göttingen, Germany (*vbendel@uni-goettingen.de), [2]Research School of Earth Sciences, The Australian National University, Canberra, Australia

Introduction: Chemically, CI1-chondrites are the most primitive chondrites in our solar system. They are used for the normalization of rare earth elements (REEs) in terrestrial samples. Our high-precision data obtained by LA-ICPMS show that planetary samples have a Tm-anomaly compared to CI1-chondrites. Our conclusion is that CI1-chondrites have a positive Tm-anomaly relative to the solar system.

Materials and Methods: A set of about 60 samples of large terrestrial reservoirs (peridotites, MORBs, OIBs, komatiites, crustal rocks) and differentiated stony meteorites from the Moon, Mars and asteroids were analyzed for REEs by LA-ICPMS together with CI1-chondrites (Orgueil, Ivuna, Alais) and other carbonaceous chondrites.

The bulk samples were prepared using a containerless melting technique described in [1] and applied in [2] and [3]. Bulk samples were first ground to fine powder. 10 to 20 mg of sample powder were premelted by the use of a 50 W CO_2 laser. The resulting spheres were then put on top of a vertical gas stream in a levitation device and briefly melted for one or two times. The samples were quenched by switching off the laser and then embedded in resin and polished for LA-ICPMS.

Cerium shows a volatile behaviour under oxidizing conditions. With our preparation technique we observe a small loss of Ce. Therefore we exclude Ce from our investigation of REEs.

LA-ICPMS analyses were conducted at the RSES at ANU Canberra (Australia). Rare earth elements were analyzed using an Agilent 7500S Quadrupole ICPMS equipped with a 193 nm Lambda Physique excimer laser and an in-house constructed ablation cell. The laser was run in line-scan mode with a spot size of 105 μm and a repetition rate of 5 Hz. Each measurement lasted about 2 min including 30 sec for the background.

All samples were prepared at least twice and analyzed once or twice.

For the calculation of REE concentrations we used NIST SRM 612 as an external standard. Absolute concentration values are taken from [4].

We observe a precision of inter-REE ratios of ±2 to ±5 % relative for a single analysis.

Results: *CI1-chondrites.* We analyzed five aliquots (~100-740 mg) of Orgueil (Fig. 1). The mean value of these five REE patterns of Orgueil has a standard error (1σ) of about 1% and is in good agreement with data from [5].

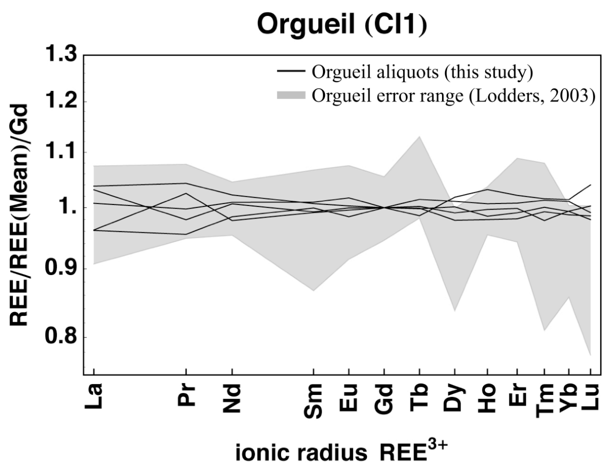

Fig. 1: Measurements of five Orgueil aliquots compared to data from [5].

Compared to Orgueil the REE patterns of Ivuna and Alais show a LREE>HREE fractionation of about 20%. This fractionation might be caused by the small sample size (205 and 69 mg respectively) and sample inhomogeneity, e.g. presence of phosphates. The samples from Ivuna and Alais, however, do not show any indication for an anomaly in Tm relative to Orgueil.

In this study, we normalize all analyses to the mean of the results from Orgueil.

Other carbonaceous chondrites. Bulk CV3-chondrites (Allende, including material of the Smithsonian powder, Axtel, Mokoia, Vigarano) show REE patterns resembling those of REE group-II CAIs, with large (~10-30%) Tm- and partially Yb-anomalies. Matrices of Allende and Leoville [6] also show group-II patterns with a Tm-anomaly of ~10%. Additionally, two of four analyzed CM2-chondrites (Mighei and Murray) and one analyzed CK4-chondrite (Karoonda) show REE group-II patterns. These patterns are caused by fractional high-temperature condensation.

Terrestrial samples and differentiated stony meteorites. Most terrestrial samples have smooth REE patterns. Aside from Eu-anomalies they also show a distinct depletion in Tm, which cannot be explained by magmatic fractionation. For the quantification of this anomaly the heavy REEs without Tm were fitted by a third order polynomial (Fig. 2). Subsequently, the deviation of the measured Tm concentration from the fitting line was calcutated for each sample. Fig. 3 shows the Tm-depletion of the terrestrial samples and differentiated meteorites. The mean value of the apparent Tm-depletion of these samples is 4.6 % with a standarderror (2σ) of 0.7 %.

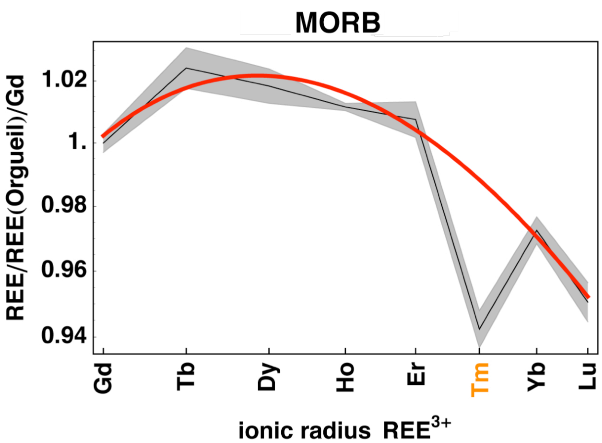

Fig. 2: Orgueil-normalized REE pattern of a MORB from Ascension Island showing a distinct Tm-depletion.

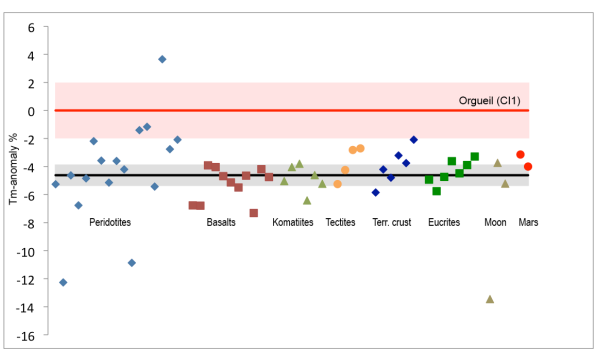

Fig. 3: Tm-anomaly in terrestrial samples and differentiated stony meteorites. The average Tm depletion is ~4.6 %.

Discussion: The negative Tm-anomaly in terrestrial samples and differentiated meteorites compared to Orgueil means that either Tm is depleted in the Earth, Moon, Mars and asteroids by approximately the same amount or that CI1-chondrites are enriched in Tm. Such a Tm-anomaly might be caused by the formation of a refractory phase enriched in Tm (such as REE group-II CAIs) and the subsequent transport of this phase to a different spatial region in the solar system.

If Earth, Moon, Mars and asteroids were depleted in Tm compared to the solar system, a Tm-rich phase had been removed from that area. In this case the removal had taken place on a very large scale (the Earth comprises about 50 wt% of the inner solar system). Therefore it is more likely that a refractory Tm-enriched phase was added to the CI1-chondrites. CI1-chondrites are not free of CAIs. One CAI was recovered in Ivuna, which was preserved despite of aqueous alteration [7].

If a refractory phase was added to the CI1-chondrites (similar to the addition of a refractory phase in CV3-chondrites), this would mean that the bulk chemistry of REEs in CI1-chondrites differs from the composition of the solar system.

We suggest that CI1-chondrites (Orgueil, Ivuna and Alais) have a positive Tm-anomaly. Such an anomaly is observed, with increasing magnitude, also in bulk CM2 and bulk CV3-chondrites.

Also [8] have found an indication of a Tm-depletion in PAAS samples compared to CI1-chondrites using a different method. These authors, however, state that this anomaly can not be resolved regarding the error range.

Conclusions: Our measurements suggest that Orgueil, Ivuna and Alais carry a 4.6% positive anomaly relative to the solar system. We conclude that, as in case of the CV3-chondrites, a Tm-rich refractory phase was added to the CI1-chondrites.

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