

AN *in-situ* TRACE ELEMENT STUDY OF REFRACTORY FORSTERITES FROM DIFFERENT TYPES OF UNEQUILIBRATED CHONDRITES. A. Pack¹, M. Shelley², H. St.C. O'Neill² and H. Palme¹, ¹Institute of Mineralogy and Geochemistry, Zùlpicher Strasse 49b, D-50674 Kùln, Germany (pack@min.uni-koeln.de), ²Research School of Earth Sciences, The Australian National University, Mills Road, Canberra ACT 0200, Australia.

Introduction: Refractory forsterites are widespread components of all types of unequilibrated chondrites. They occur in concentrations up to 0.3 vol.% and are extremely poor in Fe, Ni, Co and Mn and are rich in refractory lithophile elements (Ca, Al, Ti, Sc, V, REEs) [1,2]. A further characteristic of refractory forsterites is that they are often significantly enriched in ¹⁶O [3].

In order to trace the origin of refractory forsterites, we have conducted an *in-situ* LA-ICP-MS trace element study of refractory forsterites from carbonaceous chondrites (Murchison, Allende, Vigarano) and, for the first time, from unequilibrated ordinary chondrites (Dar al Gani 369, Dar al Gani 378 and Chainpur) and an R-chondrite (Dar al Gani 013). Preliminary results of these analyses are presented here.

Analytical technique: Prior to LA-ICPMS analysis, major and minor elements were analyzed by EPMA. Trace element analyses were performed using the ANU RSES LA-ICPMS apparatus, consisting of a 193 nm ArF-excimer laser interfaced to an Agilent 7500 ICPMS. The size of the ablation spot was varied between 24 and 40 μ m. Calibration as well as drift correction was performed by measuring NIST 612 and BCR2G glass standards after each 5–10 sample spots. A single analysis (38 isotopes) took about two minutes. For analyses of refractory forsterites, intensities were normalized relative to ²⁹Si.

RLEs: All analyzed refractory forsterites show fractionation among the rare earth elements with LREE/HREE $\approx 10^{-3}$ (Fig. 1). Concentrations of Lu are between 0.5 and 1 x C1. The concentrations of LREEs were close to or below the detection limit of the LA-ICPMS setup used. Therefore no statement can be made about possible anomalies in Eu and Ce.

There is no apparent difference in the REE content of refractory forsterites from carbonaceous chondrites, ordinary chondrites or the R-chondrite Dar al Gani 013 (Fig. 1).

The amount of REEs in the refractory forsterites correlates weakly with the concentrations of Ca, Al and Ti. The correlation between Ca and the other refractory lithophile elements is less well developed than the correlation between Al and the other RLEs.

Correlations between Al₂O₃ and Ti, Zr and Y, which is indicative of the amount of REEs, are well developed (Fig. 2). This is in agreement with earlier

observations that other refractory elements, such as Ca, Al and Ti also have similar abundances in forsterites of different groups of chondritic meteorites. As bulk carbonaceous chondrites and in particular CV-chondrites are enriched in refractory elements compared to ordinary chondrites, we conclude that the abundances of refractory elements in forsterites are independent of the bulk refractory element content of the host meteorite, suggesting independent formation of the forsterites. The patterns of RLEs in forsterites reflect forsterite/melt partition coefficients, suggesting that the forsterites could have crystallized from a melt with chondritic relative abundances and a ten to twenty-fold enrichment in RLEs [1].

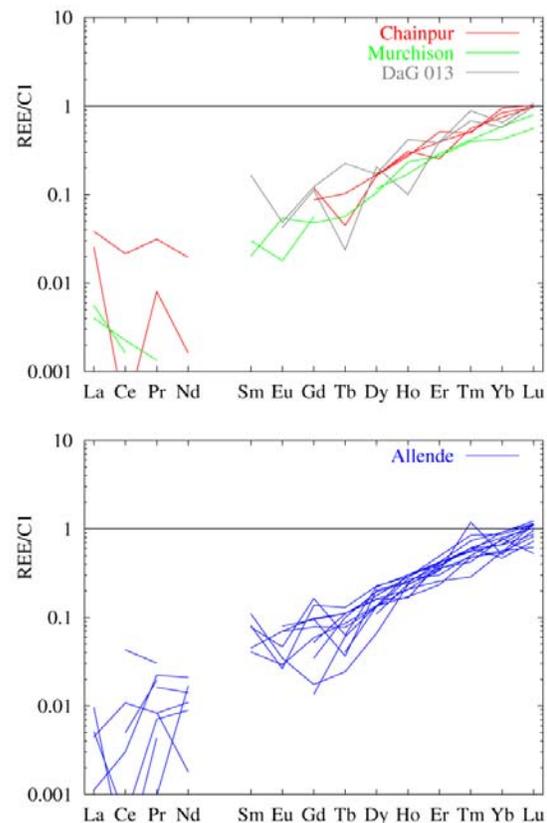


Fig. 1: Plots of the REE C1-normalized abundances of refractory forsterites from Chainpur, Murchison, Dar al Gani 013 (top) and Allende (bottom).

Transition metals: The concentrations of Mn in the forsterites vary between 23 and *ca.* 200 ppmw, with most forsterites having 20–50 ppmZ Mn. Although ordinary chondrites contain more Mn than carbonaceous chondrites by a factor of two, no apparent difference between the Mn contents of refractory forsterites from these meteorites seems to exist. This is a further constraint arguing for the primitive nature of refractory forsterites, and genetically links these to the CAIs rather than to chondrules.

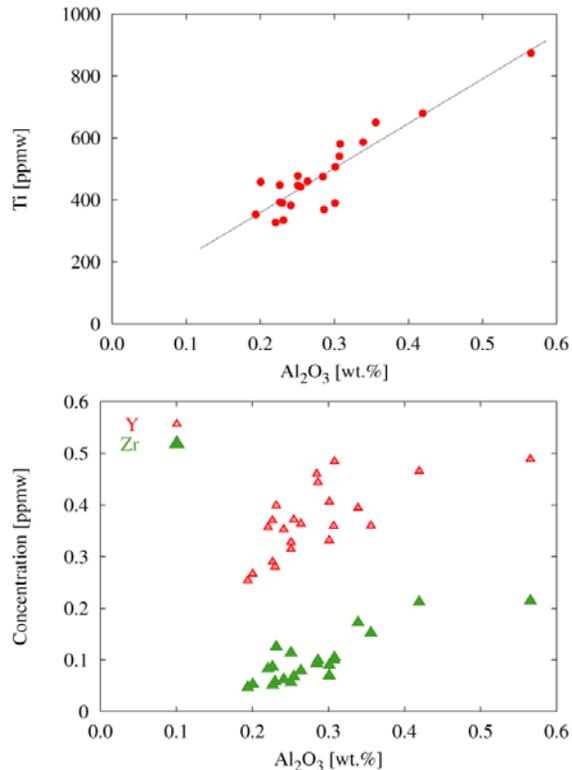


Fig. 2: Plot of Ti (*top*) and Y and Zr (*bottom*) vs. Al_2O_3 .

Nickel concentrations vary between 0.7 and 120 ppmw, with most forsterites having Ni contents between 1 and 3 ppmw. The lower limit of the Ni concentration is lower than given by [1] by a factor of ten and lower than reported by [4] by a factor of two. Two distinct trends are indicated in a Ni vs. Fe plot: the Fe/Ni ratio of the low-Ni analyses is about 10^3 , whereas that of the high-Ni analyses is *ca.* 46. This indicates the the higher Ni contents may be attributed to some Ni-rich metal inclusions in the analyzed volume. A Fe/Ni-ratio in the range of 10^3 is what is expected from an olivine in equilibrium with Fe-Ni metal condensates.

Cobalt concentrations vary systematically with the Ni contents and reach values as low as 0.2 ppmw. The Ni/Co-ratio of the low-Ni forsterites is 3–4.

Conclusions: Refractory forsterites from carbonaceous, ordinary and R-chondrites have no chemical characteristics that relate them to their specific host meteorite. The concentrations of refractory elements are similar in forsterites from the various meteorite classes.

The same conclusions can be drawn from the low concentrations of the oxidizable siderophile elements Fe, Ni and Co. The minimum concentrations reported here (Fe: 750 ppmw, Ni: 0.7 ppmw, Co: 0.132 ppmw) are the lowest values reported so far from olivine in carbonaceous, ordinary and R-chondrites.

By analyzing the O-isotope ratios, it is shown that there is no difference in the O-isotope composition of refractory forsterites from the different types of chondrites either (Pack et al., 2002, GCA, submitted).

Formation of refractory forsterite: The very FeO-poor and RLE-rich refractory forsterites clearly cannot have crystallized within type-IA chondrule melts. Using olivine/melt partitioning data, the hypothetical host melt must have been enriched by about a factor of 10–20×CI, in order to crystallize a forsterite with the high RLE concentrations. RLE concentrations of chondrules, however, are generally lower [5]. The size of the forsterites as well as the presence of melt inclusions [6] in some of the grains, however, point to growth from a melt. The concentration of FeO, NiO, MnO and CoO, on the other hand, must have been extremely low, which points to nebular affinities.

It is therefore suggested that refractory forsterites crystallized in early melt condensates [7,8]. These condensates are high in RLEs and low in oxidizable siderophiles (Fe, Ni, Co). Furthermore, they should have chondritic abundances of the RLEs including the REEs, which would then be compatible with the fractionated REEs in the forsterites.

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