REFRACTORY FORSTERITES IN CHONDRITIC METEORITES, A LINK BETWEEN CAIS AND CHONDRULES. H. Palme[1], A. Pack[2], J.M.G. Shelley[3] and C. Burkhardt [1]; [1]Universität Köln, Institut für Mineralogie und Geochemie, 50674 Köln, Germany, palme@min.uni-koeln.de; [2]CNRS/CRPG, 15 rue Notre Dames des Pauvres, 54501 Nancy, France, [3]Research School of Earth Sciences, Australian National University, Canberra ACT 0200, Australia

Introduction: Unequilibrated chondritic meteorites contain a population of FeO poor olivines (0.2–1 mol% fa) that are rich in refractory lithophile elements, such as Ca, Al, Ti, Sc, V, and REE [1,2,3]. These forsterites are termed "refractory forsterites" (RF) and occur as isolated grains within the matrices of carbonaceous chondrites (CC) and within chondrules, therein mostly as relicts [4,5]. RFs were also found in ordinary chondrites (OC) and even in the strongly oxidized Rumurutiites (RC). RFs can be identified by their cathodoluminescence, which distinguishes them from more ferrous olivines [e.g., 1,3]. Improvements in the accuracy and spatial resolution of microchemical methods and results of partition experiments have led to a better understanding of these objects. Recent improvements include:

1.) The high contents of CaO and other refractory elements require a parental source (e.g. melt) enriched in refractory elements by about 15 times CI-chondritic (~20 wt% CaO). Rapid crystallization of olivine from a chondrules melt cannot produce such high contents of refractory elements in RFs [6]. The relative abundances of the refractory elements in the parental melts are chondritic within the uncertainty of olivine/melt partition coefficients [7, 8].

2.) RFs of CC and OC, including Rumurutiites, are enriched in δ^{16}O. There is no relationship of the oxygen isotopic composition of the RFs to the oxygen isotopic composition of the host meteorites [9,4]. Some RFs in individual chondrules differ in oxygen isotopes from the rest of the host chondrules. From this and from 1.) it follows that that RF in chondrules are xenocrysts and are unrelated to the host chondrules.

Thus, forsteritic olivines in carbonaceous and ordinary chondrites are uniform in chemical and O-isotopic composition, independent of the chemical and oxygen isotopic composition of the host meteorite. The RF are the most refractory olivines and most likely the earliest formed and thus oldest Mg-silicates in chondritic meteorites. They formed either by condensation in a gas of solar composition [2], or by crystallization from a condensed melt droplet uniformly enriched in refractory elements by a factor of about 15 [3]. Both models give the same results as, in perfect equilibrium between a solar gas and a liquid condensate, the RF crystallizing from the liquid condensate implies equilibrium between the gas and the RF.

Analyses: In this contribution we report the results of trace element analyses by LA ICP-MS (ANU, Research School of Earth Sciences, Canberra) of forsterite grains that had been previously analyzed for oxygen isotopes with the ion probe [3]. Here we focus on the FeO, NiO, CoO and MnO contents of RFs.

Thirty forsterite grains of Murchison and Allende (CC) and Chainpur, DaG369 and DaG378 (OC) were analyzed. The major element compositions of these forsterites as well as Ca, Al and Ti contents were also determined by EMP, both methods give the same results.

Results: The results for Fe, Ca, Ni and Mn are shown in the form of histograms (Fig.1). The elements Fe, Ni, Mn, and Co (not shown here) have very low, but well defined concentrations. The Ni and Mn contents found here are within the same range as those determined with the IMP by [2]. For FeO and CaO additional EMP analyses of RFs are included in Fig. 1.

Discussion: The narrow compositional range in Ni, and Co and the moderately volatile Mn, together with the limited concentration range in FeO and CaO reflects identical conditions of formation of these forsterites in CC and in OC and support a common origin that is not related to the chemical and oxygen isotopic composition of the host meteorites.

There are reasonably good correlations among the minor elements in the forsterites. In particular, the olivines lowest in Fe are also lowest in Ni, Co, Cr and Mn. The CI-normalized abundances of Ni (10^{-4}), Co ($2*10^{-3}$), Fe (0.11) and Cr (0.25) in olivine increases with decreasing siderophility of these elements, suggesting the presence of a metal phase in controlling the abundances of these elements in forsterite. The lowest FeO content is approximately that of the first condensed forsterite, largely independent of nebular pressure [9].

The low but well defined Mn contents reflect the high temperature origin of the RFs and are probably buffered by the Mn vapor pressure in the nebula. It is, however, remarkable that refractory forsterites from OC and type 3 CC have the same Mn contents, despite a factor of two difference in the bulk Mn contents of the two types of meteorites.

An important feature of the chemistry of RFs is that there is a lower limit to the concentrations of Fe, Ni, Co, Mn and also Cr [see 2]. There are no olivines in meteorite with less than 0.1% FeO, the limits in Ni, Co, and Mn may have similar significance as may be seen from the limited sampling in Fig. 1. There is, however, a more continuous distribution versus higher concentrations leading ultimately to the chondrule and matrix olivines. This suggests formation in very well defined very reducing high temperature environment. As the temperature drops more oxidizing conditions prevail and more Mn, Ni, and Co are added, but less Ca, which shows the opposite trend as Fe.

The RFs must have formed at conditions appropriate for establishing the concentrations of these elements. This is a high temperature setting, either provided by crystallization from very refractory melts (slightly less refractory than CAIs) or by direct condensation from the solar nebula. Either the conditions for RF formation were the same at the formation region of carbonaceous and ordinary chondrites, or alternatively there was only one formation region where all RFs formed and they were distributed to the various locations of formation of chondritic meteorites. The Ca, Al-rich inclusions also occur in most types of chondritic meteorites and they also bear little or no relationship to their host meteorite. Some researchers believe that CAIs formed near the proto-sun and were subsequently transported to the meteorite formation regions. As RFs are similarly refractory as CAIs they may have had a similar history. However, considering the turbulent environment of the early solar system and the uniform composition of RF, it seems more plausible that RFs formed at the well defined conditions in a slowly cooling nebular environment.

An origin of RFs by evaporation of less refractory matter is unlikely as the tiny fraction of Mn that is left in the olvine would show much more variability, depending on the size of the olivine crystals the rate of heat increase etc.

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