

**EXTRATERRESTRIAL FORSTERITE: REVIEW OF PRESENT KNOWLEDGE.** Ian M. Steele, Department of Geophysical Sciences, University of Chicago, 5734 S. Ellis Ave., Chicago, IL 60637-1434.

While forsterites are in nearly all primitive extraterrestrial samples, there is no obvious conclusion for origin and relation to other components. Some questions include: 1) how its heavy oxygen can be reconciled with a chondrule origin; 2) high minor element content in light of known distribution coefficients; 3) reason for two main chemical variations associated with specific sample types; 4) an origin by condensation or from melt or more complex process? For each question there are several or possibly no answers. Suggestions are given for additional studies.

Oxygen isotopic composition: Ion microprobe measurements show that forsterite is enriched in  $^{16}\text{O}$  [1] relative to measured bulk chondrules [2] and more Fe-rich olivine [1]. These data preclude an origin of these measured forsterites (all forsterites?) from these chondrules and suggests searching for chondrules which are more likely candidates as recognized by petrographic, compositional or oxygen isotope compositions. Alternatively, original forsterite chondrules or other potential sources such as igneous rock fragments may have been recycled to give individual forsterite grains or grains included within chondrules. Evidence definitely exists for recycling in the form of relic grains and chemical signatures but it is not certain how many cycles have occurred, whether this was an episodic or continuous process, and whether some original sources could have been preserved. The heavy oxygen bears similarities to that of CAIs but without the extreme  $^{16}\text{O}$  enrichment. Some evidence exists that the oxygen in C2 and C3 forsterite is isotopically different [3] indicating, as with composition, that these meteorites contain different forsterite. Measurement of individual forsterites in C1, IDPs, Mn-enriched olivines, and other small particle samples have not been made to confirm a common oxygen composition. There are no data defining the relation between minor element composition and oxygen isotopics and therefore possibly a common process giving both effects.

Minor element composition: Forsterites contain unusually high levels of minor elements well above those observed in terrestrial and lunar samples [4]. Differences allow distinction of different forsterite groups with separation into two main and several minor groups (e.g. Mn enriched). The levels of these elements are difficult to reconcile with known (sometimes poorly) distribution coefficients. Either a very enriched source in elements like V, Sc, Ti or a process which allows enhanced incorporation into the forsterite structure is required. The levels of these elements in forsterite and measured levels of the same elements in chondrules do not easily permit forsterite to be derived from these analyzed chondrules. A logical conclusion is that these forsterites formed in a source not yet identified consistent with one conclusion regarding oxygen given above. While there is some chemical correspondence between forsterite in chondrules with forsterite in isolated grains in the same meteorite [5], special care must be made to define what forsterite is being compared. While the minor element composition can be used to compare forsterites in different sample types, it is not clear that one sample type is derived from the other or whether they simply formed under similar conditions, but independently [6]. It is

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tempting to conclude that IDP forsterite is equivalent to C2 forsterite, but this does not necessarily mean that IDP are equivalent to samples of C2s. To compare compositions in detail, analyses beyond those allowed by electron probe must be made. Elements like Ni and Cr are sensitive to oxidation state and would provide information on this parameter in the source region of forsterite. REE, although very low, may provide important constraints on the source but are seldom measured.

Forsterites with two chemical trends: From minor element contents, two distinct chemical variations of forsterite can be recognized [7] with at least one minor Mn-enriched group [8]. The first distinct group is associated with C3 and UOC meteorites and compositions can not be distinguished within these two meteorite groups. The second distinct group is common to C1 and C2 meteorites as well as smaller particle samples including deep sea particles, interplanetary dust, and Greenland ice samples [6]. A third group, enriched in Mn, is found mainly in various small particles although sometime in larger samples [8]. The two major chemical groups of forsterites are clearly associated with meteorites with different chemistries suggesting that the two groups never mixed and were incorporated into and partly define the meteorite groups. The chemical trends defined by the two major forsterite groups appear with increasing Mg content (earlier growth) to merge into a single group [7]. Given normal chemical trends this suggests that from a common, early-forming forsterite, two crystallization trends evolved possibly in concert with the different meteorite chemistries. If only one early-forming forsterite composition indeed exists, it appears to predate aggregation of the meteorites and is a common, homogeneous contributing component preserved through formation of meteorite groups and providing a sample of early material similar to CAIs.

Growth from melt or vapor: Possibly the oldest controversy is whether forsterite condensed from a gas or crystallized from a melt. Evidence for both can be found and a recent suggestion based on revised calculations is that both processes operated simultaneously by condensation to a melt [9]. Strong evidence that a melt was present is the inclusion of trapped melt (now glass) [10,11] with compositions and other features similar to olivines known to have grown from a melt. In addition oscillatory zoning may be present [12] which is known to be associated with growth from a melt for silicates. Condensation is thermodynamically possible but direct evidence is lacking. The meteoritic forsterite is commonly associated with glass (melt) inclusions which should provide compositional evidence of the melt in equilibrium with the olivine. While major element analyses have been made, few data exist for minor and trace elements which should provide chemical characterization of the equilibrium melt. These compositions would allow evaluation of melt/crystal equilibrium by using distribution coefficients. For example, the high trace element content of forsterite should be reflected in the melt inclusions.

References: [1] *Geochim. Cosmochim. Acta* **57**, 2649-2661; [2] *Chondrules and Their Origins*, 37-43; [3] *Lunar and Planetary Science XXVI*, 589-590; [4] *Geochim. Cosmochim. Acta* **50**, 1379-1396; [5] *Geochim. Cosmochim. Acta* **56**, 467-482; [6] *Meteoritics* **25**, 301-307; [7] *Lunar and Planetary Sci. XVII*, 822-823; [8] *Nature* **339**, 126-128; [9] *Geochim. Cosmochim. Acta* **59**, 3413-3444; [10] *Geochim. Cosmochim. Acta* **41**, 411-418; [11] *Bull. Mineral.* **104**, 339-353; [12] *Amer. Mineral.* **80**, 823-832.