

## ARE MEGACRYSTS IN OLIVINE-PHYRIC SHERGOTTITES XENOCRYSTS, PHENOCRYSTS, OR SOMETHING ELSE?

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**Introduction:** Most of the available Martian samples in our collection show the effects of accumulation or loss of crystals. For shergottites, olivine in particular has the most complex magmatic history. Olivine is the first major phase to crystallize, and therefore can be easily redistributed by settling within a magmatic system. Furthermore, the composition of olivine changes significantly during crystallization and can be reset by rapid diffusion. Consequently, the relationship between Martian basalts and the olivines they host is controversial. Many authors have proposed shergottitic olivines are entrained xenocrysts derived from the mantle or from cumulates [e.g., 1-3], while others [4-5] have argued that the olivines are phenocrysts, closely related to their host basalts. We will argue based on detailed analyses and modeling of meteorite LAR 06319 that its olivines actually represent antecrysts; crystals formed from a liquid similar to the current groundmass, but which spent significant time residing in a cumulate pile prior to entrainment just prior to eruption.

The olivine-liquid relationship impacts many geochemical debates regarding Martian meteorites. For example, interpretations of olivine-hosted inclusions, the oxidation state of the liquids, and parental melt compositions require understanding the relationship between olivines and their host liquids [3, 5, 6].

LAR 06319 is a recent olivine-phyric shergottite meteorite find. It has been the subject of previous studies which establish that the meteorite is Martian and argue that it represents the result of closed-system crystallization of an oxidized magma [5, 6]. Specifically, [5] argued that the olivines were likely closely related to the groundmass, as they host inclusions similar in composition to the groundmass. We have surveyed the olivines in LAR 06319 in more detail. Based on our data and the data from [5], we have calculated the parental melt composition of LAR 06319 that is consistent with the constraints from measured olivines. This calculation indicates that LAR 06319 has accumulated olivine relative to the parental liquid, but that the olivine was produced by fractional crystallization and re-equilibration from a larger pool of melt similar to the LAR 06319 parental magma.

**LAR06319 olivines:** Olivine megacrysts in LAR06319 are zoned from high Mg# cores to low Mg# rims (Fig 1). However, the zoning is not smooth; typically the cores are nearly homogenous, suggesting they have re-equilibrated in Mg #.

We have 3 constraints from olivine compositional measurements that can be applied to crystallization modeling. The highest Mg # olivine reported on this meteorite is Mg # 77, from [5]. Aside from that measurement, most of the large olivines show cores with constant Mg # close to 72 (Fig 1). Finally [7] reported a unique olivine with a sharp compositional boundary, preserving a record of the olivine composition that began crystallizing just after the end of the diffusive period represented by the homogeneous cores. This olivine constrains the Mg # when final crystallization began as just above Mg # 65.

In addition to olivine, the pyroxenes are strongly zoned and show little evidence of re-equilibration [5]. Therefore, the pyroxenes are likely the products of rapid, late crystallization, unaffected by diffusion.

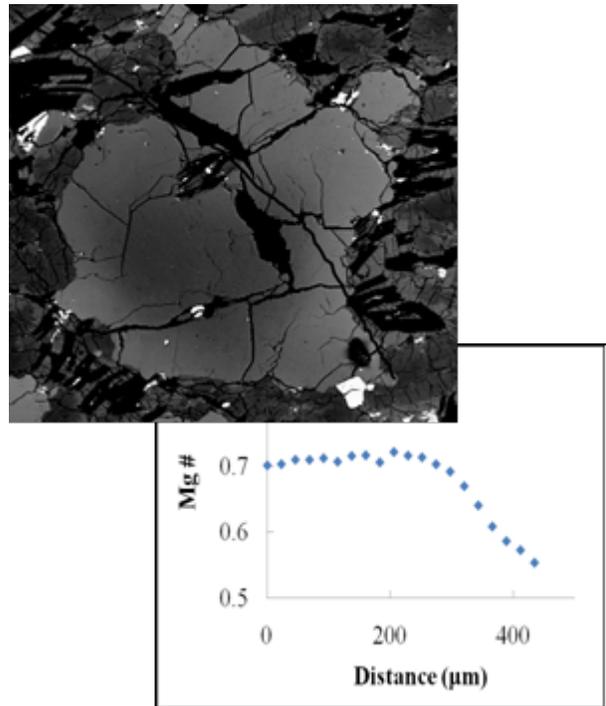


Fig 1: BSE and compositional profile of typical LAR06319 olivine, image 1 mm across.

**Calculation:** The goal was to test whether an olivine addition/fractionation trend could fit these 3 olivine constraints. To produce our estimate, we needed a starting liquid composition. We calculated this composition using the LAR06319 whole rock composition from [5]. We then assumed that the liquid composition sits on an olivine-control line with the average olivine,

close to the point that pyroxene begins to crystallize, as is typical for terrestrial magmatic systems (Fig 2).

We then used the olivine/liquid  $K_D$  calibration of [8] to calculate the olivine composition in equilibrium with this liquid. We added olivine in small increments to the liquid composition, recalculating the liquid and olivine composition at each step, adapting techniques similar to those used by [9] and [10], and accounting for trace phases. We continued the calculation until we reached equilibrium with Mg# 77 olivine, as measured by [5]. Then, using the composition and mass of olivine added at each step, we calculated the average olivine composition to be Mg # 72, which is almost exactly the composition with which the olivine cores have equilibrated. This calculation therefore produces an internally consistent estimate of the parental melt composition of LAR 06319 that can be used to unravel its petrology and crystallization history (Fig 2).

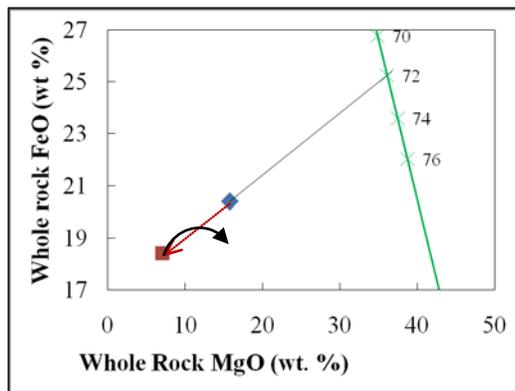


Fig. 2: Host liquid calculated as mixing between Mg #72 olivine (Green line) and whole rock composition (Blue diamond). Host liquid (red square) sits on mixing line (red) close to point of pyroxene saturation. Olivine addition calculation changes liquid composition by adding olivine until liquid is in equilibrium with Mg # 77 olivine (Black curve and arrow)

**Implications:** The calculation of a parental melt composition and a self-consistent olivine crystallization history allows us to evaluate the details of the olivine-liquid relationship in this meteorite. [5] noted that the whole-rock composition was in equilibrium with an Mg # 81 olivine, more MgO rich than the highest measured olivine (Mg # 77), but still concluded that the olivines were phenocrysts. Our analysis suggests that the Mg # 77 olivine likely preserves a composition close to the first olivine to crystallize, but on average the rock contains 45% more olivine than would be contained in a rock produced solely by crystallization of the parental liquid.

The term antecryst has recently been applied to describe terrestrial olivines which crystallized from a

melt similar to the one that hosts them but which spent time re-equilibrating in a magmatic system or cumulate pile. This term fits the olivines in LAR06319 well. The olivines in this meteorite crystallized from a melt similar to the parent of LAR06319. They then settled out of their parent melt, likely into a cumulate pile, where their Mg # equilibrated to the average composition of the olivines in that pile. The olivines were re-entrained shortly before eruption, at which point crystallization of low-Mg # olivine resumed on the rims. This magmatic history produces magmas from an LAR06319 parent liquid which have lost significant quantities of olivine, in addition to olivine-rich cumulates with Mg # ~72. Several authors, including [11], have identified olivine-rich units on Mars from spacecraft, including high-Mg # olivines, which may be produced via this mechanism. Furthermore, this self-consistent calculation argues against significant entrainment of olivine from the Martian mantle or crust in LAR06319, as entrainment of a significant quantity of olivine would offset the average olivine composition from that predicted by a closed-system crystallization path.

This calculation also constrains the conditions of crystallization. Pyroxene saturation is a strong function of the pressure of crystallization and the volatile content of the liquid. Any decrease in the amount of low-Mg # olivine crystallized would offset the average olivine Mg # to higher values than measured, and would create a situation where an internally consistent crystallization path for the liquid is impossible. Therefore, decreased water contents, increased contents of other volatiles such as  $\text{CO}_2$  or Cl or elevated crystallization pressure are inconsistent with the olivine crystallization calculations. Based on estimates of pyroxene saturation from the MELTS algorithm, we find that the crystallization trend is best accommodated by a melt with ~1.1%  $\text{H}_2\text{O}$  crystallizing its olivine at ~1 kilobar pressure. Any Cl in the liquid must be balanced by either decreased pressure or increased  $\text{H}_2\text{O}$ .

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