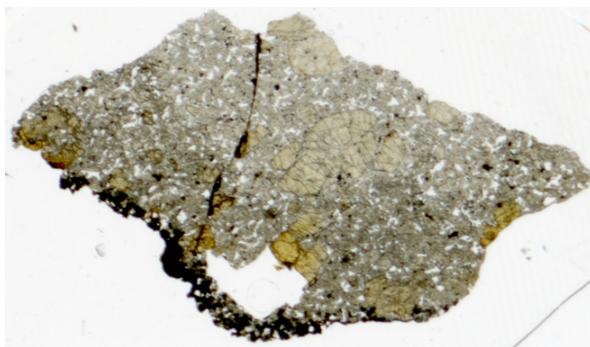


### Petrogenesis of the LAR 12095/12240 Martian Meteorite: Comparisons with Tissint and other Depleted Olivine-Phyric Shergottites.

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**Introduction:** LAR 12095 and 12240 are paired olivine-phyric shergottites found during the 2012 Antarctic field season [1]. The purpose of this study is to investigate the similarities of these meteorites with other olivine-phyric shergottites, especially the Tissint meteorite. Here we report details of the petrography, mineralogy, and bulk trace element composition, as well as the results of oxybarometry applied to early- and late-crystallized mineral assemblages.

**Petrography:** Thin sections LAR 12095,24 and LAR 12240,18 were examined by optical microscopy (Fig. 1) and electron microprobe (EMP) analysis. The groundmass is a mixture of pyroxene (72%) and plagioclase (25%) with minor amounts of chromite, ilmenite, titanomagnetite, troilite, and merillite. Large anhedral olivine inclusions appear to be phenocrystic and compose about 25% of the rock. There is no evidence for terrestrial weathering in the bulk of either rock, but some of the vesicles in the fusion crust in LAR 12095 have been mineralized. Both thin sections are crosscut by a shock vein with a minor offset.

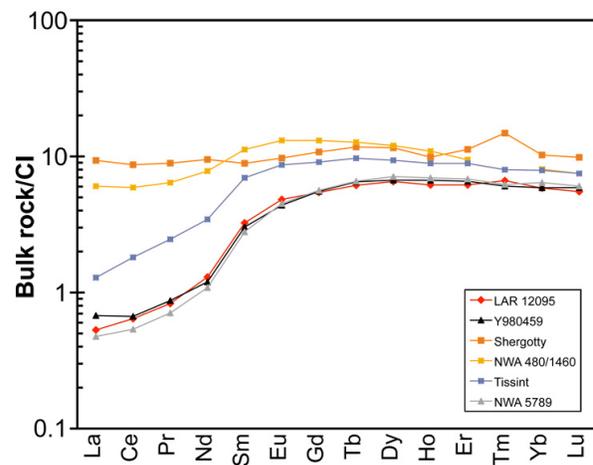


**Figure 1:** High resolution unpolarized light scan of section LAR 12095,24 showing the olivine-phyric texture. Also visible are the shock vein and fusion crust.

**Whole-Rock Chemistry:** Chip LAR12095,12 was placed in a Teflon bag and broken with a hammer, and then ground in an agate mortar and pestle under acetone and dried under a heat lamp. The powder, weighing 432 mg, was then split into two ~200 mg aliquots and dissolved in HF/HNO<sub>3</sub>. Trace element analysis was carried out on the sample solutions using a Perkin Elmer Elan6000 quadrupole ICP-MS instrument, operating at 1300 watts in dual detector mode.

REE results are shown in Figure 2, with other shergottites for comparison. The REE pattern for LAR

12095 is nearly coincident with that of Y980459 and NWA 5789 and subparallel to that of Tissint, placing LAR 12095 firmly within the depleted shergottite subgroup.



**Figure 2.** Whole-rock REE plot for LAR 12095, compared with other shergottites. Data from the Mars Meteorite Compendium, except for Tissint and NWA 5789, which were analyzed in the same laboratory using the same methods.

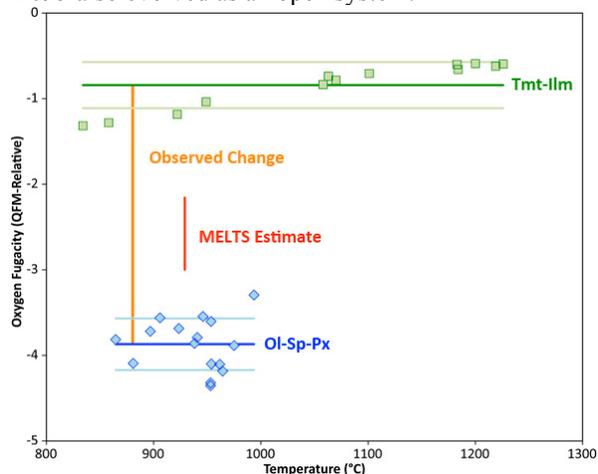
**Mineral Chemistry:** Feldspars range in composition from An<sub>56</sub> to An<sub>68</sub> with negligible Or (~0.6%). Olivines range in composition from Fa<sub>29</sub> to Fa<sub>42</sub>. Pyroxenes range in composition from Fs<sub>24</sub> to Fs<sub>33</sub> with typical Wo<sub>10±1</sub> (ranges from Wo<sub>07</sub> to Wo<sub>16</sub>). The observed mineralogy is in close agreement with the previously reported description [2]. The calculated olivine composition in equilibrium with the primitive pyroxene composition is Fa<sub>30</sub> using a K<sub>D</sub> of 1.2 for Ol-Px Fe-Mg exchange. The estimated bulk is Fe# 34.5±0.4 (n=21) from defocused beam EMP analysis of fusion crust glass. The estimated olivine in equilibrium with the bulk composition is Fa<sub>15.6±0.3</sub> using a K<sub>D</sub> of 0.35 for Ol-Lq Fe-Mg exchange [3], suggesting that olivine cores are cumulate.

**Oxygen Fugacity:** There are two possible geothermometer/oxybarometers (GTOBs) applicable to the mineral assemblage in LAR 12095: the olivine spinel pyroxene GTOB (Ol-Px-Sp) representing the early magmatic conditions, and the titanomagnetite ilmenite GTOB (Tmt-Ilm) representing the late magmatic conditions [4]. We obtain a preliminary Ol-Sp-Px estimate of QFM-3.9±0.1 (IW-0.1±0.1, n=16) using the most Mg-rich pyroxene composition, Fa<sub>30</sub>

olivine, and the compositions of the most primitive chromites. Notably, this estimate is very similar to that obtained for depleted shergottite NWA 5789 ( $IW-0.1 \pm 0.1$ , [5]).

A preliminary estimate for LAR 12095 based on the Tmt-Ilm GTOB is  $QFM-0.8 \pm 0.1$  ( $IW+2.8 \pm 0.1$ ,  $n=13$ ). The difference between the early and late redox estimates is  $\sim 3.1$  log units, representing substantially different oxygen fugacity regimes.

Previous calculations suggest that the oxygen fugacity of Tissint evolved as an open system [6]. This calculation was based on the MELTS model [7] where it was shown that for the Tissint parental composition the observed change in oxygen fugacity ( $\sim 2.3$  log units) exceeded the predicted change from mineral fractionation in a closed system ( $\sim 0.84$  log units). The observed change in oxygen fugacity in LAR 12095 also exceeds the maximum calculated, assuming a Tissint parental melt composition at reasonable starting oxygen fugacities (Fig. 3). As the two meteorites have similar bulk compositions, this suggests that LAR 12095 also evolved as an open system.



**Figure 3:** Oxygen fugacity change recorded by the early-formed Ol-Sp-Px assemblage and the late-formed Tmt-Ilm assemblage in LAR 12095.

It is difficult to assess the confidence of this finding as there are few intercalibration experiments between oxybarometers, but results within 0.5 log units are typically considered to be in agreement [8]. The error in the MELTS calculation of auto-oxidation is also difficult to assess, so a conservative estimate was used.

The temperature estimates for Ol-Sp-Px are low, likely due to sub-solidus Fe-Mg exchange. The temperature estimates for Tmt-Ilm are high, likely due to fine intergrowth. Neither error is thought to have greatly disturbed the redox estimate.

**Discussion:** There are two possibilities for an open system control of the oxygen fugacity: material

addition or loss. The difficulty in material addition is that it must be tied to other chemical systems. For example, an aqueous liquid would also add in fluid-mobile elements. The presence of water should also alter the mineral assemblage, likely stabilizing apatite rather than the observed merrillite. The alternative material addition model is assimilation, likely of the crust. This model suffers from similar difficulties [9].

A likely material loss model is oxidation by gas escape, as considered by Shearer et al. [10]. The removal of a reduced species (eg:  $H_2S$ ) would generate an oxidized residuum. Shearer et al. [10] argued for sulfur, chlorine, and carbon as potential elements involved in gas escape oxidation in an enriched olivine-phyric shergottite (NWA1183), likely requiring all three to achieve the observed redox change. A redox change in the depleted olivine-phyric shergottite Y980459 is not observed [10]; however, LAR 12095 and Tissint demonstrate that depleted shergottites also undergo late-stage oxidation likely requiring reduced gas escape.

One implication of the oxidation is that olivine is less stable at more oxidizing conditions. While this would not result in complete olivine breakdown, it should result in some of the olivine being resorbed into the liquid. This could explain why olivine phenocrysts in the olivine-phyric shergottites are frequently anhedral. It is also conceivable that this mechanism would result in olivine cores in disequilibrium with the groundmass as the olivine resorption and chemical reequilibration are likely to be kinetically limited in the rapidly cooling melt.

**References:** [1] Satterwhite C. and K. Righter (2013) *An. Met. Newsletter*, 36; [2] Corrigan C. and L. Welzenbach (2013) *An. Met. Newsletter*, 36, 17; [3] Filiberto J. and R. Dasgupta (2011) *EPSL*, 304, 527-537; [4] *CT Server Ol-Px-Sp*: [http://ctserver.ofm-research.org/Olv\\_Spn\\_Opx/index.php](http://ctserver.ofm-research.org/Olv_Spn_Opx/index.php) Sack R. and M. Ghiorso (1989) *Cont. Min. Pet.* 102, 41-68; Sack R. and M. Ghiorso (1991) *Cont. Min. Pet.* 106, 474-505; Sack R. and M. Ghiorso (1994) *Cont. Min. Pet.* 118, 271-296; Sack R. and M. Ghiorso (1994) *Cont. Min. Pet.* 116, 287-300; Sack R. and M. Ghiorso (1994) *Cont. Min. Pet.* 116, 277-286; Sack R.O. and M.S. Ghiorso (1991) *Am. Min.* 76, 827-847; *CT Server Fe-Ti oxide*: <http://ctserver.ofm-research.org/OxideGeothrm/OxideGeothrm.php>; Ghiorso M.S. and B.W. Evans (2008) *Am. JSci*, 308, 957-1039; [5] Gross J. et al. (2011) *Meteoritics & Planetary Science*, 46, 116-133. [6] Castle N. and C.D.K. Herd, *LPSC*. 2014, p. 2334; [7] Asimow P.D. and M.S. Ghiorso (1998) *Am. Min.* 83, 1127-1132; Ghiorso M.S. and R.O. Sack (1995) *Cont. Min. Pet.* 119, 197-212; Gualda G.A.R. et al. (2012) *JPet*; [8] Herd C.D.K. (2008) *Reviews Min. Geochem.* 68, 527-553; [9] Herd (2003) *MaPS*. 38, 1793-1805; [10] Shearer C.K. et al. (2013) *GCA*. 120, 17-38.