

SMALL MELT INCLUSIONS IN OLIVINES FROM MARTIAN METEORITES: VALUE FOR CONSTRAINING ORIGINAL MELT COMPOSITIONS. Y. Sonzogni¹ (sonzogni@lpi.usra.edu) and A. H. Treiman¹, Lunar and Planetary Institute, 3600 Bay Area Blvd., Houston TX 77058.

Introduction: Near-primary mantle melts may be preserved in melt inclusions trapped in early-crystallized minerals [1]. Numerous studies have thus been devoted to investigating the nature and origin of melts preserved as inclusions inside phenocrysts from Martian basalts [2]. However, it has been suggested that small melt inclusions (e.g., < 20 μm diameter) are not useful in this quest, because boundary layer effects cause their bulk compositions to deviate substantially from those of the bulk parental magma (e.g., [3,4,5]). So, melt inclusion size has been considered as a limiting criterion for their use in studying petrogenetic processes, and previous studies on melt inclusions from Martian minerals focused on larger ones (> 50 μm ; e.g., [6,7,8]).

In this study, we evaluated the significance (or existence) of boundary layer effects on melt inclusion compositions to explore whether small inclusions can be useful in retrieving parent melt compositions of Martian meteorites. Our approach is to obtain chemical analyses by EMP on small (< 20 μm) and large (~50 μm) melt inclusions in olivine crystals in the Tissint olivine-phyric shergottite.

Samples and Methods: We obtained petrographic data, phase compositions, and bulk compositions from 12 small inclusions and 2 large inclusions in olivines from a thin section of Tissint, with the Cameca SX-100 EMPA at Johnson Space Center. Analytical conditions were 15 kV, 20 nA, 30-60 s count times, and 1- μm beam.

Bulk compositions of pure glass inclusions were obtained as point analyses. Bulk compositions of crystallized inclusions were calculated in two ways: 1) as the average of many point analyses; and 2) by multiplying the weight proportions of each phase (calculated from areal proportions) and the average composition of the phase. In calculating the average analysis, we took point analyses along parallel lines covering the inclusion. Line spacings ranged from 4 to 7 μm ; point spacing was 2 μm . Bulk compositions were calculated from each set of lines by averaging all analyses excluding wall olivine. Both methods give similar bulk compositions.

Inclusion Petrography: Melt inclusions in olivines from Tissint occur in two textures: small inclusions (<20 μm , mostly <10 μm) composed entirely of glass (Fig. 1a); and larger inclusions (to ~50 μm) that are partially crystallized (Fig. 1b). The small glassy inclusions are scattered throughout the olivines (core to rim) and contain only Si-rich glass (56-72 wt% SiO_2) \pm an oxide/sulphide(?) bleb (although some inclusions may contain micrometer-sized pyroxenes on the wall of the cavity). The larger partially crystallized inclusions are

found only near the cores of the largest (0.5 to 1.5 mm) olivine crystals. They contain Si-rich glass (59-66 wt% SiO_2), augite pyroxene ($\text{En}_{21-32}\text{Fs}_{18-24}\text{Wo}_{50-54}$) as rims on inclusion walls and as skeletal crystals, and rare blebs of oxide & sulphide phases.

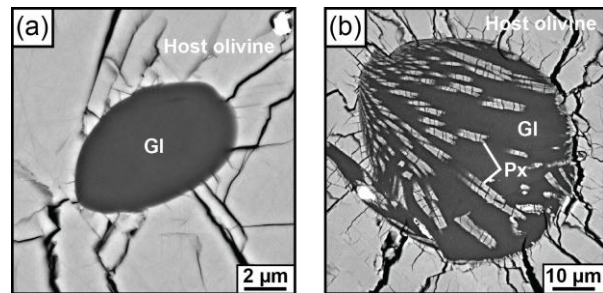


Fig. 1. BSE images of a small glass inclusion (a) and a large crystallized inclusion (b) in olivine crystals from the Tissint meteorite. Gl=Glass; Px=Pyroxene.

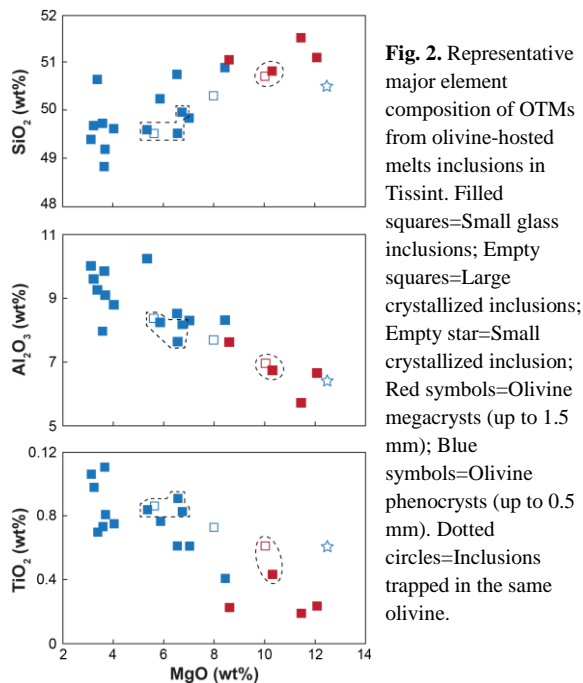
Original Trapped Melt: The composition of the original trapped melt (OTM) was reconstructed for each inclusion from its bulk composition by addition of wall olivine and correction for Fe-Mg equilibrium between the OTM and the host olivine [9] (Table 1). The amount of wall olivine to be added (25-52 wt%) is constrained to yield a melt composition co-saturated in olivine & low-Ca pyroxene (projected from Wo [10], for the Mg# of the Tissint's fusion crust). The Mg# of the OTM is adjusted to be in equilibrium with the host olivine using the Mg# of the wall olivine (Fo_{38-74}) and $KD_{ol-liq}^{Fe-Mg} = 0.35$ [11].

	Small inclusions	Large inclusions
SiO_2	48.8-51.5	50.3-50.6
TiO_2	0.19-1.10	0.61-0.73
Al_2O_3	6.7-10.2	6.4-7.7
FeO	23.1-30.1	22.1-22.7
MnO	0.30-0.47	0.28-0.35
MgO	3.1-12.1	8.0-12.5
CaO	3.5-9.2	6.0-9.0
Na_2O	0.62-1.7	0.31-0.61
K_2O	0.02-0.54	0.01-0.42
P_2O_5	0.38-0.92	0.63-0.71

Table 1. Range of major element concentrations of OTMs from olivine-hosted melt inclusions in Tissint.

Why small inclusions should be rehabilitated: OTMs from small and large inclusions follow the same line of magmatic differentiation (Fig. 2). In addition, OTM compositions from small and large inclusions trapped in the same olivine crystal are consistent. These two

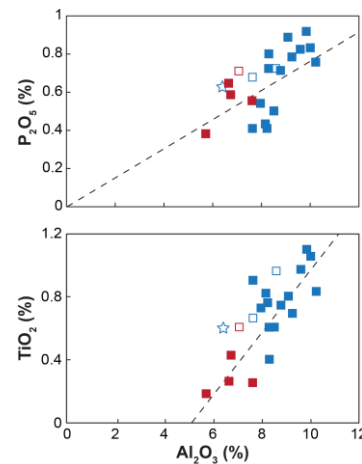
observations strongly suggest that both small and large inclusions sampled the bulk melt during intermediate steps in the evolution of the magma. Moreover, if the small inclusions had trapped a boundary layer at a fast-growth front, we would expect lower abundances of cations that diffuse slowly toward the growing olivine and higher abundances of cations that are incompatible with respect to olivine (such as Ti, Al, P) than in the larger inclusions. This appears not to be the case (Fig. 2).



If two elements have identical behaviors during melt differentiation, their abundance ratio in the melt ought to be the same throughout the differentiation process (e.g., [12]). Thus if small inclusions were affected by boundary layer effects, the abundance ratios of such elements in OTMs from small inclusions should be different from those in large inclusions. Figure 3 shows that this is not the case, further indicating that the liquids trapped in Tissint olivine crystals are representative of the bulk melts.

Our study shows that, for Tissint, the boundary layer around the growing-olivine had no effect on the composition of small (< 20 μm) inclusions. Thus, size alone is not a good criterion for selecting melt inclusions that may be derived simply from bulk magmas. Faure and Schiano [14] argued that, during polyhedral interface-controlled growth of igneous crystals, as appears to be the case for olivine in martian basalts, melt trapped in them is representative of the bulk melt whatever the size of the inclusion. Only melt inclusions formed during skeletal/dendritic diffusion-controlled growth have less representative compositions. Also, large inclusions in Martian minerals are often crystallized, making it difficult to retrieve their original composition. Taking these results

together, we strongly invite future workers to reconsider small glassy inclusions in the study of Martian basalts petrogenesis.



Future work: Two issues have not been resolved yet: (i) the SiO_2 vs. MgO trend of OTMs (Fig. 2) is not that expected in case of olivine fractionation but seems instead to evidence pyroxene crystallization, which is surprising for melt inclusions trapped in olivine crystals; (ii) the TiO_2 vs. Al_2O_3 trend of OTMs (Fig. 3) suggests that Al fractionated more than Ti during Tissint's parent melt differentiation, which appears to be again incompatible with standard olivine crystallization.

Future work will also involve modeling crystallization of the most primitive high-Mg OTM using *Petrolog3* [13]. We aim to reproduce the modal composition of Tissint as well as the chemical composition of its constituent minerals, which would provide a good test whether small glass inclusions in Tissint's olivines trapped a liquid that is representative of the bulk melt and whether that melt is representative of Tissint's parental magma.

References: [1] Roedder E. (1984) Rev. Mineral. 12, *Mineral. Soc. Am.*, 646 pp. [2] Ikeda Y. (2005) *Antarct. Met. Res.* 18, 170-187. [3] Albarède F. and Bottinga Y. (1972) *GCA* 36, 141-156. [4] Lu F. et al. (1995) *J. of Geol.* 103, 591-597. [5] Thomas J. B. et al. (2002) In: *Melt inclusions; Methods, Applications and Problems*, DeVivo B., Bodnar R. J. (eds). [6] Harvey R. P. and McSween H. Y. (1992) *EPSL* 111, 467-482. [7] Treiman A. H. (1993) *GCA* 57, 4753-4767 [8] Calvin C and Rutherford M. (2008) *Am. Mineral.* 93, 1886-1898. [9] Danyushevsky L. V. et al. (2000) *CMP* 138, 68-83. [10] Longhi J. (1991) *Am. Mineral.* 76, 785-800. [11] Filiberto J. and Dasgupta R. (2011) *EPSL* 304, 3-4, 527-537. [12] Treiman, A. H. (2003) *MAPS* 38(12), 1-16. [13] Danuyshevsky and Plechov (2011) *G³* 12(7), Q07021. [14] Faure and Schiano (2005) *EPSL* 236, 882-898.