Mg-Fe AND P-ZONING IN TISSINT OLIVINE AND PYROXENE: IMPLICATIONS FOR MARTIAN MAGMA CHAMBER DYNAMICS

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Introduction: Tissint is an exceptional martian sample, because it is an unusual depleted olivine-phyric shergottite that could testify to the composition of melts derived from the martian mantle and, despite being a find, it is remarkably fresh [1]. The rock's crystallization age is ~574 ± 20 Ma, based on Rb–Sr and Sm–Nd isotopic systematics [2]. We here report major element core-to-rim evolution of pyroxene and P-zoning in olivine in Tissint in order to provide new insights into the dynamics of its parental magma chamber.

Recently, zoning of phosphorus in olivines has been used as a recorder of crystal growth rate variations in magmatic systems [3, 4]. Phosphorus behaves incompatibly under partial melting conditions appropriate for martian magmatism [5]. Olivine crystals can incorporate relatively high concentrations of P during rapid growth events: this P comes from the elements remaining in the melt (solute trapping) after equilibrium partitioning. In terrestrial and extraterrestrial olivine the concentration of P_2O_5 ranges from below detection limits to 0.48 wt.%.

Methods: Major element chemical data and X-ray elemental maps were collected on four polished thin sections of Tissint at the Imaging Spectroscopy and Analysis Center of the University of Glasgow using a Zeiss-Sigma SEM equipped with an Oxford Instruments INCA system. Operating conditions were: working distance of 8.5 mm, beam current of 2.15 nA, and accelerating voltage of 20 kV. Acquired X-ray spectra were calibrated using mineral standards.

Results: Tissint pyroxenes (n = 21; in 4 thin sections) show normal zoning, with a core-to-rim compositional evolution from Mg to Fe, both in pigeonite and augite. The rims are relatively thin (~25-30 µm) with respect to the cores (~180-200 µm). Two types of core-to-rim zoning patterns are present: one from high-Mg to a Fe-Ca composition and another from high-Mg toward a pure Fe composition. This finding suggests longer and variable cooling conditions for the Tissint parent magma after crystallization of the first olivines [6].

Olivine in Tissint is normally zoned from core-to-rim (from Mg to Fe). Mg concentrations are variable and dependent on the crystal size. These olivines have a range from Fo_{73} in cores to Fo_{22} in rims, with an average of Fo_{43-61}. New data for P-zoning in Tissint olivines is comparable to recent analysis of P-zoning in martian olivines in shergottites [7]. Specifically, the largest olivine grains (~2 mm) have very low (~0.02 wt.%) or absent P in their cores but P_2O_5 concentrations increase toward their rims (~0.20 wt.%), while the smallest olivines (~100 µm) have higher concentrations of P_2O_5 independently of their cores and rims (ranging from ~0.05 to 0.25 wt.%).

Discussion: Some authors have suggested that Tissint was derived from the same volcano of Dhofar 019 (same crystallization ages, even if the two samples are isotopically different; [2]), so mixing with cooler and chemically distinct magmas (maybe a melt parental to Dhofar 019) could account for the differences in pyroxene zoning within Tissint. In addition, the significant Mg# range in Tissint olivine (Fo_{73} to Fo_{22}) is virtually identical to that of Dhofar 019 olivine (Fo_{72} to Fo_{25}).

However, the marked differences in P-zoning between large and small olivine grains suggests phenomena of vigorous convective mixing in the Tissint magma chamber [4]. The zoning of P in the smallest olivine and toward the rim of the largest grains is likely a result of solute trapping enhanced by the slow diffusion of P in the melt in combination with a fast magma cooling rate [3, 5]. This process could be related to convection-induced differential cooling in the magma chamber. For example, pyroxenes that evolved into a more Ca-rich compositions could have been saturated in these elements when they were in the upper (cooler) part of a magma chamber, because it was a region of super-saturation induced by heat loss. On the other hand, Ca-poor and Mg-rich pyroxenes evolved in the lower, warmer part of the magma chamber [8].

In conclusion, combining the two different pyroxene core-to-rim paths along with observed olivine P-zoning can provide useful insights into processes of martian magma chamber convection. This work could be important in constraining the thermal state of the martian mantle at the time of Tissint eruption.

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