The Tissint Martian meteorite: Raman spectroscopic characteristics of high-pressure polymorphs in melt pockets

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Tissint is a Martian meteorite that was witnessed falling to Earth on 18 July 2011 in the Oued Drâa valley region, east of Tata, Morocco. The rock has been classified as an olivine phyric shergottite (Irving et al., 2012). Based on a cosmic-ray exposure age, Tissint was lofted off the Martian surface 0.7±0.3 million years ago (Chennaoui Aoudjehane et al., 2012). The rock is highly fractured with numerous dark veins and patches of optically isotopic materials. In addition to its igneous-dominated mineralogy and texture typical of a basaltic shergottite, it contains multiple <0.1-0.5 mm-diameter subcircular to irregular-shaped vesiculated zones, referred to as melt pockets. The pockets consist of micro-mineral fragments (<0.5–20 μm) set in a finer matrix of microcrystallites, glass, and globular and anhedral grains of opaques.

Here we report the results of an investigation of melt pocket textures and mineral assemblages from a polished thin section of tissint fragments. Analytical field emission scanning electron microscopy (FE–SEM) and micro-Raman spectroscopy reveal that mineral fragments in the melt pockets are augite, low-Ca clinopyroxene, Al-rich clinopyroxene, olivine ($Fo_{60–70}$), plagioclase ($An_{61–64}$), troilite, calcium phosphate, ilmenite, and chromite inherited from the host rock. The matrix is composed of micron to sub-micron neo-crystallites of Ca-poor clinopyroxene, chromite, troilite and iron metal droplets. Most of the plagioclase has been converted to the optically isotropic phase (maskelynite). A broad Raman spectrum, similar to an amorphous state or glass, and a flow texture indicate that isotropic plagioclase (maskelynite) is glass quenched from shock-induced dense melts. Raman spectra with intense peaks at 790 and 840 cm^{-1} of ringwoodite [γ-$(Mg,Fe)_2SiO_4$], with a broad band at 680 cm^{-1} of a coexisting phase, were recorded at the inner rim of a melt pocket, adjacent to a host rock olivine phenocryst. In addition, olivine clasts in the pocket show a conflicting relationship between the Raman spectra and chemical analysis. The clast displays only a broad Raman band at 663 cm^{-1} (Fig. 1). The Raman signal at 680 cm^{-1} of the coexisting phase, with ringwoodite and olivine, and a broad Raman band at 663 cm^{-1} of the $(Mg,Fe)_2SiO_4$ phase, suggest the phase transformation of olivine to a high-density olivine polymorph with spinel structure.

There are abundant pyroxene clasts with different textures present in the melt pockets. Characteristic Raman signals of the pyroxene clasts occur in the 663–672 cm^{-1} and 965–1150 cm^{-1} regions (Fig. 2). The intense Raman band at ~1003 cm^{-1}, which is typical of internal vibrations of SiO_4 tetrahedrons of the pyroxene crystal structure, disappears in some pyroxene clasts. However, nucleated micro-crystallites of aluminous pyroxene with compositions of $MgSiO_3 \cdot 12–18$ wt% Al_2O_3 at the grain boundaries between maskylenitized clasts and cpx glass yield Raman spectra with double intense peaks at 663 and 667 cm^{-1}, and a broad feature in the high-frequency region of 800-1100 cm^{-1} (peak at 926 cm^{-1}). These features indicate nucleation of majorite on grain boundaries (Sung and Burns, 1976; Rauch et al., 1996; Ohtani et al., 2004). Stishovite occurs as microcrystals with dimensions 5 μm × 425 nm adjacent to majorite-pyrope solid solution clasts [$Mg_3(Fe,Al,Si)_2(SiO_4)_3$]. The $MgSiO_3$ clasts display an intense Raman band at 669 cm^{-1}.

The development of majorite and stishovite suggests that a precursor clinopyroxene phase dissociates into a high density polymorph with β-spinel structure and stishovite at 17.5 GPa (Akaogi and Akimoto, 1977). The co-existence of ringwoodite, spinel-type olivine polymorphs, merrillite, majorite, and stishovite indicate that the high pressure phases in the melt pockets of Tissint were formed under heterogeneous shock conditions of 16-23 GPa and 1400-2000 °C (Ohtani et al., 2004; El Goresy et al., 2013). This contrasts with bulk shock effects, which peak at around 15 GPa and 1000 °C.

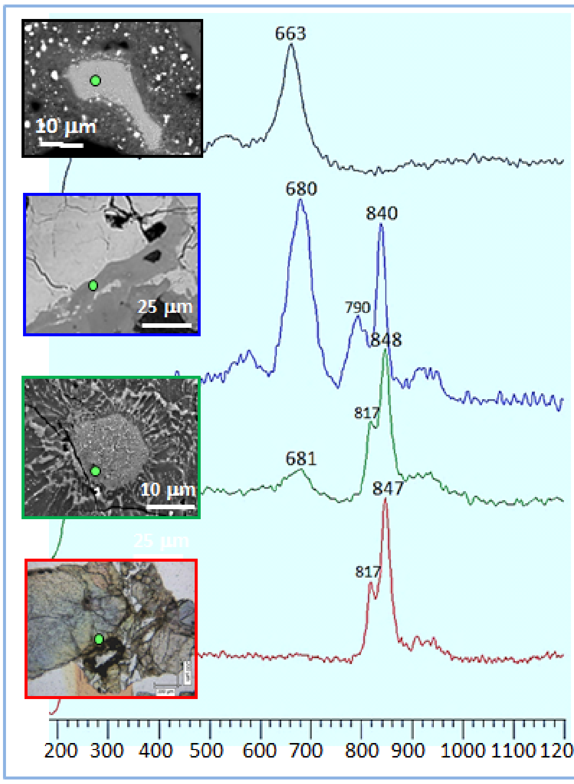

Fig. 1. *Raman spectra of Mg_2SiO_4 polymorphs.*

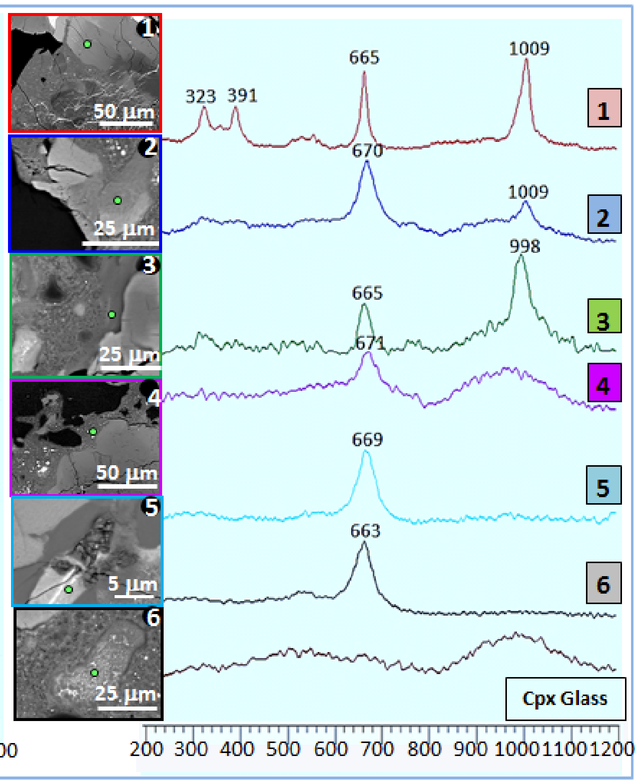

Fig. 2. *Raman spectra of $(Ca,Fe,Mg)_2Si_2O_6$ polymorphs.*

References:

Akaogi M, Akimoto S (1977) Pyroxene-Garnet Solid Solution Equilibria in the Systems $Mg_4Si_4O_{12}$–$Mg_3Al_2Si_3O_{12}$ and $Fe_4Si_4O_{12}$–$Fe_3Al_2Si_3O_{12}$ at High Pressures and Temperatures. Phys Earth Planet In 15:90–106

Chennaoui Aoudjehane H, Avice G, Barrat J-A, Boudouma O, Chen G, Duke MJM, Franchi IA, Gattacceca J, Grady MM, Greenwood RC, Herd CDK, Hewins R, Jambon A, Marty B, Rochette P, Smith CL, Sautter V, Verchovsky A, Weber P, Zanda B (2012) Tissint Martian meteorite: a fresh look at the interior, surface, and atmosphere of Mars. Science 338:785–787

El Goresy A, Gillet Ph, Miyahara M, Ohtani E, Ozawa S, Beck P, Montagnac G (2013) Shock-induced deformation of shergottites: shock-pressures and perturbations of magmatic ages on Mars. Geochim Cosmochim Ac 101:233–262

Irving AJ, Kuehner SM, Tanaka R, Herd CDK, Chen G, Lapen TJ (2012) The Tissint depleted permafic olivine-phyric shergottite: petrologic, elemental and isotopic characterization of a recent Martian fall in Morocco. 43rd Lunar Planet Sci XLIII #2510

Ohtani E, Kimura Y, Kimura M, Takata T, Kondo T, Kubo T (2004) Formation of high-pressure minerals in shocked L6 chondrite Yamata 791384: constraints on shock conditions on shock conditions and parent body size. Earth Planet Sci Lett 227:505–515

Rauch M, Keppler H, Häfner W, Poe B, Wokaun A (1996) A pressure-induced phase transition in MgSiO3-rich garnet revealed by Raman spectroscopy. Am Mineral 81:1289–1292

Sung C, Burns R (1976) Kinetics of high-pressure phase transformations: Implication to the evolution of the olivine → spinel transition in the downgoing lithosphere and its consequences on the dynamics of the mantle. Tectonophysics 31:1–32