HIGH-PRESSURE PHASES IN A MELT POCKET WITHIN AN OLIVINE MACROCRYST IN THE TISSINT MARTIAN METEORITE. Iona Summerson[1,2] (iona.summerson@gmail.com), Ansgar Greshake[2], Jörg Fritz[2], Wolf Uwe Reimold[2,3], [1]Freie Universität Berlin, Germany; [2]Museum für Naturkunde Berlin, Invalidenstr. 43, 10115 Berlin; [3]Humboldt-Universität zu Berlin, Unter den Linden 6, 10099 Berlin, Germany

Introduction

Tissint, the most recent of only five witnessed Martian meteorite falls, landed in Morocco in July 2011 [1]. The meteorite exhibits little to no terrestrial weathering, meaning that glass formed by shock melting during the impact on Mars has been preserved. In this study we searched for high-pressure polymorphs of the rock forming minerals, which form under high-temperature and high-pressure conditions in shock melt veins and pockets during an impact event [2-3]. Shocked meteorites present the only accessible natural samples of high-pressure mineral polymorphs of olivine and chromite [4]. These are also thought to be main constituents of the Earth's mantle, due to observed seismic discontinuities in the mantle [5].

Sample and methods

The sample available measures approximately 7.5 x 5 x 5 mm. A single thin section was used for optical microscopy and back-scattered electron (BSE) imaging and quantitative analyses were obtained with a Jeol JXA 8500F FE electron microprobe operated with 10 or 15 kV accelerating voltage, 15 nA beam current and beam sizes of 1-5 µm. An edge filter based Dilor LabRam Raman spectrometer operating with a HeNe Laser of 632 nm wave length was used for phase identification.

Petrography

Tissint belongs to the olivine-phyric shergottite group of Martian meteorites: olivine macrocrysts (up to 1.2 x 0.7 mm) are zoned with Mg-rich cores and Fe-rich rims and contain chromite, iron sulfides and primary melt inclusions. The groundmass consists of more ferroan olivine, clinopyroxene, maskelynite, chromite and iron sulfides. The meteorite is highly shocked with intense fracturing and localised shock melting. Olivine displays strong mosaicism, planar fractures and irregular fractures. Pyroxene has been mechanically twinned and intensely fractured. Plagioclase is completely transformed to maskelynite. In the thin section studied, localised melting formed two large melt pockets with schlieren structures and bubbles. Several shock melt veinlets cross the matrix.

Olivine macrocryst

One olivine macrocryst deserves particular attention.
This crystal is approximately 1.2 x 0.7 mm in size, euhedral and patchily zoned. It has a thin ferroan rim (up to $Fa_{56.4}$) and the core is composed of $Fa_{<21.8}$. Euhedral chromite, sulfides and primary melt were enclosed during crystallisation. The trapped primary melt inclusions (up to 180 µm in diameter) crystallised to heterogeneously zoned clinopyroxene (up to 16.6 wt. % CaO), olivine and spinel. One pyroxene crystal has a zoned spinel inclusion, the core of which consists of Mg-Al chromite ($Fe_{0.7}$ $Mg_{0.4}$ $Cr_{1.1}$ $Al_{0.7}$) and the rim of Mg-Fe spinel ($Mg_{0.6}$ $Al_{1.9}$ $Fe_{0.4}$ O_4). These spinels are also found in the mesostasis of the inclusion.

Besides the primary melt inclusions a shock-induced melt pocket (Fig. 1) was found within the olivine macrocryst.

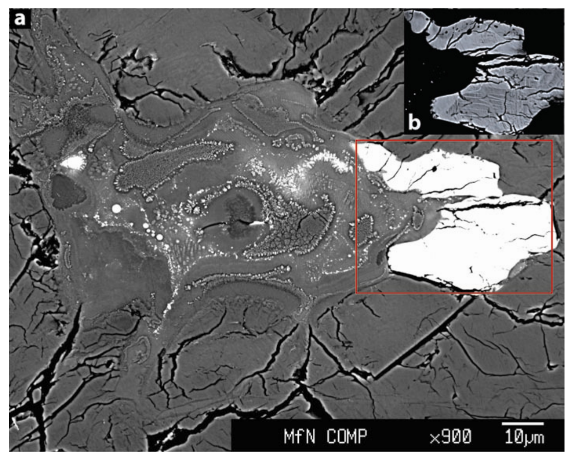

Fig 1: a) Back-scattered electron image of a melt pocket within an olivine macrocryst. b) Enlargement showing lamellae of the high-pressure polymorph of chromite.

The approximately 80 x 50 µm sized melt pocket contains entrained crystalline fragments, tiny rounded to dendritic crystallites, partly dissolved chromite, and rounded FeS droplets all set into a glassy groundmass. Crystalline fragments often serve as crystallisation nuclei for sub-micrometer dendritic crystals. X-ray elemental mapping and Raman spectroscopy identify these dendrites as (Mg,Fe,Cr)O ferropericlase. The regions adjacent to the ferropericlase crystallites are significantly enriched in silicon and very likely represent vitrified $MgSiO_3$-perovskite (Fig. 1).

Raman spectra show that one of the crystalline fragments within the melt pocket, as well as some areas at the melt pocket-host olivine crystal contact have been transformed to the olivine high-pressure phase ringwoodite (Fig. 2).

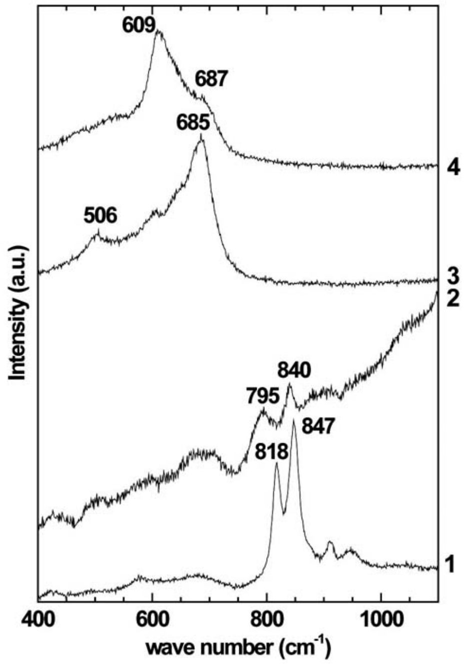

Fig 2: Raman spectra of 1: olivine, 2: ringwoodite, 3: chromite, 4: $CaTi_2O_4$-structured chromite.

The groundmass appears dominantly glassy and yields Raman spectra characteristic for amorphous materials. Compositionally it is mostly olivine-normative, however three exceptionally Ca-rich areas occur in the melt pocket (Fig. 3), with Ca contents ranging between 9.3 and 16.7 wt. %. They are round to oval in shape and up to 14 µm wide.

The melt pocket is bordered on one side by a chromite grain, the top of which appears to have been sheared and displaced and one corner seems plastically deformed. Raman spectra identified high-pressure phases of chromite (Fig. 2) along lamellae observed in back-scattered electron images (Fig. 1b).

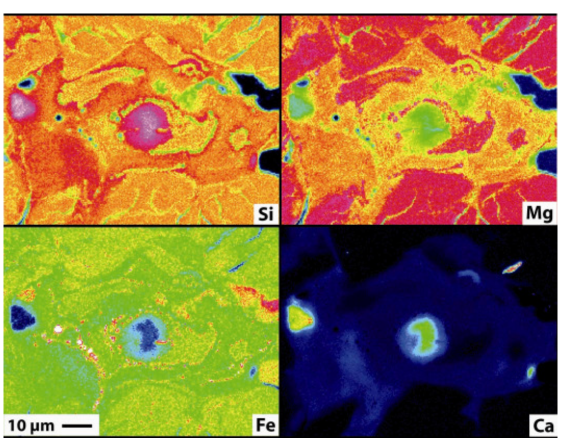

Fig 3: X-ray elemental mapping of shock melt pocket. Note the three Ca-rich areas and the SiO_2-rich halos around ferropericlase.

Discussion

The high-pressure mineral assemblage of ringwoodite, ferropericlase, and $CaTi_2O_4$-structured chromite found in the Tissint melt pocket closely resembles that found in shock-induced melt pockets in the Martian meteorite Chassigny [4]. It seems reasonable to assume that locally generated high shock pressures and temperatures lead to melting within the olivine macrocryst. At pressures above 23 GPa first the entrained olivine fragments partly to completely decomposed into ferropericlase and (Mg,Fe)SiO_3-perovskite via solid state transformation mechanisms [5]. Upon cooling and at pressures >23 GPa, ferropericlase and (Mg,Fe)SiO_3-perovskite were the first phases to crystallize from the melt. Subsequent decrease of the confining pressure (18-23 GPa) lead to the transformation of an entrained olivine fragment and regions directly adjacent to the melt pocket to ringwoodite. The small size and rounded to dendritic shape of the ferropericlase crystals as well as the preservation of ringwoodite attest to high cooling rates. Chromite at the pocket's margin is partly transformed into a $CaTi_2O_4$-structured high-pressure polymorph, that preferentially grew along certain crystallographic orientations of the parent chromite at pressures >20 GPa [7].

In contrast to similar melt pockets in Chassigny, in Tissint three Ca-rich areas were found that cannot be explained by in situ melting of only the olivine host. We assume that melting also included a clinopyroxene grain as frequently found in primary melt inclusions within the olivine host crystal. Such inclusions typically contain olivine, spinel, and clinopyroxene with nearly identical maximum CaO contents (16.6 wt. %) to those measured in the Ca-rich areas in the shock melt pocket (16.7 wt. %). This pronounced compositional difference to the host olivine therefore suggests that the shock melt pocket containing high-pressure polymorphs formed by shock-induced melting of a crystallized primary melt enclosed in the host olivine.

Further investigations will determine whether high-pressure polymorphs of clinopyroxene are present.

References [1] Chennaoui et al. (2012) Science 338, 785-788 [2] Xie et al (2007) LPSC *XXXVIII*, *Abstract.* [3] Chen et al. (2003) Geochim. Cosmochim. Acta 67, 3937-3942. [4] Fritz and Greshake (2009) Earth Planet. Sci. Lett. 288, 619-623. [5] Ohtani and Sakai (2008). Phys. Earth Planet. Int. 170, 240–247. [7] Chen et al. (2003) PNAS 100, 14651-14654.