HEMATITE IN TISSINT SHOCK MELT GLASS: INVESTIGATING THE POSSIBILITY OF A MARTIAN NEAR-SURFACE COMPONENT IN SHERGOTTITES.

C. R. Kuchka[1], C. D. K. Herd[1], and E. L. Walton[1,2]. [1]Dept. of Earth & Atmospheric Sciences, University of Alberta, Edmonton, Canada, [2]Dept. of Physical Sciences, MacEwan University, Edmonton, Canada.

Introduction: We report the previously-undocumented occurrence of hematite associated with shock-generated melt features in the Tissint meteorite. Tissint in particular has been the target of several recent studies searching for evidence for a possible surface component trapped in shock melt glass [1,2]. Tissint is a good candidate to search for surface components as melt glass is pervasive in Tissint and the meteorite was collected within months of falling in the Moroccan desert. In the desert environment, any terrestrial weathering in this meteorite will be minimal, owing to a short residence time on the surface of Earth prior to collection.

Several recent studies have reached contradictory conclusions regarding the possible inclusion of Martian surface materials in shergottites: [1] concluded that Tissint does indeed contain a surface component based on the relative enrichment of LREE in shock-melt glass compared to the groundmass, and the correlative enrichment of LREE and trapped Martian atmosphere. On the contrary, [2] found no evidence for LREE enrichment in their Tissint samples and concluded that no Martian surface component is present. [1,3] concluded that lithology C of EETA 79001 contains no surface components, and that shock melt composition reflects localized partial melting of groundmass mineralogy.

We purport that individual shock melt pockets are unique; some pockets may incorporate surface components while others may not. Shock melt pockets are known to form via shock by grain-boundary friction and shock-impedance contrasts or by collapse of pre-existing cracks or voids [4]. Because the rocks are heterogeneous, comprised of several different minerals of varying size, composition, and orientation, distinct mechanisms of shock melt pocket and shock vein formation are likely to be involved in the same rock. Some proportion of melt features would be caused by void collapse as the shock wave travels though the rock, and it is possible that some of these pre-existing voids may have contained Martian surface components. It should be noted that shock melt glass has a non-homogeneous composition on the scale of an individual glassy region; individual shock melt regions may have unique geochemical signatures not reflected by other glasses in the same meteorite. Tissint is an optimal sample in which to test this hypothesis.

Methods and results: Thin sections of Tissint were analyzed on a Zeiss Evo MA LaB_6 filament SEM and a Bruker Senterra Raman spectrometer, using the 100× objective of a microscope to focus the excitation laser (532 nm line of Ar+ laser) to a ~1 µm spot. Sections were mapped for areas of interest using the BSE imaging mode before analyses by micro-Raman spectrometry. Microscopic spots <10 µm were identified as "iron oxides" by EDS spectrometry. On Raman analyses, several of these spots exhibited two strong peaks, one ~214-224 cm^{-1} and another ~274-294 cm^{-1}, characteristic peaks for hematite, with variability in peak position owing to variation in grain size and crystallinity [5]. Hematite was observed in shock-induced melt glass and associated with phases adjacent to shock melt, particularly pyrrhotite (Figures 1, 2). Other iron-bearing oxides identified in this study include magnetite, magnesiowüstite, chromite, and titanomagnetite.

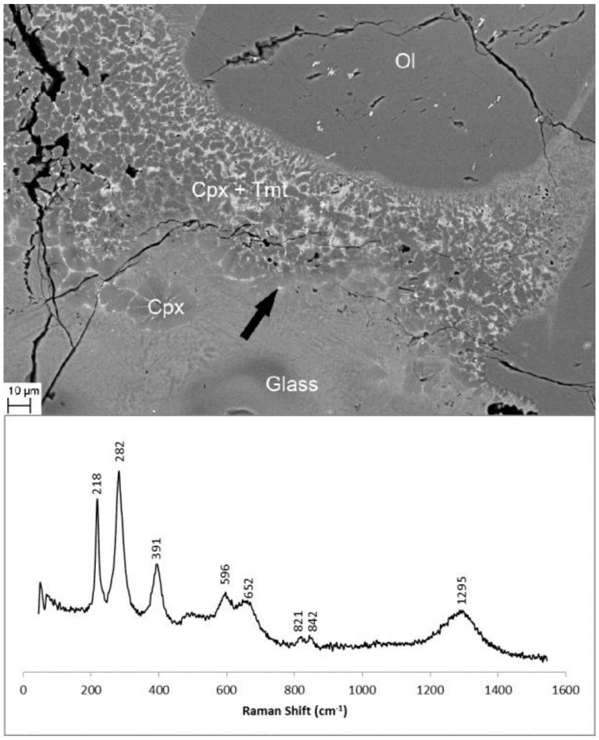

Figure 1: BSE image of a shock-induced melt pocket in Tissint. White specks in olivine are igneous chromite inclusions. Clinopyroxene has quenched from the melt as radiating or subhedral grains with interstitial oxide stringers. Black arrow indicates Raman analysis spot within a shock melt pocket. Strong peaks at 218 and 282 cm^{-1} are characteristic of hematite [5]. Ol = olivine, Cpx = clinopyroxene, Tmt = titanomagenetite.

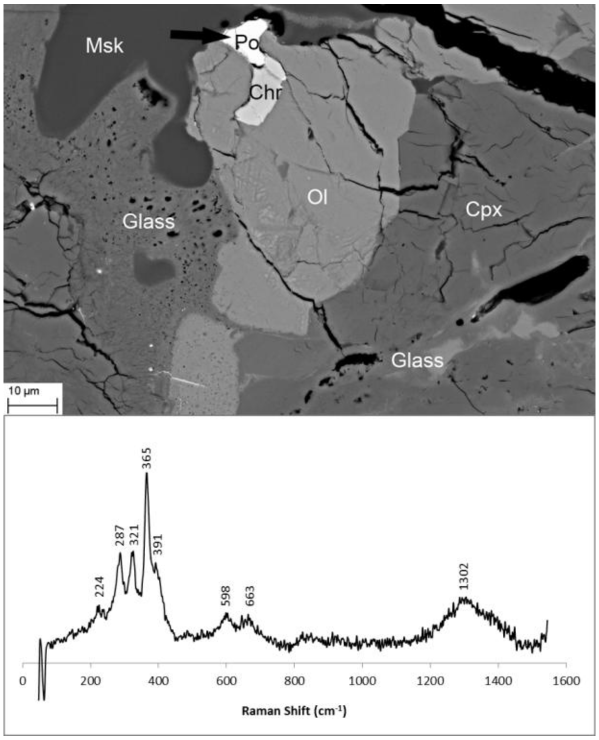

Figure 2: BSE image of sulfide and oxide grains associated with an olivine grain adjacent to shock melt glass. Arrow indicates Raman analysis spot on a pyrrhotite grain. Raman peaks at 214 and 287 cm^{-1} indicate a hematite component. Ol = olivine, Msk = maskelynite, Cpx = clinopyroxene, Po = pyrrhotite, Chr = chromite.

Discussion: Terrestrial alteration of meteorites can result in secondary mineralization, including by hematite, even in hot deserts in a relatively short time (tens of years, [6]); however, it is unlikely that Tissint experienced significant weathering during its 3-month residence on Earth prior to collection [1].

The origin of hematite by local melting of igneous phases may be ruled out because hematite represents a much higher oxygen fugacity relative to that represented by the iron-titanium oxides in the meteorite; igneous crystallization conditions of ~IW+2 [7] are far too low to allow the formation of hematite (and magnetite).

[1] proposed that shock-induced melting in Tissint occurred along fractures in which near-surface weathering products were concentrated. It is possible that the hematite found in shock melt pockets has been incorporated from a near-surface component on Mars. A Martian origin for hematite would be consistent with near-surface weathering products, as hematite is ubiquitous on the Martian surface [8].

Hematite associated with pyrrhotite (Figure 2) may be a shock-related alteration product. Pyrrhotite will alter to hematite (via magnetite) in a highly-oxidizing environment > 450 °C [9]. At such temperatures, terrestrial alteration is unlikely but this temperature is easily exceeded by shock and subsequent melt formation [3,4]. The high oxygen fugacity may have originated from a near-surface component within a pre-existing fracture subsequently becoming incorporated into the rock during void collapse and subsequent melt pocket formation following an impact event.

A number of additional mechanisms are involved in the formation of shock melt pockets, and as such any near-surface materials may be heterogeneously trapped. The initial distribution of Martian weathering products in the pre-shocked rock is also presumably non-uniform, contributing to the heterogeneous distribution of shock melt glass in the meteorite and the heterogeneous distribution of incorporated surface components therein.

Shock melt pockets that exhibit hematite as either a component of glass or as an alteration product of pyrrhotite should be considered as targets for a possible surface-related LREE signature such as the shock melt glass studies by [1]. It is expected that those shock melt pockets lacking secondary minerals such as hematite are more likely to lack a Martian near-surface geochemical signature, such as glasses studied by [2,3].

Conclusion: Hematite in Tissint is associated with shock melt pockets, exhibited as either a component of the shock melt glass or as an alteration product of pyrrhotite in a hot, highly-oxidizing environment. Preliminary identification of hematite may aid in determining which shock melt pockets may have a geochemical signature indicative of incorporation of Martian near-surface weathering products as reported by [1]. As shock melt glass is pervasive, first identification of hematite should prove useful for prioritizing regions for studies searching for Martian near-surface components in shergottites.

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