

UNUSUAL INTERACTION BETWEEN MARTIAN SURFACE AND MAGMATIC RESERVOIRS: VOLATILES IN IMPACT MELTS IN THE TISSINT METEORITE. Yang Chen¹, Yang Liu¹, Yunbin Guan², John M. Eiler², Chi Ma², George R. Rossman², and Lawrence A. Taylor³. ¹Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA 91109, USA; ²Geol. & Planet. Sci., California Institute of Technology, Pasadena, CA 91125, USA; ³Planet. Geosci. Inst., Dept. of Earth & Planet. Sci., Univ. of Tenn., Knoxville, TN 37996, USA; (Email: Yang.Chen@jpl.nasa.gov).

Introduction: It is well known that impact melts in Martian meteorites are often gas-rich, and contain noble gases of similar isotope compositions as the Martian atmosphere [1]. In detail, hydrogen and noble gas isotopes demonstrate that these melts may contain volatiles coming from both surface and deep mantle reservoirs [2,3]. However, only two studies have investigated hydrogen in mafic impact melts [2,3], and the data show a large discrepancy.

The Tissint meteorite was collected shortly after its fall and is one of the freshest Martian meteorites to date [4]. It is an olivine-phyric shergottite, highly depleted in incompatible elements similar to Yamato (Y) – 98045. Previous studies suggested the Tissint meteorite experienced the strongest shock effects among shergottites [5,6]. Furthermore, the Tissint meteorite contains glassy impact melts up to 3 mm in diameter (Fig. 1). Hence, it is an excellent candidate for examining hypotheses of impact-melt formation and its volatile characteristics. Here, we report volatile contents and H-isotope compositions of impact melts in Tissint, and examine their implications for water reservoirs and impact processes on Mars.

Methods: Major-element concentrations were measured by a JEOL JXA-8200 EMP. Hydroxyl (OH), F, Cl, and S in impact melt from 9 pockets and 7 maskelynite grains were determined by a Cameca 7f-Geo SIMS. Carbon was also analyzed as an indicator for terrestrial contamination. Terrestrial volcanic glasses and synthetic glasses were used as standards for SIMS analysis. The 2σ uncertainties (including contributions from counting statistics and uncertainties of the standards) are 120 ppm for H₂O, 7 ppm for F, 2 ppm for S, and 20 ppm for Cl. The detection limits are 10 ppm for H₂O, and less than 1 ppm for F, Cl and S. Data displaying contamination signal are not included here. The instrument mass fractionation (IMF) on D/H ($\alpha = 0.952$) was determined with several terrestrial glass standards and applied to all data reported here. The 2σ uncertainty for δD is about 50 %, including counting statistics and uncertainty in IMF.

Results: Major-element compositions of the impact melts are basaltic, consistent with melting of the groundmass (pyroxene and maskelynite), with a minor contribution from olivine, phosphates, and oxides. There is no clear correlation between CaO and P₂O₅ or

signs of an exotic component. The maskelynites reported here show a narrow composition of An₆₂Ab₃₄, falling within the composition range reported by previous studies of this meteorite [e.g., 4,5].

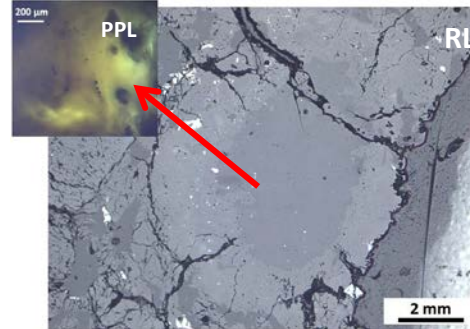


Figure 1. An example impact melt in the Tissint meteorite, showing a large, glassy interior. RL: reflective light, PPL: transmitted, plain polarized light.

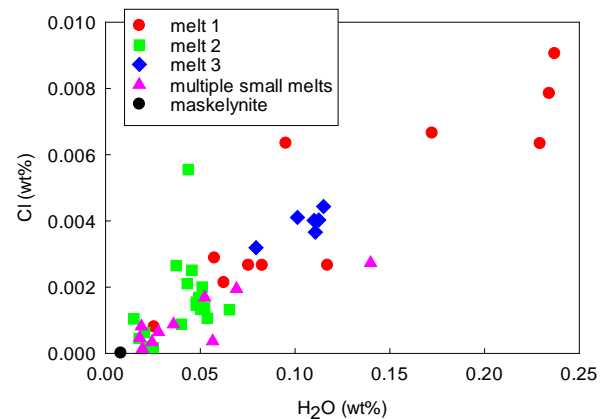


Figure 2. Positive correlation between H₂O and Cl in the impact melts in the Tissint meteorite.

Volatiles in Maskelynite: The volatile abundances in maskelynite are uniform and low. H₂O varies from 80 to <10 ppm; F, Cl, and S are below detection limits (<1 ppm). The δD values vary from -181 to 16 ‰. One exceptional point has a δD value of 1171 ‰. Although H₂O concentration was not quantitatively measured at this spot, the ¹H count suggests that it has similarly low H₂O concentration as other maskelynites.

Volatiles in Impact Melts: Volatile contents in melt pockets are highly variable: H₂O ranges from 2370 to 120 ppm, F from 84 to <1 ppm, Cl from 91 to <1 ppm, and S from 4380 to <1 ppm. The contents of

H₂O, F, and Cl show positive correlations, within each melt pocket, as well as in the whole dataset (Fig. 2). The δD values also show large variations (-400 to 4140 ‰) and correlate positively with ¹H counts and H₂O concentrations.

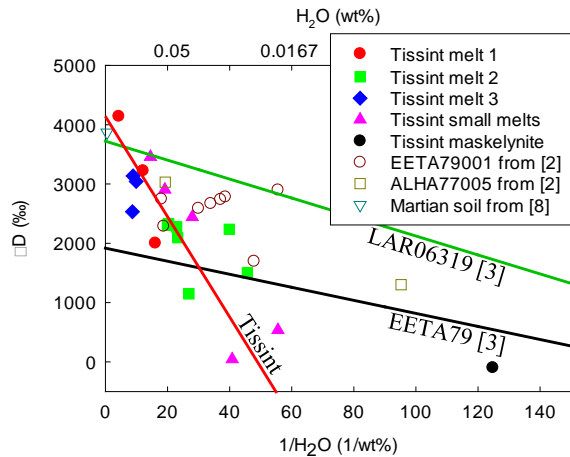


Figure 3. Comparing the impact melt in Tissint with other Martian meteorites. The Tissint data define a steeper mixing line, reflecting higher H₂O concentration in its magmatic reservoir. Only fitted lines from [3] are shown here, and the line for EET 79001 is defined by only two points.

Discussion: The δD - 1/H₂O plot of the Tissint data (Fig. 3) shows mixing between two reservoirs: surface (high H₂O and δD) and magmatic (low H₂O and δD).

Surface reservoir and incorporation mechanisms: One reservoir (intercept at y-axis) contains high H₂O concentration (close to wt% level) and high δD value (about 4000 ‰). This δD value is in general agreement with those of Martian atmosphere (~5000 ‰ e.g., [7]), Martian surface soil (e.g., 3870 ‰ in [8]), and magmatic apatite in shergottites (2794 to 4606 ‰ [9,10]). The high H₂O concentration and the lack of correlation between H₂O and P₂O₅ suggest *this reservoir is unlikely to be magmatic apatite*. Also, the carbon concentration in the impact melts is low, suggesting *any possible atmosphere contribution is indirect*.

Other possible sources are surface soil, weathered secondary minerals, or pre-existing vesicles. It was suggested that Martian surface soil could be injected, melted, and mixed into the sample to form melt pockets [e.g., 11]. However, the major-element and volatile compositions of the impact melts do not clearly support this model. We also found no secondary minerals in the Tissint meteorite. Instead, our data are consistent with impact collapse of vesicles [ref. in 12], which may have captured some surface volatiles during interaction between basaltic magma and crustal water. On

the basis of F and Cl concentrations (Fig. 2), *this reservoir may also contain a significant amount of brine*.

Magmatic reservoir: The other end of the mixing line (Fig 3) points toward a reservoir of low water concentration and low δD value, which is likely a magmatic reservoir. Literature estimates of concentration and isotope composition of water in the Martian mantle show large variations. Watson et al. [9] estimated that the pre-degassing H₂O of SNC would have δD <500 ‰. Usui et al. [3] reported contrasting data from melt inclusions: those from Y-980459 show 146 ppm H₂O and a δD value similar to Earth, while one inclusion from LAR 06319 show a high H₂O content and elevated δD similar to Martian atmosphere and impact melt. Apatite in nakhalite and other samples suggest a source comparable to Y-980459 [10,13-15]. Thus, using δD values from 0 to 500 ‰, we infer that the pre-impact magmatic water in the Tissint meteorite was 200-250 ppm. Such water might be stored as trace OH in primary silicate minerals before impact. *Our data offer a new way to infer pre-impact water concentration considering the possible impact effect on apatite* (e.g., [13]).

Implications: Impact melts in the Tissint meteorite contain the highest water content measured to date, supporting the hypothesis that stronger impact shock may yield higher water content [12]. The magmatic component (200-250 ppm H₂O; δD of 0-500 ‰) is broadly consistent with that inferred from apatite [10,13]. Magma degassing is one main source for the Mars atmosphere [16]. Given the prolonged magmatic history on Mars, *it is intriguing that H₂O from volcanic outgassing with low δD has not significantly affected Martian atmosphere, which appears to retain its high δD since ~4 Ga* (e.g., [10,13]).

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