Multiple Martian Volatile Reservoirs Preserved in Tissint and Other Martian Meteorites. Yang Chen[1], Yang Liu[1], Yunbin Guan[2], John M. Eiler[2], Chi Ma[2], George R. Rossman[2], and Lawrence A. Taylor[3]. [1]Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA 91109, USA; [2]Geol. & Planet. Sci., California Institute of Technology, Pasadena, CA 91125, USA; [3]Planet. Geosci. Inst., Dept. of Earth & Planet. Sci., Univ. of Tenn., Knoxville, TN 37996, USA; (Email: Yang.Chen@jpl.nasa.gov).

Introduction: Volatiles affect strongly the physical, chemical, and biochemical processes, hence have been long recognized as key components in planet evolution. It is well known that some Martian meteorites contain abundant volatiles, whose chemical signatures suggest contributions from multiple volatile reservoirs, including Martian atmosphere and possibly Martian mantle [e.g., 1, 2, 3]. However, the presence and interaction of the different volatile reservoirs in the Martian rocks before and during impact may be complicated. For example, recent studies on water abundance and hydrogen isotopes in impact melts and maskelynite do not show simple and consistent relations [2, 3, 4].

In [5], we reported volatile contents and hydrogen isotopes of impact melts in Tissint. Here, we present data of impact melts and maskelynite in EETA 79001, LAR 06319, and ALHA 77005. The Tissint meteorite is the most recent fall [6]. It is an olivine-phyric shergottite, depleted in incompatible elements [6]. It contains abundant high-pressure phases that indicate strong shock metamorphism [7, 8]. The large and glassy impact melts in Tissint are ideal for volatile study (Fig. 1). In comparison, regions of impact melting in the other three meteorites contain micro-crystals with much narrower interstitial glass.

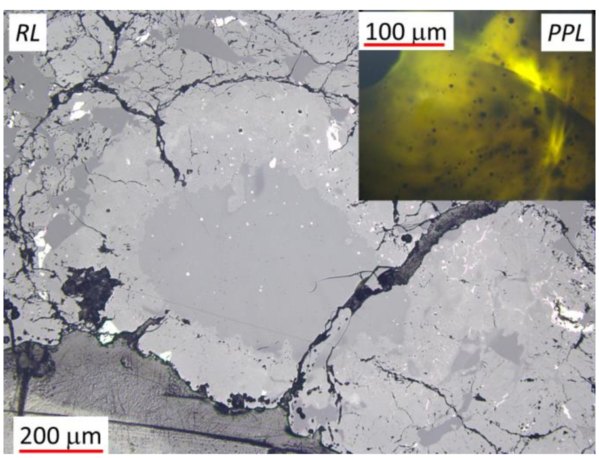

Figure 1. *A large impact melt in the Tissint meteorite with a glassy, transparent interior. RL: reflective light, PPL: transmitted, plain polarized light.*

Analytical Methods: Major-element concentrations were measured with an electron microprobe. Hydroxyl (OH), F, Cl, and S were determined with a secondary ion mass spectrometer (SIMS). Carbon was also monitored as an indicator of terrestrial contamination. The areas of interests and each SIMS spot were examined with a scanning electron microscope (SEM) before and after SIMS analyses. Natural and synthetic glasses were used as standards for SIMS analysis. The 2σ errors for the volatile concentrations are about 10%. The background values are 28 ppm for H_2O, 0.5 ppm for F, and 0.1 ppm for Cl and S, estimated using the lowest concentrations in maskelynite. The instrument mass fractionation (IMF) correction (α = 0.908 and 0.952 for two analysis sessions) on D/H ratios was determined with several terrestrial glass standards. The 2σ errors for δD values are about 50 ‰.

Terrestrial contamination has been a major concern for volatile analysis of Martian meteorites. Despite great efforts in sample preparation without using water, terrestrial contamination is still present in samples [e.g., 2, 8]. In order to minimize contamination in this study, the analysis spots were chosen in glassy regions to avoid phase boundaries, which could complicate data interpretation. During SIMS analysis, C and OH secondary ion images were frequently used to avoid suspiciously strong signals. The analytical points with cracks and holes, typically with high water content and terrestrial D/H rations, are excluded. Due to these efforts and the freshness of Tissint, the dataset show no sign of terrestrial contamination (Fig 3).

Results: Major-element compositions of the glassy regions in the impact melts in Tissint, EETA 79001, and LAR 06319 are similar, and consistent with mixing of pyroxene, maskelynite, and olivine, with minor contributions from phosphates and oxides. The maskelynites in Tissint show a composition of $An_{62}Ab_{34}$, falling within the composition ranges reported in previous studies [e.g., 6, 7].

Volatiles in Impact Melts: Among the four meteorites, the impact melts in Tissint contain the most abundant volatiles: H_2O ranges from 151 to 3543 ppm; F from 1 to 87 ppm; Cl from 0.4 to 93 ppm; and S from 0.5 to 4783 ppm. The contents of H_2O, 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 (-412 to 4963 ‰) and correlate positively with H_2O concentrations.

Data of the impact melts in the other three meteorites are limited and less reliable, due to the limited glassy regions in those impact melts. The impact melts in EETA 79001 and LAR 06319 contain similar H_2O (100-300 ppm). EETA 79001 contains 1-14 ppm F, 0.4-53 ppm Cl, and 0.1-2639 ppm S. LAR 06319 contains 16-37 ppm F, 54-93 ppm Cl, and 135-252 ppm S. The impact melts in ALHA 77005 contain the least amount of volatiles: 59-70 ppm H_2O, 2-3 ppm F, 1-2 ppm Cl, and 97-199 ppm S. In contrast to Tissint, these three meteorites show narrow ranges of δD values (Fig 3). EETA 79001 show δD values from 2837 to 4478 ‰, LAR 06319 from 1583 to 2637 ‰, and ALHA 77005 from -256 to -217 ‰. The very negative values in ALHA 77005 likely reflect background values.

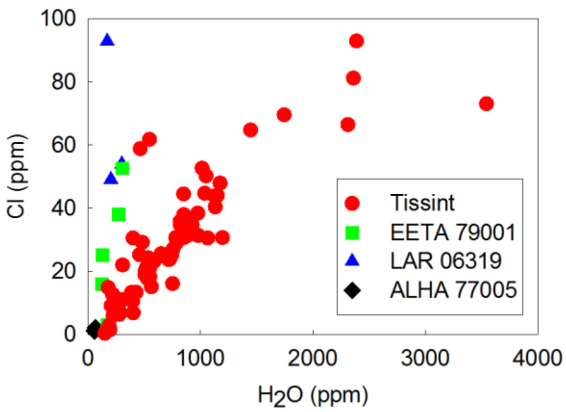

Figure 2. *Positive correlation between H_2O and Cl in the impact melts in the Tissint meteorite, and comparison to other meteorites.*

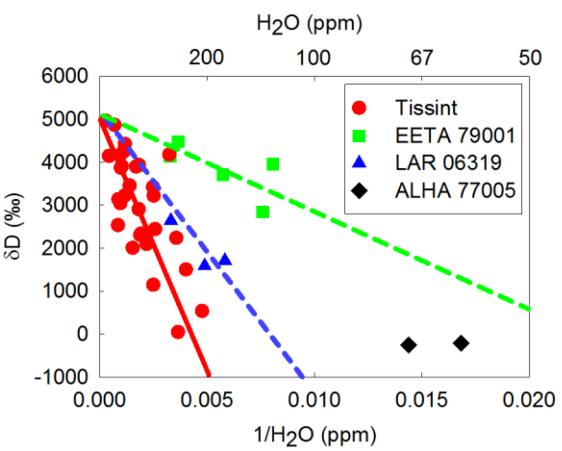

Figure 3. *H_2O concentration and hydrogen isotopes in the impact melt in Tissint and other Martian meteorites.*

Volatiles in Maskelynite: The volatile abundances in maskelynite in the four meteorites are low. H_2O varies from 28 to 111 ppm; F from 0.5 to 2 ppm, Cl from 0.1 to 5 ppm, and S from 0.1 to 26 ppm. The lowest values are used as approximate and conservative estimates of the background levels of the volatiles for the SIMS analysis. Most of the impact melt data, except for those of ALHA 77005, show volatile concentrations much higher than the background levels.

The maskelynites in Tissint and ALHA 77005 show δD values from -222 to 296 ‰. Those in EETA 79001 and LAR 06319 show more positive values: 1604-2849 ‰ in EETA 79001, and 1009-1763 ‰ in LAR 06319. Our limited data do not show large variations in H_2O concentration and hydrogen isotopes in maskelynite in Tissint as reported earlier [4]

Discussion: The δD - 1/H_2O plot of the Tissint data suggests a mixing between two reservoirs: volatile-rich and volatile-poor (solid red line in Fig 3). The data for EETA 79001 and LAR 06319 do not show clear mixing trend, but are potentially consistent with mixing of a common volatile-rich H_2O reservoir and different volatile-poor reservoirs for each meteorite (dashed lines in Fig 3). Note, importantly, that the F, Cl, and S contents in the volatile-rich reservoir are different for different meteorites. Data for ALHA 77005 are close to SIMS background, and do not show any contribution from a volatile-rich reservoir based on δD values and volatile concentrations.

The volatile-rich reservoir shows some chemical signatures similar to present Mars atmosphere and surface materials, such as abundant H_2O, Cl, and S, and high δD values [e.g., 9, 10]. The high H_2O concentration and the lack of correlation between H_2O and P_2O_5 suggest this reservoir is unlikely solely to be magmatic apatite. The volatile-poor reservoir, given its low δD values, is possibly a pre-impact magmatic reservoir [3, 11-15]. Assuming δD values from 0 to 500‰ for magmatic H_2O, the pre-impact magmatic H_2O in the Tissint meteorite was approximately 200 ppm.

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