AMPHIBOLE IN THE TISSINT MARTIAN METEORITE: COMPOSITION AND IMPLICATION FOR VOLATILE CONTENT OF PARENTAL MAGMA.

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Introduction: Titanium-rich amphibole is present in melt inclusions in many martian (SNC) meteorites, suggesting that martian magmas contained water. Amphibole has been reported within melt inclusions in olivine grains in chassignites [1, 2], and within melt inclusions in pigeonite grains in most shergottites [3-9]. Here, we report on similar amphiboles in the new Tissint shergottite, and compare them to amphiboles in the shergottite Elephant Moraine (EETA) 79001, Lithology A.

Kaersutitic amphibole is rare but widespread in the martian meteorites, and will be useful in constraining volatile abundances in martian magmas and in the martian mantle. Amphibole incorporates hydroxyl into its structure in its O(3) site, which can also contain F^-, Cl^-, and O^{2-}. Previous chemical analyses of amphiboles in martian meteorites show low halogen abundances, implying high proportions of OH^- and/or O^{2-} in the O(3) site [5, 10]. Our chemical analyses expand the database of martian kaersutites, and provide constraints on kaersutite volatile contents which, in turn, constrain the volatile content of their parent magmas.

Petrography: Amphiboles were identified in polished thin sections of Tissint and EETA79001 by their yellow-orange to light brown pleochroism. Consistent with previous observations [3-9], the amphiboles are present only in melt inclusions in pigeonite grains, and never in augite, olivine, or mesostasis. Amphibole grains are subhedral, and range up to 15 μm in diameter (although their exposures at thin section surfaces rarely exceed 5 μm). The melt inclusions are < 25 μm in diameter and irregular in shape. Beside silicic glass, amphibole is the only phase observed in the melt inclusions.

Methods: Chemical analyses were obtained with the CAMECA SX-100 Electron Microprobe at Johnson Space Center, using a 15 keV accelerating potential and a 10 nA, 1-micron-diameter beam. Point analyses of the inclusion melt and line analyses of the host pyroxene grain were taken for each amphibole.

Amphibole formulae were calculated from chemical analyses by normalizing to 13 small cations (i.e., Si+Ti+Al+Cr+Fe+Mn+Ni+Mg=13), and assuming halogens and hydroxyl fully occupy the O(3) site (i.e., OH^-+F^-+Cl^- sum to 2.0 atoms per formula unit).

Results: *Phase Compositions*. We obtained compositions for 6 amphibole-melt pairs in pyroxenes from Tissint, and 5 from EETA79001A. Amphibole compo-
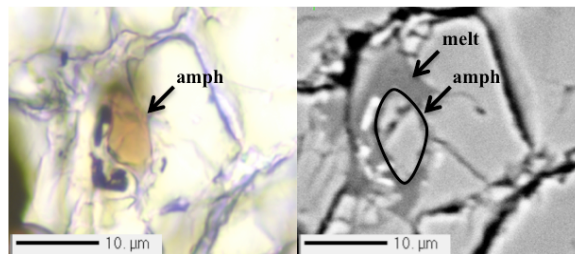
Figure 1: Transmitted light (left) and backscattered electron (right) images of an amphibole-bearing (amph) melt inclusion in a pigeonite grain from EETA79001A.

sitions are ferro-kaersutitic [11] and similar to those reported in other olivine-phyric shergottites [3-9]. Table 1 presents representative microprobe analyses of amphibole and melt for both Tissint and EETA79001A. Tissint amphiboles (Mg# = 0.38) are less magnesian than those in EETA79001A (Mg# = 0.48). Both samples have low fluorine and chlorine abundances (F < 0.4 wt%, Cl < 0.03 wt%) suggesting high OH^- (or O^{2-}) in the amphibole O(3) site. Stoichiometry implies 3.6-3.9 wt% H_2O in the amphiboles. Melt inclusion glasses are silicic, with 55-65 wt% SiO_2 in Tissint and 70-75 wt% SiO_2 in EETA79001A. Host pyroxenes are zoned from pigeonite cores ($En_{45-70}Fs_{24-43}Wo_{4-19}$ in Tissint; $En_{51-64}Fs_{25-36}Wo_{1-16}$ in EETA) to augite rims ($En_{42-57}Fs_{23-37}Wo_{21-25}$ in Tissint; $En_{50-53}Fs_{24-29}Wo_{21-23}$ in EETA). These pyroxene compositions are consistent with previous analyses of Tissint samples [12-14].

Volatile Content of Tissint Parental Magma. Using the composition and estimated proportions of amphibole and glass in each Tissint melt inclusion (30-50% amphibole), we estimated the composition of the melt trapped in the inclusion prior to amphibole crystallization. We then compared the enrichment of elements incompatible in olivine and pyroxene (Ti, Al, Na, K, P) between trapped melt compositions and a bulk Tissint composition (deduced from fusion crust analyses of our sample and consistent with published bulk Tissint compositions [12]). Based on this degree of fractionation, we calculated that the proportion of olivine and pyroxene crystallization prior to melt entrapment was 75-85%.

The amphibole-bearing inclusions contain 1.1-1.8 wt% H_2O, 0.20-0.34 wt% F, and 0.01-0.44 wt% Cl. These inclusions are calculated to have formed after 75-85% crystallization of Tissint's

Table 1: Representative electron microprobe analyses of amphibole (amph) and melt pairs in Tissint and EETA79001A. Amphibole formulae were normalized to 13 small cations and calculated so that $OH^-+F^-+Cl^-=2$. H_2O was then calculated from OH^-. Calculated cations shown in table below oxide wt%.

	Tissint		EETA	
	Amph	**Melt**	**Amph**	**Melt**
SiO_2	38.22	62.13	37.88	55.96
TiO_2	7.64	0.52	9.18	1.13
Fe_2O_3	0.00	-	0.00	-
Al_2O_3	16.07	17.70	13.68	13.14
Cr_2O_3	0.19	0.00	0.38	0.41
FeO	14.28	4.05	14.47	6.89
MnO	0.24	0.17	0.27	0.25
NiO	0.02	0.000	0.00	0.04
MgO	5.21	0.53	8.45	8.73
CaO	9.29	5.50	10.75	9.98
Na_2O	2.87	1.88	2.31	1.29
K_2O	0.79	1.75	0.18	1.04
P_2O_5	0.94	3.64	0.37	0.47
F_2	0.30	0.34	0.35	0.29
Cl_2	0.02	0.03	0.03	0.00
H_2O	3.57	-	3.65	-
F,Cl=O	-0.26	-	-0.30	-
Total	99.38	98.24	101.63	99.62
Si	5.93		5.70	
Ti	0.89		1.04	
Al^{IV}	1.95		2.26	
Al^{VI}	0.99		0.17	
Cr	0.02		0.05	
Fe^{2+}	1.85		1.82	
Fe^{3+}	0.00		0.00	
Mn	0.03		0.03	
Ni	0.00		0.00	
Mg	1.20		1.89	
Ca	1.54		1.73	
Na	0.41		0.40	
K	0.16		0.03	
P	0.12		0.05	
F	0.15		0.16	
Cl	0.00		0.01	
OH	1.85		1.83	

parent magma. Thus, if no water or chlorine was lost during the crystallization, Tissint's parent magma must have contained approximately 0.16-0.46 wt% H_2O, 0.03-0.09 wt% F, and < 0.11 wt% Cl.

Discussion: The water contents estimated here agree with studies of apatite compositions that suggest shergottite parent magmas (depleted and enriched) contained 0.07-0.29 wt% H_2O prior to degassing [15]. However, our estimate should be considered a lower limit, because we did not determine the water content of the inclusion glass. Using amphibole-melt water

partitioning relationships from [16], we estimated at least 0.8-0.9 wt% H_2O in the inclusion melts. From this, the revised estimation of water content in the Tissint parent magma is 0.25-0.56 wt% H_2O.

We attempted to model fractional crystallization of a bulk Tissint composition at 1 bar pressure and iron-wüstite oxygen fugacity using the computer code *Petrolog3* [17]. The program predicts 25 vol% Fo_{66-81} olivine crystallization from the parent magma, which is consistent with olivine proportions and compositions reported in previous studies (24-29 vol% Fo_{60-81} [14, 18]). Although *Petrolog3* successfully reproduces Tissint olivine proportions and compositions, modeled pyroxene compositions were inconsistent with sample pyroxene compositions, making *Petrolog3* results unreliable for this unusual (martian) melt composition.

Future Work: We could not analyze or calculate the proportion of O^{2-} on the O(3) site; however pure oxy-kaersutite can form at low pressure [10, 12], as is inferred for Tissint. If the kaersutites crystallized with a significant oxy-amphibole component, our estimated proportion of water would have to be reduced. However, amphibole can lose hydrogen during post-igneous oxidation and shock metamorphism, which add additional uncertainty to estimates of amphibole OH^- from microprobe analyses [5, 10, 19, 20]. Further, negative Fe^{3+} results in our stoichiometry calculations imply O^{2-} is present in place of OH^-. Direct analyses for hydrogen in the amphiboles (and the adjacent glass) would greatly improve our estimates of water content in the amphibole and parental magma.

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