ORIGIN OF PHOBOS AND DEIMOS BY GIANT IMPACT: LESSONS FROM TERRESTRIAL TEKTITTES. Ngoc Truong¹ and Pascal Lee²,³,⁴.¹Univ. of Science & Technology of Hanoi, 18 Hoang Quoc Viet, Hanoi 100000, Vietnam, tuangocvl@gmail.com, ²Mars Institute, ³SETI Institute, ⁴NASA Ames Research Center.

Introduction: The origin of Mars’ moons, Phobos and Deimos, is still a mystery. There are three prevailing hypotheses: They are 1) Captured small bodies from the outer main belt or beyond; 2) Remnants of with Mars’s own formation and 3) Reaccreted Mars impact ejecta following a large/giant impact on Mars. In the latter hypothesis, Phobos and Deimos are derived, possibly via multiple evolutionary stages, from reaccreted orbital debris following one or more large/giant impacts on Mars [1,2]. Such an origin is commonly thought to imply that the resulting original materials forming Phobos and Deimos would be depleted in volatiles, in particular water, as classically predicted in the hypothesis of the formation of Earth’s Moon by giant impact [3].

Insights into the survival and fate of target water in large planetary impact events may be gained from the study of the water content in terrestrial tektites. Tektites are natural glasses derived from the hypervelocity impact melting of terrestrial upper crustal rocks that were then ejected from the impact site, lofted through, and in some cases above, the Earth’s atmosphere into the exosphere, quenched, and then distributed over an extended area called a strewn field [4]. Due to the intense heating, suborbital flight, and massive loss of volatiles they experienced, the highest energy tektites from the Australasian strewn field, the australites, might be analogous to the original orbital debris forming Phobos and Deimos in the giant impact hypothesis for their origin.

In this study, we carry out two tasks: 1) We review what is known (and still not) about the water content in tektites, with particular focus on the Australasian tektites which present the highest energy (most heated) tektites and the most extensive strewn field known (and therefore involved the largest impact event among impacts with known tektite strewn fields); 2) We review published UV, visible, and near-infrared reflectance spectra of Australasian tektites, and compare these to published spectra of Phobos, Deimos, and martian meteorites.

Approach: Our review of the water content in tektites (Task 1) covered all tektites, but focused on the Australasian strewn field, including tektites from various localities in Laos, Thailand, Vietnam, The Philippines, Java and Australia. Particular attention was given to measurements made by Fourier-transform infrared (FTIR) spectrometry, a technique that is significantly more accurate than the manometric method (the main alternative approach). FTIR detects water occurring as OH in two main bands at 2.73 µm and 6.2 µm, one due to the OH stretching vibration, the other due to H-O-H bending. The presence of alkali atoms causes Si-O-Si bridges to break and OH to attach to a Si chain, leading to H binding by a hydrogen bond with a peak shift in the 2.77-2.9 µm range [5]. In FTIR, quantification of water content is done via the Lambert-Beer law, requiring determination of absorption intensity at the OH band maximum [6].

Separately (Task 2), we reviewed published UV, visible and near-IR reflectance spectra of Australasian tektites from Indochina and Australia as a function of grain sizes (<45, 45-90 and 90-1000µm), and compared these spectra to published spectra of Phobos and Deimos from the Mariner 9, Phobos 2, Mars Reconnaissance Orbiter (MRO) and Mars Express (MEX) missions, and also to spectra of martian meteorites.

Results: Water Content in Tektites. Extreme heating during impact shock melting, ejection, and atmospheric transit, have resulted in massive, but not complete water loss in tektites. While tektites from most strewn fields are very poor in water (~ 0.002 wt%), Australasian tektites contain significant amounts of water (typically 0.015 wt%) even if substantially less than in obsidian (~ 0.1 to 1.0 wt%) [5,6,7,8] (Fig. 1).

The data available is limited, but suggests that even australites, the highest-energy and farthest traveled Australasian tektites, contain ~ 0.01 wt% water [5]. The relatively high water content of all Australasian tektites suggests that the impact target material from which those tektites originated may have been water-rich [8], including possibly submerged offshore at the time of impact.
UV-VIS-NIR Spectra of Tektites vs Phobos/Deimos/Martian Meteorite Spectra. Tektite spectra (Fig. 2) were obtained by Cloutis 2015 (green) [9] and Iancu et al. 2011 (black) [10]. In VNIR, the spectra of coarse-grained Australasian tektites (Fig. 2, bottom) are similar in shape and slope to Phobos and Deimos spectra. There are three main absorption features at 0.65 µm, 1.1 µm and 2.8 µm. Ti content (TiO2 enrichment) in tektites and impurities are spreading the correlations at 0.65 µm [11]. The NIR spectra have a broad absorption band centered around 1.1 µm due to the presence of FeO, by crystal field (CF) absorption between unpaired d-orbitals of transition minerals (mostly Fe2+) [10]. Band depths and slopes are variable in spite of similar Fe2+ and Fe3+ contents, illustrating that other factors besides Fe content can affect spectra [9]. The absence, or much reduced prominence of this band in the spectra of Phobos and Deimos, could be due to a difference in Fe2+ content (lower Fe2+ needed; unlikely), in space weathering (unlikely, as Fraeman et al. 2012 [12] show that even the lowest albedo space-weathered basaltic materials on the Earth’s Moon retain subtle mafic absorptions), or in particle size (if regolith are coarse grains; plausible). The VNIR spectra of tektites and of Phobos/Deimos differ significantly from those of Martian (and HED) meteorites, which are basaltic [13,14,15].

Figure 2. Tektite spectra (green, purple, black; grain sizes decrease from bottom to top) vs Phobos (blue, red) and Deimos spectra (brown) from MRO.

Discussion: Implications for the Giant Impact Origin of Phobos/Deimos. The survival of significant (target) water even in distal Australasian tektites suggests that large impacts do not necessarily produce water-depleted high-energy ejecta. This opens the possibility that for the hypothesis in which Phobos and/or Deimos are reaccreted Mars impact ejecta, not all target water should be assumed to have been lost in the orbital debris resulting from the giant impact. Instead, by analogy to terrestrial tektites, we suggest that even in the Giant Impact Origin Hypothesis for Phobos and Deimos, the original materials forming these moons might have retained some water if martian crustal materials were “sufficiently” water-rich. The water content in the highest energy australites (~ 0.01 wt%) might provide an upper limit for the water content in the original materials forming Phobos and Deimos in the giant impact hypothesis for their origin. The recent detection of water in some lunar materials [8] is consistent with water surviving even in debris resulting from large/giant impact events.

Conclusions: All three prevailing hypotheses for the origin of Phobos and Deimos predict the possible presence of water (Hypotheses 1 and 2 already did). A low water abundance in surface materials on the martian moons, if found, would not imply that the giant impact origin is incorrect. A complicating factor is that any original endowment in water on Phobos or Deimos might have been progressively lost over time, due mainly to impact and radiation processing. Thus, while a high water content, if found at present, would support only Hypothesis 1, a zero or low water content cannot be used to discriminate between any one of the three prevailing origin hypotheses.

The VIS, NIR and UV spectra of Phobos and Deimos are, to first order, consistent with coarse-grained (>100µm w/ smaller particles adhering), glassy, water-poor (<0.01 wt%), Fe-bearing (Fe-poor compared to martian meteorites) silicate materials.

Future Work: More measurements of water in tektites are needed to strengthen the limited available data set. More VIS, NIR and UV spectra of tektites are needed to further explore compositional and particle size effects. Higher spatial and spectral resolution data for Phobos and Deimos are needed as well of course.