PUZZLING OUT COMETARY MG-POOR SILICATES, PHYLLOSILICATES, AND CARBONATES TO BE PRE-ACCRETIONAL GRAINS THAT FORMED IN THE NEBULA UNDER VARYING REDOX CONDITIONS. D. H. Wooden[1], [1]NASA Ames Research Center, MS 245-3, Moffett Field, CA 94035-1000, USA, dwooden@mac.com, Diane.H.Wooden@nasa.govs

Introduction: One of the surprising discoveries of the *Deep Impact Mission* was the assessment that carbonates, Fe-rich silicate crystals (fayalite and ferrosilite), and phyllosilicates comprised one-third of the dust species in the impact-induced coma of ecliptic comet 9P/Tempel 1[1]. Prior to Deep Impact, phyllosilicates and Fe-rich silicates had not been identified in comet mid-IR spectra. The carbonate band at 7 µm was tentatively identified in comet Halley [2]. The carbonate band lies in the 5–7.5 µm wavelength region that is obscured from ground-based telescopes by telluric water. Even so, Spitzer observations of other comets had not identified carbonates. These dust species in the DI ejecta appeared to be rogue cometary dust species, and were suggested to be products of the impact itself [1]. However, impact models revealed that the heat of the impact was insufficient to crystallize silicates [3], and hence, insufficient to aqueously alter anhydrous silicates.

The first year of reports on *Stardust Mission* return samples retorted the presence of phyllosilicates and carbonates [4]. Instead, anhydrous minerals were delineated due to the preponderance of high temperature and reduced (Mg-rich silicate) crystalline phases [5].

In significant contrast to the early results, more detailed analyses of *Stardust* tracks revcals (a) a handful of 0.3—0.7 µm-sized carbonate grains and a significant abundance of very tiny (0.02 µm-sized) carbonates [7]; and (b) silicate crystals with Mg/(Mg+Fe) that spans the range from 1.00—0.04, with a frequency peak at 0.98 for olivines and 0.95 for pyroxenes [8]. So, Mg-rich crystalline silicates dominate but there are significant numbers of Fe-rich crystalline silicate grains. Such Fe-rich crystalline silicates have been reported for some anhydrous chondritic porous interplanetary dust particles (anhydrous CP IDPs) of probable cometary origins [9], but the extremely high Mg-content crystalline silicates have been highlighted in more recent discussion of anhydrous CP IDPs [10] because Mg-rich crystalline silicate features are identified in IR spectra of comets [11, 12, 13, 14, 15].

Challenges to Aqueous Alteration: Since carbonates, phyllosilicates, and Fe-rich crystalline silicates are often found in meteoritic materials, many authors have suggested that these mineral species indicate that portions of cometary grains were aqueously altered in the parent body [1, 6, 7]. There are three challenges to this deduction: (1) in Stardust tracks these `aqueous alteration products' are found amongst anhydrous minerals and presumed to have been in intimate contact in the grain aggregate prior to collection. These subgrains are components of disequilibrated mineral assemblages [16], so they were not part of a domain of aqueous alteration in the comet nucleus. (2) Not all the compliment of aqueously altered grain species are found in the DI ejecta or in *Stardust* tracks (if any, limited detection of oxides [17], but no sulfates and phyllosiliccates in *Stardust* samples). (3) Comet nuclei have such low heat conductivities that if internal temperatures reach 260~K (lower than the ~300 K typically considered for asteroidal aqueous alteration), the nuclei have to be 100-200 km in radius [18].

Puzzling out Nebular Processes: Condenation under high oxygen fugacity conditions in the solar nebula can expain Fe-rich silicate crystals [19]. The delivery of water inwards of the now line by the migration of cometesimals can pump up the oxygen fugacity by factors of >600 [20], and when water dissociates the oxygen fugacity is then high enough to condense fayalite. Phyllosicates can form in water-rich shocks. Carbonates can form in regions of enhanced CO_2 [22], in somewhat cooler and lower density regions of the solar nebula [23, 24].

Cometary Fe-rich silicates, phyllosilicates, and carbonates are pre-accretional nebular grains: Instead of having these grain species form by aqueous alteration of comet nuclei, or by having comets incorporate tiny but selective submicron-sized fragments of asteroids, we suggest that comets are reservoirs of pre-accretional grains that experienced primarily low oxygen fugacity conditions but some subset were formed under high oxygen (humid) conditions. There are only 4 'pristine' (type 3.0) chodrites [25], so comets are the best probes of pre-accretional conditions in the nebula.

References: [1] Lisse et al. 2005, 2007 [2] Bregman et al. 1987 [3] Sugita et al. 2005 [4] Keller et al. 2006 [5] Ebel et al. 2006 [6] Flynn et al. 2008 LPS [7] Zolensky et al. 2008 [9] Zolensky & Barrett 1994 [10] Bradley et al. 1999 [11] Crovisier et al. 2001 [12] Wooden et al. 1999 [13] Wooden 2002 [14] Harker et al. 2002 [15] Harker et al. 2007 [16] Reitmeijer 2002 [17] Flynn et al. 2008 EMP [18] Prialnik & Podolak 1995, 1999 [19] Palme & Fegley 1990, Weinbruch et al. 1990 [20] Cuzzi & Zahnle 2003 [21] Ciesla et al. 2003 [22] Lewis et al. 1979 [23] Gail 2002 [24] Lahuis et al. 2006 [25] Scott & Krot 2005s