rest of Planum Boreum [e.g., *Tanaka and Hayward*, 2008], and while the sand sheets exhibit a marked albedo difference compared to the underlying plains (Figure 1), they may only be a few grains thick in many areas [*Tanaka et al.*, 2008].

[16] Using terrestrial relationships between dune spacing and sediment volume, *Lancaster and Greeley* [1990] estimated the volume of sediment contained in Olympia Undae at around 900 km^3, compared to approximately 1150 km^3 in the entire circumpolar erg. Using MOLA data, *Zuber et al.* [1998] estimated the volume of sediment in the circumpolar erg to be approximately 10,000 ± 3000 km^3, although it is unclear what criteria were used to determine dune coverage or individual dune volume in that study. More recently, *Hayward et al.* [2008], in initial mapping of the dune density throughout the north polar region using THEMIS, MOC, and CTX images, have found 835,000 km^2 of terrain with some type of dune coverage. As shown by *Tanaka and Hayward* [2008], dune density decreases with distance from Olympia Planum and Chasma Boreale.

[17] Previous workers have proposed that the current source of the dark dune material in Olympia Undae is the lower, platy unit of the polar layered deposits or basal unit [*Thomas and Weitz*, 1989; *Byrne and Murray*, 2002; *Fishbaugh and Head*, 2005]. In recent geologic mapping, the current source unit has been identified as the Planum Boreum cavi unit, the stratigraphically oldest Planum Boreum unit characterized by alternating layers of cross-bedded, unconsolidated, dark-toned, dune forming materials and light-toned boulder forming materials [*Tanaka et al.*, 2008]. Although the dunes appear to be actively sourced from this unit today, the Olympia Undae unit has most likely formed episodically throughout the Amazonian, and may have originally formed as a result of the erosion of the Rupes Tenuis and Scandia region units [*Tanaka et al.*, 2008].

[18] Much of the Olympia Undae unit appears to be stabilized, as indicated by mantling of many dune fields by the Planum Boreum 3 unit and the north polar veneers (section 5.4) [*Tanaka*, 2005; *Tanaka et al.*, 2008], as well as by the presence of induration features on dunes, including surface cracks, absence of dry grain flow on avalanche faces, avalanche remnants in interdune areas [*Feldman et al.*, 2008], slumps, yardangs, craters, thick dust coverings, and avalanche chutes [*Schatz et al.*, 2006]. In addition, many of the dunes exhibit muted forms, and have not been observed to move (on the scale of meters) in the 30 years between Viking and MOC observations [*Schatz et al.*, 2006]. *Feldman et al.* [2008] have suggested, on the basis of modeling of Mars Odyssey Neutron Spectrometer (MONS) data, that the dunes have water ice-rich cores, overlain by a mobile layer on the order of ~10 cm thick. The water ice-rich cores may be similar to terrestrial niveoaeolian deposits, which are composed of interbedded sand, dust, and water ice or snow, are more resistant to erosion than ice-free dunes, and would account for the overall lack of movement and muted forms. However, it must be noted that even spatially deconvolved MONS data have a 300 km footprint [*Feldman et al.*, 2008], so it is unclear how input from Planum Boreum and the surrounding terrains would affect models of the water ice content of Olympia Undae. Exceptions to the overall stabilized nature of the dune fields include dunes that are associated with dark, downwind streaks, possibly indicative of recent sand movement [*Tanaka et al.*, 2008], and two dunes that have been observed to shrink and disappear over ~3 years of MOC observations [*Bourke et al.*, 2008].

3. Composition of Olympia Undae

[19] The dunes of Olympia Undae exhibit the strongest and most areally extensive hydrated sulfate signature yet seen on Mars [e.g., *Poulet et al.*, 2007]. In this section, we review the initial sulfate detection by OMEGA and CRISM, the previously proposed gypsum deposition mechanisms, and proposed mafic mineralogies for the dunes.

3.1. Olympia Undae Sulfates

[20] *Langevin et al.* [2005a] first announced the unambiguous detection of hydrated Ca-sulfates in Olympia Undae, by the observation of a strong absorption band at 1.9 μm, indicating hydration, accompanied by several less pronounced bands between 1.0 and 2.5 μm diagnostic of Ca-sulfates, interpreted to be indicative of gypsum. Mapping the band depth of the 1.9 μm feature throughout the north polar region revealed that the signature was largely restricted to the dunes, with the largest band depth located near the eastern margin of Olympia Undae, near 80.2°N, 244.5°E [*Langevin et al.*, 2005a]. *Fishbaugh et al.* [2007] expanded on the initial OMEGA detection by presenting several regions with putative gypsum signatures outside the main dune field, including a region beyond the eastern dune margin, as well as a localized region on the floor of Chasma Boreale. *Fishbaugh et al.* [2007] also identified a lack of hydrated mineral signatures in the exposed unit between Planum Boreum and Olympia Undae, which they interpreted as indicating that the gypsum is not sourced from the Planum Boreum units.

[21] *Fishbaugh et al.* [2007] modeled the bulk composition of the sulfate-rich dunes as a mixture of gypsum grains and an unknown dark, spectrally featureless (DSF) material. An intimate mixture model of the two components yielded a best fit to the OMEGA data for 55% DSF with a grain size of a few tens of μm mixed with 45% gypsum with grain sizes between 100 μm and 1 mm. A better fit was found using an intramixture model, where oxide grains are housed as inclusions in larger gypsum grains. The model yielded a best fit with 35% pure gypsum grains with particle sizes of a few tens of μm and 65% mm-sized gypsum grains contaminated with DSF inclusions. *Fishbaugh et al.* [2007] favored the latter model because of the ability of the DSF inclusions to mask the high albedo of the gypsum grains, as well as to mask the large band depth that a nearly pure, coarse-grained gypsum dune would exhibit [e.g., *Cloutis et al.*, 2006]. The models did not include any specifically basaltic materials.

[22] The north polar region was a primary target for initial MRO observations after the spacecraft arrived in mid northern summer. In total, 6 targeted CRISM observations were located in Olympia Undae, with the goal of characterizing the distribution of gypsum within the dunes [*Roach et al.*, 2007]. Initial results indicate that CRISM data appear to confirm the gypsum detection, and show high gypsum band depths along the crests of dunes in the gypsum-rich area (section 6.1), which, when considered with the apparent aeolian distribution of the gypsum westward in Olympia Undae, suggests a dynamic process controlling the gypsum distribution [*Roach et al.*, 2007].