FORMATION OF THE MARTIAN NORTH POLAR GYPSUM DEPOSIT DURING THE AMAZONIAN

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Introduction: Based on global mineralogical mapping by OMEGA, *Bibring et al.* [1] have created an alternative timescale for Mars based on mapping of minor mineral phases with significant geological implications. The Theikian (Early to Mid Hesperian) is characterized by alteration of clays and mafics into sulfates and deposition of sulfates as evaporites. The dry surface of Mars that we see today is hypothesized to have existed throughout the Siderikian (Late Hesperian to Amazonian), with short-lived interruptions (e.g., outflow channels). However, OMEGA also detected the largest gypsum (Ca-sulfate) deposit on Mars within the Amazonian-aged dunes in the north polar region [2], apparently confounding this alternative timeline system. Here, we discuss the origin of this gypsum in an environment unique to the north polar region and how its presence does not contradict the hypothesized global patterns of mineralogy through time.

Gypsum on Earth and Mars: Gypsum is a hydrated Ca-sulfate ($2H_2O•CaSO_4$). Gypsum can be formed, for example, as a hydrothermal deposit [3], as an alteration product of iron sulfide [4] or Ca-bearing, mafic minerals, or as an evaporite in acidic water. Gypsum is soft and thus easily susceptible to physical weathering and is light in color.

On Mars, in addition to the north polar deposit, the OMEGA team has tentatively identified gypsum as one constituent in the layered deposits of Juventae Chasma [5]. The MER Opportunity rover has also detected small amounts of Ca-sulfate salts at Meridiani Planum [6] which may have been created by evaporation of fluids involved with weathering of basalts [7].

Observations in the North Polar Region: *Langevin et al.* [2, 8] have identified gypsum in the north polar region mainly by the strong 1.94 µm absorption feature in OMEGA spectra of the sand sea. In Fig. 1, we map the 1.94 µm feature using the 1.927 µm OMEGA channel in order to reduce contamination by atmospheric CO_2; it is essentially a map of gypsum concentration (purple: 6% band strength; red: 40%). We are currently investigating the translation of band strength into weight or volume percent, but we estimate that the highest concentrations are about 60 weight%. For the most part, the dunes consist of pyroxene, with the concentrations of pyroxene and gypsum having an approximately inverse relationship. We find that gypsum exists only in the presence of dunes. In other words, OMEGA does not detect gypsum anywhere where dunes are not present.

We have further investigated this relationship with the dunes by examining MOC images; we find that there is no correlation of gypsum concentration with dune morphology. Additionally, there are no obvious albedo anomalies associated with the gypsum so that it is not forming surficial crusts or windblown, fine-particle, surface deposits. No apparent color anomalies manifest themselves either in THEMIS or HRSC color images. THEMIS IR data indicate that no temperature anomalies exist in the gypsum area, implying that these dunes may have a similar thermal inertia to the gypsum-poor dunes.

These observations suggest that the gypsum is intimately mixed with the saltating sand. The low albedo (16% at 1.2 µm [8]) of even the dunes containing gypsum indicates that the gypsum grains probably contain dark, mafic inclusions. There are several reasons why gypsum would be associated with sand dunes. 1) The formation of dunes requires sand-sized particles so that within the dunes, all other species having different particle sizes have been removed, helping to concentrate the sand-sized gypsum here. 2) In areas without dunes or other sediments, gypsum (and any other wind-blown sediment) is being distributed by the wind rather than deposited. 3) At the wavelengths used to detect gypsum, OMEGA is most sensitive to sand-grained size particles. Minor amounts of undetectable finer-grained gypsum may exist elsewhere. 4) As discussed below, formation of gypsum would most likely occur where Ca-bearing minerals (in the dunes) are present.

Origin of the Gypsum: *Byrne and Murray* [9] and *Fishbaugh and Head* [10] have identified the north polar Basal Unit, lying stratigraphically beneath the polar layered deposits, as the main, if not sole, source for the north polar sand sea. However, high resolution OMEGA data (at 1 km pixel) reveal a gap between areas containing high gypsum concentration and the polar layered deposits (Fig. 2). This gap is occupied by the Basal Unit. Thus, it appears that the Basal Unit is not the source for the gypsum within the dunes.

Since gypsum is a soft mineral, it cannot saltate long distances. Thus, one would expect the gypsum source region to lie close to or within the highest gypsum concentrations. As shown in the map in Fig. 1, sinuous valleys extending from the polar layered deposits terminate just to the east of the high-gypsum area. We hypothesize that the most likely origin of these valleys is fluvial erosion resulting from the melting and outflow event which initiated the formation of Chasma Boreale to the east [11]. An alternate or additional water source could be the formation of the nearby impact crater which may also have caused the polar layered deposits in this region to melt. Note that small amounts of gypsum (associated with dunes) surround the region where the channels terminate. Currently, younger, higher albedo material (likely frost and dust) covers this area, masking any putative gypsum signature within it. Sulfur could exist in abundance in the soil from earlier volcanism and even from putative nearby volcanoes identified by the HRSC team [2/25/05 press release image, ESA website], and calcium may exist within the pyroxene of the dunes. Having identified the sources of chemistry and water to produce the gypsum, the question now becomes, "Did the gypsum form as a true evaporite or as a weathering product?".

For the gypsum to have formed as a true evaporite in a basin, a complex chain of events must have occurred. Alteration of the pyx-bearing dunes themselves proves a much simpler scenario; note that this is contrary to what we have previously asserted [12]. In this case, the acidic water circulated within the dunes, which were easily altered because of the large surface area exposed (due to the many grains). This alteration has then removed much of the pyroxene in that area. If the deposits near the mouths of the channels have been altered at all, there is no evidence in the OMEGA data, perhaps due to the fact that younger materials (likely mostly ice and dust) cover these deposits.

Conclusions. We propose that the north polar gypsum deposit was formed due to in-situ alteration of pyx-bearing sand dunes by S-rich water emanating from the Chasma Boreale melting event and/or from melting due to the nearby impact into ice. Thus, this melting event and the presence of many easily altered, pyx-bearing dunes near the mouths of meltwater channels conspired to create a unique situation wherein gypsum was able to form, even within the Siderikian (Amazonian).

Future work will include better estimates of the total amount of gypsum, investigation into whether other, secondary alteration products exist in this area, and more thorough characterization of dune composition. We also plan to fully characterize the geologic and geochemical sequence of events in creating this gypsum deposit.

References: [1] J.-P. Bibring, et al. (2006), *Science*, *312*, 400-404. [2] Y. Langevin, et al. (2005), *LPSC*, *36*, Abs. 1652. [3] J. Martinez-Frías, et al. (2004), *Earth, Planets and Space*, *56*, v-viii. [4] R. Burns, et al. (1990), *JGR*, *95*, 14,415–14,421. [5] A. Gendrin, et al. (2005), *Science*, *307*, 1587-1591. [6] S. Squyres, et al. (2004), *Science*, *306*, 1709-1714. 10.1126/science.1104559. [7] N. Tosca, et al. (2005), *Eos Trans. AGU*, *86*, Abstract P12A-07. [8] Y. Langevin, et al. (2005), *Science*, *307*, 1584-1586. [9] S. Byrne, et al. (2002), *JGR*, *107*, 10.1029/2001JE001615. [10] K. Fishbaugh, et al. (2005), *Icarus*, *174*, 444-474. [11] K. Fishbaugh & J. Head (2002), *JGR*, *107*, 10.1029/2000JE001351. [12] K. Fishbaugh, et al. (2006), *LPSC*, *37*, Abs. 1642. [13] H. Tsoar et al., *JGR 82*, 8167, 1979.

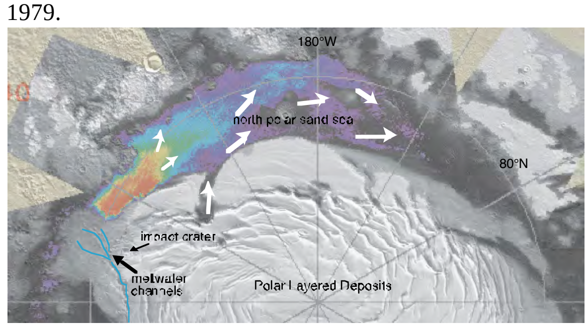

Figure 1. Map of gypsum band strength in the north polar region. Modified from [8]. Arrows indicate wind direction as mapped by *Tsoar et al.* [13] from dune morphology.

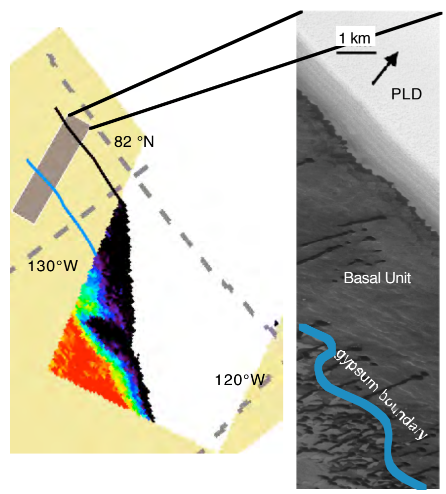

Figure 2. Illustration of the lack of gypsum in the polar Basal Unit. *Left*: High resolution OMEGA data (1 km/pix) showing gap between the gypsum- rich dunes and the polar layered deposits. *Right*: MOC image showing presence of layered Basal Unit occupying that gap. Arrow indicates sun direction.