THE ORIGIN OF GYPSUM IN THE MARS NORTH POLAR REGION. K. E. Fishbaugh[1], F. Poulet[2], Y. Langevin[2], V. Chevrier[3], and J-P. Bibring[2]. [1]International Space Science Institute, Hallerstrasse 6, Bern CH-3012 Switzerland, fishbaugh@issi.unibe.ch. [2]Institut d'Astrophysique Spatiale (IAS), Bâtiment 121, 91405 Orsay Campus, France. [3]CEREGE, Europóle de l'Arbois, BP80, 13545 Aix-en-Provence Cedex 04, France.

Introduction: The OMEGA instrument on Mars Express has recently detected the largest gypsum deposit on Mars within the north polar sand sea [1]. Here we discuss the unique geologic context and origin of this evaporite deposit.

Gypsum on Earth and Mars: Gypsum is a hydrated Ca-sulfate ($2H_2O$•$CaSO_4$). Though gypsum can be formed, for example, as a hydrothermal deposit [e.g., 2] or as an alteration product of iron sulfide [e.g., 3], the largest deposits form as evaporites in acidic water. Gypsum is soft and thus easily susceptible to physical weathering and is light in color. While on Earth there are dunes composed of gypsum (e.g. White Sands, NM), such dunes are rare due to the mechanical weakness of the mineral; gypsum can survive saltation for only relatively short distances.

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 [4]. The wide range in elevations of sulfate-containing outcrops in Valles Marineris has lead the authors to suggest that the gypsum in Juventae Chasma did not likely originate as an evaporite deposit. The MER Opportunity rover has also detected small amounts of Ca-sulfate salts at Meridiani Planum [5] which may have been created by evaporation of fluids involved with weathering of basalts [6].

Observations in the North Polar Region: Langevin et al. [1] 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: >25%). We are currently investigating the translation of band strength into weight or volume percent. 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 to the dunes by examining MOC images both of the high gypsum areas (red in Fig. 1) and of the dunes further to the west (within the main sand sea) which contain no detectable gypsum. We find that there is no correlation of gypsum concentration with dune morphology. Both high and low gypsum areas contain a variety of barchan and transverse dune morphologies. Additionally, there are no obvious albedo anomalies associated with the gypsum so that it is not forming surficial crusts or windblown deposits. No apparent color anomalies manifest themselves either in THEMIS color images (Fig. 2).

To minimize the effects of albedo and slope on calculated brightness temperature, we have chosen one THEMIS image taken soon after the end of polar winter darkness. 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. We are investigating the nature of this mixture, whether it is a mixture of mafic and gypsum sands or of mafic sands and gypsum sands with mafic inclusions. The low albedo (16% at 1.2 μm [1]) of even the dunes containing gypsum favors the latter interpretation. 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 particle sizes have been removed, helping to concentrate the sand-sized gypsum here. 2) In areas without dunes or other sediments, gypsum is being distributed by the wind. 3) At the wavelengths used to detect gypsum, OMEGA is most sensitive to sand-grained size particles. Minor amounts of finer-grained gypsum may exist elsewhere.

Origin of the Gypsum: Byrne and Murray [8] and Fishbaugh and Head [9] 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. 3). 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 cannot saltate great distances, the source region is likely close to the highest gypsum concentrations. We have outlined the source region on the map in Fig. 1. Note that, in this map, the gypsum concentration decreases with distance from the source in the same direction as the main near-surface winds. The gypsum source region itself does not appear to contain any gypsum, but MOC images and OMEGA data reveal it to be covered by younger material, probably a mix of dust and ice. Small amounts of gypsum surround the source in areas which contain patches of dunes.

The gypsum source region lies at the terminus of meltwater channels extending from beneath the polar layered deposits. These channels are associated with the Chasma Boreale melting event [11] and possibly with melting resulting from the nearby impact into the ice.

Such events provided the meltwater needed to produce gypsum as an evaporite. Catling [12] has theorized that gypsum may form early, if not first, in an evaporite sequence on Mars if $SO_4^{2-}/Ca^{2+} > 2$ and the atmospheric $P_{CO2} > 3$. We do not know the value of SO_4^{2-}/Ca^{2+} in this case, though 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]. A covering of ice and CO_2 frost may act in lieu of high atmospheric CO_2 pressure to keep enough CO_2 in the water to provide sufficient acidity. Other studies show that gypsum may also easily form by silicate weathering where abundant sulfides are present, without requiring high amounts of CO_2 [13]. The ice cover, with a small space between the water surface and ice, could also allow water to pool for long enough to allow formation of evaporites.

Conclusions. We propose that the north polar gypsum deposit was formed as an evaporite deposit in the unique conditions provided at the north pole. Water from the Chasma Boreale melting event (and possibly a nearby impact into ice) pooled beneath the ice and evaporated, precipitating gypsum. The ice has since retreated, exposing the gypsum source region, allowing gypsum to be eroded from this source by the wind. Sand sized gypsum particles are now saltating and intimately mixed with the dark, mafic sands. Future work will include quantification of the volume percent of gypsum in the sand sea and investigation of the timescales and specific chemistries involved in its creation.

References: [1] Y. Langevin et al., *Science* 307, 1584, 2005. [2] J. Martinez-Frías et al., *Earth Planets Space* 56, v, 2004. [3] R. Burns & D. Fisher, *JGR* 95, 14415, 1990. [4] A. Gendrin et al., *Science* 307, 1587, 2005. [5] S. Squyres et al., *Science* 306, 1709, 2004. [6] N. Tosca et al., *Eos Trans. AGU* 86 (52), abs. P12A-07, 2005. [7] H. Tsoar et al., *JGR* 82, 8167, 1979. [8] S. Byrne & B. Murray, *JGR* 107 (E6), 2002. [9] K. Fishbaugh & J. Head, *Icarus* 174, 444, 2005. [10] Y. Langevin et al., *LPSC 36*, abs. 1652, 2005. [11] K. Fishbaugh & J. Head, *JGR* 107 (E3), 10.1029/2001JE001351, 2002. [12] D. Catling, *JGR* 104 (E7), 16,453, 1999. [13] V. Chevrier et al., *Geology* 32, 1033, 2004.

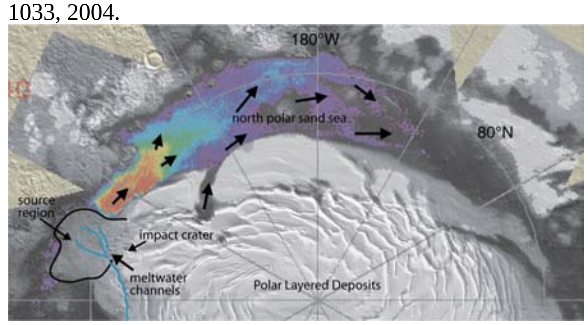

Figure 1. Map of gypsum overlaid on MOLA shaded relief. Gypsum concentrations range from >25% 1.927 µm band strength (red) to 6% (purple). Arrows represent main wind directions as determined from dune morphology by [7]. Other labeled features are discussed in the text. Modified from Fig. 1. of [1].

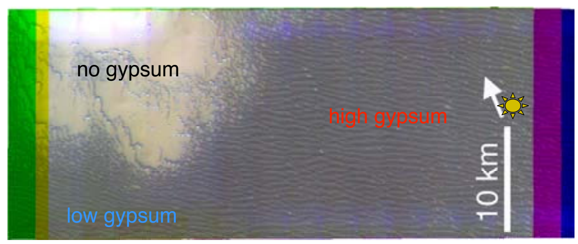

Figure 2. Example THEMIS visible false color image showing that there are no obvious albedo or color differences between areas of high gypsum concentration and areas of low gypsum concentration. The reddish tinge of the gypsum-free area (which is also nearly dune free) is probably due to dust.

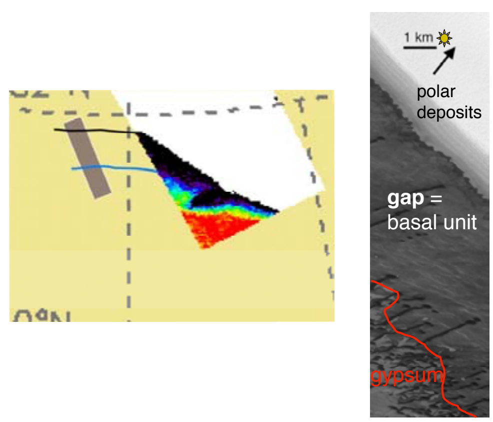

Figure 3. (Left) High-resolution OMEGA data (1 km/pix) showing gap (black) in gypsum between highest concentrations (colored) and the polar layered deposits (white). Rectangle shows location of MOC image. (Modified from [10]). (Right) MOC image showing the layered Basal Unit stratigraphically below the polar layered deposits and lying in the gap between the gypsum-rich areas and the polar layered deposits.