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Wide distribution and glacial origin of polar gypsum on Mars

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ABSTRACT

The North Polar Cap of Mars is associated with different kinds of superficial sediments, including the Circumpolar Dune Field, interior dune fields and sedimentary veneers scattered over the ice cap. In order to resolve the mineralogical composition and the regional distribution of these sediments, we processed OMEGA and CRISM hyperspectral data with an original method based on spectral derivation. We find that gypsum is present in all areas where undefined hydrated minerals had been previously detected, including superficial sedimentary veneers covering the North Polar Cap, interior dune fields and the whole Circumpolar Dune Field. Morphological and structural analyses reveal that these gypsum crystals derive directly from the interior of the ice cap. The source of superficial sedimentary veneers is the dust that was previously contained in the upper part of the ice cap, the ice-rich North Polar Layered Deposits (NPLD). This gypsum-bearing dust was released, on south-facing slopes of spiral troughs and arcuate scarps, by ice ablation controlled by katabatic winds. By the analysis of all associations of erosional scarps and dune fields over the North Polar Cap, we also demonstrate that the polar dunes are composed of sand-sized particles that were previously contained in the sediment-rich Basal Unit (BU), corresponding to the lower part of the ice cap. These particles contain gypsum and were released from the BU, by regressive ablation of ice at marginal scarps that border the North Polar Cap and by vertical ablation of ice on Olympia Planum. From a reconstruction of wind streamlines over and around the ice cap, we infer that katabatic winds descending from the polar high and rotating around the North Polar Cap control the release of these gypsum-bearing particles by ice ablation and the redistribution of these particles in the Circumpolar Dune Field.

1. Introduction

One of the most intriguing recent discoveries in the polar regions of Mars is the presence of extensive deposits of gypsum, a hydrated calcium sulfate ($CaSO_4 \cdot 2H_2O$), close to the North Polar Cap. These were detected in Olympia Planum, a portion of the Circumpolar Dune Field (Figs.1a and 2; Fishbaugh et al., 2007; Tanaka and Hayward, 2008), first by the OMEGA imaging spectrometer (Langevin et al., 2005a) and later by the CRISM imaging spectrometer (Roach et al., 2007). From complementary CRISM and OMEGA hyperspectral data, it was shown that gypsum is also present in other parts of the Circumpolar Dune Field and on the North Polar Cap itself (Massé et al., 2010).

Various hypotheses have been suggested for the origin of these polar gypsum deposits. Because of its softness, gypsum is easily susceptible to physical weathering; therefore the gypsum detected around the North Polar Cap has probably formed in-situ or within a short distance from its current location (Fishbaugh et al., 2007). On this basis, Langevin et al. (2005a) suggested two different hypotheses for its formation: interaction of Ca-rich minerals with snow containing H_2SO_4 derived from volcanic activity or formation as an evaporite deposit after major meltwater outflows from the ice cap during warm climatic incursions. Fishbaugh et al. (2007) suggested that water from nearby channels percolated through dunes that cover the eastern end of Olympia Planum and attributed the formation of gypsum there to a combination of (1) in-situ aqueous weathering of sulfide- and high-calcium-pyroxene-bearing dune materials and (2) formation of evaporitic gypsum crystals in the pore spaces of these materials. Szynkiewicz et al. (2010) suggested that gypsum crystals were formed by evaporation of saline waters and were later transported by winds toward Olympia Planum. Alternatively, it has been suggested that gypsum crystals could derive directly from the sediment-rich Basal Unit of the North Polar Cap (Fig. 1b) (Calvin et al., 2009; Roach et al., 2007).

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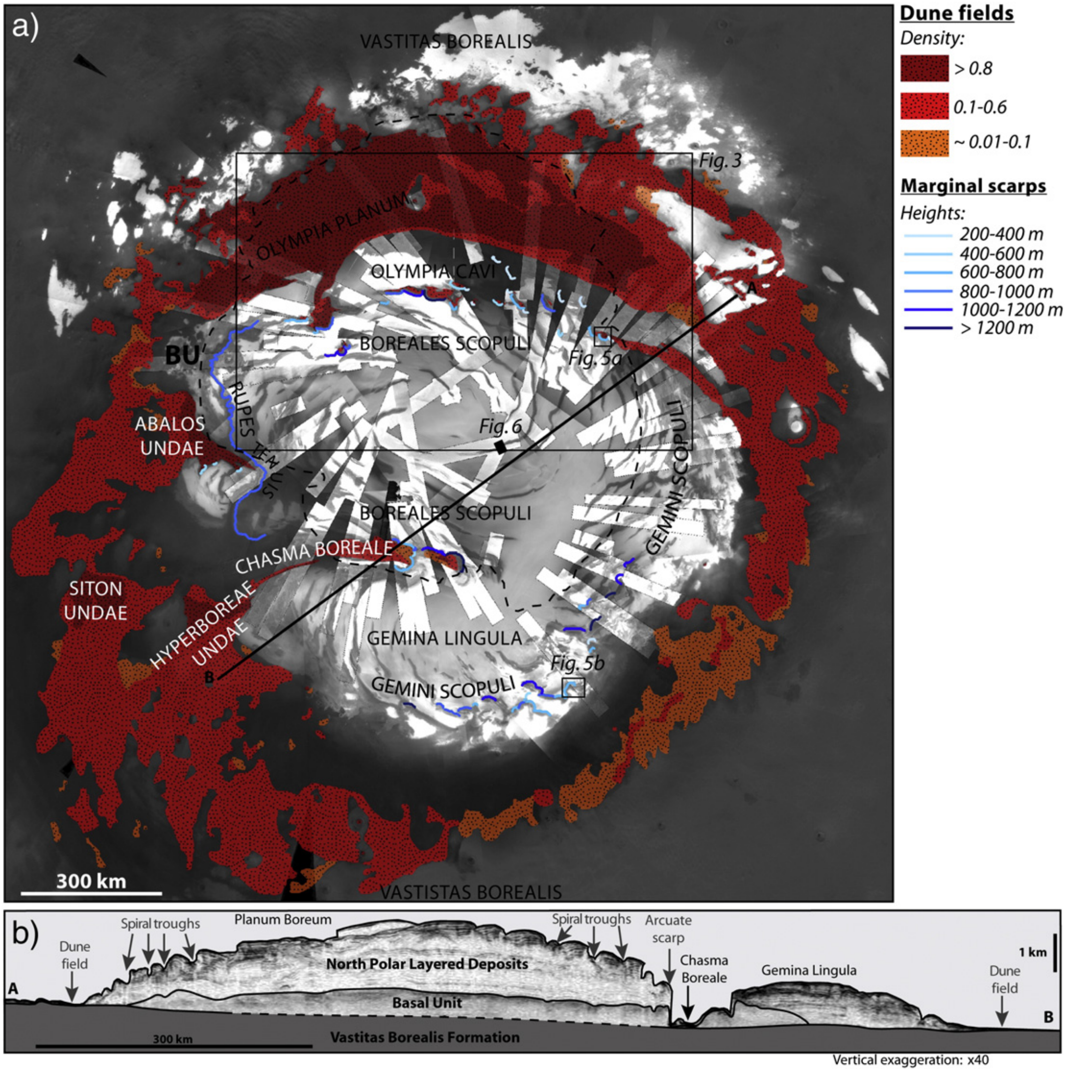

Fig. 1. a) Map of the North Polar Cap and Circumpolar Dune Field on a global MOC and CTX mosaic. Red, orange and yellow areas correspond to the Circumpolar Dune Field, ordered from the highest to the lowest dune density (modified from Tanaka and Hayward, 2008). Blue lines delineate North Polar marginal scarps and the blue scale represents the height of these scarps. The black stippled line represents the extension of the Basal Unit (BU) inferred from radar soundings by Selvans et al. (2010). b) Interpretative cross-section of the North Polar Cap (location indicated by a black line in a) based on SHARAD radargrams (Putzig et al., 2009). The dotted line indicates the top of the Vastitas Borealis Formation (VBF), as interpreted from scarce radar returns. Black boxes indicate locations of Figs. 3, 5 and 6.

In a restricted area located at the margin of the North Polar Cap, Massé et al. (2010) demonstrated that gypsum crystals that are now present in circumpolar dunes were originally trapped within the ice layers of the North Polar Cap and have been released by sublimation of the ice. On the basis of comparisons with sulfates present in terrestrial glaciers (Iizuka et al., 2006, 2008; Ohno et al., 2006), Massé et al. (2010) suggested that gypsum crystals trapped in the North Polar Cap had formed initially by weathering of dust particles, either in the atmosphere prior to their deposition during the formation of the ice cap, and/or in the ice cap after their deposition.

The present study aims at going a step further by mapping the distribution of north polar gypsum on a regional scale, so as to better constrain its origin and the processes by which gypsum crystals are released from the North Polar Cap and transferred toward the Circumpolar Dune Field. For that purpose we performed a morphological and compositional analysis of different kinds of superficial sediments associated to the North Polar Cap: (1) the Circumpolar Dune Field as a whole, (2) smaller interior dune fields associated with scarps cutting through the polar cap margin and (3) superficial sedimentary veneers covering the surface of the polar cap. We also reconstructed wind streamlines over the North Polar Cap and the Circumpolar Dune Field. On the basis of this reconstruction, we show how katabatic winds descending from the polar high and rotating around the ice cap control the release of gypsum from the ice and its redistribution in the Circumpolar Dune Field.

2. Geological setting

The North Polar Cap rests in the lowest part of the Vastitas Borealis topographic basin (Fig. 1a and b). It is 1300 km in diameter and reaches a maximum thickness of 3 km at its center (Zuber et al., 1998). The formation of the whole ice cap took place during the Amazonian (Carr and Head, 2009). It is a stack of water ice layers containing various amounts of intermixed sediment (dust and/or sand) (Fishbaugh et al., 2008; Howard et al., 1982; Kieffer et al., 1976; Tsoar et al., 1979).

Two distinct units have been recognized in this stack (Fig. 1b). The first one corresponds to the Basal Unit (BU), which rests directly on the Vastitas Borealis Formation (VBF). High-resolution images reveal that the BU consists of a low albedo, 1 km-thick formation displaying platy interbedded sequences of ice-rich and sediment-rich layers (Byrne and Murray, 2002; Edgett et al., 2003; Fishbaugh and Head,