GLOBAL DISTRIBUTION, COMPOSITION AND SETTING OF HYDROUS MINERALS ON MARS: A REAPPRAISAL

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Introduction: Strong evidence for several wet eras on early Mars has been found in the mineralogical record of the planet' surface (1). Mineralogy data from the OMEGA and CRISM hyper-spectral imaging instruments (2,3) have revealed diverse hydrated minerals, including phyllosilicates and sulfates, found in equally diverse geological settings of Noachian and Hesperian age (e.g. 4,5).

Using orbital data from OMEGA and CRISM as well as high-resolution imagery, a number of key sites of interest have been put forward based on their outstanding mineralogy and morphology, and are often candidates for future ground-based missions. The most spatially extensive sites include Mawrth Vallis (e.g. 6), Nili Fossae (e.g. 4), Meridiani Planum (e.g. 7) and Valles Marineris (e.g. 8).

While these sites have been thoroughly studied, they may not be representative of the aqueous alteration settings on Mars as a whole. The purpose of this work is hence to identify, map and characterize all hydrated mineral exposures on Mars on a planetary scale so as to infer global trends in aqueous alteration.

Datasets: Our global hydrated mineral map of Mars is based on data from the OMEGA and CRISM instruments. OMEGA samples the Martian surface from 300m/pixel to 4.1km/pixel spectrally binned at ~12nm. CRISM benefits from a two-fold increase in spectral sampling and up to a 20-fold increase in spatial resolution at the expense of spatial coverage. OMEGA has achieved good coverage (>70%) at low resolution while CRISM high-resolution observations (15-30m/pixel) only cover a small fraction of the surface (<1%). Both instruments benefit from each other as sites of interest identified by OMEGA can be subsequently targeted at higher resolution with CRISM.

Method: Previous work on global mapping using the OMEGA dataset included a survey of surface dust, mafic minerals pyroxene and olivine as well as hydrated minerals (9,10,11). The latter are however difficult to detect due to small exposure sizes (typically <1km) and spatial mixtures. As a consequence previous works under-estimated the number of sites where they occurred. This survey utilizes high-resolution CRISM observations to partly tackle this issue and we develop tools to more efficiently mine both datasets for mineral exposures. The project is still ongoing and the goal is to provide a global map of the aqueous alteration record.

We build a database of hydrated exposures on Mars with their mineral composition and geological setting. We processed the entire OMEGA surface reflectance dataset spanning ~7000 orbits and comprising of 700+ observations. Surface reflectance data are derived following the standard procedure common to both instruments as exemplified in (12). Hydrated minerals are identified through specific absorption bands and other spectral features in the [1.4-2.7] µm spectral region (e.g. 13). Using spectral criteria diagnostic of these absorptions we map the mineral exposures and then use imagery data for context.

We systematically screen the OMEGA dataset for the 1.9 µm absorption feature common to most hydrated minerals. Sites with a clustering of pixels exhibiting the 1.9 µm band above a conservative threshold are selected then verified manually. Dozens of new sites were identified with this method. In addition, a number of careful manual regional examinations of OMEGA observations based on geology or morphology revealed many new sites.

We used the CRISM high-resolution observations (15-30m/pix) to verify and further characterize OMEGA detections but also as a standalone in regional enquiries. A total of 1680+ high-resolution observations have been studied as well as ~100 medium-resolution multispectral observations (200-300m/pix). We developed automated software to batch process and analyse the data in a time efficient way and which allows us to quickly browse through observations and identify those of particular interest. An example is given in fig. 1: we generate mineral maps based on select spectral criteria, for each of which is computed a filtered median spectral endmember

Results: We have identified 990+ hydrated mineral exposures on Mars as shown in fig. 2. The regions with extensive deposits aforementioned have been left out, as well as the north polar gypsum sulfate deposits (14) and crater fills.

Hydrated mineral exposures are found at all longitudes and at a wide range of latitude though mostly equatorward of 40°. Young, poorly cratered terrains (late Hesperian/Amazonian) are almost devoid of detections: the Tharsis rise, the northern plains and southern highland volcanic structures. A few noticeable exceptions exist however (e.g. 15,16).

Spectrally, the most dominant phase (>90%) are phyllosilicates, then zeolites or sulfate (~7%), then hydrated glass/opaline silica (~1%). Zeolites and hydrated sulfates have similar spectral features making them hard to distinguish in many cases. Within the dominant phyllosilicate class, the most common mineral assemblage is a Fe-Mg cat-ion bearing, mixed layered interstratified (I/S) smectite-chlorite, or perhaps an I/S smectite-vermiculite (>70%), followed in equal occurrences by Fe-rich smectite akin to nontronite, Al-smectite or kaolin-class minerals and Fe-Mg- bearing chlorite. Fe-Mg phyllosilicates are a low temperature, surface to near-

surface phase which require non acidic and low water-to-rock ratio. The dominant phyllosilicate unit differs somewhat from that found in the Nili Fossae and Mawrth Vallis regions where Fe-nontronite is found. Sulfates are present in Valles Marineris and neighbouring chaos and in Meridiani Planum. They are however seldom found elsewhere on Mars.

CRISM observations reveal that the typical scale of the hydrated deposits is <1km, while deposits down to the single pixel have been found indicating that we are still limited by spatial resolution, thus underestimating the occurrence of deposits of hydrous minerals.

Most detections (>70%) are associated with impact structures, and have often been excavated by the impact (17). Many others are associated with outcrops exposed by aeolian or fluvial erosion, in scarps or troughs.

Fig. 3 shows the main sources of biases in the distribution of hydrated exposures. Variability in data availability and focus on particular regions on Mars are the main cause for the clustering of detections in areas (e.g. Terra Tyrrhena and northern Hellas) and the depletion in others. Surface dust and polar processes are also a main source of bias. Despite this, some regions (e.g. E. Thaumasia Planum, Terra Sirenum and Terra Tyrrhena) appear particularly dense in detections, which could indicate peculiar regional aqueous sets of events.

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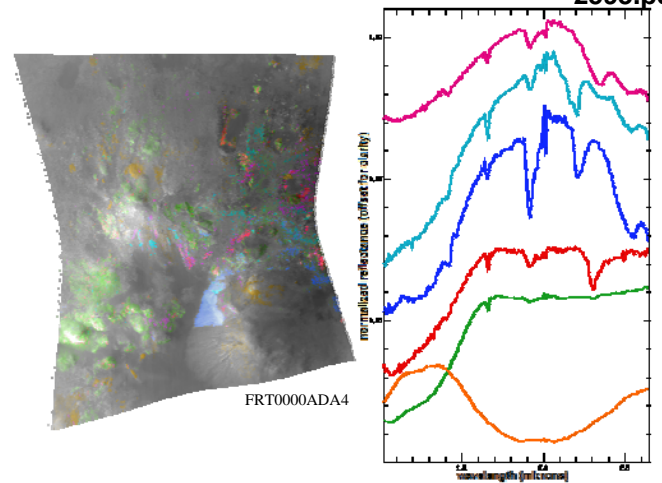

Figure 1. Automated mineral map and spectral endmembers generated from a CRISM observation of Stokes crater (171.4°E, 55.6°N). Spectra akin to chlorite (pink), kaolinite (cyan), montmorillonite (blue), Fe-Mg smectite with olivine (red), olivine (green) and pyroxene (orange).
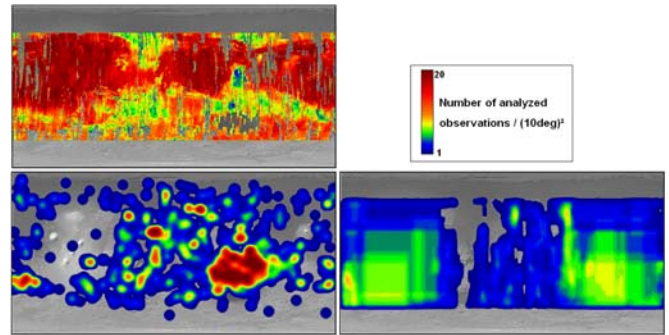

Figure 3. Top: Fe3+ spectral index, high values (reddish) represent high surface dust content (credit: A. Ody). Bottom: Studied observation density (per 10 deg²) for CRISM (left) and OMEGA (right). Same map extent as figure 2.

Figure 2. (bottom) OMEGA and CRISM based global map of hydrated exposures on Mars (MOLA background). 994 detections on map, excluding hydrated exposures in Valles Marineris and eastern chaoses, Meridiani Planum and Nili Fossae.