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Aqueous minerals on Mars: an orbital perspective

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1. Introduction

The surface of Mars bears the mineralogical record of past aqueous activity early (mostly > 3.6 Ga) in the planet's history [1,2]. A number of the resulting secondary alteration products have been detected both from orbit and in-situ, which provide strong geochemical constraints on the aqueous environments. An increasing number of rover measurements have provided detailed petrological context and quantitative analyses of aqueous minerals which allow refining local alteration settings on Mars [3-6]. The coarser view provided by orbital instruments remains however necessary to infer global trends regarding the planet's aqueous history. This is due to planetary-wide coverage providing broader context and access to a wider range of aqueous alteration environments than landed missions, but also to the use of near infrared reflectance spectroscopy, not available on roving missions so far. Here we re-appraise the detection sample of aqueous minerals identified and mapped thus far on Mars based on near-infrared data from the OMEGA and CRISM imaging spectrometers [7,8]. This work builds upon previous global mapping approaches aiming at inferring the global distribution and nature of alteration minerals [9-12].

2. Datasets

The map presented in Figure 1 shows the location of the near entirety of aqueous minerals reported from orbit thus far, to the exception of (i) anhydrous chlorides reported at thousands of location with THEMIS but which are featureless in the near infrared [13], and (ii) the ferric oxide hematite identified at select locations of Mars with TES [14] which is not a hydrated or hydroxilated mineral although an aqueous origin has been proposed.

OMEGA and CRISM data at various spectral and spatial resolutions were used to build this map, ranging from ~8 m/pixel to ~4 km/pixel, spectrally sampled from ~6.5 to ~55 nm. To-date, 2975 sites have been identified and characterized based on the site definition used in [12]. OMEGA observations (0.3-4 km/pixel, *orange dots*) contributed to 619 sites, while CRISM high-resolution observations (~8-36 m/pixel, *red dots*) contributed to 1443 sites, and CRISM medium resolution multispectral observations (100-200 m/pixel, *blue dots*) to 913 sites. A large fraction of sites are detected using several overlapping observations from both instruments.

Global mapping efforts suffer from a number of limitations which include:

(i) Low signal-to-noise, instrument artifacts and spectral mixing with non-aqueous phases which dominate the spectra. These result in an effective resolution lower than that allowed by the spatial sampling of both instruments and the datasets require complex data processing and data mining strategies.

(ii) Limited spectral resolution in some OMEGA observations and CRISM multispectral products, at times insufficient to identify the fine chemistry of alteration products.

(iii) The lack of global coverage (topping at a few %) at the highest spatial sampling provided by CRISM. The precise mineralogy of most of the surface has not been mapped.

(iv) The in-ability of NIR data to determine the parent high-silica phases (e.g. plagioclase, quartz), *as well as spectral ambiguity between some aqueous phases* (e.g. hydrated sulfates and zeolites) which collectively complicate geological interpretation efforts.

Collectively these factors make the detection of these spatially minor phases tedious on Mars, precluding a straightforward blind mapping approach. The map presented here is therefore a collection of identified spots of aqueous minerals, not a global homogenous map.

3. Results

Each identified aqueous mineral spot is characterized in terms of mineral composition, morphological context and geological unit age. These allow inferring global trends in terms of the chemistry of the parent fluid, the possible geological formation process, and their evolution with time in the frame of the planet's geological history. The overall distribution of aqueous minerals is in agreement with early work on Mars clays and sulfates [1]. With a sample orders of magnitude larger, the distribution confirms a pervasive Noachian-aged alteration both at the surface and at depth [11,12,15], and reveals the primary role of erosional windows in dictating the observed deposits. Generally, any high SNR observation of the Noachian crust with a low dust content will exhibit alteration signatures. A secondary objective is the identification of new, potentially interesting regions for further in-depth investigations. In particular, the identification of large mineral deposits (100s km in size) that suit engineering constraints participate to the landing site selection effort for the upcoming ExoMars and Mars 2020 missions.

4. Perspectives

The combination of global approaches and localized, in-depth investigations has demonstrated the existence of several geological formation processes accounting for the diverse aqueous mineral chemistry and morphological settings. The next leap forward in our understanding of the geological and aqueous history of Mars will require clarifying the roles of these diverse processes and putting them into a coherent temporal and spatial context. To achieve this, a global approach using a large population of aqueous deposits is necessary, as it mitigates the poor preservation state of most deposits and the degeneracies between minerals and their formation pathways (a given mineral may form in different environments, and these would have evolved through time). A more systematic inclusion of medium/low resolution CRISM and OMEGA observations will provide additional context for the numerous in-depth but highly localized studies of the aqueous alteration on Mars that have been carried out. Convergence between NIR data and TIR data from TES/THEMIS has been achieved locally for aqueous minerals [16-19], revealing interesting prospects for a multi-wavelengths global mapping of alteration phases, additionally providing better petrological constraints. Finally, the chronology of the terrains in which the deposits are found will provide further constraints on the evolution of aqueous processes early in Mars's history, which are of relevance for other bodies of the Solar System.

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Figure 1: Aqueous minerals (silicates and hydrated salts) detected from orbit based on the OMEGA instrument (orange), CRISM high resolution data (red) and CRISM 'multi-spectral' data (blue).