Recent Aqueous Alteration Associated to Sedimentary Volcanism in Acidalia Planitia, Mars

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Introduction:

Sedimentary volcanism includes multiple geological processes (e.g., mud volcanism, sandstone injectites/extrudites) that bring buried sediments to the surface [e.g., 1]. The existence of sedimentary volcanoes has been proposed on Mars, notably in the Northern Plains (NPs) where several landforms, like the intriguing Thumbprint Terrains (TT), are observed [e.g., 2]. TT are commonly described as an alternation of parallel alignments of 10s of meters high high-albedo ridges and dome-like mounds, separated by shallow depressions with contrasting low albedo [3]. These smooth surface deposits are composed of fine-grained loose materials [4]. TT mounds have been tentatively proposed as being formed by: explosive volcanism [5], glacial processes [3,6], sedimentary volcanism [4,7,8], or tsunami-driven events formed after giant impacts [4,8,9]. TT formation may be recent (Late Hesperian-Early Amazonian), period overlapping with the outflow channel activity timing and a possible transient Hesperian Ocean on Mars [9,10]. However, our lack of knowledge about the nature of these deposits persists, not least because no mineralogical clue has been found [11]. This study proposes to provide constraints on the nature of these deposits and their possible subsurface layering, thanks to the recent observation of hydrated silica (HySi) and sulfates (PHS) on the TT of Acidalia Planitia [12].

Observations of HySi and PHS:

HySi is systematically associated with TT's mounds [Fig.1A,B,C,D]. HySi is only observed in these mounds and seems to be directly linked to the activity of these. We calculated spectral criteria on HySi CRISM detection to decipher the type of silica and to infer its possible geological origins [13,14]. Silica possibly occurs as altered volcanic glasses, or as dehydrated opals. These criteria also suggest that the silica was formed by low-T fluid-rock interactions and/or late-stage water-limited alteration. We propose that HySi in the Acidalia's TT cones represents weathered, Si-rich fine materials. Possibly in the form of low-density volcanic ashes, HySi was extruded to the surface by sedimentary volcanism involving low quantity of fluids/volatiles (no surface flow observed). Such type of mounds could be indicative of sand volcano-like mounds and/or hydrodynamic blowouts whose sources, constrained by the thickness of the TT (less than 100m), may be shallow.

PHS are mainly associated with impact craters with diameters less than or close to ~1 km, and mostly located in their (sometimes lobate) ejecta [Fig.1A;B]. As such small impacts can excavate materials up to 100-150 m depth, PHS may indicate the presence of sulfate-bearing lithologies in the TT' subsurface or in the underlying units. This is inferred from observations such as the one presented in Fig.1B where two impacts excavate PHS in two different settings. Further evidence of the presence of sulfates within the TT (or in deeper underlying units) is the observation of PHS in one large 165 m high mound that also display HySi at its base [Fig. 1C].

Implications for the presence of aqueous reservoirs in the Northern Plains:

These observations, validating the sedimentary volcanism hypothesis, also indicate that aqueous reservoirs were present in the NPs subsurface, in the TT and underlying Vastitas Borealis Formation (VBF). Using the equations of a buoyancy-driven upwelling model applied to sedimentary volcanism [15], we infer that silica-rich materials/fluids were sourced in the near subsurface, several dozen meters deep (-10 to -80m), in the TT' stratigraphy. Conversely, sulfates-rich materials/fluids may be related to deeper geological reservoirs several hundred meters deep (-200 up to -600m) [Fig.2]. These results are in agreement with previous estimations [15,16].

In such a configuration, as the PHS-related sources are buried at greater depths than HySi-bearing reservoirs, they are geologically older. We hypothesize that the HySi reservoirs are "mostly Early-Amazonian" in age as they precede the formation of the TT's geomorphologies by sedimentary volcanism that we date between 2.0 and 2.5 Ga ago. Possibly in the form of buried evaporitic deposits, these "mostly Late-Hesperian" sulfates may indicate a locally salt-rich aqueous origin of deep VBF layers.

Ongoing perspectives:

Our findings set new horizons and opportunities for future Mars' science and exploration missions. Exploring these extruded sediments will give us an indirect window of aqueous reservoirs of the NPs. This will help the scientific community to resolve still ongoing enigma regarding ocean-related hypotheses [4,9,10,17]. This will also precise climate modelling to understand fluid nature and stability in the late Martian hydrogeological history [17,18].

The presence of HySi extruded in such contexts is also of major astrobiological relevance. The fact that these sediments were buried at depths could have enabled possible organic molecules (i.e., biosignatures) to be protected from solar and cosmic radiation [e.g., 19]. Furthermore, it is well-known that HySi-minerals exhibit a great capacity to protect biomolecules over geological time ranges [e.g., 20,21,22,23] as proved by the observation of the oldest terrestrial traces of life in Paleoarchean cherts [e.g., 24]. The geological contexts on Mars observed in this study therefore present a double benefit due to the presence of extruded sediments that are rich in silica.

These observations, linked to recent Martian sedimentary volcanism, should be therefore considered as prime targets for access to well-preserved biosignatures in these siliceous phases, should they one day be present on Mars.

References:

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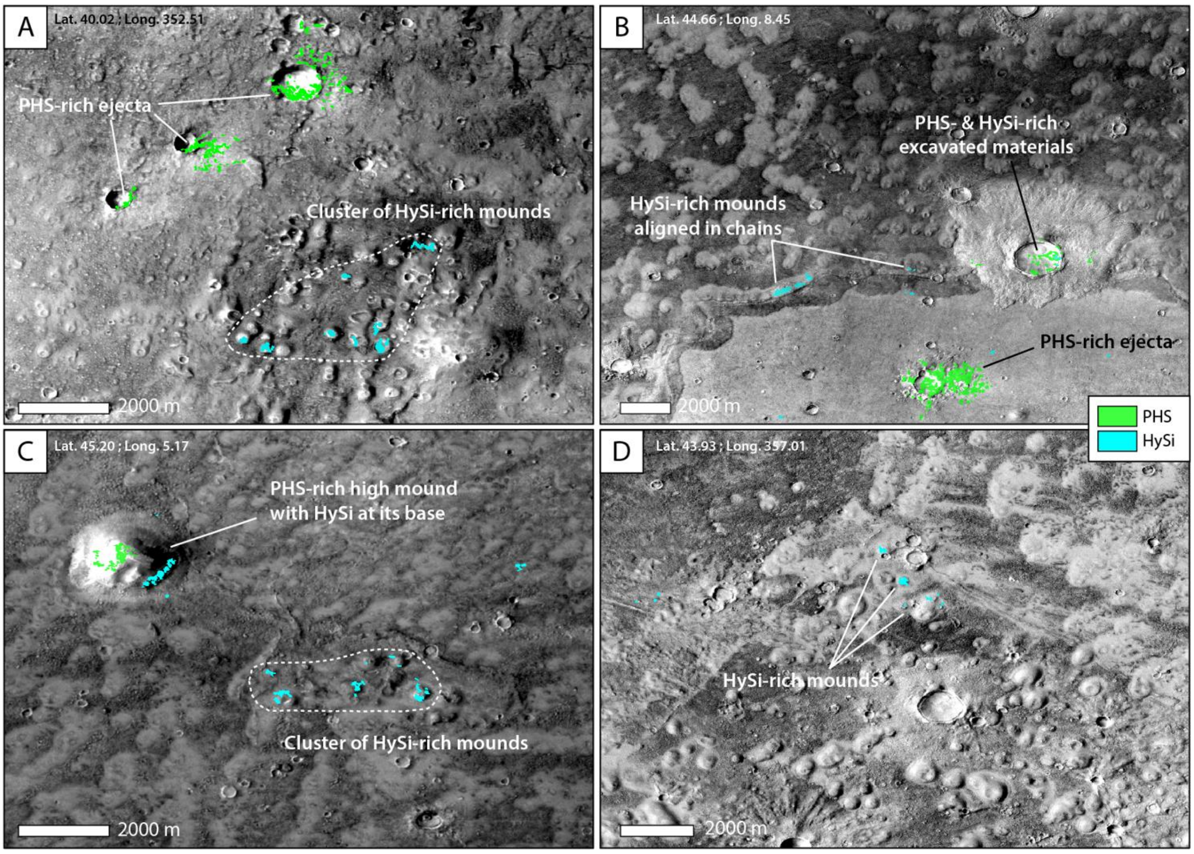

Fig. 1. A. to **D.** PHS (green) and HySi (cyan) CRISM detections in four sites within the Acidalia's TT over CTX background, North is up. For each, coordinates of CRISM cubes are provided. Scale bars indicate 2000m.

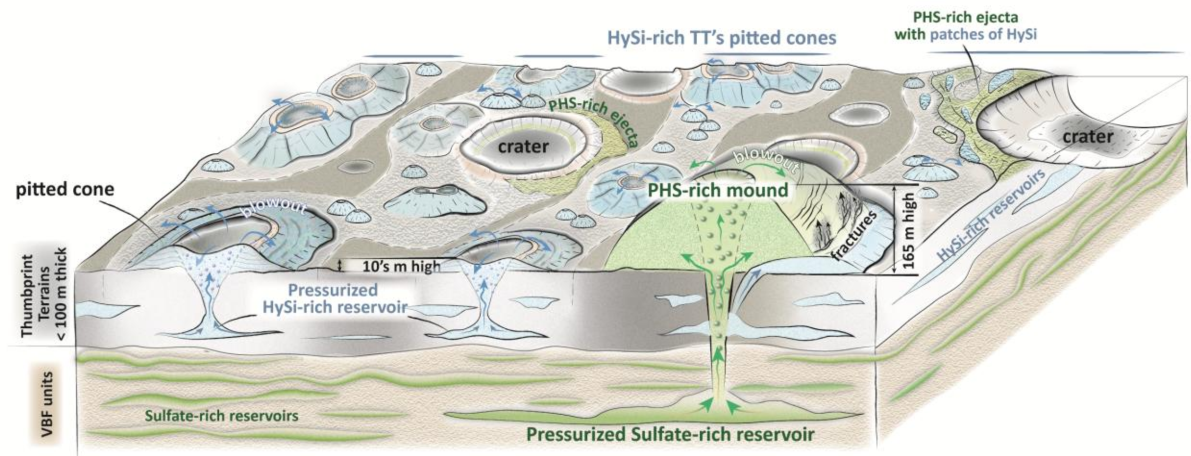

Fig. 2. Interpreted sketch displaying the relations between HySi and PHS-rich deposits in pitted cones and mounds in the NPs of Mars, respectively. In this scenario, PHS-rich materials are extruded from deep "Hesperian" units and may have incorporated HySi-rich "Amazonian" more superficial materials through their ascent to the surface. For the latest, their extrusion from shallow depth to the surface (in blowout-like process) was responsible of the formation of pitted cones that constellate the NPs' young. Note that horizontal and vertical scales are not respected.