

INVESTIGATING THE FORMATION OF IMPACT-EXHUMED HYDRATED SULFATES IN TYRRHENA TERRA, MARS. L. M. Aaron¹ and K. D. Seelos², ¹Johns Hopkins University (laaron2@jhu.edu), ²Johns Hopkins University Applied Physics Laboratory.

Introduction: The dominant secondary mineralogy of Mars is closely associated with the geologic eras in which they formed. The presence of clays, such as phyllosilicates and carbonates, are indicative of a warmer environment with a neutral pH and seen primarily within Noachian-aged terrains [1]. Sulfates are commonly found in layered Hesperian geologic units, which formed in a more acidic environment [2]. The current Amazonian era is cold and dry, and resulting primarily only in ferric oxides. Because of these mineralogical tendencies, locating a secondary mineral outside of the regime in which it typically forms is cause for further study. In this way, we previously documented three occurrences of hydrated sulfates in a setting suggestive of impact-induced exhumation from Noachian crust. Here, we focus on the different processes that may have been responsible for the formation of Noachian sulfates, how these processes inform the heterogeneity of the Noachian crust, and if these processes could explain the coexistence of both sulfates and phyllosilicates.

Noachian Crater Sulfates: Previous results from our CRISM hyperspectral analysis show detections of polyhydrated sulfates, Fe/Mg-smectite, chlorite, and high- and low-calcium pyroxene (HCP and LCP, respectively), distributed among the floors, rim, and ejecta deposits of each of three craters examined in the Tyrrhena Terra region [3]. Less prominent outcrops of bassanite/analcime, analcime, talc, and prehnite were also observed. All of the minerals except for the polyhydrated sulfates are commonly found in similar exposures throughout the highlands [e.g., 1].

However, the placement of polyhydrated sulfates within the ejecta and in central peak materials of these craters indicates formation prior to impact. While each crater shows relatively little degradation, suggesting the impact occurred during the late Hesperian/early Amazonian, subsurface sulfate formation might have occurred during the Noachian by either of the following processes: hydrothermal, oxidation, or post-oxidation precipitation and evaporation.

Hydrothermal Processes: Hydrothermal processes provide the necessary conditions to form sulfates, oxides, and sulfides when sulfuric acid, formed from aqueous dissolution of subsurface sulfur-bearing minerals, bonds with primary cations (Fe, Mg, Ca, Al) [4]. Both volcanism, and impact cratering can induce the required conditions at temperatures of 500-300° C.

[5]. Volcanically-induced hydrothermal processes would not be possible for the three craters as no nearby morphological features associated with volcanism could be identified where sulfates were detected. An impact-induced hydrothermal system would also not be likely as this would only produce deposits in the crater floors and rim, not ejecta (Fig. 1). In addition, the maximum depths of the three craters range from 760 m to 1.7 km, which are too shallow to reach depth-related hydrothermal conditions.

Occurring under less extreme conditions, epithermal processes require lower temperatures of 50-200° C and can be observed at shallow depths (Fig. 1), ideal for forming subsurface sulfuric acid in the presence of water [5]. Resulting subsurface sulfuric acid-bearing fluids could ultimately produce secondary minerals such as sulfates.

Sulfide Oxidation: Sulfate can also form as secondary alteration of sulfides found within ultramafic igneous rocks. Meteorite data from Allan Hills 84001 (~4.5 to 4.0 Ga) and Northwest Africa 7034 (~4.44 Ga) confirms detections of the sulfides pyrite and pyrrhotite, as well as microscopic aqueous alterations [6]. Although rover data shows very little evidence of sulfides (on the order of ppm) [7], these observations compared to meteorite data concludes the dissolution of sulfides was potentially caused by warm groundwater or acidic hydrothermal systems.

Sulfide oxidation would occur upon impact as sulfides are exposed to an oxygen-rich atmosphere (Fig. 2), and thus convert to sulfates. Most likely these sulfides would form Fe-sulfates, which if subsequently exposed to an aqueous environment would be highly soluble [8]. For this formation process to be viable, further aqueous processes are necessary to explain the presence of the more stable Mg-sulfate.

Precipitation & Evaporation: Fe-sulfates are highly soluble in an aqueous environment. This dissolution could lead to the conversion of Fe-sulfates to Mg-sulfates after the fluid evaporates (Fig. 3). Mg-sulfate has a relatively lower molality than Fe-sulfates which causes Mg-sulfate to precipitate earlier in a dissolved solution [9]. However, the degradation state of the three craters seems to indicate an exhumation that could have occurred during a time where the aqueous conditions needed would not present.

Noachian Crustal Heterogeneity and Co-occurrence of Phyllosilicates:

A major concern regarding the formation of Noachian sulfates is the presence of phyllosilicates within the same or nearby outcrops (i.e., within the same uplifted central peak materials or along the rims, in ejecta). The processes necessary to form phyllosilicates (e.g., Fe/Mg smectites, chlorite) would be expected to result in the dissolution of Fe-sulfates and vice versa. Future work focusing on the co-occurrence of phyllosilicates and sulfates could shape our understanding of Mars' primary crustal heterogeneity and evolution. However, our results illustrated in Fig. 1-3 assume that the formation of phyllosilicates occurred after that of the sulfates or sulfate precursor material, but prior to impact. A heterogeneous crust could account for the rarity of sulfates when applied to the three processes mentioned. This crustal heterogeneity could have occurred through groundwater demineralization in the subsurface. Combined with the highly soluble nature of Fe-sulfates, groundwater could have easily mobilized sulfates down-gradient to eventually be deposited in sedimentary layers like those found in Terby crater [9].

Conclusion: Compared to other craters in Tyrrenia Terra, the three craters in this study were the only ones with detectable polyhydrated sulfates within the crater central peak and ejecta, indicating exhumation from the subsurface, formation prior to impact, and under acidic conditions. This suggests the most likely formation scenario involved epithermal alteration. However, localized surficial oxidation of precursor sulfides could potentially be a viable formation process. Additional aqueous alteration would be needed to form Mg-sulfates. Regardless, either process suggests a heterogeneous Noachian crustal composition.

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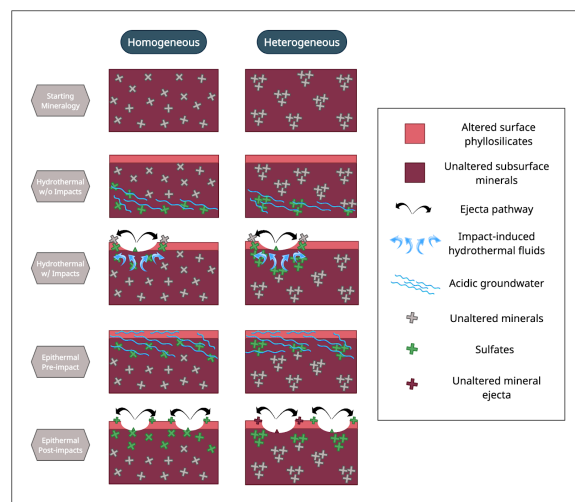


Figure 1. Hydrothermal sulfates caused by impact or at depth are unlikely; epithermal processes provide the shallow depth and lower temperatures to plausibly form sulfates.

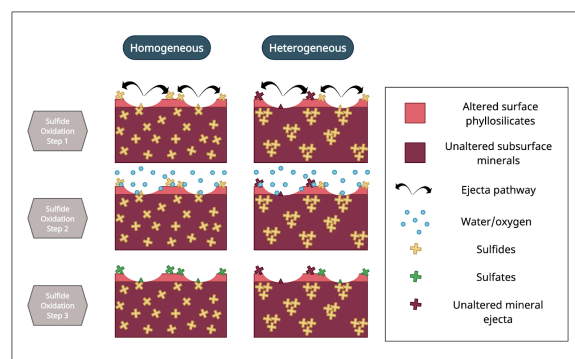


Figure 2. Sulfides exposed to oxygen post-impact can result in the formation of Fe-sulfates. A heterogeneous crust could account for the minimal detections of sulfates in the region.

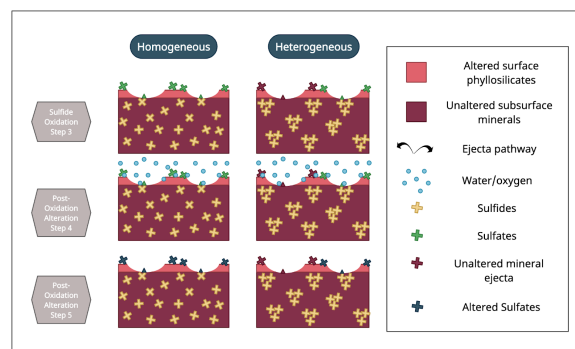


Figure 3. Fe-sulfates could become Mg-sulfates through evaporation and precipitation following sulfide oxidation (Fig 2).