HYDROTHERMAL ALTERATION PRODUCTS IN THE CIRCUM-HELLAS REGION: GEOLOGIC SETTING
E.Z. Noe Dobrea[1] and G. A. Swayze[2], [1]Planetary Science Institute (1700 E. Ft. Lowell, Suite 106, Tucson, AZ, 85719; eldar@psi.edu), [2]United States Geological Survey, Denver, CO, United States).

Introduction: The Hellas basin is thought to have formed during the early Noachian as the result of a massive impact. Such an impact would not only have excavated rocks from the deep stratigraphy, but it would have also deposited enough energy into the ejecta to support hydrothermal conditions for extensive periods [1, 2]. Of particular interest to the question of habitability is the possibility that a variety of aqueous systems, in particular marine/lacustrine [3, 4] and hydrothermal systems [1], may have formed in the region after the Hellas impact. Spectroscopic evidence for aqueous activity in the greater region has been presented [5, 6] and more recently, phyllosilicates and sulfates have been identified on and near the rim of Hellas in association with multiple geological features [7, 8].

In this study, we have focused on the analysis of spectral and imaging data of a roughly 5x5 degree region centered around 56.5 E, 26.1 S, where prehnite is identified. We have characterized the regional geological context of the deposit as well as its implications for past habitability.

Mineralogical and spectral indicators of hydrothermal activity: Multiple terrestrial studies to date have reported on a variety of mineral assemblages resulting from the hydrothermal alteration of primary minerals as a function of temperature, pressure, and aqueous chemistry [*e.g.*, 9]. Often, however, the individual minerals do not unequivocaly indicate hydrothermal conditions. Published analyses of CRISM and OMEGA data to date have revealed the presence of several of these alteration products on the surface of Mars, including kaolinite, chlorite, serpentine, prehnite, alunite, and carbonates [10, 11, 12]. Of these, prehnite and serpentine are exclusively hydrothermal minerals. Prehnite [$Ca_2Al(AlSi_3O_{10})(OH)_2$] is of particular interest to this study because it is identified in the circum-Hellas region, and forms under specific conditions ($P < 2.5$ kbar, $200° < T < 250°$; and $XCO_2 < 0.002$) [13]. On Earth, prehnite is derived from the alteration of basalt under metamorphic conditions, and prehnite-bearing facies are indicative of low-grade metamorphism, transitioning to greenschist facies at higher pressures. At higher XCO_2, prehnite formation is suppressed in favor of clays/carbonate minerals.

Prehnite can be identified by a sharp OH overtone at 1.48 μm, and metal-OH combination bands at 2.23, 2.28, 2.35-2.36, and 2.57 μm, where the 2.35-2.36 μm band is the strongest [12]. In particular, the 1.48, 2.23, and 2.28 bands make it distinguishable from chlorite, which has a similar spectral shape, but exhibits its OH overtone at 1.40 μm and metal-OH combination bands at 2.25-2.26 (as a shoulder), and 2.33-2.35 μm.

Our study region exhibits spectra consistent with prehnite, chlorite, and illite, all of which can be of hydrothermal origin. Often, the chlorite spectra in CRISM data will also exhibit a secondary absorption 1.48 μm, suggesting that it is present in association with prehnite.

Location and geological context: The prehnite deposits are exposed over several semi-contiguous outcrops extending at least 15 x 5 km on a local topographic high on the cratered plains northwest of Hellas. The prehnite-bearing units consist of both rocky outcrops and rippled mantles. Although the prehnite units is found in proximity to 10-km craters, it occurs up to two crater radii away from the rims of these craters, and its formation is therefore not thought to be associated to impact that produced these craters. The units on which the prehnite is found are mapped as Hilly units (Unit Nh) in [14], where they are interpreted as components of the “Hellas rim assemblage formed by kilometers of uplift of crustal material caused by the Hellas impact” containing uplifted material, basin ejecta, and younger, undifferentiated mantling material.

These hilly units are locally embayed by etched plains units of Hesperian origin that exhibit mineralogical indicators of aqueous processes. In contrast to the hilly units, the plains are poorly undissected, and exhibit broad (10s of km in width) pits in multiple locations.

Most of the craters in the region also exhibit evidence for modification: their floors are flat and smooth, their walls are dissected, and sometimes their rims are breached. In many cases, the smooth crater floors also exhibit broad pits.

The material forming the walls of the pits both on the plains and in the crater interiors is yardanged and appears extensively layered at HiRISE scales. The pits are typically 100-250 m deep on the plains, and 300-500 m deep in the interiors of craters. CRISM spectra of the pit walls and other outcrops on the smooth plains unit exhibit absorptions around 1.42, 1.92, and 2.29-2.31 μm, consistent with the presence of Fe/Mg smectites. However, in most cases, the 2.3 μm band occurs in association with a sudden dropoff in reflectance. This dropoff has been interpreted in the past to be due to a mixture of smectites and chlorites [15] or chlorite-smectite mixed-layer phyllosilicates such as corrensite [16].

These extensive, etched, and thick sequences of layered, embaying hydrated material occurring at the termini of truncated drainage systems suggest that the smooth plains units were deposited in either a lacustrine or aeolian setting akin to that of the Meridiani Planum deposits, and consist of fluvially reworked material derived from higher elevations. [14] proposed that the embaying plains may have resulted mainly from the deposition of alluvium on cratered material and possibly also from local eolian or volcanic resurfacing.

Hence, we observe two sets of aqueous mineralogies: prehnite/chlorite-bearing, and mixed-layer phyllosilicates, associated to two different morphologic units emplaced at two different periods of martian history. The identification of prehnite/chlorite in the Hellas ejecta allows us to constrain the hydrothermal conditions that the rocks were subjected to during the Noachian. However, the low CO_2 fugacity and high temperatures needed for their formation brings into question the astrobiological potential of the exposed Hellas ejecta, and begs for the identification of nearby areas with lower temperature and higher CO_2 fugacity.

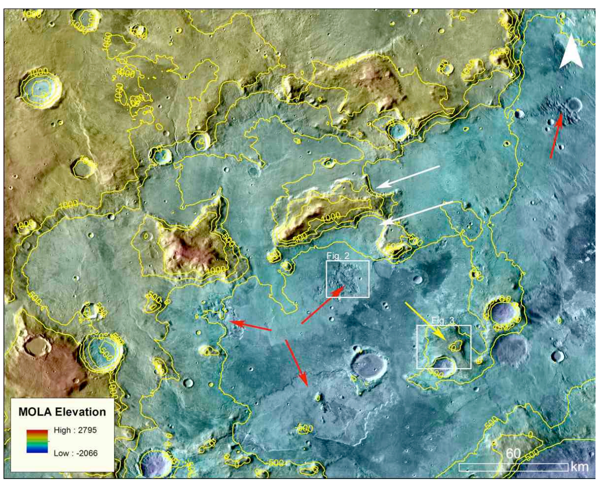

Figure 1. Regional view of the study area, centered on 55.3 E, 25.2 S. White arrows indicate examples of embayment relationship between the smooth, pitted unit (blue tones) and the higher unit. Red arrows indicated examples of pits, and yellow arrow indicates prehnite-bearing mound. White boxes indicate inset for figures 2 (upper left) and 3 (lower right).

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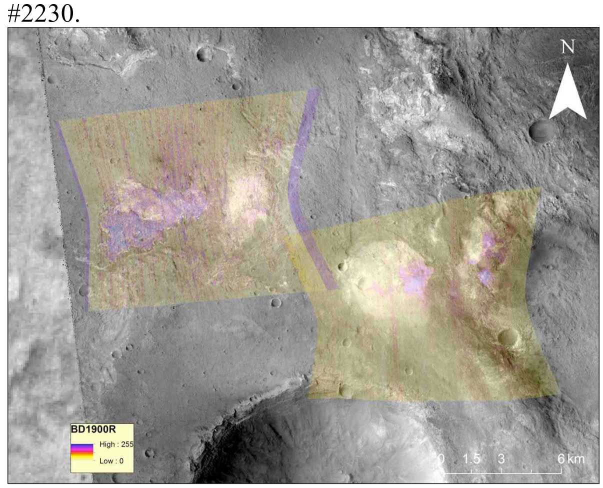

Figure 2. CRISM parameter maps showing the distribution of of prehnite/chlorite-bearing units (magenta) overlayed on CTX image.

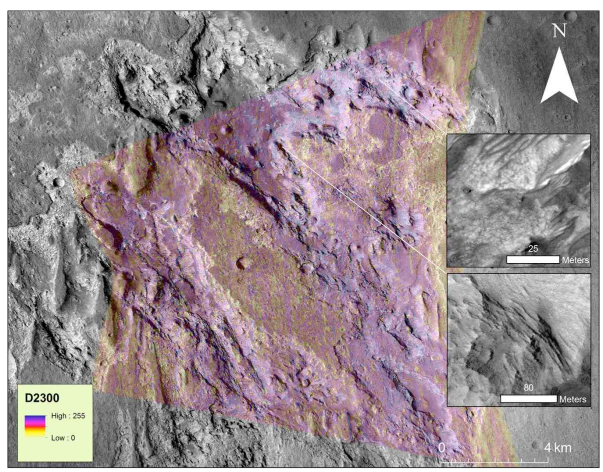

Figure 3. CRISM parameter map of Fe/Mg smectite/chlorite-bearing units (magenta) overlayed on CTX data.