INTEGRATING IN SITU AND ORBITAL DATA OF MARS: A WATER STORY AT GUSEV CRATER.

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Introduction: The geologic record preserved in the rocks visited by the Spirit rover reveals periods in Martian history in which volcanic and impact events were widespread and water was episodically present [1]. Of special interest is the identification of rocks in the Columbia Hills that underwent substantial alteration after their formation with action of liquid water most clearly implicated in the major alteration of Clovis Class rocks [1,2]. On the other hand, Spirit did not encounter the Ma'adim-related sediments that originally drew the mission to Gusev crater as a landing site [3]. The predicted aqueous origin of the crater infilling deposits has been nevertheless recently confirmed by orbital detection of phyllosilicates in sedimentary units [4]. In this paper, we attempt to reconcile analyses from orbital and rover-based observations so as to relate the aqueous episodes that occurred at Gusev crater.

Deposition of fluvial-lacustrine and phyllosilicate-bearing sediments on the floor of Gusev crater. Based on CRISM data, [4] reported the identification of Fe/Mg phyllosilicates in deposits interpreted to be fluvial-lacustrine sediments formed during widespread ponding inside Gusev (Figure 1). The clays may have been detrital or authigenic, implying formation/transformation into clays during the depositional event(s) and in ponding water. Two observations are in favor of a detrital/fluvial origin: 1- the absence of authigenic products such as poorly crystalline hydrated mineral precursor that forms during deposition and detected in numerous deltas and alluvial fans; 2- the spectral similarity between these clays and those found in the Noachian crust including the source region for Ma'adim. Based on crater counting, this aqueous activity occurred sometimes before the emplacement of flood basalts during early Hesperian [5].

Aqueous alteration of Columbia Hills rocks. Water played an important role in the formation of minerals in rocks of the Columbia Hills [1]. Among them, Clovis class rocks that dominate the West Spur of Husband Hill were extensively altered according to several observations (Figure 2) [1,2,6,7]: 1- the correlation of CaO vs. SO_3 indicating the presence of Ca-sulfates as from extensive chemical weathering and deposition; (APXS); 2- the almost absence of olivine combined with the presence of goethite supporting a high degree of alteration (MB); 3- the enrichments in S, Cl and Br suggesting the presence of precipitated salts from brines (APXS); 4- an Al-Si-enriched silicate chemistry after the removal of salts (APXS) and Fe-oxides/hydroxides (MB); 5- the low specific grinding energy values (RAT) indicating low hardness of the rocks; 6- the very-fine grain sizes of RAT abraded grind targets (MI).

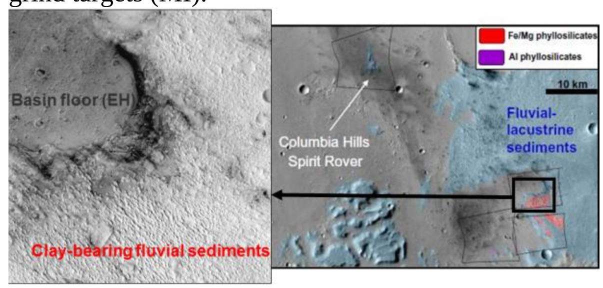

Figure 1. Mapping of phyllosilicates (in red) over the Gusev crater floor (right image) and CTX geological context of the eroded fluvial clay-bearing deposit (left). The basin floor assemblage corresponding to sediments is mapped in in blue.

Figure 2. Rocks on West Spur (Sol 191 Pancam P2390).

[2] developed two different models for the alteration mineralogy of Clovis class rocks, reflecting the possibilities of moderate and extreme aqueous alteration. Fe is present in the form of nanophase oxides (np-Ox), goethite, hematite, as well as in residual pyroxene whose abundance depends on the degree of alteration. Significant alkali feldspar is present in the moderately altered model, while secondary aluminosilicates dominate in the heavily altered one. After removing the % of ions associated with salts and Fe-oxides/hydroxides, all West Spur rocks form a linear trend similar to chemical weathering trend of terrestrial plutonic and volcanic rocks [6]. Corundum-normative mineralogies of most West Spur outcrops and rocks also suggest the presence of secondary aluminosilicates such as allophane, amorphous silica, phyllosilicates, and zeolites [2]. Phyllosilicates were not detected directly in Clovis class rocks by instrument payload of Spirit; however, Wang et al [6] suggested that kao-

linite type of clays could be present based on above six reasons and a mass-balance mixing model analysis on Al-Si-enriched silicate chemistry.

Using a stacking method to attempt to detect any alteration signature over West Spur, we reanalyzed all CRISM data cubes available over the Columbia Hills. From a pool of > 15 CRISM observations, we down-selected 7 overlapping observations of the Columbia Hills with the lowest surface dust content and the lowest instrument noise level. After precise geo-referencing corrections of each observation to correct for geometric distortions, all 7 observations were stacked together according to the methodology specifically developed for CRISM data cubes [8]. This stacking has the advantage of increasing SNR by a factor of 2.6. In addition to orbital confirmation of in-situ detections of carbonates at the Comanche Outcrops and the presence of Fe/Mg phyllosilicates scattered in the southern part of the Columbia Hills [4], this new analysis reveals clear spectral signatures of Fe-rich phyllosilicates in the West Spur area (Figure 3), which does not fully match with the Al-Si-enriched silicate chemistry (APXS) from the observations at surface. A kaolinite type signature is also detected in the southeastern part of the Columbia Hills, making even more diverse the composition of Columbia Hills rocks. The CRISM data thus favor the model with extreme aqueous alteration and indicate that the aluminosilicate alteration phases up to 60% as modeled by [2] partly contains phyllosilicates. Neither Mini-TES nor MB detected phyllosilicates in Clovis class rocks although both show evidence for an abundant amorphous or nanophase component [7,9]. It is not yet clear how to reconcile these surface observations with those from orbit.

Discussion. Overall, both the geological context and the complex composition of altered products (including phyllosilicates) in the Columbia Hills seem to indicate formation process(es) very different from that forming the altered phyllosilicate-sediments in the eastern part of the crater floor [10]. A detrital origin is proposed for the clay-rich sediments with formation of phyllosilicates in the ancient Noachian crust. Alternatively, in situ alteration of Columbia Hills rocks occurred after their formation [1]. This questions whether this alteration is related to the aqueous episode that deposited the altered sediments on Gusev floor. Although hydrothermal conditions could explain many of the altered deposits [11], the complex mineralogy shares some similarities with the compositions and chemical gradients of some altered deposits identified on Mars and especially in the Terra Sirenum region [12]. The intercrater plains of this region contain scattered exposures of Al-phyllosilicates and one isolated mound with opaline silica, in addition to more common Fe/Mg-phyllosilicates with chlorides. A possible geochemical analog for the deposits of northwest Sirenum is provided by Western Australian acid saline lakes and groundwaters [12]. These playa lakes precipitate halite, various sulfates, kaolinite, and ferric oxides in addition to Fe-bearing phyllosilicates. All of these minerals are identified in the Columbia Hills making possible a ponding-related formation, with a short period of liquid water possibly coming from the aqueous deposition of sediments on the crater floor.

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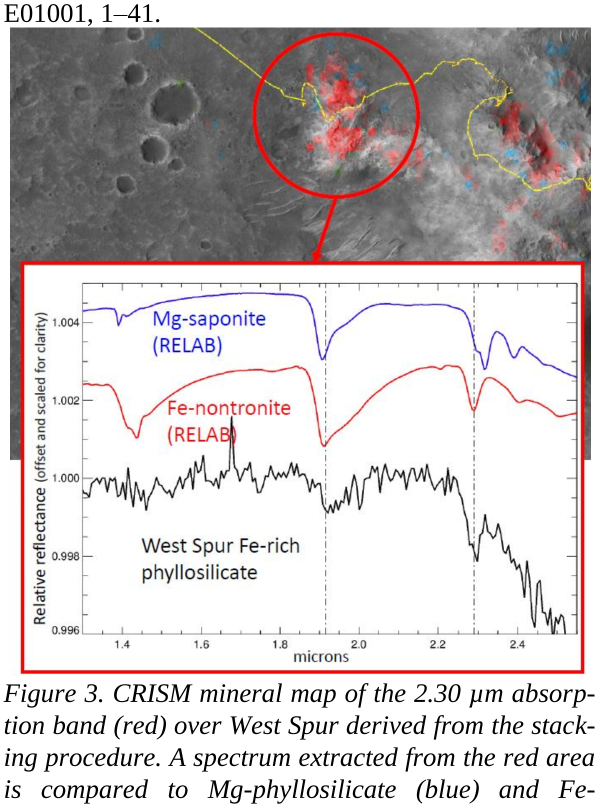

Figure 3. CRISM mineral map of the 2.30 µm absorption band (red) over West Spur derived from the stacking procedure. A spectrum extracted from the red area is compared to Mg-phyllosilicate (blue) and Fe-phyllosilicate. The yellow line indicates the track of Spirit.