EVIDENCE FOR A NOACHIAN-AGED EPHEMERAL LAKE IN GUSEV CRATER, MARS. S. W. Ruff[1], P. B. Niles[2], F. Alfano[1], and A. B. Clarke[1] [1]Arizona State University, School of Earth and Space Exploration, Tempe, AZ 85287-6305, steve.ruff@asu.edu [2]Astromaterials Research Exploration Sciences, NASA Johnson Space Center, Houston, TX 77058.

Introduction: Gusev crater was selected as the landing site for the Spirit rover because of the likelihood that it contained an ancient lake [1]. Although outcrops rich in Mg-Fe carbonate dubbed Comanche were discovered in the Noachian-aged Columbia Hills, they were inferred to result from volcanic hydrothermal activity [2]. Spirit encountered other mineral and chemical indicators of aqueous activity [e.g., 3; 4; 5], but none was recognized as definitive evidence for a former lake in part because none was associated with obvious lacustrine sedimentary deposits. However, water discharge into Martian crater basins like Gusev may have been episodic, producing only small amounts of sediment and shallow ephemeral lakes [6]. Evaporative precipitation from such water bodies has been suggested as a way of producing the Mg- and Fe-rich carbonates found in ALH84001 [7; 8] and carbonates and salts in some nakhlites [9], a hypothesis we examine for the Comanche carbonate [10].

Mineralogic Characteristics: The olivine composition of Comanche outcrops is comparable to that of the Mg-rich olivine in a rock dubbed Algonquin (~Fo_{75}), part of a resistant ridge of knobby outcrops ~85 m to the north [2]. Linear least-squares spectral unmixing calculations [11] applied to a Mini-TES spectrum of Comanche show that it is modeled remarkably well as a mixture of Algonquin, Mg- and Fe-rich carbonates, and an amorphous silicate of basaltic composition (Fig. 1). These results demonstrate that Comanche outcrops are mineralogically comparable to Algonquin rocks with the addition of multiple carbonates and amorphous silicate. One interpretation for multiple carbonates is that they are the result of compositional zoning, as observed in ALH84001 carbonates [12].

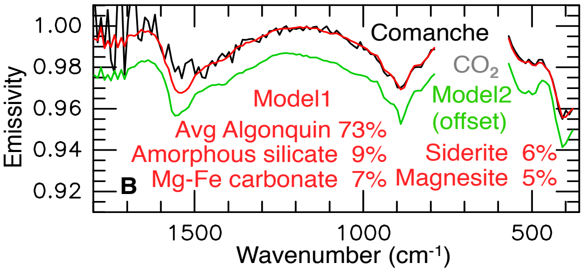

Fig. 1. Unmixing of Comanche spectrum shows that multiple carbonate phases are required to achieve the best fit (Model 1; red line). Model 2 (green line) demonstrates the inferior fit when only a single solid-solution Mg-Fe carbonate is used.

Chemical Modeling: We investigated the chemical relationship between Comanche and Algonquin using APXS data and a mass balance model indexed to Ti, an element commonly assumed to be immobile. Comanche shows substantial additions of MgO, FeO, and SiO_2 amounting to 30% more material on a molar basis, indicative of contributions by fluids strongly enriched in these components plus CO_2. Thermochemical calculations [13] of fluids in equilibrium with a rock of Algonquin composition result in strong enrichments of Fe^{2+}, Mg^{2+}, SiO_2, and HCO_3^-. This is consistent with the fluid that altered Comanche having been a dilute, mildly acidic solution derived from limited stoichiometric leaching of an Algonquin-like rock.

Textural Features: Although Comanche initially was described as "granular" and Algonquin as "massive" [2], these are descriptors of the eroded surfaces rather than rock textures. Mosaicked MI images show that because layering is not evident, both outcrops actually are massive. The granular appearance of the Comanche surface likely is due to dissolution of carbonate cement, leaving silicate grains etched into relief. We identified 147 particles in Comanche and 200 in Algonquin large enough (> 250 µm) to characterize their size and shape. Our observations support the characterization of Comanche and Algonquin outcrops as volcanic tephra. Particle size differences are small enough to be the result of particle size sorting associated with increased distance from the volcanic vent or slightly different eruptive conditions.

Morphologic And Thermal Expression: Additional exposures of Comanche/Algonquin-like terrain are evident in the Columbia Hills and adjacent plains based on its distinctive knob and ridge morphology and higher thermal inertia shown in THEMIS nighttime temperature images (Fig. 2). A thin dust cover precludes orbital spectral characterization, but we hypothesize that they are remnants of formerly more extensive Algonquin-like tephra deposits that mantled the region. Comanche and Algonquin outcrops thus appear to represent an outlier of a much larger unit that was emplaced and eroded prior to the emplacement of the early Hesperian plains basalt [14].

Discussion: Our spectral and chemical models indicate that the Comanche alteration was an addition to an Algonquin-like host rock rather than a depletion or isochemical replacement of primary phases. A key result is that the chemistry of the added phases strongly

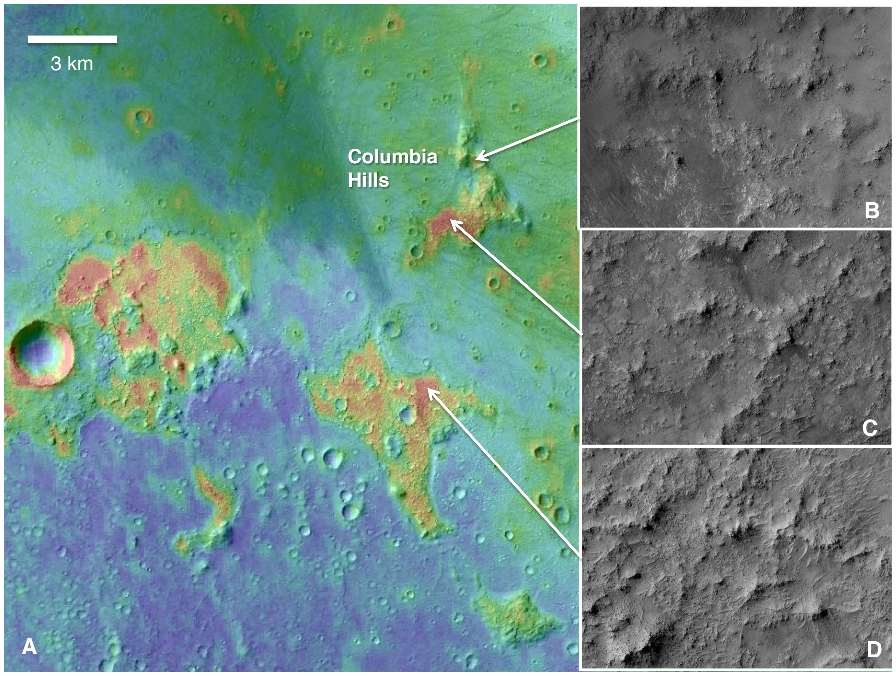

Fig. 2. Morphological (CTX/HiRISE) and thermal characteristics (colorized THEMIS) of terrain similar to that of the Comanche/Algonquin outcrops contained in frame B.

resembles that of fluids in equilibrium with Algonquin-like rocks. If these notably Ca-poor rocks served as a cation source, it explains the lack of Ca-rich carbonates in Comanche. Because low temperature fluids are required to generate abundant Fe^{2+} under the modeled conditions, the case for hydrothermal fluids is weakened. The CO_2 necessary to generate abundant carbonates most likely came via water in contact with the atmosphere. Subsurface CO_2 sources like buried ice or magmatic gases are more speculative. Given the likelihood of water flows from Ma'adim Vallis, we suggest a scenario in which flooding led to water-limited leaching of formerly widespread Algonquin-like tephra deposits followed by transport and evaporative precipitation of the fluids into the Comanche rock.

Mini-TES evidence for both Mg- and Fe-rich carbonate phases in Comanche is consistent with evaporative precipitation [7; 8; 15; 16]. The apparent absence of sulfates and chlorides, indicative of a full evaporation sequence like that found in some carbonate-bearing Mars meteorites [e.g., 9], could be the result of spatial segregation driven by an evaporating lake [e.g., 15]. Possible evidence for this comes from the enigmatic sulfate-cemented but otherwise unaltered sandstones known as Peace class on north side of Husband Hill that were hypothesized to result from evaporative precipitation [4]. Alternatively, downward percolation of floodwaters through Algonquin-like rocks could have produced a calcrete-like occurrence without other salts, as suggested for ALH84001 (Warren, 1998).

Based on our results and the geologic context of Gusev crater, we favor a scenario in which evaporation of an ephemeral lake, perhaps recharged by multiple floods, led to the occurrence and significant abundance of carbonates in Comanche. The Columbia Hills are in the lowest portion of Gusev, so a deep, crater-spanning lake need not be invoked. Alternatively, if CO_2-charged floodwaters contributed to a subsurface aquifer, upwelling spring-fed flows that traversed Algonquin-like rocks may have yielded a similar result. In either case, the low temperature, mildly acidic solutions indicated by our work lends astrobiological significance and scientific merit to Gusev crater as a candidate landing site for surface missions oriented toward the search for past life on Mars.

Conclusions: The Comanche outcrops are olivine-rich volcanic tephra equivalent to the nearby Algonquin outcrops but altered by low temperature carbonate and silica-bearing solutions. Brines produced from minor leaching of Algonquin-like tephra deposits by ephemeral waters would have a composition consistent with the alteration evident in the Comanche outcrops. Infiltration of such fluids into these outcrops followed by evaporative precipitation could have produced the observed Mg and Fe carbonate phases and amorphous silicate.

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