

**OLIVINE-RICH, CARBONATE-BEARING ASH DEPOSITS LINK JEZERO AND GUSEV CRATERS.**

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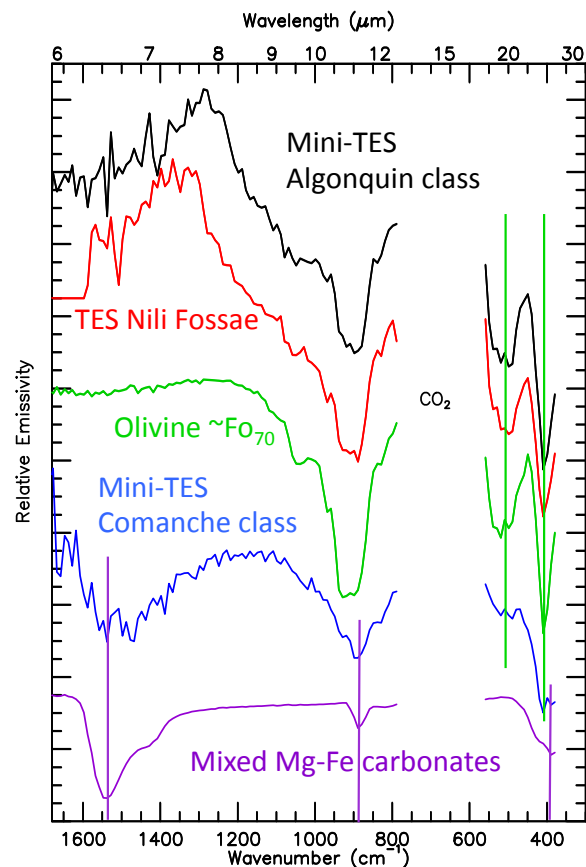
**Introduction:** The largest surface exposure of olivine-rich bedrock on Mars was first identified in the Nili Fossae region northeast of Syrtis Major using data from the TES instrument [1; 2], in what are now recognized as likely volcanic ash deposits of Noachian age [3]. The first orbiter-based identification of carbonate-bearing rocks on Mars is coincident with these rocks, where Mg-rich carbonate provides the best match to features identified in near-infrared spectra from the CRISM instrument [4]. The co-occurrence of Mg-rich olivine and Mg-rich carbonate also is a feature of Jezero crater (in the Nili Fossae region), the landing site for NASA's Mars 2020 rover. In the Columbia Hills of Gusev crater, Mg-Fe-rich carbonates associated with Mg-rich olivine in outcrops of tephra (ash) dubbed Comanche were identified using data from the Spirit rover [5; 6].

The presence of lithified ash deposits (tuffs) with Mg-rich olivine and carbonate in both the Nili Fossae region and Columbia Hills raises the possibility that they have a common formation history. Our work shows that this possibility is strengthened by the similar morphologic and thermal expression of these rocks in both locations, including the appearance of more widespread examples on the floor of Gusev crater. We suggest that the Comanche/Algonquin outcrops in the Columbia Hills may represent ground truth for olivine-rich carbonate-bearing rocks in Jezero, the Nili Fossae region, and perhaps elsewhere on Mars.

**Composition:** Thermal infrared (TIR) spectra from the Mini-TES instrument clearly link the Mg-rich composition of the olivine-rich ash deposits known as Algonquin class to olivine-rich bedrock in Nili Fossae (Fig. 1). Algonquin class rocks, which host Mg-Fe carbonates in the Comanche outcrops [6], display chemistry comparable to Archean ferropicrite ashfall tuffs on Earth, for example, in Ontario, Canada [7] (Table 1). The carbonate occurrences in Nili Fossae are too small to be detected with TES, but CRISM spectra show features attributable to magnesite throughout the region, including the watershed and interior of Jezero crater in the mottled terrain (MT) unit [8]. Magnesite and Mg-rich carbonates dominate the Comanche carbonate component (Fig. 1).

**Morphology:** The Comanche and Algonquin outcrops are expressed as bouldery knobs and ridges

amidst light-toned fractured bedrock (Fig. 2). This morphology is distinct from all other terrain units encountered by Spirit. Also notable is the lack of craters across this terrain unit. Many of the olivine and carbonate-bearing terrains throughout Nili Fossae, including the mottled terrain unit within Jezero (Fig. 2), share these characteristics. The lack of small-scale craters in these terrains suggests that the rocks are sufficiently friable that erosion outpaces crater production [e.g., 9].



**Fig. 1.** Olivine-rich Algonquin ash deposits in Columbia Hills match TIR spectra of olivine-rich bedrock in Nili Fossae (sol 691 P3945 and OCK 8200 ICK 1962-1968 average, respectively). Position of key diagnostic features of Mg-rich olivine are found in Mars spectra (green vertical lines). Comanche spectrum (sol 701 P3340) shows olivine features (green lines) and carbonate features due to magnesite, siderite, and solid solution intermediates (purple lines).

**Thermal Expression:** Images from the THEMIS instrument of the olivine-carbonate terrains display relatively high thermal inertia compared with surrounding terrains, attributable to the rocky materials. This is especially notable in Gusev where the basaltic lava plains with their comminuted regolith have lower thermal inertia compared to the olivine-rich bedrock unit. This characteristic is recognized among other olivine-rich relatively high thermal inertia terrains with similar morphology in the Columbia Hills and other kipukas in Gusev as well as in Jezero and Nili Fossae, and at the global scale [10].

**Table 1.** Geochemistry of olivine-rich ash on Mars and Earth with diagnostic oxides in red.

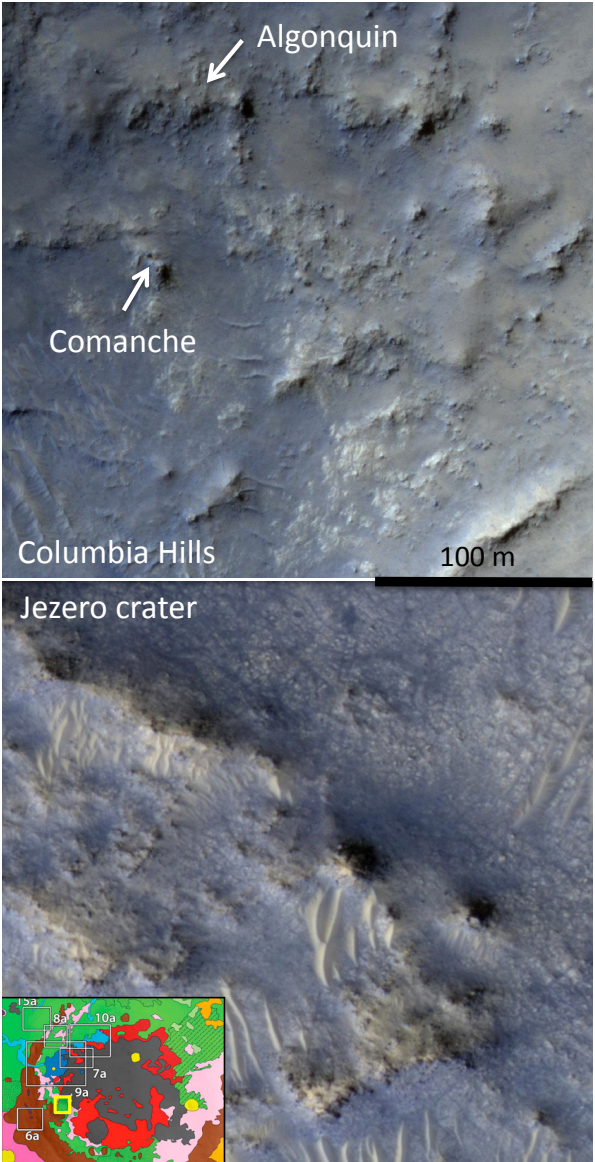
Oxide	Algonquin*	Canadian ferropicrite tuff <sup>+</sup>
SiO <sub>2</sub>	40.6	41.51
TiO <sub>2</sub>	0.35	1.40
Al <sub>2</sub> O <sub>3</sub>	4.0	5.50
FeO <sub>tot</sub>	21.2	18.71
MnO	0.38	0.24
MgO	22.3	22.38
CaO	2.6	4.93
Na <sub>2</sub> O	1.6	0.24
K <sub>2</sub> O	0.12	0.05

\*[11] <sup>+</sup>[7]

**Conclusions:** Mg-rich olivine-phyric bedrock that hosts Mg-rich carbonate in the Columbia Hills is an ashfall tuff that shares notably similar composition, morphology, and thermal inertia with terrains throughout Nili Fossae, including Jezero crater. These rocks may have originated through explosive volcanism during the Noachian. Subsequent alteration by carbonic acid, as would arise from rainwater, glacial melt, or near-surface groundwater in contact with an early Mars high P<sub>CO2</sub> atmosphere [12], could be responsible for production of the carbonates. The persistence of olivine following carbonate alteration is a critical observation, probably indicating an incomplete process.

**References:** [1] Hamilton, V. E., et al. (2003), *Meteor. Plan. Sci.*, 38, 871-885. [2] Hoefen, T. M., et al. (2003), *Science*, 302, 627-630. [3] Kremer, C. H., et al. (2018), *Lunar Planet. Sci. Conf.*, 49, abstract #1545. [4] Ehlmann, B. L., et al. (2008), *Science*, 322, 1828-1832. [5] Morris, R. V., et al. (2010), *Science*, 329, 5990, 421-424. [6] Ruff, S. W., et al. (2014), *Geology*, 42, 4, 359-362. [7] Goldstein, S. B., and D. Francis (2008), *J. Petrology*, 49, 10, 1729-1753. [8] Goudge, T. A., et al. (2015), *J. Geophys. Res. Planets*, 775-808. [9] Golombek, M. P., et al. (2014), *J. Geophys. Res. Planets*, 119, 12, 2522-2547. [10]

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**Fig. 2.** Morphologic expression of olivine-rich, carbonate-bearing rocks in Columbia Hills (top; cropped color HiRISE PSP\_009174\_1650) and Jezero crater (bottom) as shown by the MT unit of [8]. Yellow box in inset map shows location of cropped HiRISE view (ESP\_022680\_1985). Bouldery knobs and ridges amidst light-toned fractured bedrock and a lack of small craters are the morphologic hallmarks of this material.