OVERLOOKED EVIDENCE FOR IGNIMBRITE DEPOSITS IN GUSEV AND JEZERO CRATERS, MARS.

S. W. Ruff[1], B. D. Brand[2], and A. D. Rogers[3], [1]Arizona State University, Tempe, AZ 85287, steve.ruff@asu.edu, [2]Boise State University, Boise, ID 83725, [3]Stony Brook University, Stony Brook, NY 11794.

Introduction: Throughout the Nili Fossae region and in the Columbia Hills of Gusev crater visited by the Spirit rover, recent work has documented textural and geomorphic evidence for ignimbrite deposits, the products of pyroclastic density currents from explosive caldera eruptions [1]. Most notable are features that strongly resemble fiamme, the lens or flame shapes formed from plastic deformation of hot pumice or scoria fragments in ignimbrites, which were overlooked during Spirit's mission. Here we present additional examples of overlooked observations from Spirit and Perseverance in Jezero crater that are consistent with ignimbrites. An ignimbrite origin for rocks of the Séítah and Máaz formations can better reconcile observations unresolved by the cumulate and lava flow origin hypotheses, respectively, recently proposed by [2].

Columbia Hills: Watchtower class rocks include one with the best fiamme candidates (Fig. 1). Spectra of these and chemically similar Wishstone class rocks obtained with the Miniature Thermal Emission Spectrometer (Mini-TES; ~2000 – 340 cm^{-1}) display a clear transition from well-expressed features of plagioclase feldspar in Wishstone Class to a loss of these features in Watchtower Class, replaced by features more similar to basaltic glass (Fig. 2a)[3]. An ad hoc hypothesis by [3] suggested low water-to-rock ratio alteration in the extreme aridity and cold of the Martian environment led to an amorphous silicate component. However, an amorphous to crystalline transition known to occur in ignimbrites was not considered.

Ignimbrites are known to undergo devitrification, the process by which non-crystalline components (glass) transform to crystalline phases during post-emplacement welding. In the Trail Bridge Reservoir mafic ignimbrite of eastern Oregon, USA we see evidence for devitrification in our laboratory spectra of samples representing partially to fully welded zones (Fig. 2b). The transition from glass to plagioclase features demonstrates how devitrification of glass in Watchtower Class may have led to plagioclase in Wishstone Class if these rocks formed as ignimbrite deposits, a scenario supported by evidence for fiamme.

Jezero Crater: Perseverance landed among outcrops in the Crater Floor Fractured Rough unit mapped from orbit and subsequently named the Máaz formation [2]. The igneous nature of these rocks and some of their morphologic and textural features were considered most consistent with a lava flow origin [2]. However, a key characteristic of the Máaz formation that helped distinguish it from orbit are the polygonal fractures, which strongly resemble cooling joints in ignimbrites (Fig. 3). Ignimbrites also can have a slabby erosional expression that resembles paving stones and layering (Fig. 4). The fractures and paving stone-like expression (aka, "pavers" [4]) of the Máaz formation have not been explained in the context of lava flows, which typically do not show such features. The well documented basaltic lava flows on the floor of Gusev crater traversed by Spirit show no polygonal fractures, pavers, or outcrops of any kind, in sharp contrast to the Máaz formation. This is consistent with the recognition that lava plains on Mars accumulate a thick regolith of material too coarse to be mobilized by wind, burying the competent rock of lava flows [5].

An olivine-rich unit known as Crater Floor Fractured 1 from orbital mapping was subsequently named the Séítah formation and explored by Perseverance [2]. Its igneous nature, large olivine grains (2-3 mm), poikilitic texture (pyroxene enclosing a smaller olivine grain; [6]), and a "predominantly crystalline, not glassy" nature [4] were interpreted as features of olivine cumulates rather than pyroclastic rocks [2]. However, because poikilitic texture can form via devitrification processes [7; 8], and devitrification produces crystalline phases from glass [e.g., 9], ignimbrites remain a plausible hypothesis. Furthermore, the lack of compositional changes across what are interpreted as thin layers challenges the cumulate hypothesis [4]. The lack of clearly defined layers with continuity across outcrops also challenges a cumulate hypothesis given that well-expressed layers are common in such rocks. Ignimbrites are known to have both vertical and horizontal fractures related to volumetric contraction and vertical compaction [10]. What are described as layers in the Séítah formation may instead be due to horizontal fractures or erosional processes in an ignimbrite.

Summary: Spectral evidence for devitrification combined with textural features resembling fiamme support an ignimbrite origin for Wishstone-Watchtower Class rocks in Gusev crater. Devitrification is a process that could have contributed to characteristics of Séítah rocks in Jezero crater. Fracturing and erosion of ignimbrite deposits could explain geomorphic features of the Séítah and the Máaz formations.

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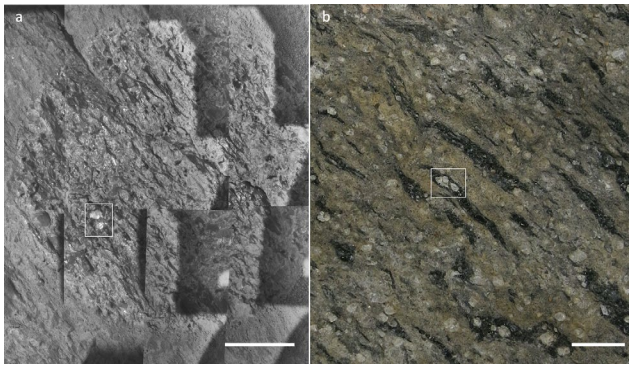

Fig. 1 (a) Diagonal dark-toned features are possible fiamme in this Spirit Microscopic Imager mosaic from target Kestrel from sol 646 [1]. Dark angular portions are rover hardware shadows. Rectangle encloses example of possible fiamme-wrapped crystals. (b) Welded ignimbrite (Bishop Tuff, Scripps sample GRD00JFS0) with wispy dark-toned fiamme and abundant light-toned crystals, including wrapped examples in rectangle. Scalebar is 1 cm.

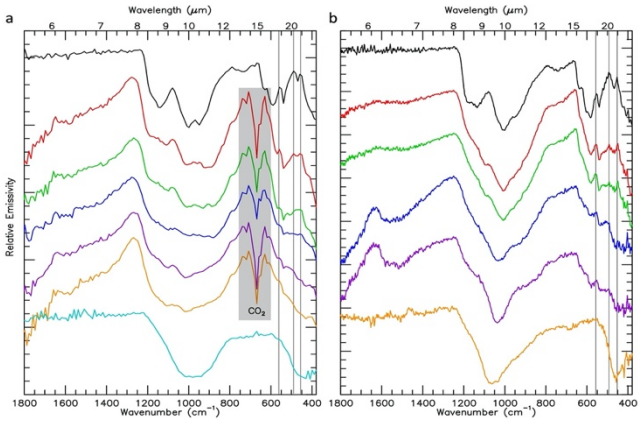

Fig. 2 (a) Mini-TES spectra of Wishstone Class rocks show plagioclase features from labradorite (lab spectrum in black, highlighted by vertical lines), which disappear in Watchtower Class rocks (top to bottom). Lab spectrum of basaltic glass (cyan) is shown for comparison. (b) Trail Bridge Reservoir ignimbrite spectra compared to andesine (black) and andesitic glass (orange). Plagioclase features (lines) are prominent in densely welded samples (red and green) but not in the partially welded samples (blue and purple).

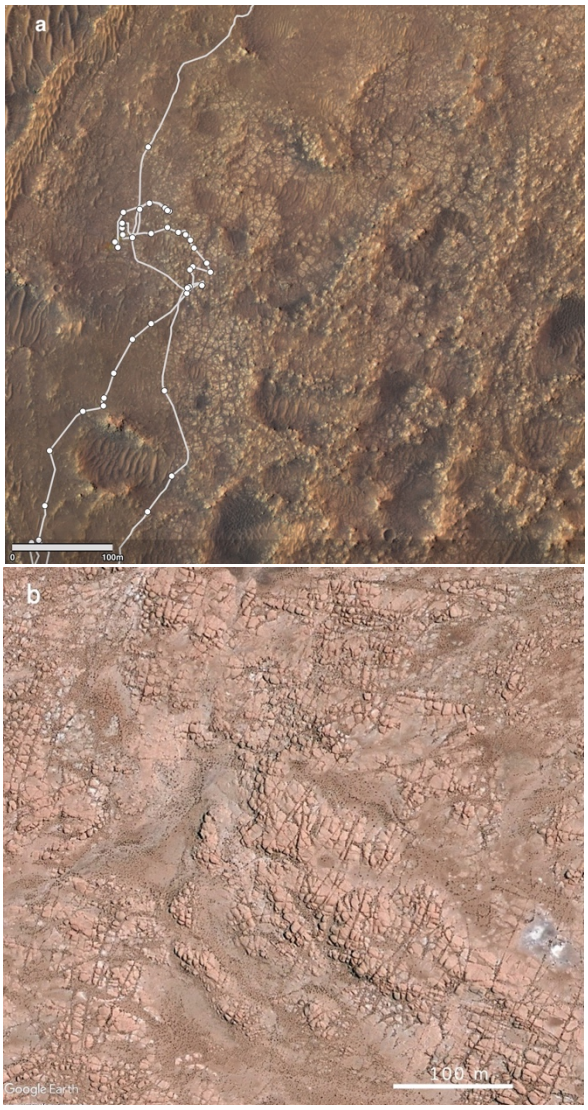

Fig. 3 (a) HiRISE view of Crater Floor Fractured Rough unit, aka Máaz formation, with rover traverse in white (https://mars.nasa.gov/mars2020/mission/where-is-the-rover). (b) Cooling joints in the Vilama ignimbrite, Bolivia, 22.13°S, 67.33°W at the same scale.

Fig. 4 Putoyane ignimbrite, Chile, 19.32°S, 69.09°W with slabby erosional expression resembling paving stones and layering. Orange backpack for scale.