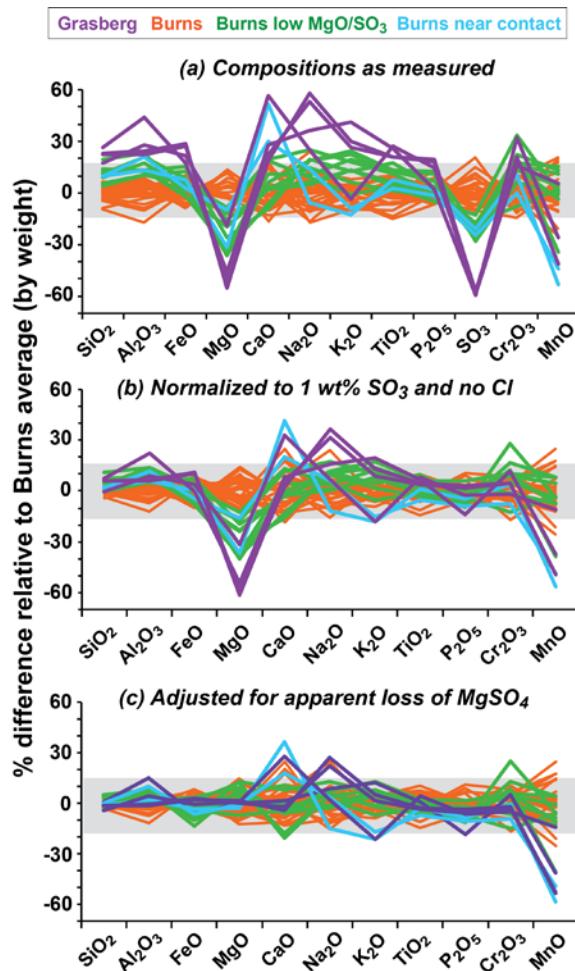


**THE GRASBERG FORMATION: A ROSETTA STONE FOR UNDERSTANDING THE ORIGIN AND DIAGENETIC HISTORY OF THE BURNS FORMATION AT MERIDIANI PLANUM?** T. M. McCollom<sup>1</sup> and B. M. Hynek<sup>1,2</sup>, <sup>1</sup>Laboratory for Atmospheric and Space Physics and <sup>2</sup>Department of Geological Sciences, University of Colorado, Boulder, CO 80309 (mccollom@lasp.colorado.edu).

**Introduction:** The layered sedimentary rocks of the Burns formation on Meridiani Planum are underlain by a thin (2 m) lithologic unit referred to as the Grasberg formation [1,2]. The Grasberg rocks are finer grained than Burns rocks (siltstones vs. sandstones), and lack the crossbedding and other sedimentary structures that are ubiquitous in the Burns formation. While Grasberg rocks contain substantial amounts of sulfur, they are less enriched in SO<sub>3</sub> than the Burns rocks (6.3-13.1 wt% vs. 17-28.6 wt%). Grasberg rocks also have lower Mg and Ni contents, and higher amounts of Si, Al, K, Fe, Ti and Zn than Burns rocks [1,2]. In addition, Grasberg rocks lack the hematite spherules (“blueberries”) that are characteristic of the Burns formation.

Based on morphological and chemical differences with the overlying Burns formation, the Grasberg rocks have been interpreted as a distinct lithological unit having a separate origin [1,2]. However, we recently undertook a detailed re-evaluation of the chemical compositions of the two units, and found that both units have nearly identical compositions except for variable amounts of MgO and SO<sub>3</sub> [3]. This result implies a much closer connection between the Grasberg and Burns formations than previously recognized. Here, we explore some possible implications of the similar chemistry for the origin and diagenesis of the units.

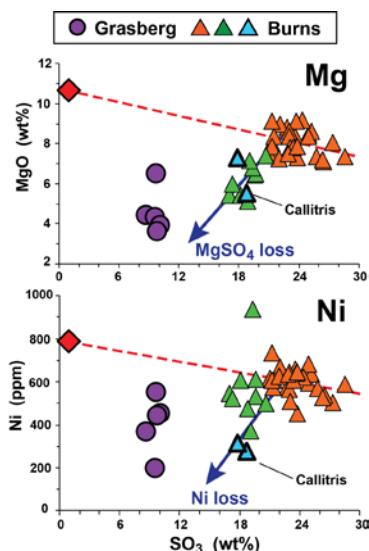
**Similar chemistry of Grasberg and Burns formations:** When the chemical compositions are plotted as measured by Opportunity, Grasberg rocks are seen to contain substantially less Mg, Mn, and SO<sub>3</sub> and higher amounts of other elements than most rocks from the Burns formation (Fig. 1a). However, when the data are normalized to account for differences in SO<sub>3</sub> among samples, most elements in the Grasberg other than Mg and Mn overlap with the Burns rocks (Fig. 1b). The relatively low Mg and SO<sub>3</sub> abundances of the Grasberg are shared by a subset of Burns formation rocks encountered at Victoria and Endurance craters (green lines in Fig. 1), where the low levels of these components has been attributed to partial loss of Mg-sulfate minerals during diagenesis [e.g., 4-6]. This apparent loss is illustrated in Fig. 2a, where the Mg and SO<sub>3</sub> levels in the subset of Burns samples (green triangles) are seen to be depleted along the expected trajectory for removal of Mg-sulfate (blue arrow). These same samples have also lost Ni (Fig. 2b), which would be consistent with the inferred high Ni contents of Mg-sulfates on Mars [7,8].



**Fig. 1.** Comparison of the compositions of Grasberg and Burns formation rocks relative to the Burns formation average. Compositions plotted: (a) as measured by Opportunity, (b) normalized to 1 wt% SO<sub>3</sub> and no Cl, and (c) adjusted for the apparent loss of Mg sulfates from Grasberg and some Burns samples. Burns rocks that have evidently lost MgSO<sub>4</sub> during diagenesis (green) and adjacent to Grasberg contact (blue) plotted separately. Grey boxes indicate <15% enrichment/depletion of elements relative to the Burns average.

Notably, the Burns samples that are closest to the contact with the Grasberg (Callitris and CapeFairweather) also show the same loss of Mg-sulfates and Ni (Fig. 2).

A logical inference to explain the low Mg & SO<sub>3</sub> in the Grasberg rocks is that they experienced the same diagenetic loss of Mg-sulfates as the subset of Burns rocks, which is supported by the similar levels of Mg and Ni to the Burns samples that lost Mg-sulfates in-



**Fig. 2.** Abundances of Mg and Ni in Burns/Grasberg rocks as a function of  $\text{SO}_3$ . Burns rocks from Victoria and Endurance craters that have evidently lost Mg sulfates (green) and the two Burns rocks closest to the Grasberg contact (blue) are plotted separately. Dashed line indicates expected trajectory for addition of  $\text{SO}_3$  to a basaltic endmember (red diamond).

cluding those closest to the contact (Fig. 2). When compensation is made for the diagenetic loss of Mg-sulfates, all Grasberg and Burns rocks converge on very similar compositions (Fig. 1c), indicating the rocks from both formations had nearly identical chemical compositions prior to diagenesis. This interpretation is further supported by hierarchical cluster analysis and trends in elemental abundances as a function of  $\text{SO}_3$  &  $\text{TiO}_2$  [3].

**Implications for sediment origin:** The highly similar chemical compositions indicates that the Grasberg and Burns formation are probably derived from the same basaltic source, or closely related sources. Indeed, the chemical compositions of both formations can be accounted for by addition of  $\text{SO}_3$  to the same pristine basalt, followed by diagenetic redistribution of divalent cations and loss of Mg sulfates from some deposits [3,6]. The fine-grained, homogenous textures of the Grasberg rocks has led to the interpretation that they are airfall deposits from either a volcanic or impact source [7,8], and geologic context suggests a volcanic ashfall is more likely. By extension, the Burns sediments may have also been initially deposited as an ashfall. Induration of the ash followed by erosion could then have created sulfate-cemented siliciclastic sand grains that were reworked by eolian and fluvial processes to form the bedding structures currently observed in the Burns rocks. This scenario would be consistent with the interpretation that the sand grains that comprise the Burns sandstones were eroded from a pre-existing rock that was composed of fine-grained sulfate and siliciclastic components [e.g.,

9,10]. The texture and chemical composition of this inferred precursor would have been indistinguishable from the Grasberg rocks before they experienced diagenetic loss of Mg-sulfates.

**Diagenetic processes:** If the Grasberg and Burns rocks are derived from the same source, it provides an opportunity to place additional constraints on the diagenetic history of both units. For instance, the apparent loss of Mg-sulfates from the Grasberg formation and immediately overlying Burns rocks extends the number of locations where this loss has been observed beyond Endurance and Victoria craters. Any future model for diagenetic Mg-sulfate transport must therefore take into account the geologic setting of all three sites.

The Grasberg rocks also have lower Mn and higher Fe/Mn ratios than most Burns rocks, which has been attributed to diagenetic loss of Mn from the Grasberg [11]. The two Burns rocks closest to the contact, Callitris and Capefairweather, have similarly low Mn and high Fe/Mn ratios (Fig. 1), implying that any diagenetic loss of Mn extended into the Burns formation and therefore occurred after some Burns deposits were in place.

Two rocks from underlying Shoemaker formation, Pinnacle Island and Stuart Island, have fracture surfaces coated with mineral deposits enriched in Mg, Ni,  $\text{SO}_3$ , and Mn [12], the same elements that were evidently depleted in the overlying Grasberg and Burns rocks. The natural inference is that the same fluids that removed these elements from the Grasberg/Burns rocks deposited them in the underlying Shoemaker rocks [3]. This would imply that: (1) the fluids were migrating downward at the time, (2) the transport occurred after at least some Burns rocks were emplaced, and (3) the rocks were fairly close to the surface at the time (otherwise, the fluids would have become saturated with respect to Mg-sulfates before reaching the lower Burns/Grasberg rocks and lost their capacity to dissolve Mg-sulfates).

Further study may reveal additional insights. For example, while both units were initially deposited with almost identical chemical compositions, hematite spherules formed in the Burns rocks but not the Grasberg. Comparative studies may provide new insights into the long-standing conundrum of spherule formation.

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