GEOCHEMICAL DATA INDICATE THE BURNS AND GRASBERG FORMATIONS AT MERIDIANI PLANUM HAD THE SAME SEDIMENT SOURCE (AND THE SOURCE WAS PROBABLY VOLCANIC). T. M. McCollom¹ and B. M. Hynek¹, ¹Laboratory for Atmospheric and Space Physics, University of Colorado, Boulder, CO 80309 (mccollom@lasp.colorado.edu).

Introduction: The layered sedimentary rocks of the Burns formation investigated by the Opportunity rover are sandstones whose framework consists of sulfate-cemented siliciclastic sand grains [1-3]. The rocks are highly enriched in SO₃ (17-28.6 wt%) and, except for the elevated SO₃ contents, have compositions that closely resemble typical martian basalts [2,4,5]. Bedding structures in the rocks indicate deposition by eolian and fluvial processes [3,6].

The Grasberg formation is a thin rock unit (~2 m thick) that directly underlies the Burns formation in the vicinity of Endeavour crater, separated by an unconformity. Based on morphological and chemical differences from the overlying Burns formation, the Grasberg rocks have been interpreted as a distinct lithological unit having a separate origin [7,8]. The Grasberg rocks are much finer grained than the Burns formation and are texturally homogeneous, lacking the sedimentary structures that are ubiquitous in Burns rocks. Compared to the Burns, the Grasberg rocks have lower SO₃ (6.3-13.1 wt%), Mg, and Ni contents, and higher amounts of Si, K, Fe, Ti and Zn [7,8]. Grasberg formation rocks also lack the hematite spherules (“blueberries”) that are characteristic of the Burns formation.

To more closely examine possible connections between the Grasberg and Burns formations, we undertook a detailed comparison of the chemical compositions of the two units [9]. The results reveal a much closer connection between the Grasberg and Burns formations than indicated by previous studies.

Comparison of Grasberg and Burns formation chemistries: A framework for comparing rocks from the two formations is provided by our recent in-depth study of geochemical trends and element mobility in the Burns formation (Fig. 1) [5,10]. A number of chemical elements in rocks from the Burns formation conform to linear trends as a function of SO₃ and TiO₂, including Si, Al, K, Na, P, Ti, and Cr [5,10]. These trends are essentially dilution lines, and indicate that this group of elements were immobile during both the addition of the SO₃ component and all diagenetic processes that occurred after emplacement at their present location [5]. Conversely, the divalent cations (Fe, Mg, Ca, Mn, & Zn) show scattered distributions as a function of SO₃ and TiO₂, which reflects partial mobilization and re-distribution of these elements during diagenesis. A subset of Burns rocks from Endurance and Victoria craters contain lower amounts of Mg, SO₃ and Ni than other targets (green triangles in Fig. 1), which is most likely attributable to partial removal of Mg sulfate minerals from these samples during diagenesis [5,11]. Notably, this same loss of Mg sulfates is apparent in Burns rocks that lie close to the contact with the Grasberg formation (e.g., Callitris in Fig. 1).

![Fig. 1. Abundances of representative elements as a function of SO₃ for Burns and Grasberg formation rocks. The red dashed lines are calculated trajectories for addition of SO₃ to a pristine basalt endmember represented by the red diamonds; these are effectively passive dilution lines for addition of mass as SO₃ to the endmember basalt. For the Burns formation, samples that have evidently lost Mg sulfates are plotted separately as green triangles, while those targets encountered near the contact with the Grasberg formation are shown as yellow triangles (the Callitris target adjacent to the contact is highlighted). The Grasberg rocks include the targets Grasberg, Wally Wombat, Hoover, and Platypus.](image-url)
The compositions of rocks from the Grasberg formation form a continuum with the elemental trends established by the Burns formation (Fig. 1) [9]. For the elements Si, Al, K, Na, P, Ti, and Cr, the compositions of Grasberg rocks fall on, or close to, the linear trends established by the Burns rocks. Although Fe and Ca show scattered distributions for the Burns rocks, the Grasberg compositions fall near the dilution trends based on average Fe and Ca contents of the Burns formation. The Mg and Ni contents of Grasberg rocks are lower than many Burns samples but are similar to the subset of Burns rocks that have evidently lost Mg sulfates, indicating the Grasberg rocks likely experienced a similar loss of Mg sulfates during diagenesis.

The consistent trends indicate that the Burns and Grasberg rocks have essentially the same chemical composition except for differing amounts of Mg and SO3 (which is largely attributable to diagenetic loss). This is further supported by comparing the chemical compositions of the two formations after normalizing the compositions to the same SO3 contents as shown in Fig. 2. After normalizing, the Grasberg rocks are seen to have nearly identical compositions to the Burns formation, and are especially close to those Burns rocks that experienced diagenetic loss of Mg sulfates. The data in Fig. 2 also illustrates that the compositions of Grasberg and Burns rocks are far more similar to one another than to most other martian basalts.

Implications for sediment origin: The close similarity of chemical compositions indicates a high probability that the Grasberg and Burns formation are derived from the same basaltic source. Indeed, the chemical compositions of both formations can be accounted for by addition of SO3 to the same pristine basalt, followed by diagenetic redistribution of divalent cations and loss of Mg sulfates from the Grasberg and some Burns rocks [9].

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], although the geologic context suggests a volcanic ash deposit may be more likely. The logical extension is that the Burns sediments were also originally deposited as an ashfall. The ash may have become somewhat indurated after deposition (perhaps resembling the Grasberg rocks), then eroded as sulfate-cemented siliciclastic sand grains and reworked by eolian and fluvial processes to form the bedding structures currently observed. For both formations, the addition of SO3 to the original basalt probably took place prior to an explosive event that transported the materials to Meridiani, perhaps in a fumarolic setting [4].

While it has been proposed that the sediments of the Burns formation originally formed as evaporite deposits [1-3], it would be highly problematic to explain the similar compositions of the Grasberg rocks by a similar process. The higher Fe and Ca contents of the Grasberg (Fig. 1) would require either a substantially different mixture of evaporite and basaltic components than has been invoked for the Burns rocks [2] or extensive diagenetic enrichment of these elements. However, it seems highly unlikely that either of these could occur and yet result in nearly identical final compositions. Furthermore, the bedding structures in the Burns formation rocks are commonly invoked as strong support for the evaporite scenario. These structures are interpreted as a wetting-upward sequence culminating in aqueous surface environments [3,6], and are thought to be consistent with widespread groundwater upwelling [12] and precipitation of sulfates from evaporating fluids in penecontemporaneous playa lakes [2,3,6]. However, the absence of similar structures in the Grasberg rocks would appear to preclude formation of the sediments as evaporites in playas or similar environments. Consequently, any effort to explain the chemistry of the Grasberg rocks as evaporites would require invoking entirely different environments and processes than those inferred for the Burns formation.