CONSTRAINING THE ROLE OF DIAGENESIS IN VERA RUBIN RIDGE OF GALE CRATER, MARS: INSIGHTS FROM A TERRESTRIAL ANALOG SEDIMENTARY ENVIRONMENT. S. N. Lamm¹, M. R. Salvatore¹, B. Horgan², and M. A. Chan¹, ¹Department of Physics & Astronomy, Northern Arizona University, Flagstaff, AZ, sl2447@nau.edu, ²Purdue University, ³University of Utah.

Introduction: Vera Rubin ridge (VRR) of Gale crater is one of the most prominent spectral and geomorphic features explored by the Mars Science Laboratory (MSL) Curiosity rover to date. The strong spectral signature consistent with hematite detected from orbit by the Compact Reconnaissance Imaging Spectrometer for Mars (CRISM) instrument suggests an aqueous origin for this material [1,2], although the nature and geologic context of these mineralogic signatures remained largely unconstrained. VRR was explored in situ by Curiosity from September of 2017 through January of 2019, which provided detailed compositional, spectral, and morphological information regarding its formation and evolution. In this study, we compare these findings of VRR to the Jurassic Navajo Sandstone and related sedimentary units of southern Utah to help decipher acquired VRR data and provide geologic perspective.

Vera Rubin Ridge: Initial data acquired by Curiosity suggested that VRR was an extension of the lacustrine mudstones of the upper Murray formation [3,4]. VRR consists of two members: the lowermost Pettegrov Point member defined by thinly laminated mudstones with fewer veins than the underlying Murray formation and the uppermost Jura member, which can be separated into the gray and red sub-members based on their appearance. The Jura member exhibits more color, spectral, and dip orientation variability than the underlying Pettegrov Point member [5].

Mastcam [6] and ChemCam passive spectra [7] confirmed an increased hematite signature, although ChemCam laser-induced breakdown spectroscopy (LIBS) analyses found no significant systematic increase in Fe abundance relative to the underlying Murray formation, with the exception of localized pseudomorphosis of earlier mineral phases [8,9]. Based on the evidence gathered by Curiosity, the leading hypothesis is that reducing fluids remobilized Fe from the gray Jura member of VRR and recrystallized hematite within the red Jura member [6,9,10], potentially facilitated by differences in grain size and porosity [11].

Analog Site - Navajo Sandstone: The Jurassic-aged Navajo Sandstone and associated sedimentary units in southern Utah are primarily aeolian in nature and make up the largest sand sea deposit in North America [12,13]. These well-sorted aeolian sandstones contain high-angle cross-stratification and high porosities (10% - 30% porosity) [14-16], promoting fluid migration and making the Navajo Sandstone one of the largest fluid reservoirs in the United States [14]. These sandstones have been extensively investigated for decades, and there has been clear insight into diagenetic processes and the role of fluid flow in the mobilization and redeposition of iron [13-20]. These studies showed how reducing fluids interacted with the oxidized Navajo Sandstone and resulted in widespread bleaching through the dissolution and removal of pervasive hematite coatings on individual quartz grains. Reducing fluids might have also dissolved previous cements [15].

Comparing VRR & Navajo Sandstone: Much like the Navajo Sandstone, VRR exhibits ample evidence for secondary alteration resulting from the migration of fluids and their influence on the nature, abundance, and state of iron (Fig. 1). In this section, we highlight a few of the intriguing similarities between VRR and the Navajo Sandstone, identify key differences, and detail how additional work may be able to support the hypothesis that these two units are geologically similar.

Spectral Signatures. Hematite-rich and bleached sections of the Navajo Sandstone show clear spectral differences, primarily at wavelengths shorter than ~1.0 μm [21]. Hematite-rich sandstones show rapid and concave-up increases in reflectance with increasing wavelength through visible wavelengths, along with strong Fe³⁺ crystal field absorptions at 0.86 μm indicative of crystalline hematite [21]. Alternatively, bleached sandstones exhibit a nearly linear increase in reflectance through visible wavelengths that flatten at ~0.6 μm and lack a 0.86 μm absorption feature [21]. CRISM and Mastcam data from VRR are largely consistent with these observations from the Navajo Sandstone [1,6]. The red Jura exhibits strong concave-up increases in reflectance through the visible wavelength range, while the gray Jura’s reflectance increases more linearly with increasing wavelength [6]. In the infrared, the red Jura shows a broad absorption feature near 0.9 μm that could be consistent with either hematite, akaganeite, or a combination of the two [6]. Therefore, the oxidized and bleached portions of the Navajo Sandstone are good spectral analogs to the Jura member of VRR.

Porosity & Permeability. The variable porosity, primary depositional textures, fracturing, and faulting in the Navajo Sandstone are the primary reasoning behind the diversity in the distribution, width, and magnitude of bleached units throughout this sedimentary unit [13-15,22]. In VRR, the gray and red Jura sub-members exhibit different grain sizes that are likely related to the relative porosity of these units. The red Jura shows a mean grain size consistent with mud (Gmean of 0.05 ± 0.03) whereas the gray Jura shows a mean grain size consistent with silt to fine sand (Gmean of 0.09 ± 0.03) [11]. These larger grain sizes (and potentially greater permeability) is consistent with the hypothesis that the infiltration of altering fluids resulted in the observed differences between the red and gray Jura sub-members of VRR [6].

Nature & Prevalence of Fe-Oxides. The classic red coloration of the Navajo Sandstone results from thin (2 - 4 μm...
thick) hematite-rich coatings that rim larger quartz grains [13,15], which likely formed during early diagenesis that occurred during the initial deposition and burial of dune sands [23]. The measured abundance of hematite in these units is surprisingly low at less than 1.5 wt.%, showing the powerful optical influences of small quantities of Fe-oxides [13,15]. These Fe-oxide-rich coatings are partially and preferentially removed where reducing fluids were able to migrate through the sandstones. Preliminary assessments of VRR mineralogy suggest a significantly greater abundance of hematite (> 10 wt.%) in the Pettengrove Point and gray Jura members, and the red Jura contains less hematite yet greater amounts of akaganeite [24], suggesting formation in acidic aqueous environments [25]. Akaganeite has been shown to be a metastable precipitate of oxidized iron at oxic-anoxic boundaries [18,19,26] and provides important information about the fluid chemistry during Fe-precipitation [25].

Bleaching & Staining. The bleached Navajo Sandstone likely had hematite grain coatings that were dissolved and removed by reducing groundwater [15], resulting in its bright “bleached” color. Bleached rocks are generally more altered than the red sandstones, with K-feldspar altering to kaolinite, illite, and other clay species [15]. The initial hypothesis that the gray Jura was once a member of the red Jura and subsequently bleached by reducing fluids is challenged with the recent mineralogical results from these Jura sub-members [24]. Unlike the bleached components of the Navajo Sandstone, the gray Jura exhibits increased hematite and feldspar abundances relative to the red Jura. These preliminary results suggest that the relationship between the gray and red Jura sub-members is likely more complex than a single episode of reducing fluid flow. This relationship will become clearer when the nature of the X-ray amorphous materials are better constrained, as they compose roughly 40% and 50% of the red and gray Jura sub-members, respectively [24]. Once constrained, it will be possible to compare these results to local alteration environments within the Navajo Sandstone.

Future Work & Conclusions: As the final results from VRR continue to be interpreted, the utility of the Navajo Sandstone as a useful terrestrial analog for this geologic feature on Mars will become clearer. The mineralogical differences between the red and gray Jura provide critical insights into the nature of the altering fluids that may have passed through VRR. The Navajo Sandstone has experienced multiple episodes of fluid intrusion over a variety of Eh/pH conditions [14,18] that have resulted in the remobilization of Fe-oxides and corresponding spectral signatures [14]. Additional work to understand the role of fluid chemistry and the behavior of authigenic minerals during aqueous alteration in the Navajo Sandstone and related sedimentary units is ongoing and will help us to constrain the potential formation environments for the different geologic units found in Vera Rubin ridge.


Figure 1. Differences in oxidation state within sedimentary rocks of Vera Rubin ridge (left) and the Navajo Sandstone (right). Left image is a Mastcam mosaic (enhanced color) from sol 1930. Right image is courtesy of Google StreetView.