LESSONS LEARNED WHEN RECONCILING ORBITAL AND IN SITU EXPLORATION OF VERA RUBIN RIDGE, GALE CRATER, MARS. M. R. Salvatore1, A. A. Fraeman2, P. J. Gasda3, E. B. Rampe4, T. S. J. Gabriel5, O. Gasnault6, G. David7, L. A. Edgar3, E. Dehouck3, 1Department of Astronomy and Planetary Science, Northern Arizona University, mark.salvatore@nau.edu, 2Jet Propulsion Laboratory, Caltech, 3Los Alamos National Laboratory, 4NASA Johnson Space Center, 5Arizona State University, 6IRAP-OMP, 7US Geological Survey, Flagstaff, 8Université de Lyon.

Introduction: The Mars Science Laboratory (MSL) Curiosity rover explored hematite-bearing Vera Rubin ridge (VRR) from September of 2017 through January of 2019, investigating its composition, structure, and geologic history. VRR is a ~200 m wide, ~6.5 km long topographic ridge on the flank of the 5 km high Aeolis Mons (informally known as Mt. Sharp). The MSL team’s strategic plan for exploration of VRR was initially guided largely by orbital analyses of the morphology of the ridge and the orbital identification of strong hematite signatures relative to other nearby geologic units [1].

Prior to the in situ investigation of VRR, several hypotheses were defined regarding the formation of the ridge and its uniquely strong hematite signature. These hypotheses included the localized oxidation of anoxic groundwater [2,3], acidic corrosion and leaching of silicates [2], redox-stratified lacustrine oxidation [4], or even lateritic formation [5]. The orbital identification of hematite was confirmed through in situ analyses [5], and Curiosity surface investigations provided additional insight into hematite formation hypotheses [1]. Curiosity data suggest at least one (though likely several) episodes of diagenetic alteration of preexisting lacustrine mudstones [6,7] by groundwater resulted in localized recrystallization of red and gray hematite [1,5].

The in situ investigation of VRR has complemented our orbital investigation of Gale crater (Fig. 1) and has allowed us to test these hypotheses in real time. This presentation focuses on looking back at what we knew prior to Curiosity’s arrival at VRR and what we now know following the in situ investigation. By studying where our initial orbital-based hypotheses were consistent and inconsistent with in situ observations of VRR, we can help to better inform future investigations of units in Gale crater, in the upcoming investigation of Jezero crater with the Mars 2020 rover, and beyond.

Consistent Observations: Orbital spectroscopy and thermophysical analyses identified unique signatures associated with VRR [8] that were subsequently confirmed on the ground. For example, the strong hematite signatures that were observed from orbit were also identified using remote sensing instruments on Curiosity [1,9,10]. The high thermal inertia identified from orbit was also observed on the ground and was found to be primarily due to the relative lack of soil cover relative to other regions of the Murray fm [11]. In conjunction with the confirmation of hematite-bearing units on VRR by CheMin [5], these observations confirm the uniqueness of VRR relative to other units on the margin of Mt. Sharp and confirm several observations made from orbit.

Inconsistent Observations: Prior to the exploration of the Murray fm and VRR, it was hypothesized that VRR was uniquely enriched in hematite relative to surrounding strata. However, hematite was identified throughout much of the Murray fm well before reaching VRR [12]. As articulated in [13], the abundance of soil on the surface relative to underlying bedrock, as well as spectral properties of the bedrock that were correlated with hematite grain size and crystallinity rather than abundance, plays a significant role in the observed strength of spectral signatures. For example, the Blunts Point member of the Murray fm shows strong hematite signatures in ChemCam passive spectra, yet weak signatures in CRISM data owing to the dominance of hematite-poor surface cover over the hematite-bearing bedrock. Similarly, the addition of unconsolidated soil and sediment lowers the remotely predicted thermal inertia of the surface, as the spatial resolution of the Thermal Emission Imaging System (THEMIS) instrument is 10,000 m² [8].

The variability in the depth of the hematite-related spectral absorptions in portions of VRR and the underlying Murray fm were first identified from orbit, where the observed strength of the 860 nm hematite absorption appeared as if it may be stratigraphically controlled [2,8]. However, in situ observations by Curiosity show obvious cross-cutting trends in spectral variability, and localized investigations show a variety of sharp and diffuse gradients between colors within these units [1,14]. In addition, the relative decrease in hematite absorption strength within the brighter bedrock patches was originally hypothesized to represent a product of leaching (removal of hematite) or that hematite never originally formed in these patches [3,15]. Upon further inspection of these red and gray units, hematite was also found to be abundant in the gray units [5]. Instead of a leaching or lack of Fe-oxides, these gray units instead likely represent zones of recrystallization where gray hematite dominates over red hematite [17,18].

Lastly, the stratigraphy and sedimentary structures of VRR relative to the other members of the Murray fm was difficult to assess from orbit because of the small scale of the diagnostic features [6,7]. It was only after the outcrop expressions were studied in situ that these textures could be regionally mapped using orbital data [7].

Implications for Future Surface Investigations: Remote sensing is a powerful tool in identifying
differences between geologic units and, when validated, in providing quantitative metrics of such differences. Such benefits are now being seen in furthering our understanding of the origin and evolution of VRR. However, the exploration of VRR represents a valuable lesson in the possible sources of apparent discrepancies between remote signatures and those observed on the ground. It is therefore important to constantly refine and reassess our use of remote sensing data in deciphering the characteristics of different surfaces.

The greatest challenge in characterizing geologic surfaces using remote spectroscopic datasets has been converting these signatures to quantitative information. Indices of refraction, absorption coefficients, thermal diffusivities, conductivities, particle sizes, and every environmental parameter imaginable each influence the appearance of resultant spectral signatures. Mixtures of phases with varying properties and parameters only make these associations more difficult. Our investigation of VRR has served as a valuable example of how remote sensing and field observations, in tandem, enable a more complete understanding of local and regional geology. For example, VRR has again shown us how and why stronger spectral absorption features do not necessarily correspond to greater mineral abundances. While seemingly impossible to completely overcome these challenges, we benefit from making relatively simple assumptions, conducting experiments and field observations, and through iterations of trial and error.

Conclusions: The remote and in situ investigation of VRR in Gale crater allowed for the testing of geologic hypotheses originally formulated using only remote sensing data. By identifying the different features and properties that were accurately and inaccurately predicted from orbit, we can learn important lessons about the use of remote sensing data in our future investigation of planetary surfaces. This exercise can help us to understand where additional spectroscopic research is needed and how to minimize the number of incorrect assumptions during future investigations. Ongoing and future investigations by Curiosity in the “clay-bearing unit” (now Glen Torridon) [19] and “sulfate unit” will further improve our ability to interpret orbital datasets.


Fig. 1. Demonstrating different analytical techniques and physical properties at orbital and in situ scales. (a) A portion of Gale crater geologic maps [8,16]. (b) A HiRISE image of VRR with the Blunts Point (BP), Pettigrove Point (PP), and Jura (Jm) members identified, and the viewshed of (c). Representative outcrops of red and gray portions of the Jura member are highlighted in red and gray boxes, respectively. (c) Mastcam mosaic showing red and gray Jura exposures. (d) The failed Inverness drill target and the Grange ChemCam target in the Gray Jura. (e) MAHLI image of the Grange target, showing the bright Fe-poor matrix and dark geometric Fe-oxide crystals.