CURIOSITY'S INVESTIGATION AT VERA RUBIN RIDGE. A.A. Fraeman[1], L.A. Edgar[2], J.P. Grotzinger[3], A.R. Vasavada[1], J.R. Johnson[4], D.F. Wellington[5], V.K. Fox[3], V.Z. Sun[1], C.J. Hardgrove[5], B.N. Horgan[6], C.H. House[7], S.S. Johnson[8], K.M. Stack Morgan[1], E.B. Rampe[9], L.M. Thompson[10], R.C. Wiens[11], A.J. Williams[12], [1]Jet Propulsion Laboratory, California Institute of Technology (abigail.a.fraeman@jpl.nasa.gov), [2]USGS, Flagstaff, [3]California Institute of Technology, [4]Johns Hopkins Applied Physics Lab, [5]Arizona State University, [6]Purdue University, [7]Penn State University, [8]Georgetown University, [9]Johnson Space Center, [10]University of New Brunswick, [11]Los Alamos National Lab, [12]Towson University

Introduction: The Curiosity rover is exploring Vera Rubin Ridge (VRR), a ~6.5 km long and ~200 m wide topographic feature trending northeast-southwest across Aeolis Mons (informally known as Mt. Sharp) (Fig 1). In orbital data, VRR is distinct from the underlying Murray formation due to its relative erosional resistance and greater exposure of bedrock. Compact Reconnaissance Imaging Spectrometer for Mars (CRISM) orbital data show a hematite spectral signature over much of the ridge (Fig. 2) [1]. On the ground, Curiosity also observed hematite associated with the sedimentary rocks of the underlying Murray formation [2,3], although these detections are difficult to see with CRISM due to mixing with sand and dust.

The presence of hematite associated with VRR led to the hypothesis that the area marked a site of past iron oxidation and possible habitable environment [1]. Since arriving at VRR, Curiosity has been taking measurements as part of a dedicated campaign to test hypotheses related to the ridge's depositional and geochemical history, including its relationship to the underlying Murray formation and implications for past redox conditions.

VRR from Orbit: VRR divides into lower and upper sections. The lower ridge, including the adjacent northern slope, is characterized by light-toned, fractured, well-stratified bedrock that retains relatively few craters. In contrast, the upper ridge is darker and more heavily cratered; stratificiation and cross-cutting fractures are not readily apparent from orbit. Several distinct bright patches, ~10 meters in size, are also visible in the upper ridge. These patches are too small to clearly resolve in CRISM. The 860 nm hematite-related absorption is pervasive throughout the upper VRR. Within the lower VRR, the 860 nm band is weak or absent, and its spatial distribution loosely correlates with locations of meter scale fractures (Fig. 2).

Lower VRR Observed by Curiosity: The lower VRR is primarily comprised of finely laminated mudstones, similar to the underlying Murray formation [4-8]. The bulk chemical composition of these mudstones falls within the compositional range of Murray formation rocks, although there are some variations in trace elements [9,10]. Diagenetic features, including veins and nodules, are also present [7,11,12].

Curiosity investigated the meter scale fractures that were visible from orbit in the lower VRR, but observed no chemical or spectral differences between rocks in and away from the fractures. Flat-lying bedrock far from fracture zones did initially appear to have weaker hematite-related absorption features in Mastcam multispectral landscape observations, but brushing showed this was due to greater dust accumulation on the flat surfaces between fractures compared to the angular, tilted rock fragments within the fractures. This observation demonstrated the important role of dust and surface texture in governing visibility of the 860 nm CRISM absorption in this region.

Every ChemCam passive spectrum and Mastcam spectral observation of brushed lower VRR bedrock targets had spectral properties consistent with the presence of hematite. Additionally, the strength and variability of ferric oxide-related absorption features in ChemCam passive spectral data (535 nm band depth, 750 to 840 nm slope) were similar to the strength and variability of ferric spectral features throughout the hematite-rich parts of Murray formation bedrock (Fig. 3) below the ridge.

Upper VRR Observed by Curiosity: The majority of the upper VRR explored through sol 1914 also comprises finely laminated mudstone. The modern-day surface of the upper VRR is dominated by small, angular fragments of displaced laminated mudstone. Major element compositions are also still in family with typical Murray formation and lower VRR targets, but again there are some notable variations in trace element abundances [9,10].

On sol 1901, Curiosity drove to one of the bright patches that was visible from orbit (Fig. 4). Ground based data demonstrated this patch is exposed as a small topographic depression whose wall exposes a significant geological boundary between gray and red rocks (Fig. 4). Mastcam multispectral and ChemCam passive data show the gray rocks do not have an 860 nm spectral absorption. The lack of any absorption near 860 nm likely indicates an absence of hematite and other ferric oxides, although we cannot exclude the possible presence of coarse grained, gray hematite (>5 – 10 μm crystals).

Conclusions and Future Work: There is no evidence for a change in depositional facies between the underlying Murray formation and lower VRR, all of which were likely deposited in a lacustrine environment [4,5,13]. The reason for the ridge's erosional resistance and moprhology is not clear, but minor variations in grain size or cement in the ridge rocks compared with the underlying Murray likely play a key role.

The pervasive hematite spectral signatures seen throughout the lower ridge by the rover, as well as observations that dust and sand in this region govern remotely-sensed spectral parameters, suggest that hematite is likely present throughout the entirety of the lower VRR, not just the limited sections detectable from orbit. The ubiquitous relationship between hematite spectral signatures and lacustrine mudstones within the Murray formation and lower ridge suggests that hematite or a precursor ferric-phase formed either as a primary depositional phase at a redox interface in the lacustrine setting [14], or via pervasive and relatively uniform postdepositional oxidation [15].

As of sol 1929, Curiosity is currently collecting additional data to characterize the relationship between the gray and red rocks within the upper VRR. This color change may mark a facies change within the Murray formation, or a new geologic formation. Alternatively, the color change may record a diagenetic front that reduced hematite that was originally present, or that caused additional crystallization and formation of coarser grained, gray hematite.

References: [1] Fraeman et al., (2013) *Geology, 40(10)*, 1103–1106. [2] E. B. Rampe et al. (2017) *EPSL* 471, 172-185. [3] T. F. Bristow et al. (in revision) *Sci. Adv*. [4] Edgar, L. et al., this conf. [5] Fedo, C. et al., this conf. [6] Heydari, E. et al., this conf. [7] Bennett, K. et al., this conf. [8] Rivera-Hernandez, F., et al., this conf. [9] Thompson, L., et al., this conf. [10] Frydenveng, J., et al., this conf. [11] Sun, V., et al., this conf. [12] L'Haridon, J., et al., this conf. [13] Grotzinger, J, et al., (2015) *Science,* 350, 6257 [14] Hurowitz, J. et al., (2017), *Science*, 356, 6341. [15] Fraeman, A., et al., (2016), *JGR,* 121, 9.

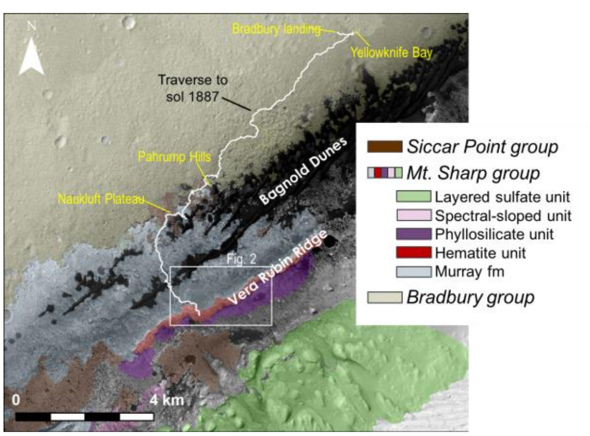

Fig. 1: Overview of Curiosity's traverse and associated geomorphic units that were defined from orbital data. After [15].

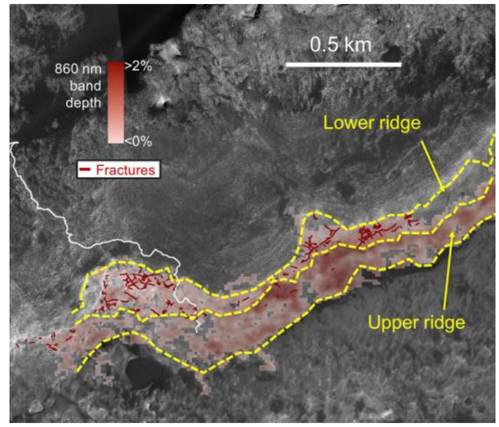

Fig. 2: Hematite (860 nm band depth) map from CRISM. Curiosity investigations suggest hematite is pervasive throughout the lower ridge and detectability from orbit is controlled by dust and surface texture. Detectability of hematite below the ridge is controlled by dust, surface texture, and sand.

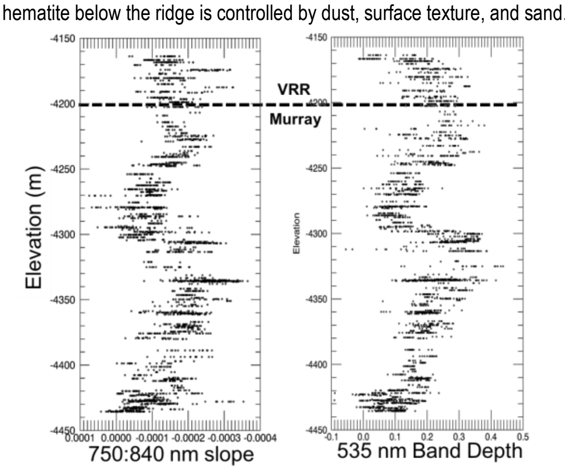

Fig. 3: Variation of ChemCam-derived ferric-oxide related spectral parameters in bedrock. Values to the right correspond to deeper ferric absorption features. The transition onto the ridge occurred around elevation -4200m.

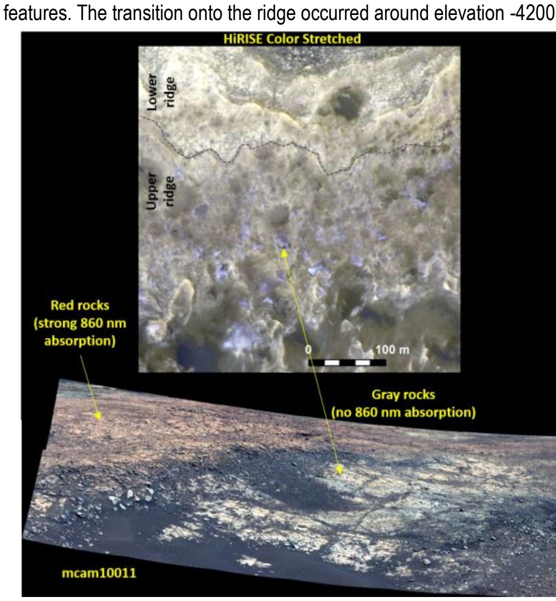

Fig 4: (top) Orbital view of bright patches found in upper ridge. (Bottom) View of one of these patches investigated by Curiosity from the ground. Gray rocks at the bottom of local depression ("blue" in HiRISE color stretch) lack the 860 nm hematite absorption that is ubiquitous throughout the ridge.