**LATE-STAGE DIAGENESIS IN THE MURRAY FORMATION, GALE CRATER, MARS: EVIDENCE FROM DIVERSE CONCRETION MORPHOLOGIES.** V. Z. Sun[1], K. M. Stack[1], M. Nachon[2], S. S. Johnson[3], R. E. Kronyak[4], R. C. Wiens[5], M. E. Minitti[6], and L. C. Kah[4], [1]Jet Propulsion Laboratory, Pasadena, CA (Vivian.Sun@jpl.nasa.gov). [2]UC Davis, Davis, CA. [3]Georgetown University, Washington, D.C. [4]Univ. of Tennessee, Knoxville, TN. [5]Los Alamos National Laboratory, Los Alamos, NM. [6]Framework, Silver Spring, MD.

**Introduction:** The Mars Science Laboratory (MSL) Curiosity rover has been investigating the Murray formation (fm.) of Mount Sharp since September 2014. The Murray fm. is largely composed of lacustrine mudstones [1] and contains numerous diagenetic features, including Ca-sulfate veins [2,3], alteration halos [4], and nodular features [3,5].

Concretions – broadly defined here as cemented relief-enhanced features – are prevalent throughout the Murray fm. and exhibit diverse morphologies **(Fig. 1)**, including several that were not seen during Curiosity's earlier investigation of the Yellowknife Bay fm. [6] and have never been observed elsewhere on Mars. Concretions are evidence of post-depositional cementation from diagenetic fluids and may indicate environmental changes in temperature, fluid pressure, volatile content, or redox conditions [7]. The diversity of concretion morphologies and concretion-host rock relations may also reflect varied or multiple diagenetic episodes or different host rock properties. Here we present the distribution of diagenetic concretion morphologies, size, density, and chemistry throughout 310 meters of Murray stratigraphy (Sols 750-1900) and place constraints on the timing of the depositional and diagenetic processes that formed them.

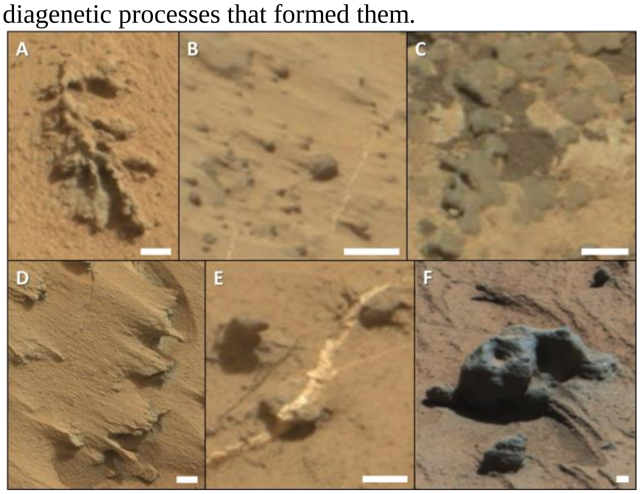



**Fig. 1.** Concretion morphologies in the Murray fm.: A) dendrites (mcam03304); B) smooth, dark spherules (mcam04970); C) smooth, dark, flat (mcam07124); D) lamination-enhancing (mcam03423); E/F) irregular (mcam07190; mcam06039). Scale bars indicate 5 mm.

**Concretion Morphology Classification:** Concretion morphologies, qualitative size ("small" <5 mm; "medium" 0.5-5 cm; "large" >5 cm), and relative density ("low," "medium," "high") were documented in 2300 Mastcam observations of the Murray fm. (Sols 750-1900), 1450 of which contained concretions. The primary concretion morphology types are described as follows **(Fig. 1)**. "Lamination-enhancing" concretions are preferentially cemented, erosionally-resistant features that occur along and enhance host rock bedding planes but are otherwise texturally indistinguishable from the host rock **(1D)**. In contrast, other concretion types exhibit shapes and colors distinct from the host rock, suggesting an increased cement to sediment ratio. "Dendrites" are tabular clusters of elongate crystal laths [5] **(1A)**. "Spherules" are small, dark, spherical concretions with smooth surfaces **(1B)**, similar in appearance to the Meridiani Planum "blueberries" [8] or the Yellowknife Bay "solid nodules" [6]. "Flat" concretions have tabular shapes and sometimes coalesce into contiguous dark "sheets" **(1C)**. "Irregular" encompasses all other concretions that have discrete, non-spherical shapes **(1E)**, indicating nonisotropic diagenetic conditions at the time of precipitation, and can be larger (>5 cm) with more complex morphologies **(1F)**.

**Stratigraphic and Chemical Trends:** Concretions are prevalent throughout the entire 310 meter Murray section traversed thus far by Curiosity **(Figs. 2,3)**. Dendrites are found only in the lowermost section of the Murray fm. at the base of the Pahrump Hills member [5]. Irregular concretions are more common in the Pahrump Hills and Hartmann's Valley members, while spherules and flat concretions are more common in the Karasburg and Sutton Island members. Lamination-enhancing concretions are prevalent throughout the entire Murray fm. and suggest diagenetic cementation even if discrete concretion morphologies were not formed. The Vera Rubin Ridge (VRR) member is under current investigation [9] but results thus far suggest that the abundance and diversity of concretions decreases with increasing elevation on the ridge **(Fig. 3)**.

Compositional trends from ChemCam are available for 84 concretion targets **(Fig. 3)**. Spherules tend to be Fe-enriched (up to 30% FeOT), possibly consistent with a hematitic composition. Smooth, dark, flat concretions are enriched in Mg, Fe, or both. Dendrites tend to be Mg-enriched [3], while irregular concretions can be variably and slightly enriched in Mg, Ca, or Fe. Lamination-enhancing concretions are Mg-enriched from Pahrump Hills to Sutton Island, but become more Ca-enriched in the higher VRR section.

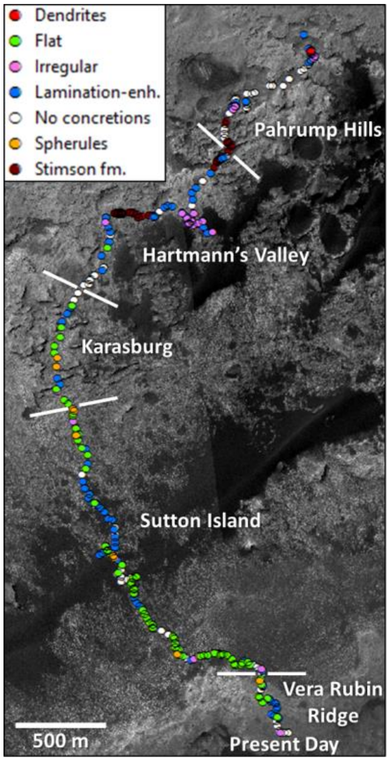
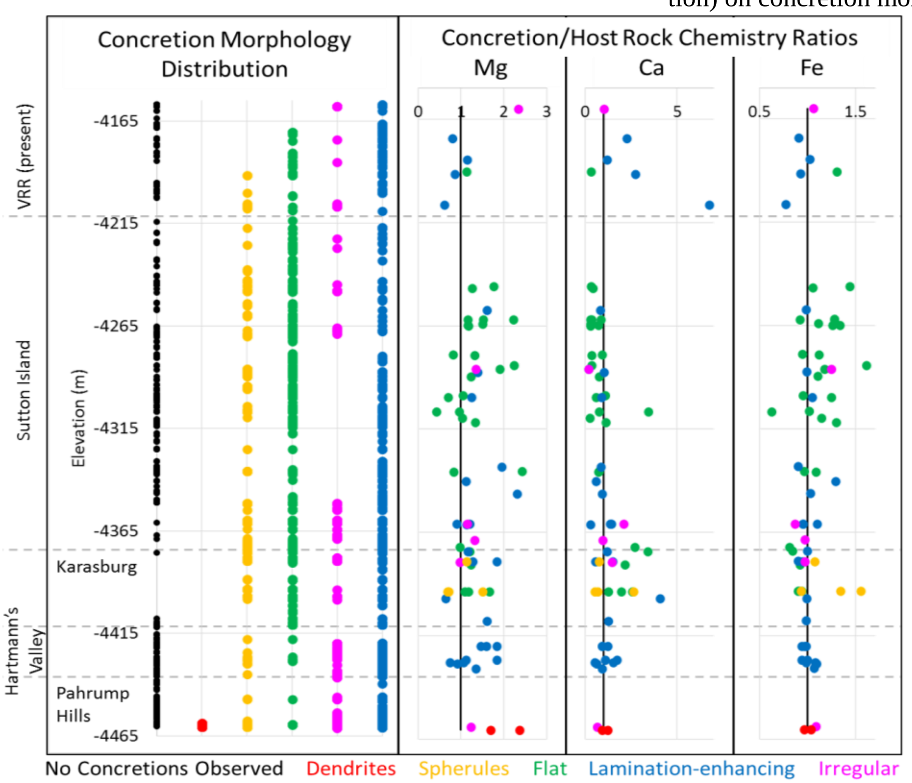



**Fig. 2.** Dominant concretion types observed during Curiosity's traverse through the Murray fm. Each point indicates the rover's location on a certain sol; colors indicate the dominant concretion morphology observed in the Mastcam images from those sols. Irregular concretions dominate in Pahrump Hills and Hartmann's Valley, while spherules and flat concretions are more prevalent in the higher Karasburg, Sutton Island, and VRR members.

**Evidence for Multiple Late-Stage Diagenetic Events:** Relationships between the concretions, host rock, and other diagenetic features can help constrain the timing of these diagenetic events. Murray concretions sometimes preserve host rock lamination, but no concretions have been observed to deflect host rock lamination. This suggests that the observed concretions are late-stage diagenetic products that formed after compaction and lithification of sediments [7]. An exception is that the smooth, dark, flat concretions are not observed to crosscut or preserve lamination, thus they may be early diagenetic products [see also 10].

Concretions also have complex relationships with other diagenetic features such as veins. Concretions occasionally are observed in association with veins and may have formed concurrently in these cases. However, there are numerous examples of concretions crosscut by veins **(Fig. 1E)**, indicating that the concretions formed prior to the veins. Several instances of antithetical concretion-vein relationships (typically in higher strata) are also consistent with the veins postdating concretion formation and possibly dissolving preexisting concretionary cements during vein formation. Different concretion compositions (Mg- and Ca-enriched concretions, Fe-enriched spherules) also suggest multiple diagenetic fluid events of distinct compositions. The diversity of concretion morphologies and mineralogy and their complex relations with veins support the conclusion that there were multiple late-stage fluid or diagenetic episodes within the Murray fm.

Further work will constrain the number and nature of the diagenetic episodes required to form these diverse concretion morphologies. Quantitative measurements of size and density [6,8] will assess the effect of host rock properties (grain size, permeability, lamination) on concretion morphology, size, and density.




**References:** [1] Fedo et al., this conf. [2] Kronyak et al. (2015) *LPSC 46*, #1903. [3] Nachon et al. (2017) *Icarus* 281, 121-136. [4] Frydenvang et al. (2016) *GRL* 44, 4716-4724. [5] Kah et al. (2015) *LPSC 46*, #1901. [6] Stack et al. (2015) *JGR* 119, 1637-1664. [7] Selles-Martinez (1996), *Earth-Sci. Rev.* 41, 177-210. [8] Calvin et al. (2008) *JGR* 113, E12S37. [9] Fraeman et al., this conf. [10] Meslin et al., this conf.

**Fig. 3.** Concretion distribution in the Murray fm.; colors indicate concretion type. The left plot shows the presence/absence of the concretion type within a Mastcam scene. The right three plots show the Mg, Ca, and Fe content of ChemCam concretion targets, plotted as the ratio of concretion chemistry to that concretion's host rock chemistry. Vertical black lines indicate a 1:1 ratio.