

SEDIMENTOLOGY OF DARWIN WAYPOINT FROM CURIOSITY OBSERVATIONS. R. M. E. Williams¹, D. Y. Sumner², S. Gupta³, J. P. Grotzinger⁴, D. Rubin⁵, R. C. Wiens⁶, K. S. Edgett⁷, M. S. Rice⁴, L. A. Edgar⁸, K. W. Lewis⁹, M. E. Minitti¹, J. Schieber¹⁰, K. Williford¹¹, D. L. Blaney¹¹, R. A. Yingst¹, M. C. Malin⁷, N. Mangold¹², A. Cousin¹³, J. Lasue¹³, R. B. Anderson¹⁴, S. Schroeder¹³, O. Gasnault¹³, M. R. Fisk, ¹Planetary Science Institute, 1700 E. Fort Lowell, Suite 106, Tucson, AZ 85719 (williams@psi.edu), ²UC Davis, ³Imperial College, ⁴Caltech, ⁵UC Santa Cruz, ⁶Los Alamos National Laboratory, ⁷Malin Space Science Systems, ⁸Arizona State University, ⁹Princeton University, ¹⁰Indiana University, ¹¹Jet Propulsion Lab, ¹²Laboratoire de Planétologie et Géodynamique de Nantes, France, ¹³IRAP, Toulouse, France, ¹⁴USGS, Flagstaff, AZ, ¹⁵Oregon State University.

Introduction: Between sols 390 and 401, *Curiosity* investigated an outcrop informally named Darwin, and performed contact science at two locations. At the initial site, observation points included Bardin Bluffs and Altar Mountain (Fig. 1). On sol 396, *Curiosity* bumped 4.6 m to a second location at Darwin, for in situ examination of veins as well as further characterization of sedimentary facies. Here, we report on sedimentological observations at Darwin based on images from the Mastcam and MAHLI instruments, and compositional data from ChemCam. Clast size, morphology, and texture provide insights into sediment transport processes, including the relative duration, energy, and entrainment nature of the flows.

Observations: Within the region of the Darwin outcrop there are interbedded packages of light-toned sandstone and darker pebbly sandstones. There are significant variations in grain size populations across small spatial scales. Four facies have been identified at Darwin (Fig. 1).

Facies descriptions: Altar Mountain facies. This basal unit is a poorly sorted, pebble-rich sandstone facies. Pebbles are subangular to subrounded in shape, with no well-developed fabric. Post-depositional aqueous alteration of this facies is indicated by an isolated, light-toned veinlet (Eureka; Fig. 2), and a locally occurring set of veins at the bump site (Fig. 3)

Bardin Bluffs facies: This pebbly sandstone is a massive layer that appears to fine upward. MAHLI images confirm the sandy matrix between moderately rounded pebbles. Fine pebbles are <1 cm in diameter, and some show evidence for bedload collisions in high energy flows (Fig. 4). Fractures and veins cross-cut this facies.

Thin, platy facies: This fine-grained facies appears to be interbedded with other facies. The facies appears as a thin layer that separates the Bardin Bluffs from the Altar Mountain facies (Fig. 1). Although much of this contact is obscured by outcrop of Bardin Bluffs, there are exposures of thin resistant beds protruding from sand drapes. Patchy exposures of this facies (yellow in fig 1) are also present higher in the section.

Dark-capping facies: At the local topographic high are dark blue-gray, pitted boulders with a smooth, almost glossy surface. Similar dark-capping rocks were

observed at multiple sites along the Bradbury Rise, including capping Shaler, Elsie Mountains, and nearby Edgecliff. However, it is unknown if these are the same lithology and facies, or if a surface coating produces a visual similarity among these outcrops.

Additional Observations: Light-toned bands: Located ~3 m to the east (left) of the Darwin outcrop, there is a pair of light-toned, <10-cm-wide bands on the rocks that appear to follow a constant elevation (Fig. 1). ChemCam observations on this substrate (Kukri target) indicate a silica-rich material, perhaps reflecting aqueous alteration of the rock.

Veins: Veins in the Darwin site are found regionally within the Altar Mountain facies and cross-cut a thin, platy facies (Fig. 3). Where exposed as ridges, cemented pebbles are observed. A localized conjugate fracture set (Camp_Ridge) reflects a tensile stress field in a well-lithified substrate. ChemCam observations of veins (Camp_Ridge and Beacon_Heights targets) show variation in composition, with some sites enhanced in Si and Al, consistent with a feldspathic composition and suggestive of a silica cement for the Darwin veins.

Discussion: The Darwin deposits are consistent with a complex scenario of dominantly fluvial activity. The limited areal continuity of these facies is consistent with significant, but spatially-variable post-deposition aeolian deflation. The bulk of the deposits are likely from ephemeral flows through the region, rather than deposits associated with sustained river flows. The disorganized and poorly sorted basal Altar Mountains facies is consistent with rapid deposition. The topmost Bardin Bluffs outcrop shows clear evidence for bedload transport with grain to grain contact [1]. Isolated pebbles floating in a sandy matrix, as observed in the topmost Bardin Bluffs facies, is a typical fabric for alluvial fan deposits. Some flows were vigorous, as evidenced by moderately rounded clasts and pock-marked pebbles (Fig. 2). The sediment supply appears to differ between Altar Mountains and Bardin Bluffs [1], and there is no evidence that the lower unit was reworked in the emplacement event for the upper unit.

The facies observed at Darwin have been observed elsewhere along the Bradbury Rise traverse [e.g., 2], however the stratigraphic succession varies. This pattern of repeated facies with differences in the vertical

sequence is consistent with our preferred interpretation that many of the outcrops encountered on Bradbury Rise are fluvial-lacustrine deposits with sediment largely originating from the crater rim. An outstanding question is the nature of the dark-capping unit.

The Darwin site has undergone an extensive diagenetic history, resulting in a well lithified and fractured outcrop. Deposits at Darwin were likely buried, with lithostatic pressure producing an echelon fracture patterns (e.g., Camp_Ridge). Taken together with evidence of exhumed rocks at Yellowknife Bay [4, 5] several kilometers to the northeast, there is a developing story of widespread burial and exhumation within Gale crater.

References: [1] Yingst et al. (2014) *LPSC*. [2] Edgar et al. (2013) *LPSC*. [3] Grotzinger, J. P. et al., (2013) *Scienceexpress*, doi:10.1126/science.1242777. [4] Farley, K. A. et al. (2013) *Scienceexpress*, doi:10.1126/science.1247166.

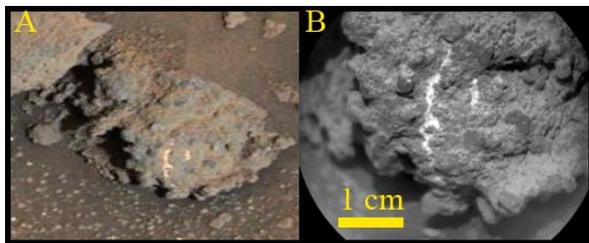


Fig. 2: Images of Eureka veinlet in Altar Mountain facies at site 1. A) Mastcam image acquired on sol 390. B) Standalone Remote Micro-Imager (RMI) image acquired on sol 396 (no LIBS data was obtained for this target).

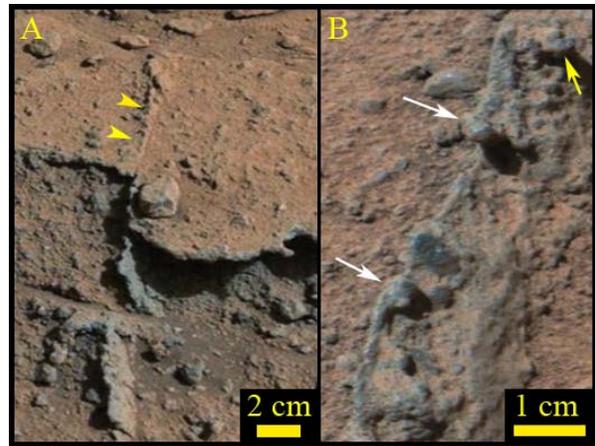


Fig. 3: Darwin veins at site 2. A) Veins cross-cut Altar Mountain and thin platy facies (yellow arrows) at Camp_Ridge. B) Cemented pebbles in raised ridges. (L to R) Mastcam images from sols 396 and 401.

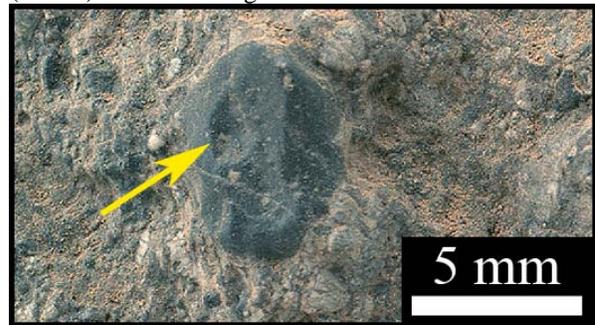


Fig. 4: Pock marked clast in Bardin Bluffs facies. MAHLI image acquired on sol 394 at 5 cm stand-off.

Fig. 1 (below): Sketch-map of facies contacts in Darwin outcrop with the approximate location of two parking sites marked by numbers. Facies include Altar Mountain, thin platy layer, Bardin Bluffs (BB), and dark capping unit.

