I. Report on Research Activities

A. Reconstructing the Aqueous History Within Southwestern Melas Chasma, Valles Marineris, Mars.

In Valles Marineris, a perched basin located in southwestern Melas Chasma has widely been recognized in prior studies as the site of a postulated paleolake, and is a landing site now under consideration for the 2020 Mars Rover. Valley networks converge from the east and west into an enclosed 30 x 120 km basin and terminate in fan-shaped landforms. Fan deposits are interbedded with layered beds that are largely presumed to be lacustrine deposits. New details of the aqueous history in the Melas basin have been revealed from analysis of high-resolution image, topographic and spectral datasets as reported in a manuscript published this year in *Icarus* (Williams and Weitz, 2014). We examined high-resolution images (THEMIS, CTX, HiRISE), topographic data (derived from HRSC stereo pairs), and complimentary CRISM spectral data of key regions to refine our understanding of the sequence of events within this basin. Eleven fan-shaped landforms have been identified which reflect various depositional environments and some fans indicate lake level (Fig. 1). Synthesizing the emplacement processes and the stratigraphic succession of fan-shaped deposits enables reconstruction of various lacustrine phases.

A range of depositional environments is recorded by these fans from deep subaqueous to shallow subaqueous to subaerial emplacement. In addition, there is a marker bed with inferred aeolian bedforms within the stratigraphic record of presumed lacustrine deposits. This observation, taken together with the stratigraphic succession of fan-shaped deposits, indicates fluctuating lake levels with, at a minimum, early and late-stage lake highstands (Fig. 2). Landform scale was used to estimate average discharge (~30 m$^3$/s), formative discharge (200-300 m$^3$/s), and fan formation timescale, which further inform the duration of lacustrine activity within the basin. Warm surface conditions and precipitation recharge of source basins is required to generate and sustain this long-lived lake over periods of at least centuries to millenia.

![Figure 1](image_url)

**Figure 1:** Study region and sketch map of eleven fans within the southwestern Melas basin. Landslides (I1, J), debris flows (C1, D1), fan-deltas (C2, E, H), deltas (D2, F, G, I2), and deep sublacustrine (A, B) deposits are present within the basin. Figure from Williams and Weitz (*Icarus*, 2014).
Figure 2. Examples of potential lake levels in southwestern Melas Basin are illustrated in this digital elevation model derived from HRSC stereo images, overlain on a CTX image mosaic. Scale bar in (A) applies to all panels. Elevation of lake levels for each panel is given at upper right. (A) Maximum lake level is defined by the outline of an enclosed depression in the modern topography with an associated maximum water depth is ~415 m. This lake level matches a number of fan apices, as labeled. (B) This illustration an intermediate lake level (maximum water depth ~230 m), however no morphological evidence for this lake level, or any specific intermediate lake level, was found in this study. (C) Maximum lake level (~65 m) where the marker bed would be above water. Figure from Williams and Weitz (Icarus, 2014).

B. In Situ outcrop investigations at Gale crater with the Mars Science Laboratory (MSL) Curiosity rover.

The main events and science results from the first 500 sols of the mission are summarized in Vasavada et al., (JGR, 2014). One of the early major findings from the Curiosity mission is documentation of a habitable environment at Gale crater based on the identification of a lacustrine deposit at Yellowknife Bay (Grotzinger et al., Science, 2014). Since departing Yellowknife Bay in the summer of 2013, the MSL science team and Williams have been investigating the outcrop properties and stratigraphic context of several prominent locations, including the Darwin waypoint, along Curiosity’s traverse before reaching the Pahrump Hills in September 2014 for an intensive campaign. At these sites, the presence of sandstones and pebbly sandstones with grain-supported textures, and the common presence of cross-stratification, both provide strong evidence for a hypothesis of bedload sediment transport in an ancient fluvial system (Figures 3 - 5).

In this report, the Darwin site (Williams et al., LPSC, 2014b; Vasavada et al., JGR, 2014) is used as an illustration of some of the major findings observed throughout Curiosity’s traverse across Aeolis Palus. The Darwin deposits are consistent with a complex scenario of dominantly fluvial activity. 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, while the topmost Bardin Bluffs outcrop shows clear evidence for bedload transport with grain to grain contact and clast texture (moderately rounded and pockmarked pebbles) reflects vigorous flows. The Darwin site has undergone an extensive diagenetic history, resulting in a well lithified and fractured outcrop. Multiple fluids have circulated through these rocks, initially cementing the fluvial deposits and subsequently resulting in fracture filled veins after lithification (Figures 4 and 5). There is abundant evidence for widespread burial and exhumation within Gale crater.
Figure 3: Sketch map of four rock types in the Darwin outcrop, with the approximate locations of the two parking sites marked by numbers. Mastcam mosaic acquired on sol 390. Figure from Vasavada et al. (JGR, 2014).

Figure 4: Localized fracture set, interpreted as veins, at the Darwin outcrop (location 2 in figure 3) are closely spaced and nearly parallel. These deposits were likely buried, with lithostatic pressure producing this en echelon fracture pattern. Mastcam image acquired on sol 396. B) Discrete fine pebbles (white arrows) are bound within the vein-filling material and are especially prominent on the surface of the vein ridge top, where they are more resistant to weathering. Mastcam image acquired on sol 401. Figure from Vasavada et al. (JGR, 2014).
Figure 5: MAHLI images of the Bardin Bluffs outcrop at the Darwin waypoint (location 1 in figure 3) were acquired on sol 394. A) Overview of Bardin Bluffs outcrop. B) An immature sandstone of very coarse sand, bearing small pebbles (<1 cm diameter). Pock marked pebbles (white arrow) record high energy collisions in fluvial transport. Note that the footprint of figure #F extends off the scene. C) Yellow circles mark irregularly shaped, dark-toned patches interpreted as pore-filling cements. The left one is triangular shaped and appears rimmed by a light-toned secondary cement phase possibly with isopachous texture. Hairline fracture marked by blue arrows. D) Yellow circle outlines a dark-toned triangle interpreted to be pore-filling cement. Hairline fractures are marked by blue arrows. E) Dark-toned cement surrounds light-toned sand grains within the yellow circle. F) Blue arrows point to a grey curvilinear band outlined by light-toned material of uniform thickness, interpreted as evidence for multiple cement phases and temporal changes in fluid composition that flowed through the rock.
C. Martian Alluvial Fans

The most detailed record of fan stratigraphy exposed on Mars is the deflated large alluvial fans located in Saheki crater. Morgan et al. (Icarus, 2014) used knowledge gleaned from examining fine-grained alluvial fans in Chile’s Atacama Desert to unravel the processes responsible for constructing the Saheki fans and constrain the associated flow events. Sediment (sand to boulder size) is deposited by channelized flows and overbank mudflows; subsequent wind erosion leaves channels expressed in inverted topographic relief (Figures 6 and 7). The study concludes that hundreds to thousands of short duration, modest magnitude flows (probably less than ~60 m$^3$/s) were involved in the formation of the uppermost 100 m Saheki fan deposits. Saheki fan construction occurred over an extended time period around the Hesperian-Amazonian boundary, requiring climate conditions favorable to surface water flow relatively late in martian history.

**Figure 6 (left):** Inverted channels (1-2 m relief, white arrows) on an alluvial fan in the Atacama Desert, Chile. Inversion is due to coarser grain size of the channel deposits, protecting them from wind erosion and possibly chemical cementation. Recent overbank deposits are pinkish. GeoEye imaging from Google Earth centered at 21.115°S, 69.576°W. Figure from Morgan et al. (Icarus, 2014).

**Figure 7 (right):** Shaded relief image of the distal end of one alluvial fan within Saheki crater. Digital elevation map (DEM) is constructed from HiRISE stereo image pairs, centered at 22.10° S, 72.97° E. The overall slope of the fan surface has been subtracted from the DEM so that portions of the fan surface at approximately equal stratigraphic level have the same relative elevation. Portions of image (lower right) not mantled with fan deposits are uncolored. Figure from Morgan et al. (Icarus, 2014).
D. Fieldwork on Terrestrial Inverted Channels.

Inverted channels are a prevalent feature of martian landscapes. As part of a Mars Fundamental Research grant, Williams is collecting data from a number of terrestrial field sites that span a range of formation histories for these landforms. In September 2014, Williams led a field team including Dr. Ross Irwin (Smithsonian Institution) and Dr. David Miller (USGS) to collect data on inverted channels in the Mojave Desert, California (Figure 8). Topographic and grain size data as well as observations about the degree of induration of these fluvial deposits are important characteristics to document and compare with other inverted channel sites to better understand the range of formation conditions and diagnostic attributes that are unique to specific development pathways.

Figure 8: Dr. Ross Irwin conducts a topographic survey along an inverted channel ridge crest in the Mojave Desert, California. These modest relief (~1 m) landforms are capped by unconsolidated, fluvially-transported pebbles.
E. MARS\textsubscript{DROP}

In conjunction with the Aerospace Corporation and NASA’s Jet Propulsion Laboratory, Williams is serving as a science consultant on development of the MARS\textsubscript{DROP} architecture (Figure 9), a steerable parawing glider and guided flight for a targeted landing with a small (~1 kg) payload (Staehle, et al., 2014a,b). Proof-of-concept tests have been conducted from high-altitude balloons (reaching ~1000,00 feet/~30 km) demonstrating the parawing could withstand deployment dynamic pressure, and the landing system fits within the capsule leaving sufficient volume and mass for a useful landed scientific payload. MARS\textsubscript{DROP} represents a new approach to augment Mars exploration by enabling precisely-targeted science at minimal cost for in situ investigation at scientifically compelling locations. MARS\textsubscript{DROP} can double or triple the number of Mars landers at small additional cost for each mission opportunity. With a guided flight capability, the payload can be delivered to regions previously considered high-risk. In addition, this targeted delivery enables distributed network science applications and/or provide reconnaissance data for future missions. In short, this delivery system can dramatically enhance the scientific return of Mars exploration, providing access to sites of high geologic and astrobiologic interest.

![Figure 9: A) MARS\textsubscript{DROP} microprobe landing architecture. B) MarsDrop balloon test descending to Nevada desert floor superimposed on MER scene. Image “color matched” to Mars. C) Engineering team holding parawing with balloon test article on table.](image-url)
II. Publications

A. Peer-Reviewed Manuscripts


B. Reports


C. Book


R. M. E. Williams was interviewed for this book, detailing the discovery of fluvial conglomerates during the early days of ground-based rover operations, her experience with the Curiosity mission, and reviewed portions of the manuscript.

D. First-Author Conference Abstracts


Williams, R. M. E., Weitz, C. M., Grindrod, P.M., Davis, J., Quantin-Nataf, C., and G.


**E. Co-Author Conference Abstracts**

i. **Lunar & Planetary Science Conference**


ii. Geological Society of America Conferences


iii. American Geophysical Union Fall Meeting


### iv. Other Conferences


III. Service to the Science Community
   A. Member of the European Space Agency’s (ESA) ExoMars Landing Site Selection Working Group (LSSWG)
   B. Session chair at Northeastern sectional meeting of the Geological Society of America (NE-GSA) held in Lancaster, PA for thematic session: "Gaining a Greater Understanding of Mars from Gale Crater and Beyond."
   C. PSI Prize Committee

IV. Public Outreach Activities

February 15, 2014 Interacting with BadgerBots clubs, high school students that build robots for the FIRST competition.


