CURIOSITY'S MASTCAM IMAGES REVEAL CONGLOMERATE OUTCROPS WITH WATER-TRANSPORTED PEBBLES. R. M. E. Williams[1], W. E. Dietrich[2], J. P. Grotzinger[3], S. Gupta[4], M. C. Malin[5], M. C. Palucis[2], D. Rubin,[6] K. Stack[3], D. Y. Sumner[7], R. A. Yingst[1], J. C. Bridges[8], W.Goetz[9], A. Koefoed[10], J. K. Jensen[10], M. B. Madsen[10] S. P. Schwenzer[11], R. G. Deen[12], O. Pariser[12], and the MSL Science Team. [1]Planetary Science Institute, Tucson, AZ, williams@psi.edu, [2] University of California, Berkeley, [3]Caltech, Pasadena, CA, [4]Imperial College, London, UK, [5]Malin Space Science Systems, San Diego, CA, [6]USGS, Santa Cruz, CA, [7]University of California, Davis, [8]University of Leicester, UK, [9]Max-Planck-Institut für Sonnensystemforschung, , Katlenburg-Lindau, Germany, [10]Niels Bohr Institute, University of Copenhagen, DK, [11]Open University, UK, [12]JPL, Pasadena, CA.

Introduction: Rock fragment morphology reflects the origin, transport, deposition and modification history of a clast. In terrestrial studies, documenting the dimensions, shape, texture and fabric of rock fragments is a standard technique used in field studies to help determine the depositional history [*e.g.*, 1].

Prior observations of rock fragments (constrained here to diameters between 4-256 mm) at Mars rover and lander sites show a dominance of clasts with sharp edges and corners [2-4]. The relative roundness of these clasts was most often characterized as angular or subangular/subrounded. Collectively, the particles reflected a single lithology of volcanic origin with minimal modification by ballistic impacts and aeolian processes [2-4]. Intermediate roundness values for a portion of the particles at the Viking 1 and Pathfinder landing sites, located in circum-Chryse outflow channels, are consistent with high-energy, short duration abrasion associated with catastrophic flooding [2, 4].

New observations from Curiosity's Mast cameras (Mastcam [5]) show rock fragments with morphology that is distinctly different from previous observations. These particles contrast with the highly angular rock fragments present at other martian landing sites, and reflect high-energy sediment transport. In outcrops, the stratification and arrangement of pebbles suggests aqueous bedload transport. These rounded pebbles provide the first direct observation of an ancient martian stream bed, and the first conglomerate on another planet.

Observations: Rounded pebbles are present in discrete, unconsolidated deposits and bound in outcrops along the 400 m route from Bradbury Landing to Rocknest that Curiosity traversed in the first 60 sols.

Rounded Pebbles in Outcrops. Indurated deposits of rounded pebbles and sand are best exposed in three rock outcrops: Goulburn_scour, Link and Hottah. These outcrops are located along the first 175 m traveled by the rover, and are within a ~3 m elevation range.

The tabular Goulburn_scour outcrop was exposed when the rover's descent engine plumes removed unconsolidated sediment from the surface. Rock fragments are embedded in finer-grained sediment forming a fine-pebble conglomerate. This thin (~6 cm thick), indurated deposit contains light to dark-colored, rounded to sub-rounded pebbles (5-30 mm in diameter) that appear to be arranged in clast-to-clast contact.

Link is a weakly stratified and ungraded conglomerate. Grains in the rock are pebbles (5-20 mm diameter) and very coarse sands. At the base of the outcrop, pebble piles have accumulated, presumably a reflection of clasts that eroded from the conglomerate. The pebble piles display a range of colors, are tabular to equant, and range from subrounded to well rounded.

The Hottah outcrop contains multi-colored, rounded pebbles (5-30 mm diameter) and sand (Figure 1). Hottah pebbles have a mean relative roundness of ~0.38, an order of magnitude greater than measured at Pathfinder [3]. It is a thinly laminated, moderately sorted outcrop with pockets of tightly packed pebbles. Elongate clasts are aligned parallel to stratification, and in several examples, stacked, elongated clasts show imbrication. In places, there are alternating layers of pebbles with intervening, finer-grained, recessive layers. Like Link, Hottah has piles of loose pebbles adjacent to the outcrop with similar attributes to the pebbles in the rock.

Loose Rounded Pebbles. Patches of unconsolidated rounded pebbles are located intermittently along Curiosity's route over an elevation range of 15 m (Figure 2). Loose pebbles range in size from 2 to 30 mm (median size ~8 mm). They vary in shape (ranging from flat to equidimensional) and color, two attributes that suggest heterogeneous lithologies are present. Most areas show no alignment of elongated clasts, but in one location near Rocknest the long axes of the pebbles are strongly aligned parallel to each other.

Discussion: The qualitative roundness of these pebbles is diagnostic of a sediment transport process involving abundant collisions to wear away irregular edges and produce a smooth surface [*e.g.*, 6]. The clast size (few tens of mm) requires a rapid flow speed to move. The pebbles are too coarse to be mobilized by wind [7-9] and are best explained by water flow transport. Further evidence in support of this interpretation includes local observations which indicate tractional aqueous transport: planar lamination, clast-supported fabric, and the presence of imbrication. In

addition, the cumulative size frequency of rock fragments within the outcrops is comparable to sedimentary deposits in terrestrial rivers [*e.g.*, 10]. Using conventional hydraulics [11], we determine the critical flow depth (0.08 – 0.8 m) and average velocity (14 – 63 cm/s) to mobilize the observed grain size for a range of slopes (0.1%-1%).

We interpret these rounded pebbles as sediment transported and deposited by vigorous fluvial flows. The qualitative roundness of the pebbles suggests a transport distance of >10 km, based on published fluvial abrasion experiments that document the control of lithology on progressive diminution and rounding on sediment [12]. This is consistent with the location of the conglomerate ~14 km down slope from the Peace Vallis alluvial fan apex [13]. The pebbles likely sample ancient crustal rocks from the Gale crater rim.

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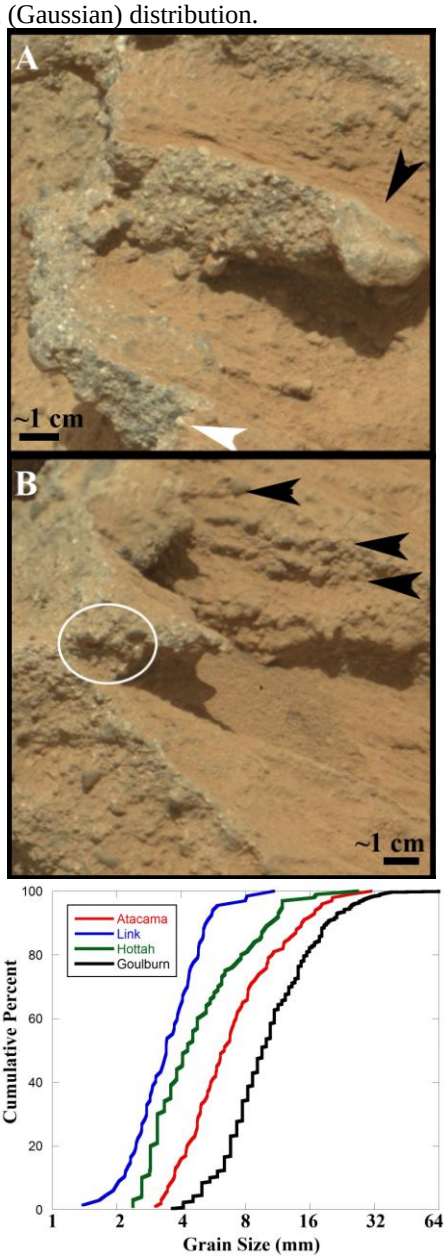
Figure 1 (top right): The Hottah outcrop was imaged by the 100-mm Mastcam on sol 39. **A)** Planar lamination (white arrow) and rounded pebble (~30 mm long axis) protruding from outcrop (black arrow). **B)** Black arrows mark couplets of alternating pebble (protruding) and finer-grained (recessive) layers. A clast-supported pebble cluster is within the white oval.

Figure 3 (bottom right): Cumulative grain size distribution plot for Link, Hottah, and Goulburn, and a representative terrestrial fluvial deposit (Atacama Desert, Chile). Stream deposits tend to approximate a normal (Gaussian) distribution.



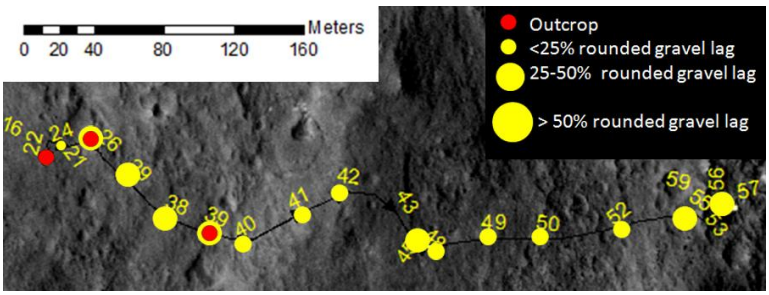


Figure 2: Distribution of conglomerate outcrops (red dots) and relative percent ground cover of unconsolidated, rounded pebbles observed in Mastcam clast surveys (yellow dots) along Curiosity's route. Martian sol is marked by yellow number.