MULTI-CYCLE SEDIMENTARY ROCKS ON MARS AND IMPLICATIONS. K. S. Edgett[1], L. A. Edgar[2], C. H. House[3], J. P. Grotzinger[4], K. A. Bennett[5], H. E. Newsom[6], N. Mangold[7], M. J. McBride[8], C. S. Edwards[5], R. C. Wiens[9], R. M. E. Williams[10], D. M. Fey[1], R. A. Yingst[10], [1]Malin Space Science Systems, San Diego, CA USA, [2]U.S. Geological Survey, Flagstaff, AZ USA, [3]Pennsylvania State Univ., University Park, PA USA, [4]California Institute of Technology, Pasadena, CA USA, [5]Northern Arizona Univ., Flagstaff, AZ USA, [6]Univ. New Mexico, Albuquerque, NM USA, [7]Université de Nantes, France, [8]Purdue Univ., West Lafayette, IN USA, [9]Los Alamos National Lab., Los Alamos, NM USA, [10]Planetary Science Institute, Tucson, AZ USA.

Introduction: Clastic sedimentary rocks signal a history of fragment production, transport, and sorting, followed by deposition, diagenesis, and a return to the surface from a modest (decameters) to deep (kilometers) depth of burial. Upon return to (or near) the surface, both clastic and chemical sedimentary rocks can be fragmented and the resulting clasts (sedimentary rock fragments, diagenetic products, and singular clasts liberated from storage in the preceding sedimentary rock) can be transported, sorted, deposited, and ultimately can become part of a new sedimentary rock. Sediments can also change to metamorphic rock or they can be melted such that their constituent atoms become part of new igneous or impact melt rocks—these, too, can be re-exposed at the surface and subjected to disaggregation, transport, sorting, deposition, diagenesis, and so on. These processes and events constitute a sedimentary rock cycle.

The presence of sedimentary rocks on Mars has been certain for ~19 years. Whether Mars has a sedimentary rock cycle, however, has been unclear or envisioned to be very simple, consisting of "primary deposits with very limited recycling" [1]. Impact breccias interpreted to be from Mars are sedimentary rocks, and some of their clasts are fragments of previous sedimentary rock [2, 3]. To those meteorite observations, we can now add *in situ* examples from the Mars Science Laboratory (MSL) *Curiosity* rover mission.

Observations and Interpretations: The sedimentary rocks that compose Aeolis Mons, the 5-km-high mountain in Gale crater under exploration via *Curiosity*, exhibit several erosional unconformities [4–6] and are cut by fluvial channels [7, 8], some of which have lithified fan-shaped deposits at their termini [9]. Unknown is whether all of the channels and unconformities represent a single or multiple episode(s) of erosion. What is apparent is that denudation of a mountain composed of sedimentary rock should produce fragments of sedimentary rock that undergo new transport, sorting, deposition and, potentially, lithification as clasts in a new sedimentary rock. Along the *Curiosity* traverse thus far, we have identified examples of sedimentary rock fragments in younger sedimentary rocks at four sites (**Fig 1**). Here, we briefly described each example and their overall implications.

1. Bimbe site. Several conglomerate boulders examined at Bimbe [10] (**Fig 1a, b**) contain sandstone pebbles, and some have veins within them (**Fig 1c, d**). Recessive, white, striated objects in the same boulders (**Fig 1e**) are either diagenetic void fills, chemical sediment lithic fragments, or vein mineral pieces from a previous rock; analysis of *Curiosity*'s Alpha Particle X-ray Spectrometer (APXS) data suggest they consist of calcium sulfate. The boulders are down-slope from Gediz Vallis, a fluvial system cut into Aeolis Mons that could have produced conglomeratic sediment. However, no outcrop of the conglomerate from which the boulders at Bimbe were shed has been found (it is possible that none exists anymore, that the rock occupied space that is now above the present surface).

2. Marias Pass site. A specific sandstone facies of the Stimson formation at the Clark outcrop [11] contains very coarse sand-sized fragments of mudstone (**Fig 1f, 1g**). These occur within 2–3 cm of an erosional unconformity [5] between Stimson sandstones and recessive high-Si [12] Murray formation mudstones. These lithic fragments are the same color as the subjacent mudstone (**Fig 1g**) and this color, very light gray, is uncommon throughout most of the exposed Murray formation [13], bolstering the interpretation that these might have come from nearby, subjacent strata [11]. The Stimson sandstones exposed at Marias Pass also contain irregular-shaped white clasts interpreted to be vein mineral fragments that might also have been liberated from underlying Murray formation rocks [11].

3. Dingo Gap site. A weakly stratified, poorly-sorted conglomerate interpreted to occur in fluvial channel bodies [14] includes angular, fine-cobble-sized, layered rock fragments interpreted as sandstone lithic fragments (**Fig 1h, i, j**). Their size and angularity suggest they were not transported far, and were likely incorporated into the conglomerate via scouring of the underlying sandstone facies [14].

4. Cooperstown site. An erosion-resistant, dark gray sandstone contains protrusive, angular, plate- or chip-shaped pebbles that are more resistant to erosion than the host sandstone (**Fig 1k, l**). The lithology of these clasts is uncertain but their shapes suggest they were not transported far and might come from a rock containing mm- or sub-mm-scale laminae.

Implications: In Gale, most of the deposition, lithification, and exhumation—including the events recorded by and post-dating major erosional unconformities—is thought to have occurred during a 200–300 (up to 500) million year period before ~3.1 Ga [e.g., 8]. During this time, sediments were deposited in Gale, buried, cemented in the presence of fluids to form rock (in some cases fractured with attendant vein mineralization), then exhumed, returned to the surface, such that the rocks contributed sedimentary rock fragments (and singular clasts liberated from storage within the rocks) to new sediments that became new rock, again in the presence of subsurface fluids and cementation. Considering the rest of Mars, and that the events in Gale perhaps occurred before 3 Ga, similar processes—a sedimentary rock cycle—must have occurred all over Mars during the first ~1.5 Ga of Martian history.

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Figure 1. (a) Map of a portion of the MSL Curiosity rover traverse (white) showing locations of the Bimbe, Marias Pass, Dingo Gap, and Cooperstown sites; base map from MRO HiRISE. Inset is an India Mars Orbiter Mission view of the 155 km diameter Gale crater. **(b)** Sol 1406 Front Hazcam Left-B view of boulders and cobbles at Bimbe. **(c)** Sandstone pebble, Tumba, in conglomerate boulder at Bimbe (MAHLI 1411MH0005840000502998R00). **(d)** Close-up of sand grains in pebble named Tumba. **(e)** White clast *or* vug fill at Funda in conglomerate boulder (MAHLI 1411MH0005840000503006R00). **(f)** Sandstone outcrop, Clark, in the Stimson formation (Mastcam-34 mosaic mcam04507). **(g)** Mudstone lithic fragments in sandstone at Clark; note resemblance to underlying light gray mudstone (MAHLI 1032MH0001700000400199R00). **(h)** Dark gray conglomerate outcrop, mantled with dust and loose stones, at Dingo Gap (Mastcam-100 mosaic mcam02092). **(i)** Stratified fine cobble in the conglomerate at Dingo Gap (Mastcam 0529MR0020920150303337C00). **(j)** Stratified fine cobble in the conglomerate at Dingo Gap (Mastcam 0529MR0020920170303339C00). **(k)** Dark gray sandstone with protruding chip-shaped clasts at Cooperstown (Mastcam mosaic mcam01795). **(l)** Protrusive, chip-shaped clasts at Cooperstown (MAHLI 0443MH0003290000200185R00).