GALE CRATER AND IMPACT PROCESSES FROM CURIOSITY. H.E. Newsom[1], L.C. Kah[2], N. Mangold[3], J.M. Williams[1], A.M. Ollila[1], R.E. Arvidson[4], N. Stein[4], J.C. Bridges[5], S.P. Schwenzer[6], J.G. Spray[7], J.A. Grant[8], F.J. Calef[9], P.L. King[10], N.T. Bridges[11], R.C. Wiens[12], D.T. Vaniman[13], and the MSL Science Team, [1]Inst. of Meteoritics, Univ. of New Mexico, Albuquerque, NM 87131, (newsom@unm.edu); [2]Dept. of Earth and Planet. Sci., Univ. of Tenn., Knoxville, TN, [3]Univ. de Nantes, France, [4]Washington Univ. in Saint Louis, [5]University of Leicester, UK, [6]The Open Univ., Milton Keynes, UK, [7]Univ. of New Brunswick, Canada, [8]Smithsonian, [9]Jet Propulsion Lab, [10]Res. School Earth Sci., Australian Nat. Univ., [11]Applied Physics Laboratory, Laurel, MD, [12]Los Alamos National Lab., Los Alamos, NM; [13]Planetary Science Inst., Tucson, Az.

Introduction: The surface of Mars has been affected by impact cratering processes throughout its history. Gale crater (155 km diameter) formed in the late Noachian to early Hesperian. [1, 2]. The record of impact cratering on surficial materials in Gale crater provides insight into how impacts and subsequent aeolian processes may complicate the interpretation of the preserved sedimentary record, and provides additional constraints on resurfacing rates [1].

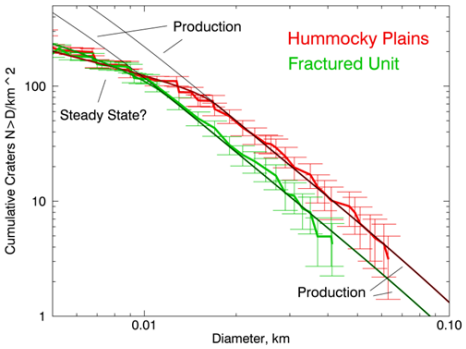


Figure 1. Impact crater data for the Hummocky Plains (HP) and Bright Fractured (BF) units. Two crater production curves are shown. At diameters less than ~10-15 m, the downturn in cumulative crater count may reflect a steady state combination of crater degradation and production .

Small crater frequency: During the first year of operation the MSL rover Curiosity investigated both the Hummocky Plains (HP) and Bright Fractured (BF) surfaces, which preserve an extensive impact crater record. From HiRISE data (Fig. 1), the Bright Fractured surface has a smaller crater abundance than that of the Hummocky Plains, consistent with erosional exhumation of strata underlying (or adjacent to) the Hummocky Plains. The crater size-frequency distributions for the data turn over for crater sizes less than ~12 to 15 m, consistent with removal of smaller craters. Once the BF unit was exhumed by erosion, vertical resurfacing rates appear to have been very low, with slightly lower values for BF as opposed to HP.

The smallest crater identified in the rover images, at 0.6 m diameter, is illustrated in Fig. 2 The size of craters on the surface, particularly at the smaller diameters, is modulated by the atmosphere, and theoretical calculations suggest there should be a cutoff at a diameter of ~ 20 cm (0.2 m). However, extensive surveys of the MER images [3] do not reveal candidate hypervelocity craters at centimeter scales, in agreement with our more limited observations during the first 360 Sols of an area ~ 3800 m^2, potentially reflecting the rapid modification of the smallest craters.

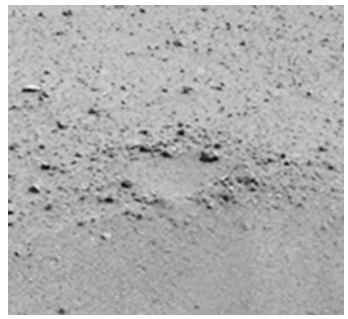


Figure 2. NavCam frame from Sol 338 showing a 0.6 meter diameter crater on the rim of a larger crater. Images: NASA/JPL-Caltech.

Erosion and resurfacing rates: Craters observed by Curiosity exhibit a range of erosional states, from nearly erased with only a depression (Fig. 3a), to deeper depressions with blocky rims (Fig. 3b), to craters still deep enough to contain drift deposits (Fig. 3c), and often with crater rims lined with upturned clasts, here conglomerate clasts ranging from 0.1-0.75 m.

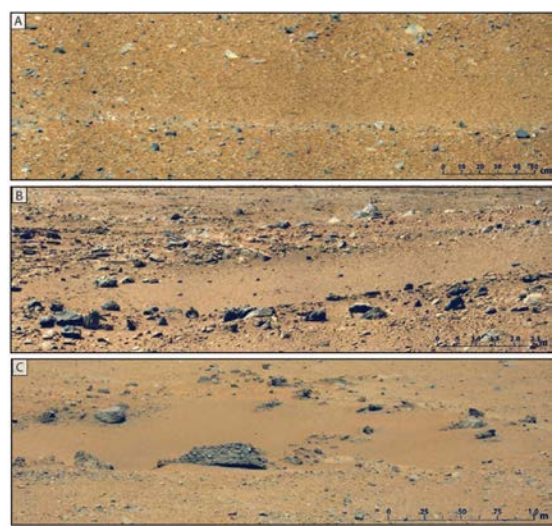


Figure 3. MastCam images of craters near MSL's path (a) 3.4 m diameter. (b) 20 m diameter. (c) 16 m diameter. Images: NASA/JPL-Caltech/MSSS.

Combined observations from orbit and from Curiosity, based on the exposure age data from Farley et al. [4] and a paucity of craters <2 m in diameter, constrain

the resurfacing rates at Gale crater to the order of ~30 mm/Myr, based on removal of ~2 m overburden at John Klein in ~70 Myr. This rate is substantially greater than rates that can be ascribed to impact cratering alone, and is consistent with aeolian modification.

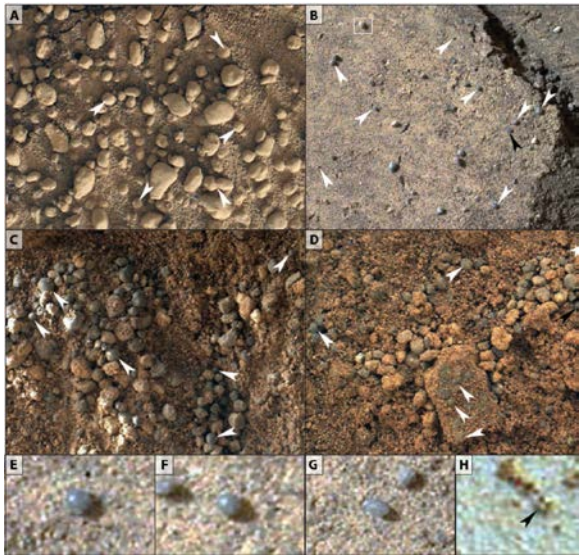
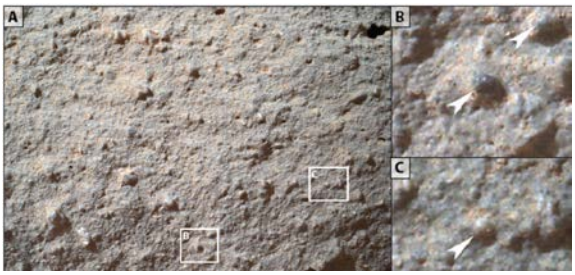


Fig. 4 MAHLI images of possible impact spherules at Rocknest. (A) (image 3.8 x 2.3 cm) Spherules are 1.32 to 1.65 mm in diameter, consistent with average grain size of coarse-grained sediment that often armors the substrate. (B) (image 3.5 x 2.7 cm) Abundant spherules (white arrows) atop Curiosity wheel tracks at the Rocknest sand shadow, including ovoid splash forms (black arrow), and a single, grain with substantially greater surface roughness, as is observed in armored lapilli (white box). Spherules range from 250 to 700 µm in diameter. (C) (image 1.5 x 1.1 cm) Spherules (white arrows) within wheel scuff, ranging from 225 to 780 µm in diameter. (D) (image 1.6 x 1.2 cm) Spherules (white arrows) and possible ellipsoid (black arrow) within scoop at Rocknest sand shadow. Spherules range from 200 to 624 µm in diameter. (E-H) Details of spherule morphology: (E) highly spherical, reflective grain; 375 µm in diameter; (F) slightly ovoid, reflective grain; 280 µm long; (G) highly ovoid, reflective grain; 500 µm long. (H) Smallest spherule from sieved sediment deposited on Curiosity's observation tray; 106 µm in diameter, from image 0095MH013100100C0.

Impactites: Possible impactites observed during the first 360 Sols of MSL observations include distal ejecta blocks, shatter cones, shatter-textured rocks, possible layered impact melts, spherules, and impact breccias. The surface of the HP contains blocks that are diverse in texture and composition. This diversity suggests an origin as distal ejecta from craters in or around Gale crater. Impact spherules, produced from impact melts represent the most convincing impactite evidence. Although no discrete stratigraphic horizons of spherules were identified, perhaps due to rapid deposition, impact spherules occur within the disturbed soils at the Rocknest wind drift (Fig. 4). Spherules comprise at least 2% of the most coarse-grained fraction of surface veneers [5], and also occur sporadically as coarse constituents within the fine-grained fraction of aeolian accumulations and in the Gillespie Lake sediments (Fig. 5). MAHLI O-tray investigation of sieved sediment records a small population of potential impact spherules <100 microns in diameter [5]. A few highly spherical grains are considerably dustier than candidate spherules, suggesting a lapilli coating, as also seen in terrestrial Lonar Crater ejecta [6].

Fig. 5 (A) Potential in situ spherules within lithified Gil-



lespie Lake rock in Yellowknife Bay. Possible impact spherules are defined by their sphericity and their glassy, reflective surfaces. (B) Dark grey spheroid is ~440 µm in diameter; medium grey spheroid is ~375 µm in diameter. (C) Potential impact spherule; pale grey spheroid is ~530 µm in diameter. Image 0132MH0163000010R0; field of view in (A) is 5.0 x 3.7 cm, at a resolution of 31.2 µm/pixel.

Conclusions: The first 360 sols turned up no fresh craters close to the rover, but there is a distinct variation in the preservation state of craters imaged from the rover. The oldest craters are simply shallow depressions with no blocks on the rim, and a crater fill that includes a substantial component of the coarser fraction of the regolith fund outside the craters. Younger craters can have blocky rims and are deeper, and often contain finer grain fill material. Resurfacing rates for this area of Gale crater may be on the order of ~30 mm/Myr based on the exposure age data [4] and the paucity of craters < 2 m in diameter observed by Curiosity. This rate is consistent with a large role for aeolian erosion and deposition. No strong evidence of hydrothermalism has been observed by the Curiosity instruments: the abundance of lithium is relatively low in most rocks [8], and the presence of clay minerals in the Yellowknife Bay rocks is interpreted to be due to diagenesis [9].

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References: [1] Newsom et al., 2014, *J. Geophys, Res.*, in preparation. [2] Anderson and Bell (2010), *Mars, 5*, 76. [3] Paige, D.A., et al., *7th Intl. Conf. on Mars*, 3392. [4] Farley et al., 2013, *Science 342*, [5] Minitti et al., 2014 *J. Geophys, Res.*, in press. [6] Newsom et al., 2013 in *Impact Cratering: Processes and Products*, Wiley-Blackwell. [7] Ollila et al. 2014, *J. Geophys, Res.*, in press. [8] McLennan et al., 2013, *Science 342*.