FIELD STUDIES OF CRATER GRADATION IN GUSEV CRATER AND MERIDIANI PLANUM USING THE MARS EXPLORATION ROVERS. J. A. Grant[1], M. P. Golombek[2], A. F. C. Haldemann[2], L. Crumpler[3], R. Li[4], W. A. Watters[5], and the Athena Science Team [1]Center for Earth and Planetary Studies, National Air and Space Museum, Smithsonian Institution, Washington, DC 20560, [2]Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA 91109, [3]New Mexico Museum of Natural History and Science, Albuquerque, NM 87104, [4]Department of Civil Engineering and Remote Sensing, The Ohio State University, Columbus, OH 43210, [5]Department of Earth, Atmospheric, and Planetary Sciences, Massachusetts Institute of Technology, Cambridge, MA 02139.

Introduction: The Mars Exploration Rovers Spirit and Opportunity investigated numerous craters since landing in Gusev crater (14.569°S, 175.473°E) and Meridiani Planum (1.946°S, 354.473°E) over the first 400 sols of their missions [1-4]. Craters at both sites are simple structures and vary in size and preservation state. Comparing observed and expected pristine morphology and using process-specific gradational signatures around terrestrial craters as a template [5-7] allows distinguishing gradation processes whose relative importance fundamentally differs from those responsible for most crater modification on the Earth.

Impact Structures in Gusev Crater: Craters dominate the surficial landscape on the Gusev Plains [2] and most have depth-to-diameter ratios generally <0.10 and possess raised rims and obvious ejecta deposits. Walls bounding the 210 m-in-diameter Bonneville crater (Table 1) are debris-mantled and slope an average 11 degrees, but there is little evidence of down slope movement (e.g. debris chutes or talus). Bonneville is currently only 10-14 m deep, but eolian infilling is generally only a few meters based on observations of protruding rocks. The 163 m-in-diameter Missoula crater and 90 m-in-diameter Lahontan crater located to the south and southeast of Bonneville are even shallower (Table 1) and possess walls sloping only ~6 degrees that are also devoid of talus or debris chutes. Some blocks that partially covering the floor of Missoula are probably ejecta from nearby Bonneville.

Basaltic ejecta around Bonneville, Missoula, and Lahontan craters possess a size and spatial distribution consistent with that expected for pristine deposits [2]. Largest fragments at Bonneville and Missoula, however, are only ~2.5 and ~1.5 meters, respectively, and smaller than the 3.5-10.5 and 2.9-8.6 meter blocks predicted for impact into bedrock [8]. Eolian deposits are local and <50 cm thick, whereas exposed surfaces experienced no more than 10's of cm deflation [9].

Smaller and generally more modified impact structures referred to as hollows (<20 m in diameter) are distributed across the Gusev plains. These craters are mostly sediment-filled and surrounded by abundant fractured and perched rocks [2], though some pristine examples occur.

Impact Structures in Meridiani Planum: Craters explored at Meridiani are fewer and farther between than at Gusev and all are formed into sulfate bedrock [3]. With the exception of the most degraded examples, Meridiani craters have depth-to-diameter ratios >0.10 and preserve walls sloped generally >10 degrees. Endurance crater is 150 m-in-diameter, 22 m deep, and possesses walls sloped between 15-30 degrees, but locally exceeding the repose angle (Table 1). Profiles across Endurance generally display an inflection halfway up the walls corresponding to the occurrence of large rocks. Eagle crater is 22 m-in-diameter, only 3 m deep, and has walls sloping 10-15 degrees and mostly mantled by drift encroaching from the surrounding plains (Table 1). Fram, Geographe, and Naturaliste craters are 10 meter diameter and ~1.1 meter deep, 6.5 meter diameter and ~1.4 meter deep, and 11 m in diameter and ~2.5 meter deep, respectively, and are the only craters retaining visible ejecta. Nevertheless, many ejecta rocks appear planed off at level of the plains and others may be buried.

The most subdued craters are Jason and Alvin, both ~11 m-in-diameter, and the ~45 m-in-diameter Vostok. Drift covers most walls, floor, and the exterior of these craters and minimal rims merge almost imperceptibly with the surrounding plains. Vostok has all but disappeared and is only visible as a low, narrow ring of sulfate outcrop that surrounds a mostly filled and only slightly lower interior.

Gradation Models for Gusev and Meridiani: Many of the craters in Gusev appear to be the result of secondary cratering events. Observed depth-to-diameter ratios are low, there is little evidence that they have been significantly modified by gradation, and forms are most consistent with those expected for secondary craters [10-12]. By contrast, craters in Meridiani are mostly primaries. Current depth-to-diameter ratios are 0.11 to just over 0.2 and most show good evidence for gradation consistent with modification of pristine, primary craters. Fram is the sole candidate for a secondary crater in Meridiani.

Eolian erosion/deposition has dominated at both Gusev and Meridiani since the Hesperian and Amazonian, respectively, and is generally more important in gradation than at terrestrial craters. Nevertheless, significant differences in the amount and range in modification exists between the two sites. At Gusev, crater formation into relatively competent basaltic rubble results in a pristine form that is comprised of more durable basaltic rocks and creates only limited sediments available for transport [2, 13]. By contrast, at Meridiani, crater formation into plains comprised of relatively soft sulfate bedrock and capped by a thin layer of mobile sediments [3] enables eolian stripping of the ejecta, rim, and upper walls that is accompanied by eolian infilling by sediments transported from the surrounding plains. At Endurance, stripping likely accounts for back wasting of at least 5-10 meters of the upper walls and likely creates the inflection noted across blocky talus on the mid wall.

Mass wasting plays a limited role in crater gradation at Gusev and Meridiani relative to Earth, but for different reasons. At Gusev, down slope movement of debris is limited by relatively low wall slopes at even the most pristine craters. At Meridiani, mass wasting is more limited by the higher rate of eolian stripping that removes talus and back wastes to low angles. None of the Martian craters has debris chutes or significant talus associated with mass wasting at terrestrial craters.

At Gusev, impacts occurred in sufficient numbers to account for some modification of pre-existing craters. At Meridiani Planum, the younger Amazonian surface preserves relatively fewer craters, none of which overlap and highlights a gap in the preserved crater record corresponding to the time between the wetter Noachian when the sulfate rocks were deposited and the present dry conditions [13]. Ongoing eolian erosion that continues to modify craters at Meridiani may mostly account for this gap in the crater record.

An absence of evidence for crater modification by water highlights the dry conditions persisting since the Hesperian at Gusev and at least the Amazonian in Meridiani. Analogy with the Earth indicates that signatures associated with appreciable fluvial gradation should persist at these craters if formed [5, 7], but are not present. Small amounts of water at both sites may account for surface coatings and textures, but is not required and did not result in runoff. Instead, craters in these two widely separated locations record a history of dry conditions over much of Martian history that contrasts with the wetter conditions that enabled formation of the sulfates in Meridiani during the Noachian.

Summary: Craters formed on the Hesperian aged floor of Gusev and larger than ~100 m in diameter are generally more pristine than many craters formed on the younger Amazonian aged Meridiani Plains. This conclusion may not be representative of crater gradation across regional landscapes characterized by markedly different landforms and may contradict some interpretations drawn from orbital views. For example, it is difficult to distinguish pristine craters (e.g., Naturaliste) from more degraded craters (e.g., Eagle) in the orbital data and Endurance crater displays a relatively lower albedo deposit of differing radial extent that might be interpreted as ejecta that is not present. Similarly, orbital data may lead to the impression that larger craters (e.g., Bonneville) visited in Gusev are degraded when they are actually fairly pristine secondaries. Results highlight the need for surface and/or higher resolution orbital imaging in order to accurate definition of crater gradation state and processes.

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Table 1. Selected Observed and Predicted Dimensions for Craters in Gusev and Meridiani Planum

	Observed Crater Dimensions					Predicted Crater Dimensions[a]			
Gusev	**Diameter**	**Depth**	**Rim Height**	**Ejecta at Rim**	**Depth/ Diameter**	**Transient Diameter[b]**	**Transient Depth[b]**	**Rim Height[b]**	**Ejecta at Rim[b]**
Bonneville	210 m	10-14 m	4.1-6.4 m	N/A	0.07	176 m	65 m	7.4 m	2.3 m
Missoula	163 m	3-4 m	~3 m	N/A	0.03	137 m	51 m	5.7 m	1.9 m
Lahontan	90 m	4.5 m	~2-3 m	N/A	0.05	77 m	29 m	3.2 m	1.3 m
Meridiani									
Eagle	22 m	2-3 m	0.1-0.7 m	0	0.13	18.5 m	7 m	0.8 m	0.4-0.5 m
Endurance	150 m	21 m	<1-5 m	0-1 m[c]	0.14	126 m	47 m	5.3 m	1.8 m
Naturaliste	11 m	2.5 m	<0.5 m	<0.5 m	0.22	9.2 m	3.4 m	~0.4 m	~0.3 m

[a] Predicted Crater Dimensions Derived Using Equations 1-4
[b] May Be Over-Estimated if Craters are the Result of Secondary Impact Events
[c] Almost all Ejecta is Removed, Only Very Local, Nearest Rim Occurrences Where Preserved Rim is Highest