BRIGHT GULLY DEPOSITS: GEOLOGICAL AND TOPOGRAPHICAL SETTINGS.
K. J. Kolb[1], A. S. McEwen[1], V. C. Gulick[2], and the HiRISE Team, [1]Lunar and Planetary Laboratory, University of Arizona, Tucson, AZ 85721; kkolb@LPL.arizona.edu, [2]NASA Ames/SETI Institute, NASA Ames Research Center MS 239-20, Moffett Field, CA 95135.

Introduction: The Martian gullies[1] are thought to be young features (< 1 Ma [2]) likely formed by a combination of fluvial and mass-wasting processes. Recently, Malin et al.[3] published the discovery by the Mars Orbiter Camera (MOC) of two new bright gully deposits (BGDs) that appeared over a time period of several years. HiRISE[4] observations of the two new deposits have confirmed that they mostly circumvent, but also overtop, topographical obstacles[5]. No resolvable changes in their shapes have occurred since MOC imaging; change would be expected if the bright material were frost. The HiRISE camera has detected three similar bright deposits that might also be very recent. It is very likely that there are more bright deposits to be discovered or that are forming today.

It is possible that not all new gully deposits will be bright. However, even if new deposits are not bright, they probably will be detectable based on albedo differences between them and their surroundings before the deposits are covered with dust, modified through time, or both. Also, not all bright deposits are necessarily recent. Some have been found that are bright due to deposition of eolian materials[5]. The BGDs discussed in this work have not undergone any resolvable modification since emplacement and thus formed recently.

The BGDs discussed are located in four craters and one trough in the southern hemisphere of Mars. The craters that have the BGDs are all apparently relatively young based on steep slopes and raised rims. Analysis of slopes of the bright deposits shows that they lie on steep slopes[5]. All but one of the slopes (Terra Cimmeria), has a slope ~30°, very close to the angle of repose for dry material. The BGDs exhibit low relief[3] and are seen to emanate from existing channels. No new channels have been observed to form where images exist before and after deposition. They overlap the channel margins on many occasions and parallel pre-existing channels. It is likely that all of the BGDs emanate from pre-existing channels because they start midslope. However, the material might have originated at the slope top while only depositing on the lower half of the slope. More precise slope elevations are needed to determine if there is a slope break that leads to a change from transporting to depositing material.

A wide range of gully morphology exists across Mars. It is interesting to note that all of the new BGDs are found in locations with gullies that have narrow channels and abbreviated alcoves. There is frequently a noticeable difference in the morphologies of gullies on the slopes with BGDs and other gullied slopes within the same crater. The slopes with BGDs often have narrow, pristine gullies, while other nearby slopes have larger gullies that have been visibly modified over time by eolian and periglacial processes.

The goal of this project is to study the BGDs to learn about gully evolution and formation and to predict locations of future gully activity.

Methods: For each BGD, relevant MOLA tracks are identified using PIGWAD[6] from the United States Geological Survey. The tracks are obtained from the PDS geosciences node and read into a table using PEDR2TAB[7]. The MOLA footprints are ~168 m in diameter spaced ~300 m apart along track[8]. We choose not to interpolate the MOLA data because of their sparseness and the inevitable introduction of errors. Slope rim and base coordinates are obtained from HiRISE images using qview's measure tool. The coordinates of the crater center or a point that appeared representative of the crater or trough depth are also recorded.

The MOLA elevations are color-coded and plotted with the qview coordinates on top of them (see Figure 1). The black empty squares are slope coordinates measured in qview, and the filled in squares are the locations of the BGDs. It can be seen that there is a noticeable offset between the coordinates of the top and bottom of the slope and where the slope actually occurs (gradient in color). This offset has not yet been quantified, but a shift based on matching large-scale features is applied to locate the MOLA track(s) closest to the BGD in each setting. Both datasets use planetocentric latitude and east longitude.

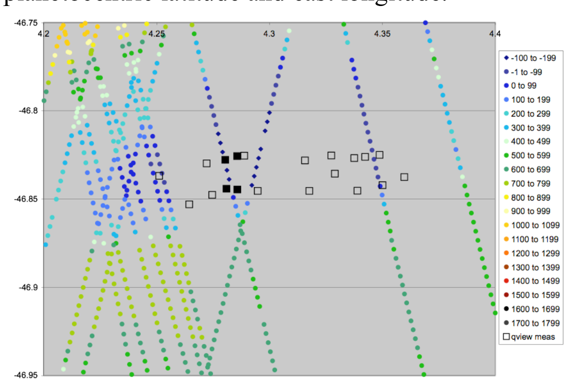

Figure 1. MOLA elevations with qview measured locations.

Crater depth, maximum crater depth, and slope angle are calculated for each of the BGD settings. Details and results are presented below. Crater diameters are obtained from the Barlow Crater database in PIGWAD[6], if available, or by using qview measure to measure it on a HiRISE image. The HiRISE images studied are listed in Table 1.

Crater Depth There are two methods used to calculate crater depth. Shadow measurements are used to calculate depth wherever available. If no shadow exists, then we look at a general range of elevations on the crater floor and rim and round to 100's of meters. Shadow measurements are obtained in the down-sun direction as stored in the ISIS3 [9] HiRISE image labels. Lines parallel to the downsun direction are drawn over shadows using qview to measure the slopes where applicable. Relative elevations are calculated using Equation 1. Shadow measurements are available for the BGDs in Terra Sirenum (A) and Terra Cimmeria.

Table 1. HiRISE Images Used

Observation ID	Scale (m/pixel)	Location
PSP_001714_1415	0.25	Centauri Montes
PSP_001846_1415	0.25	Centauri Montes
PSP_002040_1435	0.25	Terra Sirenum A
PSP_002136_1415	0.25	Centauri Montes
PSP_002179_1330	0.25	Noachis Terra
PSP_002185_1435	0.25	Terra Sirenum A
PSP_002200_1380	0.50	Terra Cimmeria
PSP_002812_1330	0.25	Noachis Terra
PSP_003252_1425	0.50	Terra Sirenum B

Crater Depth There are two methods used to calculate crater depth. Shadow measurements are used to calculate depth wherever available. If no shadow exists, then we look at a general range of elevations on the crater floor and rim and round to 100's of meters. Shadow measurements are obtained in the down-sun direction as stored in the ISIS3[9] HiRISE image labels. Lines parallel to the downsun direction are drawn over shadows using qview to measure the slopes where applicable. Relative elevations are calculated using Equation 1. Shadow measurements are available for the BGDs in Terra Sirenum (A) and Terra Cimmeria.

(1) $$z = \frac{L}{\tan\theta_i}$$

z: relative elevation, m
L: shadow length in down-sun direction, m
θ_i: inclination angle,°

Maximum Depth The maximum depth of each crater is calculated by looking at extremes in elevation along analyzed MOLA tracks that occur along the slope in line with the BGD or by taking the highest elevation of the probable rim and the lowest of the floor.

Slope Angle Slopes are calculated using close MOLA track elevations and shadow measurements as available. The elevations of the closest MOLA tracks are used and a horizontal distance between the center coordinates of each footprint is calculated using the horizontal distance along a sphere equation (Equation 2 [10]). The horizontal distance in degrees is converted to meters using Equation 3.

(2) $$\cos d = \cos(90-\vartheta_1)\cos(90-\vartheta_2) + \sin(90-\vartheta_1)\sin(90-\vartheta_2)\cos(\beta_2-\beta_1)$$

d: horizontal distance,°
$\vartheta_{1,2}$: latitude, °S
$\beta_{1,2}$: longitude,°E

(3) $$1^\circ = \frac{\pi R_{Mars}\cos\vartheta}{180}$$

R_{Mars}: 3396190 m (IAU definition) at the equator
ϑ: latitude, °

The m/° scale is calculated for ϑ_1 and ϑ_2, then averaged to convert the horizontal distance in degrees to meters. Typical differences in scale between the latitudes of the MOLA shots are 4-8 m/°. The slope angle is determined by Equation 4.

(4) $$\theta_{sl} = \tan^{-1}\left(\frac{\Delta z}{d}\right)$$

θ_{sl}: slope angle, °
Δz: change in elevation between two consecutive MOLA points, m
d: horizontal distance between MOLA shot centers, m

The derived slopes are minimum values that are limited by the resolution of the MOLA data as well as errors in shadow measurements (typically a few pixels, < 5 meters). The MOLA tracks analyzed are not necessarily immediately up/downslope from the BGDs, but we look at the HiRISE images to make sure that the slopes they crossed are representative, as much as possible, of the slopes hosting the BGDs. To do this more accurately will require overlaying MOLA tracks on HiRISE images using the Generic Mapping Tools (GMT) Software[11]. While this is more precise, it is unlikely to significantly affect the slopes calculated because, in general, the MOLA tracks analyzed are the only ones near the BGD locations. Many of the BGDs are on slopes that are visibly steeper at the top, but this is not taken into account unless MOLA tracks that line up with the BGD slope are available.

Shadow measurements are used to derive the slope angle in regions where the shadow extended across the crater floor, which we assumed to be flat.

Results: See Table 2.

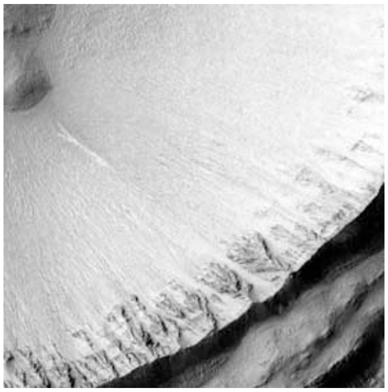

Figure 2. HiRISE PSP_001846_1415, ~2.3 km across. Full resolution, 0.25 m/pixel. North is up with illumination from the upper left in this and all following images.

Figure 3. HiRISE PSP_002185_1435, ~1 km across. Reduced resolution, 1 m/pixel.

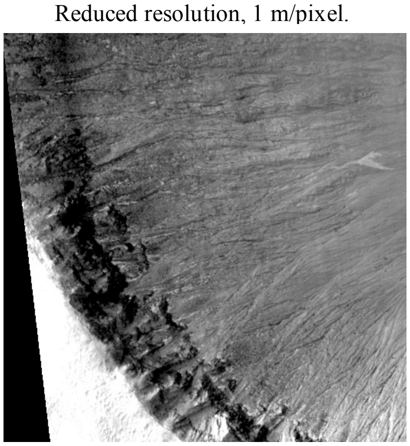

Figure 4. HiRISE PSP_002200_1380, ~1.8 km across. Reduced resolution, 2 m/pixel.

Discussion: The BGDs have many of the same characteristics. They start midslope and reoccupy existing channels. Even if an image before a BGD formed does not exist, the channels they occupy extend the length of the slope, while the BGDs do not. This suggests that repeated occupation of channels might be common on Mars. The majority of the BGDs, with the exception of Terra Sirenum A, have noticeable bright, steep layers upslope that are likely the source of the bright material. The BGDs flow

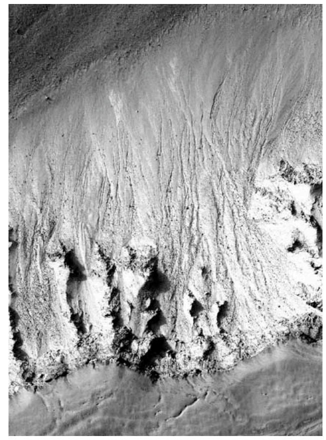

Figure 5. HiRISE PSP_002179_1330, ~1.2 km across. Full resolution, 0.25 m/pixel.

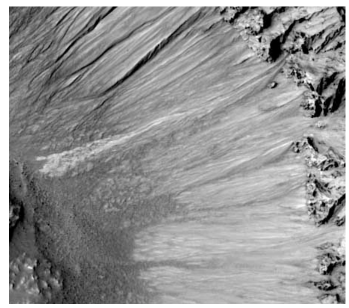

Figure 6. HiRISE PSP_003252_1425, ~1.5 km across. Reduced resolution, 2 m/pixel. This is not a map-projected product, but north is up.

around and over obstacles suggesting that the flows were fluidized; yet not ruling out debris flows. The BGDs are commonly found on walls with small, narrow channels while other local gullies are more incised, have wider alcoves, and are more widely spaced.

Centauri Montes The BGD in a crater in the Centauri/Hellas Montes (Fig. 2) formed between August 1999 and February 2004 [3]. Nearby gullies are more deeply incised. Since gully channels likely get deeper with ongoing activity, the nearby gullies probably experienced more flow events than the fine, narrow gullies. These flow events may have occurred more frequently or occurred during another period of gully activity, making the slope with the BGD the location of more recent and ongoing gully activity.

Terra Sirenum A This BGD (Fig. 3) in Terra Sirenum formed between December 2001 and April 2005 [3]. The BGD is on the northwest wall, and the gullies on the north wall have polygonal fractures on their walls which may have formed by desiccation or seasonal thermal cycling[12]. The fractures probably require a significant amount of time to form, thus making the gullies on the north wall relatively old, possibly indicating separate activity periods. They might also indicate regions where ground ice is preferentially stable. No such features are observed near the BGD.

Terra Cimmeria A BGD in Terra Cimmeria (Fig. 4) was published by McEwen et al.[5]. There are no images of the slope from before the BGD was discovered. The finest channels are on the southwest wall where the BGD is seen. The BGD has several discontinuous companion BGDs to the south (see Fig. 4) that appear to start at approximately the same elevation as it. This is the only BGD that lies on a slope that is markedly less (~20°) than the typical angle of repose (~35°). Its formation is difficult to explain with mass wasting because of the shallow slope.

Trough in Noachis Terra Two BGDs (Fig. 5) were discovered in a crater in Noachis Terra[5,12,13]. Acquired MOC images show that the BGDs have been present since at least January 2000. This "trough crater" is a circular feature that is almost a continuous ring. The BGD on the left is brighter than that on the right, so it might be the most recent. There are lots of boulders in the channels on the trough wall, including the channels associated with the BGDs. This indicates that smaller sediment was preferentially transported while resolvable boulders (~0.5-1m) were left behind. This suggests a flow with liquid as opposed to a dry debris flow[5].

Terra Sirenum B Another BGD (Fig. 6) in Terra Sirenum was recently detected in HiRISE images[5]. At the time of submission, no map-projected product was available for analysis. No MOC images cover the BGD, so it is not possible to know when it formed.

Summary: Except for the BGD in Terra Cimmeria, the other BGDs are all located on steep slopes and could be generated by mass wasting. All of the craters involved are relatively pristine and young. Steep slopes are expected in young craters because crater degradation has not had time to operate.

There appears to be no preferred orientation (see Table 2) for the BGDs suggesting that insolation is not the dominant factor in their occurrence. It is interesting to note that the bright deposits are all found near bright layers suggesting that the color of new deposits depends on the material transported. It is possible that the bright layers, whatever their composition, are inherently weaker than other layers. It is unknown why the bright materials and layers are bright. It is possible that they were bleached by water or that they contain evaporites.

Even though the BGDs appear to start downslope, they might contain material transported from the top of the slope with deposition beginning near a change in slope or when the supply of a transporting fluid, likely water, diminishes enough to start depositing transported sediment.

If water is involved in the formation of the BGD, then the bright deposits represent a location of current or very recent water. However, because of the steep nature of most of the slopes, there is no conclusive evidence that the bright deposits are formed by recently flowing surficial water[5]. It is possible that the BGDs are actually debris flows, possibly aided by water. It is difficult to explain the BGD in Terra Cimmeria as a dry flow because of the shallow slope on which it lies. The BGDs can probably be explained as water-transported material with varying amounts of sediment, such that some flows might be better classified as drier debris flows.

Future Work: In the future, this project will be extended to include morphological studies to compare gullies recently formed to those on other steep and shallow slopes. We plan to target relatively young craters with steep slopes in hopes of detecting future gully activity. This monitoriing will aid in understanding the rate and controls on current gully activity.

Acknowledgements: This work used HiRISE images processed with ISIS3 [9] software and MOC images from the MOC gallery[14]. Thanks to the HiRISE team for suggestions, comments, and input.

References: [1] Malin M.C. and Edgett K.S. (2000) *Science, 288*, 2330-2335. [2] Mellon M.T. and Phillips R.J. (2001) *JGR, 106*, 23165-23180. [3] Malin M.C. et al. (2006) *Science, 314*, 1573-1577. [4] McEwen, A.S. et al. (2007), *JGR*, in press. [5] McEwen, A.S. et al. (2007), *Science*, submitted. [6] http://webgis.wr.usgs.gov/pigwad/maps/mars.htm [7] PEDR2TAB software by G. Neumann, Smith et al., NASA Planetary Data System, MGS-M-MOLA-3-PEDR-L1A-V1.0, 2003. [8] Neumann, G.A. et al. (2001), *JGR*, 106, E10, 23,753-23,768. [9] http://isis.astrogeology.usgs.gov/ [10] http://en.wikipedia.org/wiki/Spherical_law_of_cosines [11] http://gmt.soest.hawaii.edu/ [12] Gulick, V.C. et al. (2007), *LPSC XXXVIII*, abs. 1338. [13] Gulick, V.C. et al., this conference. [14] www.msss.com/moc_gallery

Table 2. Topographical Settings of Bright Gully Deposits

Location	Lat (°S)	Lon (°E)	Orientation	Diameter		Depth		Maximum Depth		Slope		Figure
				(km)	Method	(m)	Method	(m)	Method	°	Method	
Centauri Montes	-38.4	96.8	NW	9.2	B	700	G	900	M	28	M	B
Terra Sirenum A	-36.2	198.3	SE	4	Q	500	S	473	R	29.5	S	C
Terra Cimmeria	-41.6	150.6	NE	6	Q	888	S	849	R	20	S	D
Noachis Terra	-46.9	4.3	N	--	--	700	G	955	R	31	M	E
Terra Sirenum B	-37.7	229.0	SE	7.2	B	TBD	--	TBD	--	TBD	--	F

B: Crater in Barlow Crater database, G: general elevations of floor and rim, rounded to 100s of meters, M: MOLA topography, Q: measured in ISIS3 qview, R: highest elevation of probable rim and lowest point, S: shadow measurements