GLOBAL DOCUMENTATION OF MARTIAN GULLIES WITH THE MARS RECONNAISSANCE ORBITER (MRO) CONTEXT CAMERA (CTX). T. N. Harrison[1*], G. R. Osinski[1,2], and L. L. Tornabene[1], [1]Centre for Planetary Science and Exploration/Department of Earth Sciences, University of Western Ontario, [2]Department of Physics and Astronomy, University of Western Ontario. (*tanya.harrison@cpsx.uwo.ca)

Introduction: Gullies in the mid- and high-latitudes of Mars were first observed in Mars Global Surveyor (MGS) Mars Orbiter Camera (MOC) images in 1997 [1] Appearing to be geologically young [1], they quickly became a feature of interest for the Mars science community because of the implication of liquid water in their formation. A number of models have been proposed to explain the formation of gullies, including both “dry” mass movement processes [2,3] and “wet” mechanisms such as the release of liquid water/brine from shallow [1] or deep [4] aquifers or through the melting of near-surface ground ice [5] or snowpacks [6,7].

Previous surveys of gully distribution have been conducted using either MOC narrow-angle (NA) images [8,9], or MOC NA images combined with Mars Odyssey Thermal Emission Imaging System visible subsystem data (THEMIS VIS, ~18 m/pixel) [10] and Mars Express High Resolution Stereo Camera (HRSC, 12.5–50 m/pixel) data [10,11]. However, surveys utilizing only MOC NA suffered from low spatial coverage (<1% of the planet) and possible sampling biases due to the narrow image footprint. While lower resolution datasets provided larger spatial coverage (~6% of the planet by Balme et al. [11] and ~42% of the planet by Kneissl et al. [12], many gullies are not resolvable at THEMIS VIS and HRSC scale. Kneissl et al. [12] noted that ~42% of the gullies imaged with MOC NA in their survey could not be detected by HRSC due to their small size. Poor atmospheric conditions and unfavorable illumination angles were also cited as issues.

Methods: The Mars Reconnaissance Orbiter Context Camera (CTX) has covered ~85% of Mars at a resolution of ~6 m/pixel through the end of phase D09 (February 2013). Covering up to 9,390 km^2 in a single image, CTX provides large aerial coverage at a resolution capable of resolving >95% of Martian gullies and removes any sampling bias from previous studies using MOC NA [13]. Landforms potentially hosting gullies were specifically targeted by CTX during optimal illumination and atmospheric conditions to maximize slope visibility [13].

Notable gaps in current CTX coverage are observed in the higher mid-latitudes, arising from poor atmospheric conditions throughout much of the martian year. In the northern hemisphere, the majority of the gaps occur over the plains; however, over 90% of the craters in the mid to high latitudes large enough for gullies to be resolved with CTX have been imaged. In the southern hemisphere, the gaps occur over areas of low surface roughness [14] blanketed with the mantle characteristic of the higher latitudes [15] where gullies have rarely been found in previous surveys [8,11], and in our survey the occurrence of gullies is indeed sparse in the areas of the high latitudes that have coverage with CTX. Therefore, the documentation effort presented here is globally representative, and the trends observed will not be significantly changed with additional areal coverage by CTX.

We inspected all 54,040 CTX images acquired during phases T01–D09 planet-wide (90°S–90°N) to search for occurrences of gullies, documenting their setting (e.g., crater wall, massif, scarp wall, etc.), the geographic coordinates of each gullied landform (e.g., crater center coordinates), and the orientations of the gullies present at each location.

Malin and Edgett [1] defined gullies as consisting of three characteristic features: alcove, channel, and apron. However, not all gullies have distinctive alcoves and/or aprons. Features in the equatorial regions classified as gullies by some authors [e.g., 2,3] host alcoves and aprons (which are characteristic of multiple mass movement processes [16]) but lack the incised channels of mid- to high-latitude gullies, which often display fluvial characteristics such as tributaries, streamlined features, and terraces [17]. Therefore, these equatorial features are not considered gullies in this study; the defining characteristic of a “gully” is the presence of an incised channel. It is important to note that the term “gully” describes only a morphologic feature, and not a specific genetic process [16,18]. Typically on Earth, multiple processes contribute to gully formation and evolution—even within a single gully system [e.g., 19]—and many different types of mass movements can occur within a gully channel.

Results: We have documented 4,861 separate gullied landforms (e.g., individual craters, massifs, pits, valleys, etc.), hosting tens of thousands of individual gullies [Fig. 1]. This data confirms that gullies are confined to ~27–83°S and ~28–72°N and span all longitudes. Gullies are found at elevations from -7500 m to +5700 m, with a strong preference for the -500 m to +2500 m range. This range is expanded relative to the MOC NA-based surveys of Heldmann and Mellon [8] and Heldmann et al. [9], although the elevation range preference is relatively consistent. Only 5 occurrences

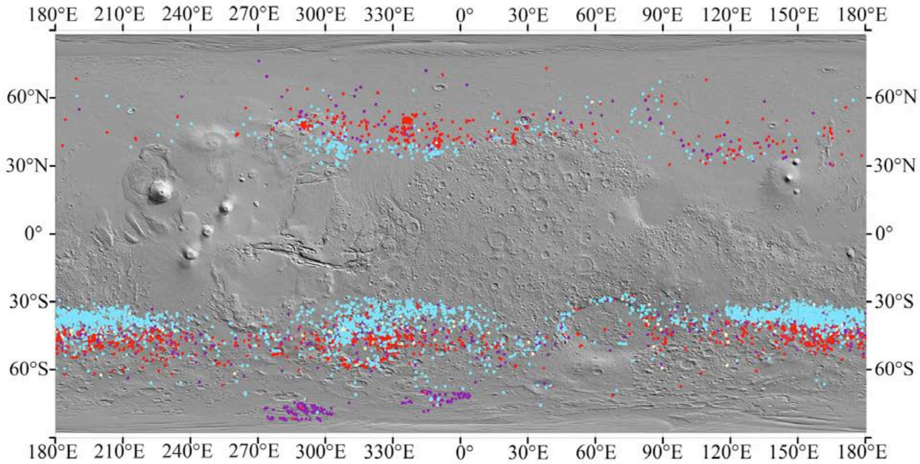

Figure 1. Global distribution of gullied landforms as mapped using MRO CTX data through mission phase D09 (February 2013). Colors indicate orientation preference at each landform. Blue = poleward-facing, yellow = east/west, red = equatorward, purple = no preference.
Basemap image credit: NASA/JPL-Caltech/MSSS

of gullies at elevations above 4000 m and one lower than -7000 m were observed.

Regional clusters of gullied landforms are observed in both hemispheres. In the southern hemisphere, three distinct peaks in gully density (number of gullied landforms per unit area) are observed: central-eastern Terra Cimmeria/western Terra Sirenum (peaking near Gorgonum Chaos), in the vicinity of 36°S, 204°W in Terra Cimmeria, and the Argyre rim complex (Nereidum and Charitum Montes). These clusters are consistent with the results of Balme et al. [11], although the cluster at Gorgonum Chaos is more prominent in the CTX mapping results.

In the northern hemisphere, regional clustering of gullies is observed in Tempe Terra near the boundary with Acidalia Planitia, the fretted terrain along the dichotomy boundary, and Acidalia and Utopia Planitiae. A relative lack of gullies is observed in the northern high latitudes (>55°N), on the southern flanks of Alba Patera, and in the areas of Tempe and Arabia Terrae north of 30°N until reaching the boundary with Acidalia and the fretted terrain, respectively. The decrease in gully density in both hemispheres roughly correlates with the lowest latitudinal extent of subdued ("basketball") terrain as mapped by Kreslavsky and Head [14], neglecting the effects of the steep mountain slopes of the Argyre rim complex.

A clear transition in dominant gully orientation is observed in the southern hemisphere, moving from poleward-facing preference in the lower mid-latitudes to equator-facing at ~45°S. The only exception is the highest latitude occurrence of gullies, in the south polar pits of Sisyphi Cavi and Cavi Angusti, which show no orientation preference. The transition of pole-facing to equator-facing preference with increasing latitude is also roughly observed in the northern hemisphere, most clearly in Acidalia, at ~40°N. Poleward of 50°N, no dominant orientation preference is observed. These observations in both hemispheres are broadly consistent with previous studies utilizing less areally extensive coverage [8–12].

Implications: We suggest that the latitudinal distribution and shift in orientation preference with increasing latitude point towards insolation and atmospheric conditions (temperature, pressure, etc.) playing key roles in martian gully formation. The morphology of many gully channels (banked/sinuous channels, terraces, streamlined features in some examples, occurrence on angles well below the angle of repose [e.g., 1,8,17]) requires formation by a process other than dry granular flow. These results are most consistent with melting of either snowpacks or near-surface ground ice as the source of water for gully formation; further study is planned to determine if evidence can be found to favor one water source over the other.

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