NERC Geophysical Equipment Facility Project 871 – Scientific Report

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Water Flows on Mars: a laboratory, field and image-based approach

Abstract

The loan of three differential Leica System 1200 GPS from NERC GEF was used to facilitate the collection of long profile and cross profile data of gullies formed by ephemeral water flow in La Gomera, Canary Islands, Spain. This data provided long profile data to compare to other gully systems with different formation processes on Earth and to gullies on Mars where the formation process is under current debate. Three gullies were surveyed and over 1500 points collected. The majority of the points had better accuracy than the inherent terrain roughness (10-25cm) in both the vertical and horizontal. The profile data suggest gullies in La Gomera are more similar to gullies on Mars than debris flow gullies on Earth. Isopach maps were generated from the data to assess the effect of channel slope on the volume of erosion and deposition. Analysis of the isopach data reveals a more complex relationship between erosion and slope than that revealed by similar analysis of debris flow gullies in Iceland. However the saw-tooth slope profile exhibited by gullies in La Gomera could provide a diagnostic feature to look for on Mars.

Background

Gullies on Mars are kilometre-scale features, which have an alcove, channel and debris apron structure (Figure 1). They are known to be geologically recent, with <1.25Ma being the current estimate [1] and they are potentially active under present day conditions [2]. Current temperatures and pressures on Mars mean that liquid water is unstable, so the presence of these gullies, which resemble fluvial-like features on Earth, presents an apparent paradox.

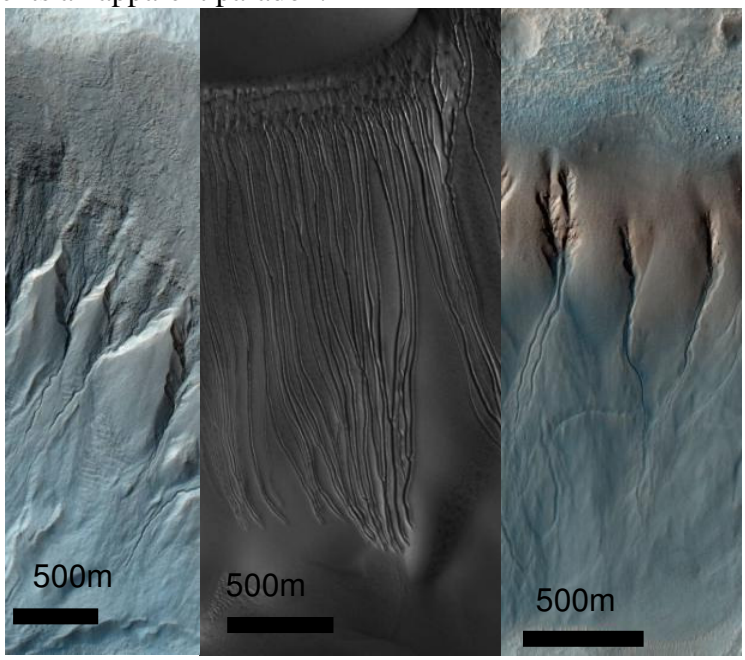

Figure 1: Example images of gullies on Mars. Image credit: HiRISE team.

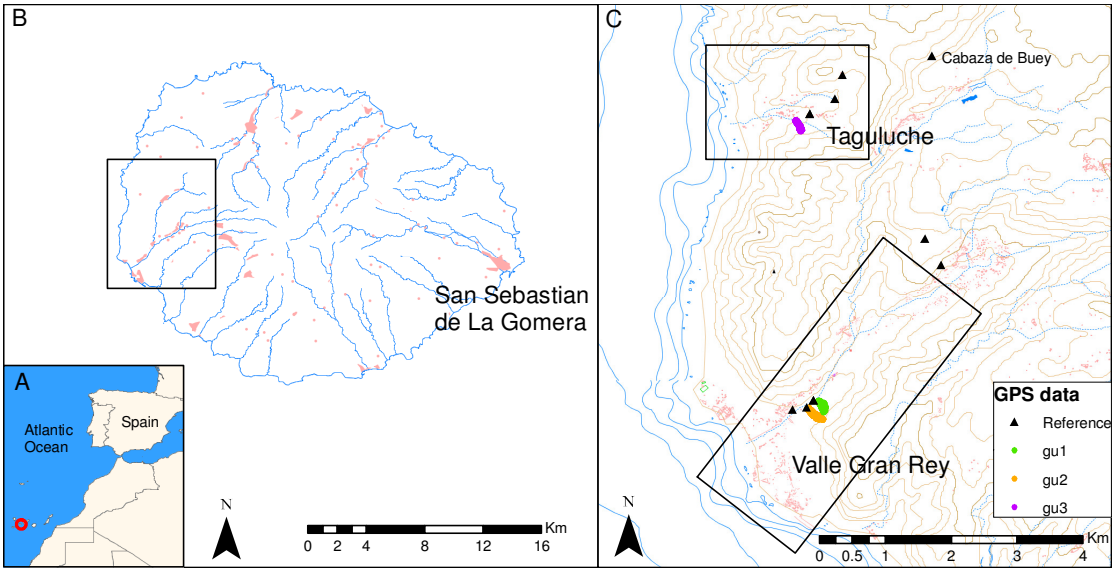

Figure 2: (A) Red dot marks La Gomera in the Canary Islands, (B) Map of La Gomera, showing hydrology and major settlements, (C) larger scale of highlighted inset in B, showing the two field areas, with 100m contours and location of measured GPS data. Base map data from Infraestructura de Datos Espaciales de España.

Differential GPS were requested from NERC GEF to facilitate the surveying of long profiles and cross profiles of gullies in La Gomera in the Canary Islands. This work was done in collaboration with Alvaro Marquez of Grupo de Geología at ESCET, University Rey Juan Carlos who first noticed the similarity between gullies in La Gomera and those on Mars [3].Comparisons between long profiles of gullies on Earth and Mars has not been done before, due to the lack of high resolution elevation data on Mars. As this has now become available through stereo-photogrammetry using HiRISE images [4], we have chosen several sites on Earth with gullies formed by different processes to compare to Mars, where the process of gully formation is debated. Our study aims to distinguish between debris flow, alluvial, aquifer-sourced, and grain-flow gully systems using morphometric measurements and then apply this to gullies on Mars. The gullies on La Gomera represent the alluvial end-member; they are formed by ephemeral water flow in calcrete cemented talus cones.

Figure 3: GPS rover surveying set-up, author on left, Alvaro Marquez, right.

Survey Procedure

Three gullies were surveyed in La Gomera, two located in Valle Gran Rey and one near to the village of Tagaluche (Figure 2). Three Leica System 1200 differential GPS were used. For each gully a base station was set up near to the site. The base station and rovers were used in RTK (Real Time Kinematic) mode allowing the corrections from the base station to be radio-transmitted to the rovers. We took long profile and cross profile measurements using two roving GPS units every meter, with the antenna mounted on the operator's

helmets (Figure 3). This allowed the use of both hands while traversing the difficult terrain and protected the antenna from damage if the operator was to fall. Each operator had personalised template files, which set the moving and stationary antenna height to that particular for each person. The operator stopped surveying if the accuracy of the point was above 0.25m (~GDOP 5). Each operator stood still to collect at least 3 epochs of data for every point surveyed (with a one second recording rate), and more if the indicated accuracy was low. Each gully took approximately one day to complete with the collection of 373-715 points. At the end of each day the data were downloaded to Leica GeoOffice and post-processed. Any low quality or missing data were re-surveyed on the next day. In addition the equipment was used to provide six ground control points (marked as 'Reference' on Figure 2) enabling the georeferencing of base maps and satellite images.

Data Quality

In total 1717 good quality data points were collected, with an average vertical error of < 0.061 m and horizontal of 0.070-0.040 m. This is below the inherent error introduced by the terrain roughness and the mounting of the antenna. 145 points had a standard deviation over 0.5 m in any of the X, Y or Z directions, but this was only 8.4% of the total number of points collected (and the majority of these were re-surveyed). A summary of the points collected and associated errors is given in Table 1.

Date	Gully ID	Oper -ator	Height - Z (m)			Horizontal – X (m)			Horizontal – Y (m)			Count
			Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	
29/05/2008	gu1	AM	0.007	0.001	0.022	0.008	0.002	0.026	0.004	0.001	0.022	281
29/05/2008	gu1	SJC	0.005	0.001	0.012	0.005	0.002	0.017	0.003	0.001	0.008	154
30/05/2008	gu2	AM	0.140	0.002	1.372	0.155	0.002	1.302	0.096	0.001	1.300	404
30/05/2008	gu2	SJC	0.090	0.001	1.438	0.119	0.001	0.873	0.063	0.001	0.973	311
31/05/2008	gu3	AM	0.027	0.008	0.453	0.033	0.009	0.666	0.017	0.005	0.239	194
31/05/2008	gu3	SJC	0.004	0.002	0.013	0.006	0.002	0.028	0.003	0.001	0.011	179
01/06/2008	gu3	AM	0.007	0.003	0.037	0.007	0.003	0.039	0.003	0.001	0.015	105
01/06/2008	gu3	SJC	0.120	0.003	2.042	0.108	0.003	1.287	0.061	0.001	0.954	89

Table 1: Summary of GPS data points collected with vertical and horizontal errors.

Processing and modelling

The cross sections and long sections have been used for direct comparison to similar measurements made by point-photogrammetry [5] on Mars and other locations on Earth. For the long profiles we compared: the overall and section (alcove, channel, debris apron) lengths, slopes and curvatures. For La Gomera we also used a 10m digital elevation model to extend the surveyed long profiles and to add additional low resolution profiles (not surveyed due to time and/or accessibility).

For two of the surveyed gullies the measured gully topography was subtracted from the estimated pre-gully topography make isopach maps. The pre-gully topography was estimated by linear interpolation between the two sides of the gully. The gully topography was estimated using Krige interpolation method provided within the Geostatistical Analyst extension of ESRI ArcGIS. This method was used as it can take into account the asymmetry of the feature and the asymmetry of the data collection and in addition provides an estimate of the error associated with the resulting interpolated map. The isopach maps were used to provide an indication of

the quantity of material removed whilst forming the gully and to analyse the associations between the long and slope profiles and the gully erosion.

Interpretation & Preliminary findings

An example of the data extracted from the profiles is given in Figure 4, where gully length is plotted against curvature. The gullies on La Gomera are spread over a large range and about half of the data-points plot within the Martian gully data and Death Valley gully data. La Gomera and Death Valley represent ephemeral alluvial systems and plot away from the debris flow systems of Colorado Front Range and Icelandic Westfjords. These initial results suggest that gullies on Mars could be formed by ephemeral alluvial systems rather than debris flow.

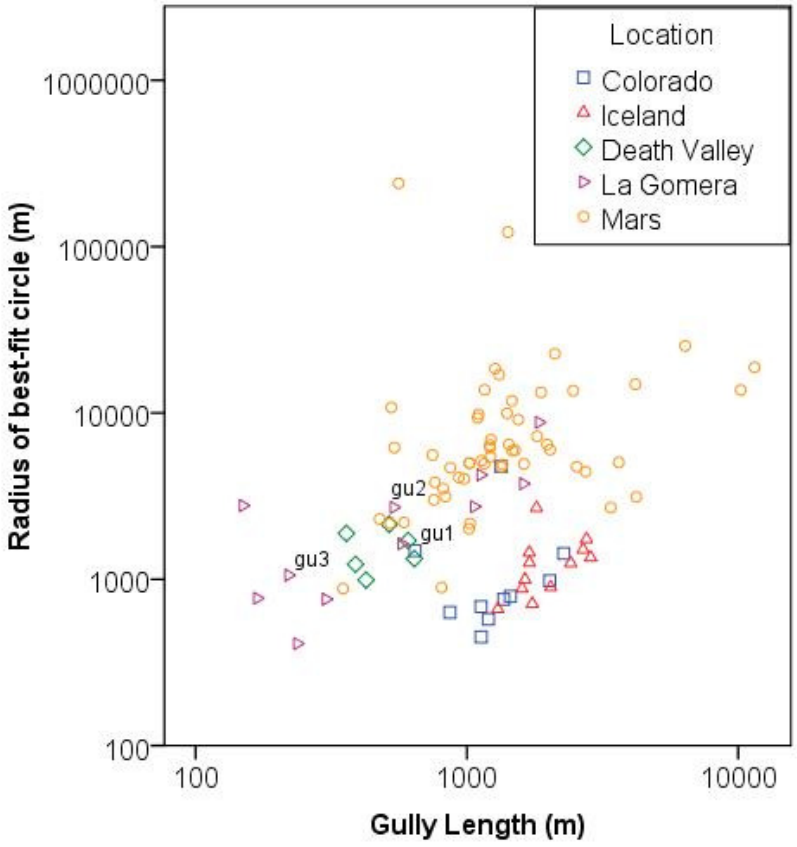

Figure 4: Gully length against curvature (the greater the radius of best-fit circle, the less the curvature) for debris flow gullies (Colorado and Iceland), ephemeral alluvial gullies (La Gomera and Death Valley) and for gullies on Mars. Gullies surveyed by GPS on La Gomera are labelled.

The relationship between slope and erosion in the La Gomera gullies is unclear, unlike the debris flow gullies that we studied in Iceland [6], where there is a distinct relationship between slope and erosion/deposition. As an example, Figure 5 shows the isopach map for gully gu3 plotted with its long profile and slope data. The total erosion calculated from this plot is approximately 7000 m^3. The dips in slope, marked I-IV correspond to both high erosion and low erosion reaches, unlike in Iceland where we found dips in slope corresponded with deposition or low erosion. However the saw-tooth pattern in the slope-data is distinctive to this type of gully. This may be a good indicator to look for when studying gullies on Mars. Gullies in La

Gomera are primarily square in cross section, which from the limited data we have for gullies on Mars seems a good fit.

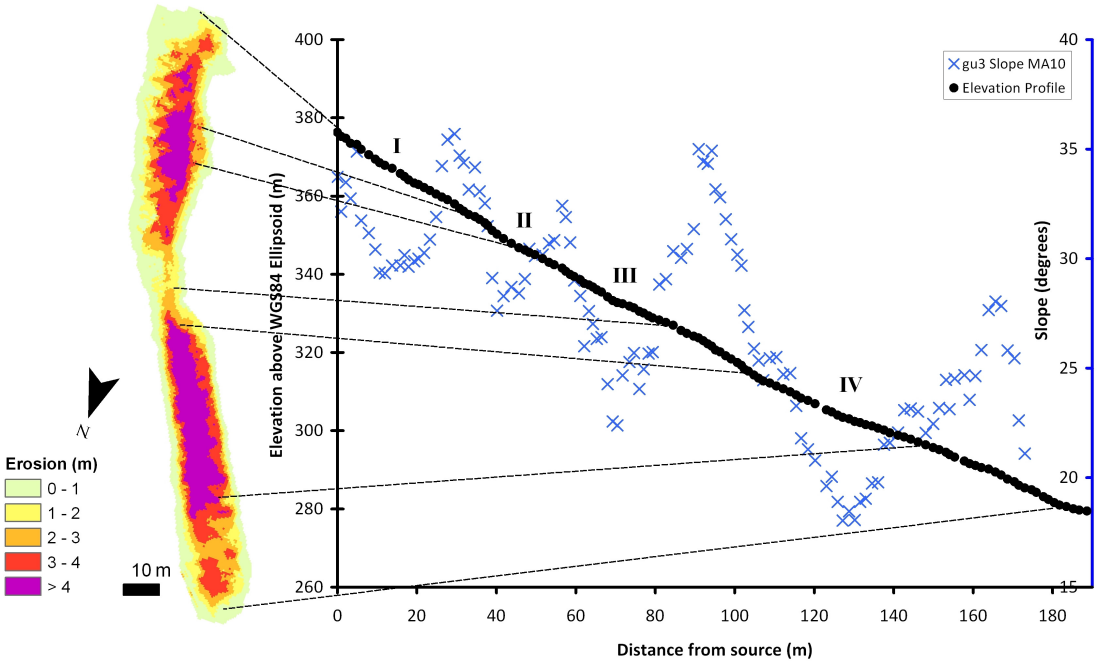

Figure 5: Isopach map of gu3 with associated elevation and slope profiles. The slope profile has been derived from the 10-step moving average of the raw slope data to reduce noise.

Conclusions and Recommendations

The gullies studied in La Gomera provide a good match in terms of their long profiles to gullies on Mars. This suggests an ephemeral alluvial process may be more appropriate as a formation mechanism for martian gullies. GPS surveying presents a quick and accurate method of obtaining long profiles and cross profiles of gullies. This enables both the estimation of erosion and deposition volumes as well as the accurate determination of reach elevation and slope profiles. The adaptations we made to the GPS rover equipment deployment in this survey provide a safe data collection technique in difficult terrain. The Real Time Kinetic approach used in this study offers several advantages: a real-time estimation of accuracy in centimetres and the ability in the field to approximately locate points without post-processing.

Publications

Conway S. J., Balme M. R., Murray J. B. and Towner M. C. (2009) Comparison of gully long profiles on Earth and Mars *Icarus* (in preparation)

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[2] Malin M. C. et al. (2006) *Science, 314*, 1573-1577.
[3] Marquez A. et al. (2005) *Icarus, 179*, 398-414.
[4] Kirk R. L. et al. (2008) *Journal of Geophysical Research (Planets), 113*,
[5] Kreslavsky M. A. (2008) *Workshop on Martian Gullies 2008, 1303*, 54-55.
[6] Conway S. J. et al. (2009) *Geophysical Research Abstracts, 11*, EGU2009-5189