GEOMORPHIC AND FLOW ANALYSIS FOR GULLIES IN PALIKIR CRATER. C. A. Narlesky[1] and V. C. Gulick[2], [1]MBK Engineers (1771 Tribute Road, Sacramento, CA 95815; narlesky@mbkengineers.com), [2]NASA Ames/SETI Institute, NASA Ames Research Center (MS 239-20, Moffet Field, Moffett Field, CA 94035; virginia.c.gulick@nasa.arc.gov).

Introduction: Understanding the quantities and flow frequencies necessary for gully formation on Mars is essential in developing a detailed picture of past Martian climates. Malin and Edgett describe three distinct structural features: the alcove, or source region; main gully chute; and debris apron, or depositional region [1]. Though liquid water is unstable at the current average temperature and atmospheric pressure on Mars, it has been hypothesized that a super concentrated brine solution may be stable enough to flow on or just below the Martian surface [2]. A subsurface ice deposit or confined aquifer could also potentially provide source waters to drive the excavation of Martian gullies. A conceptual model for gully formation based on fluvial activity is presented in [3]. We present geomorphic analysis of 17 gullies in Palikir Crater to support the hypothesis of fluvial origins and compare a variety of methods for estimating the flows that excavated these features.

This study focuses on the extensive gully system in Palikir Crater (-41.5ºN, 202.2º E), a ~15km diameter impact crater located in the larger Newton Crater basin. Palikir Crater is a confirmed site for Recurring Slope Lineae (RSL), another feature thought to be caused by super-concentrated brine flows [4].

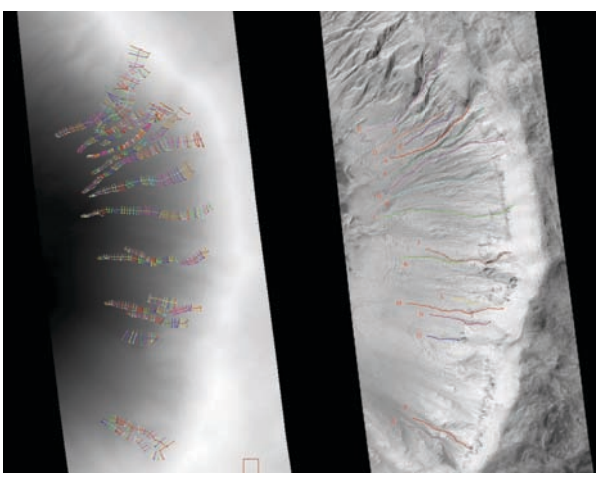

Figure 1: 17 Gullies in Palikir Crater. DTM (left) and Orthoimage Representation (right)

Methodology: We selected 17 gullies in the western crater wall, ranging from young to highly-developed systems. Each gully shows a likely origin point just below the crater rim; older gullies have eroded into the crater rim and have exposed bedrock. We used High-resolution stereo images acquired by the HiRISE camera on the Mars Reconnaissance Orbiter (PSP_005943_1380 and ESP_011428_1380) to examine the Palikir Crater and the corresponding digital elevation model produced by the HiRISE team to estimate flow velocities and calculate a number of geomorphic quantities pertinent to a fluvial model for the origin of the Palikir Crater gullies.

Palikir gully topography was analyzed using the HiRISE digital elevation model and ENVI (the ENvironment for Visualizing Images) GIS software. Evenly-spaced transects were sampled along the length of each gully. Measurement tools in ENVI were used to record downstream reach lengths, drainage areas, debris apron characteristics, and representative meander wavelengths for the gullies. We processed this data in a Python environment to produce estimates for transect cross-sectional areas, gully slope, concavity, sinuosity, and volume deposited. We calculated gully excavated volume by numerically integrating over the transect areas along the length of each gully.

We estimated flow velocities using a suite of methods that explicitly depend on gravity as in [5], ensuring applicability to Martian conditions. We used the Ikeda [6], Kleinhans [7], and Wilson [8] equations and also compared this to a scaled version of the Manning estimate nondimensionalized for gravity as in [9].

For [7,8] the width-averaged velocity is estimated using the Darcy-Weisbach equation:

$$U = (8\, ghS / f)^{1/2} \qquad (1)$$

Where g is 3.74 m/s^2, the Martian gravitational acceleration, h is the characteristic depth in m, S is the slope, and f is a friction factor based on channel roughness and grainsize.

As in [5], we also applied the Ikeda method, which relates the channel meander wavelength in m, λ, to the Froude number, Fr, and the friction factor C_f. We obtained a solution for U_I using iteration.

An important assumption in our calculations was the designation of a representative flow depth, which we calculated as the difference between the elevation of the lowest visible terrace and the channel thalweg at a given transect. This assumes bankfull flow, and yielded an average flow depth of 1.9 m, with a minimum and maximum flow depths of 1.0 m and 2.7 m respectively across all 17 gullies. Additional assumptions for flow and transport estimations included a vis-

cosity of $1.67*10^{-6}$, specific gravity of sediment set at 3.4 (assumed for Martian basalt), and a median grain size [4]. We assumed a sediment distribution based on data from [7,8]. A typical gully alcove in the Palikir system exposes a ridge of bedrock near the crater rim. Traditionally, erosion into the bedrock implies continuous erosive processes over extended periods of time. We assumed sediments overlaying the bedrock to be unconsolidated and noncohesive for modeling purposes.

Results: Longitudinal profiles for the 17 chosen gullies clearly indicate a concave-up shape, which is consistent with a fluvial origin [10]. Gully slopes are typically steepest in the alcove region, averaging approximately 20.0º , with average chute slopes of 16.4º.

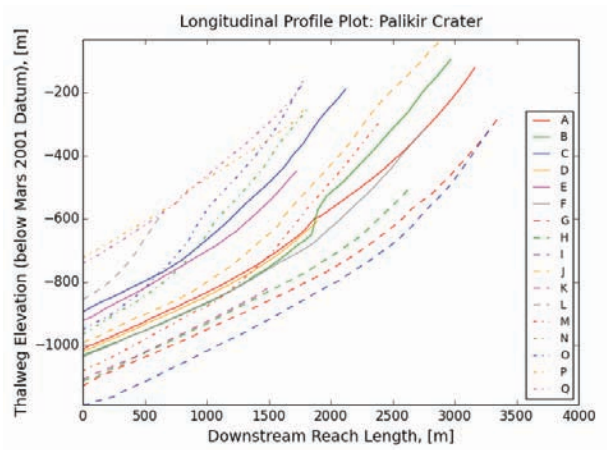

Figure 2: Gully Longitudinal Profiles

Velocities calculated using Ikeda's equation [6] and an average wavelength of 64.3 m ranged from 0.71 to 1.53 m/s. At these magnitudes, the model is suboptimal because flows are subcritical. Given the relatively low average sinuosity of the gully channels, which ranged from 1.0 to 1.2, it is concluded that flow measurement based on channel wavelength is not the best method for Palikir.

More consistent results were achieved using the formulas described in Kleinhans and Wilson [7,8]. Assuming a sandy or gravel-filled channel, the flows ranged from 2.3 to 16.9 m/s. The following table summarizes velocities calculated in this study.

Table 1: Summary of Velocity Calculations, m/s

Model	Min	Max	Std. Dev.	Mean
Manning	6.31	15.25	2.16	8.58
Ikeda	0.71	1.53	0.19	1.01
Wilson (sand)	13.31	20.16	1.87	16.57
Wilson (gravel)	10.33	15.65	1.45	2.86
Kleinhans	2.30	2.75	0.12	2.50
White-Colbrook	10.32	16.92	1.79	13.82

Palikir Crater gullies are similar in size to gullies on Lyot Crater's central peak ($12*10^6$ m^3). Meander wavelengths, gully alcove and chute slopes, and flow estimates fall into similar ranges [5,12], making this an ideal location for future comparison studies so that the effects of variables such as latitude and sun exposure can be quanitfied.

The determination of flow depth and rate allows the further estimation of sediment transport capacity in the gully channels. We assumed that sediment load is primarily bedload and used a formula adapted to steep slopes [11], which yielded an average sediment transport rate of 0.012 m^3/s per unit width. Given an average gully volume of $2.6*10^6$ m^3 (max $12*10^6$ m^3), the timescale of formation can be estimated using the ratio of volume divided by transport rate. The resulting timescale is up to 15 years of continuous scour for the largest gullies. However, given the unfavorable conditions for stable water on the Martian surface, erosion of these gullies was intermittent, at best. Despite the difficulties inherent in remotely measuring the channel geometry and sediment composition of Martian gullies, the data is consistent with the fluvial origin hypothesis.

Summary: We present flow and initial transport estimates for 17 gullies in Palikir Crater assuming fluvial origins in addition to detailed analysis of geomorphic features using high-resolutuion profile data. We analyzed a digital terrain model synthesized from HiRISE images and observed eroded bedrock and fluvial features such as sinuous channels, levee deposits, and terracing within all 17 gully channels. We calculated average slopes of 16.4º for gully chutes and 20.0º for alcoves, though alcove slopes reached up to 28.1º. Flow estimates based on assumed roughness parameters and grainsize distribution resulted in a range of 2.3 to 16.9 m/s. The average sediment transport rate was calculated at 0.012 m^2/s. Future studies will use these results to constrain hypotheses on source regions for flows in Palikir Crater.

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