COMPUTATIONAL ANALYSIS OF DRAINAGE BASINS ON MARS: APPRAISING THE DRAINAGE DENSITY.

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Abstract. We have computationally extracted 26 Martian drainage basins from the dissected Noachian surfaces using digital topography data. The basins have been reconstructed and their drainage networks have been delineated by a computer algorithm. Summary of values for major properties characterizing the basins and their networks are given. A typical value of drainage density, calculated for individual basins, is $D = 0.1$ km^{-1}. We argue that these, relatively high, values of D do not necessary imply past precipitation.

Introduction. Martian valley networks are geomorphic features, found on Noachian surfaces, that are visually reminiscent of terrestrial river systems. This visual resemblance gave rise to an early suggestion that Martian valley networks were sculpted by surface runoff erosion, a process requiring precipitation at the time of valley networks formations. However, further examination of imagery data revealed presence of morphometric features associated with erosion by groundwater sapping, a process that does not necessary require warmer climate. One property of dissected terrain that is thought to be able to diagnose the origin of valley networks is its drainage density, D. Low values of D are inconsistent with an origin by terrestrial-style surface runoff erosion. Estimation of D based on Viking imagery data (1) gave values of D in the range of 10^{-3} to 10^{-2} km^{-1}. Such values are low by terrestrial standards and have been interpreted as an argument against the runoff origin of valley networks. Recently (2), estimation of D based on combination of MGS images and MOLA digital topography gave the values of D approaching 10^{-1} km^{-1} for five Martian locations. The higher values of D have been attributed to higher data resolution. This result has been used (2) to argue for the runoff origin of the valley networks because these higher values of D are comparable to the low-end terrestrial values determined using a similar method (1).

We use a different approach to study Martian valley networks. Working exclusively with digital topography data we use computer algorithms to extract and analyze Martian drainage basins underlying visible valley networks. Using a computer algorithm a Martian terrain can be represented as a series of drainage basins, regardless of the historical presence or absence of actual fluid flow. Thus, our analysis does not presuppose the existence of precipitation. The emphasis here is on calculating values of D for 26 specific Martian drainage basins (this is a standard method of calculating D in terrestrial hydrology). In contrast, all previous estimates of D on Mars pertained to an arbitrary area and not to an isolated drainage.

Data. We have selected 26 Martian locations from the Npld geological unit to extract and analyze drainage basins. The names and coordinates of these locations are given in Fig. 2. The input data for our analysis is a digital elevation model (DEM) constructed from the MOLA global topographic model grid, which has a resolution of 1/128 degree in both latitude and longitude. The finite resolution of the grid results in an upper bound on the value of drainage density that we can find, $D_{max} = 2$ km^{-1}.

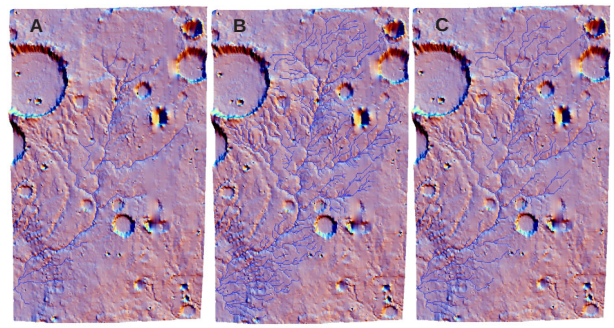

Figure 1: Visual rendering of the landscape from a DEM at Millochou E location. Blue lines indicate extracted channel network using A) arbitrary value of $A_{th} = 1000$ pixels, B) arbitrary value of $A_{th} = 30$ pixels, C) value of $A_{th} = 130$ pixels established from the constant drop property for streams.

Methods. Our procedure consists of two steps, extracting and reconstructing a drainage basin from a DEM and then analyzing it, including computing the value of D.

A drainage basin is extracted from a DEM using an algorithm developed for studies of terrestrial river basins (3). In the first step (referred to as “flooding") the algorithm modifies the original elevation field in order to make it drainable. This step is very important in the context of Martian terrain. Not flooding a typical Npld terrain produces unrealistically small basins, because, due to the presence of craters, unadjusted Npld topography breaks into a large number of very small drainage basins, majority of them internal. Complete flooding of a typical Npld terrain produces large basins, but incurred properties of such basins are skewed by the fact that basins embody large, artificial lakes (flooded craters). A reconstruction is a process to flood these craters that prevents continuity of a basin, but to exclude large craters from being incorporated into a basin. It is an attempt to reproduce a primary drainage basin before it was contaminated by posterior cratering. In the second step, each site is assigned a drainage pointer to a neighboring site in the direction of the steepest slope. In the third step, the total contributing area, A, is calculated for each site. This quantity is the total number of sites draining through a given site, an area (in pixel units) of a drainage basin culminating at a given site. The contributing area at the outlet, A_{out} is the total area of the basin.

A drainage network is this part of a drainage basin where the flow is concentrated, or channelized. A given site is a part of a channel if $A \geq A_{th}$. Thus, a value of a threshold, A_{th} controls extent of the network and sets the drainage density

LOCATION				BASIN			NETWORK			
#	name	longitude (E)	latitude	basin area (km^2)	% of pixels flooded	mean flood (m)	A_{th}	# of links	Ω	drainage density (km^{-1})
1	Pollack	31.3	-8.9	11213	13	29	150	161	5	0.12
2	Verde Vallis	30.2	-2.5	19503	16	27	225	175	4	0.1
3	Evros Vallis W	14.4	-13.	33434	17	35	375	193	4	0.08
4	Mosa Vallis S	22.05	-15.25	22611	23	32	175	253	5	0.11
5	Mosa Vallis N	24.4	-13.2	28858	18	24	210	313	5	0.1
6	Tisia Valles W	49.4	-11.6	19874	18	32	123	345	5	0.13
7	Dawes E	45.2	-5.8	35864	20	28	275	277	5	0.09
8	Dawes W	42.	-7.65	18788	13	25	200	163	5	0.1
9	Liris Valles N	56.	-5.9	6624	11	23	60	219	4	0.18
10	Naro Vallis	61.3	-4.6	29668	22	44	200	309	5	0.1
11	Millochou W	88.2	-20.15	59787	18	39	650	185	4	0.06
12	Millochou E	93.9	-23.	12800	9	15	130	215	4	0.15
13	Graff	149.	-15.	18383	16	26	225	79	4	0.08
14	Evros Vallis N	15.1	-8.3	48561	14	26	250	391	5	0.1
15	Arda Valles	-32.35	-20.8	15749	15	31	270	125	4	0.1
16	Galu	-21.55	-22.8	3448	9	27	49	157	4	0.22
17	Millochou S	88.	-23.	12552	11	42	350	75	4	0.09
18	Douglass	-76.5	-48.	12909	13	14	375	59	4	0.09
19	Molesworth NW	144.	-23.5	8482	16	15	100	177	5	0.15
20	Hadley	158.5	-20.	15441	12	23	500	63	4	0.07
21	Hadley N	155.	-14.5	9567	8	14	163	121	4	0.12
22	JarryDesloges	83.	-7.5	19000	13	27	215	197	5	0.1
23	Tagus Valles	115.	-7.	7197	10	19	225	71	4	0.11
24	Huygens	65.	-18.	26675	11	44	181	337	5	0.11
25	Warrego Valles	-93.	-42.	17918	4	14	375	101	4	0.1
26	Maadim V. Trib	174.	-24.3	11590	13	23	200	119	4	0.11

Figure 2: Table summarizing properties of Martian basins and their drainage networks.

of the basin. We calculate A_{th} objectively, using the constant drop property for streams (4). Fig. 1 illustrates importance of choosing the right value of A_{th}. (A) Using large, arbitrarily chosen value of $A_{th} = 1000$ pixels results in under-extracted network and too small value of $D = 0.05$ km^{-1}. (B) Using small, arbitrarily chosen value of $A_{th} = 30$ pixels results in over-extracted network and too large value of $D = 0.27$ km^{-1}. (C) Using $A_{th} = 130$ pixels, as calculated from the constant drop criterion, we obtain a satisfactory extraction and $D = 0.15$ km^{-1}.

Results. Our results are summarized in the Fig. 2. The first four columns describe selected locations. The name in the column 2 is the name of a nearest prominent landscape feature. Coordinates in columns 3 and 4 are those of the center of a DEM. Columns 5 to 7 describe a basin. In particular, column 6 shows that up to a quarter of the pixels require some degree of flooding in order to obtain continuous drainage. For comparison, a typical terrestrial DEM requires flooding to $< 5\%$ of pixels. Column 7 gives an average amount of flooding to be compared to a typical terrestrial average flood of ~ 10 m. Last four columns give properties of channel networks, constant drop extraction threshold, A_{th}, number of links, network order, Ω, and the drainage density, D, respectively.

Conclusions. Using digital topography and applying automated technique, Martian drainage basins and their constituent drainage networks can be rapidly acquired and their properties can be quantitatively analyzed. A proper appraisal of the drainage density requires a correct choice of the network extraction threshold, A_{th}. A weak dependence of D on A_{th}, $D \sim {A_{th}}^{-0.5}$, (see examples on Fig. 1) alleviates somewhat this problem, a rough estimate of A_{th} produces a reasonable estimate of D. Using the constant drop criterion for A_{th} yields values of D that are of the order of 0.1 km^{-1}. These values are not influenced by a coarse resolution of the DEM as they are an order of magnitude smaller than D_{max}. Numerically, our appraisal of Martian drainage density is in agreement with Hynek and Phillips (2) estimates obtained using MGS imagery data. However, note that whereas our values of D pertain to specific basins, their values pertain to arbitrary areas.

We argue that $D \sim 0.1$ km^{-1} found for Martian valley networks does not necessary imply their origin by terrestrial-style surface runoff. First, terrestrial values of D, when calculated for individual basins, are in the range of $1 - -10^2$ km^{-1} (5). Second, drainage density alone is not a sufficient tool to diagnose an origin of valley networks, although low values of D preclude surface runoff, relatively high values of D do not prove it. Third, other properties of Martian drainage basins (see Stepinski and Coradetti abstract) seem inconsistent with terrestrial-style surface runoff.

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