AGE CONSTRAINTS ON MARTIAN VALLEY NETWORKS FROM BUFFERED CRATER COUNTING.

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Introduction: Valley networks on Mars are mostly found in the cratered highland terrain which dates from the earliest (Noachian) period of Mars' history [e.g., 1]. Thus, these features are commonly invoked as geomorphological evidence for an early surface environment differing from that of today [2], although their implications for climate has continued to be controversial [see e.g., 3]. Because the process of valley network formation is important for understanding surface conditions of the early planet, there has long been substantial interest in constraining when valleys were active and when the transition occurred from a "valley network-forming" Mars to the Mars we see today [e.g., 4, 5].

To date, the primary constraint which has been utilized for determining the period when valley networks were active has been superposition relationships: for a terrain transected by valleys, a determination is made of its crater population. This has the advantage of allowing for a crater count over a much wider area than is traversed by a given valley itself, but has the disadvantage that it typically will provide only an upper limit for the activity of a valley. In other words, a valley network found cutting across mid-Noachian terrain is only constrained to be post-mid-Noachian. The global distribution of valley networks and their commonality only on Noachian surfaces has led most workers to the intepretation that valleys are old (earliest Hesperian or Noachian) [1], with a few possible exceptions of valleys on a few volcanoes and on plateau surfaces around Valles Marineris [6,7]. However, others have disagreed with this general view [8], pointing to the fact that some valleys in the highlands appear to cross into units mapped as Hesperian or even Amazonian, and certain valleys appear fresher than others. Thus, we have attempted to derive direct constraints on the superposed crater populations of individual valley systems.

Methodology: Crater counting typically relies on the assessment of the number of superposed craters on a given mapped unit emplaced over a short period of time [e.g., 9, 10]. The difficulty in directly applying a straightforward crater counting approach to valley networks has been the fact that valleys have minimal surface areas. Small craters superposed on valley floors are also particularly easy to remove by mass wasting and aeolian processes. Thus, counts on valley floors will typically yield much younger model ages than counts on the surrounding terrains using larger craters.

We have therefore taken a different approach, aiming to utilize the fact that large craters subtend a much larger potential area than small ones. We have chosen to count around valleys in a series of buffers (Fig. 1), as has been attempted before for other planetary surface features [e.g., 11]. We first map the valley we wish to examine, and then find all craters clearly superposed upon the mapped valley. For each crater (and its ejecta), a stratigraphic judgment is required, and we assume that any topographic barrier (e.g., a crater rim or its ejecta) which crosses a valley must have formed after valley activity ceased. Because only craters which are clearly superposed on valleys are included, our results should be a robust lower limit for a valley's last activity.

For a given crater size D, we count in a buffer of size 1.5D from each valley side (assuming that it is possible to determine stratigraphic relationships for craters within one crater diameter of the valley walls). The total count area A we use for a linear segment of a valley (length L) as a function of crater diameter D is $A(D)= (3D+W_v)L$, where W_v is the total valley width. Appropriate count areas were computed for a given crater size by applying the ArcMap buffer function to mapped valley shapes.

Results: Counts have been completed on 21 valley network systems (Table 1), covering a broad sample of those on the planet and including valleys which have been considered especially strong candidates for being young [6,7,8]. Our work show that valleys commonly are dated to near the Noachian-Hesperian boundary, implying that almost all valley networks on Mars ceased activity about this time with only a few exceptions. Where valleys cross unit boundaries into regions mapped as Hesperian or Amazonian [8], we find little evidence that the valleys themselves are especially youthful. The cause of this interpretation [8] may have been difficulty in precise unit boundary location, as well as the fact that some valleys may been seen through thin superposed later units.

Our results imply that across the highlands, valley formation ceased by ~3.7 Gy (in the Neukum absolute age system from [9]) or ~3.5 Gy (using the Hartmann age system [10]), which is consistent with a global shift in environmental conditions between the period before and after the Early Hesperian.

A few of the valley systems that have been considered candidates for comparatively recent activity do appear to be younger (Table 1). In each case, these valley networks are outside the highlands terrain where most valley networks are found. For example, we find that the small valleys on the volcanoes Ceraunius Tholus (Fig. 2) and Hecates Tholus both have crater populations appropriate for the Hesperian/Amazonian boundary, and the small valleys on the Valles Marineris plateau [7] have an Early Amazonian crater population using this technique. This emphasizes that valley formation persisted in special local environments beyond the time when it was an important global process.

References: [1] Carr, M.H. (1996) *Water on Mars.* [2] Craddock, R.A. and Howard, A.D. (2002) *JGR, 107,* 5111. [3] Gaidos, E. and Marion, G. (2003) *JGR, 108,* 5055. [4] Masursky, H. et al. (1977) *JGR, 82,* 4016-4038. [5] Pieri, D.C. (1980) *Geomorphology of Martian valleys,* NASA TM-81979, 1-160. [6] Gulick, V.C. and Baker, V.R. (1990) *JGR, 95,* 14,325-14,244. [7] Mangold, N. et al. (2004) *Science, 305,* 78-81. [8] Scott, D.H. et al. (1995) USGS Misc. Invest. Ser., Map I-2461. [9] Neukum, G. and Ivanov, B.A. (2001) *LPSC XXXII,* 1757. [10] Hartmann, W.K. (2005) *Icarus 174,* 294-320. [11] Namiki, N. and Solomon, S.C. (1994) *Science 265,* 929-933.

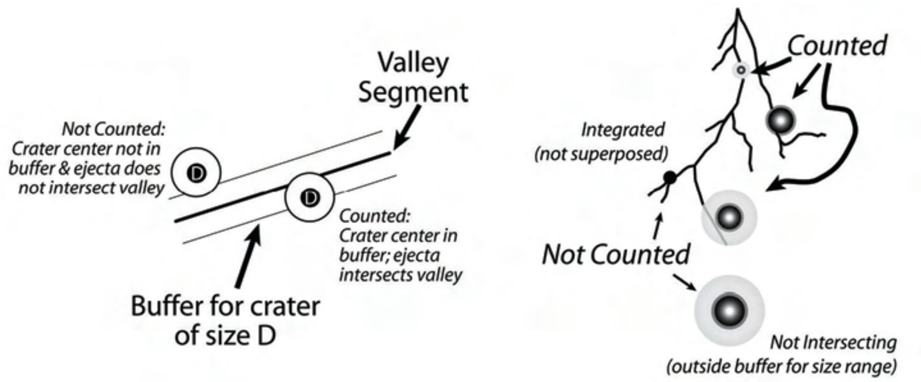

Figure 1. Schematic diagrams of how buffer counting was applied: all craters with centers inside a buffer defined for their size range and clearly superposed on a valley were counted.

Valley name or *approx. location*	$N(5)_{model}$	Neuk Age (Gy)	Hart Age (Gy)	Period
Licus Vallis	348	3.84	3.73	LN
123E, 0N	473	3.89	3.77	MN
131E, -8N	169	3.71	3.50	EH
155E, -12.5N	153	3.69	3.50	EH
Al-Qahira Vallis	310	3.82	3.71	LN
Evros Vallis	198	3.74	3.62	LN/EH
Meridiani: 0E, -5N	153	3.69	3.54	EH
-9E, -5N	232	3.77	3.67	LN
5E,-17N	309	3.82	3.69	LN
Naro Vallis	473	3.89	3.81	MN
Parana & connected	169	3.71	3.49	EH
-13E, -7N	220	3.76	3.61	LN
-7E, -16N	291	3.81	3.67	LN
Vichada Vallis	260	3.79	3.65	LN
Nanendi & conn.	232	3.77	3.59	LN
Nili Fos:77E, 18.5N	291	3.81	3.74	LN
Naktong/Scamander	160	3.70	3.50	EH
Hecates Tholus	107	3.61	2.26	LH
Ceraunius Tholus	82	3.54	2.96	EA
Echus Chasma	46	3.25	1.98	EA
Nirgal Vallis	67	3.47	3.07	EA

Table 1. Results for 21 valleys; note that no 'classical' highland valley has an age younger than the Early Hesperian.

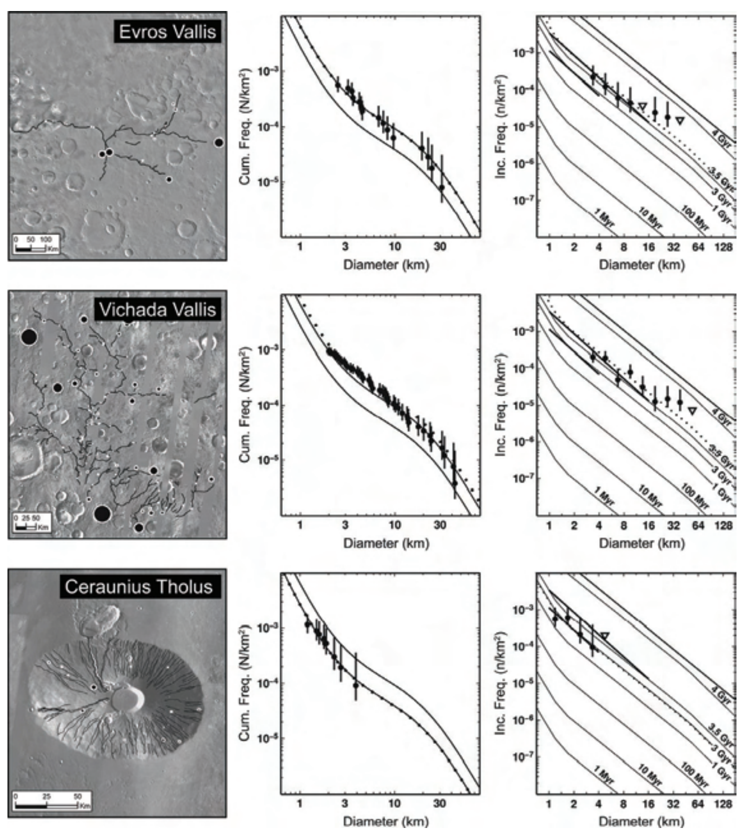

Figure 2. Crater Size-Frequency diagrams (cumulative & incremental) for Evros and Vichada Valles (LN/EH & LN) and Ceraunius Tholus valleys (LH/EA). Best fit function (dotted) in the cumulative plot is a Neukum production function [9]; in incremental diagram isochrons and best fit are from Hartmann's 2005 iteration [10]. Error bars in both plots are the 90% Poisson confidence region, and triangles are 90% confidence upper limits.