WARREGO VALLES REVISITED: VALLEY NETWORK FORMATION, MODIFICATION, AND CLIMATIC AND STRUCTURAL CONTROLS. S. C. Schon[1] and K. L. Tanaka[2], [1] *Department of Earth and Environmental Sciences, Columbia University, New York, NY 10027,* (scs2016@columbia.edu). [2] *U.S. Geological Survey, Flagstaff, AZ 86001,* (ktanaka@usgs.gov).

Introduction: This investigation focused on Warrego Valles, a region of well-developed valley systems located in Thaumasia Planum of the southern highlands at ~42°S, 267°E. Some previous workers interpreted the valley systems in this area as being of fluvial origin [1-3], while others focused on sapping [4-6] or hydrothermal activity [7-10] as formative mechanisms. It is clear that no single model can adequately elucidate the disparate valley system morphologies observed at Warrego Valles and many other sites on Mars, but rather that different processes predominated during multiple epochs and in various geologic settings with unique implications for Martian paleoclimate.

Review of Proposed Valley Formation Processes: The nomenclature has become a bit muddled, but in general "valley" only implies a topographic feature: an elongate low-lying area surrounded by higher terrain, while a "channel" typically refers to the bed of a stream; therefore, valleys *may* contain channels and channels *may* contain streams [2, 11].

Fluvial Systems. Run-off fed, high-density (km/km^2), dendritic networks epitomize fluvial systems on Earth. These systems originate with rills that feed into ephemeral gullies and then into perennial streams. Fluvial systems, which are characterized by numerous branching tributaries, yield higher Strahler orders than comparable sapped drainage systems. These systems cut distinctive V-shaped valley planforms that widen progressively downstream. The primary implication of fluvial systems of this type on Mars is abundant precipitation in the past—requiring a vastly different climate system than is observed today [3]. Some workers argue that a precipitative climate is not reconcilable with the asymmetric distribution of fluvial valley systems that is observed [8].

Groundwater Sapping. Sapping is an erosive, channel-forming process in which groundwater outflow (seepage) weakens valley head- and side-walls leading to collapse and retreat (primarily by removing basal material at the site of outflow). Sapping produces U-shaped valleys characterized by relatively constant widths and theater-style heads. On Earth, the influence of sapping in valley system formation is usually swamped by the predominating influence of runoff [12]. Some well-known examples are located in permeable sandstone formations overlying impermeable shales—conditions that favor the development of erosive seeps at the lithologic contacts. In particular, the Navajo Sandstone of the Colorado Plateau exhibits numerous sapping features, which have been studied as Mars analogs [6]. Because many Martian terrains are thought to be basaltic in origin, the less-analyzed Box Canyon in Idaho, which occurs in flood basalts and is described as an analog by Lamb and Dietrich, may be a superior comparison in these cases [13].

Geologic Setting and Channel Types: Fractured and dissected terrains as well as complicated tectonic structures and impact debris characterize the Warrego Valles region. These terrains are Early Noachian to Early Hesperian in age according to the published mapping of Dohm et al [14]. The primary features are a large impact structure and debris outflow in the northwest, branched valley networks in the central part of the region, sapped channels in the east-central portion, and regional fractures in the northeast, which exhibit structural control on sapping channel orientation.

Fluvial Valley Networks. The large valley networks in central Warrego Valles appear to be heavily modified fluvial systems; the gross morphology is similar to that observed in terrestrial fluvial systems. Dendritic networks with many high order tributaries and gradual widening of valleys in the downstream direction are observed. The highly branched structure of the systems provides strong evidence for a precipitation-dominated fluvial origin. While many tributaries head near the top of inter-valley highs, which is also indicative of a fluvial system, the fine rills that would feed into highest-order tributaries in terrestrial drainage networks are not observed, even in highest-resolution MOC images. This may be due to surficial erosion and modification in later epochs since most Martian valley networks are Noachian in age, > 3.5 Ga, including Warrego Valles [15-17]. For example, numerous MOC images provide evidence of eolian deflation and infilling as well as dune structures that could obscure fluvial rills. Further, impact gardening as described by Hartmann [18] could have reworked existing regolith and removed any evidence of rills. Also, highly permeable material may not develop rills or channels and infiltration occurs instead.

Width trends within the central drainage systems support a fluvial interpretation for their origin. Terrestrial drainage systems are characterized by increasing channel width in downstream directions as a function of discharge (in contrast to sapped channels which maintain relatively constant widths) [19]. Channel width measurements along the central drainage system illustrate this relationship as shown in Figure 1. The distance measurements in Figure 1 are normalized distances measured from the most downstream location accurately measurable using MOC images (42.67°S., 267.65°E.) where the channel is approximately 1,809 meters wide. Figure 1 contains an anomalous lack of data on narrow (high-order) tributaries, which is due in part to the preferential destruction of smaller structures through time as outlined above, as well as non-uniform MOC coverage in the study area.

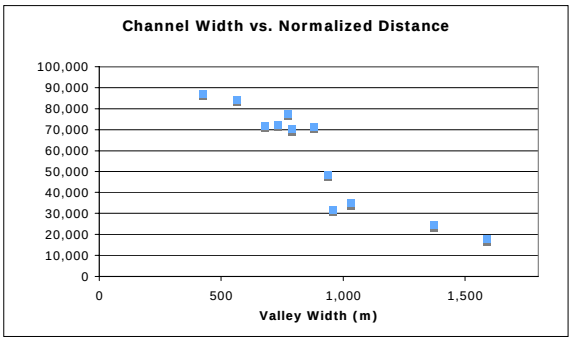

Figure 1: Chart illustrating the relationship between valley width and upstream distance (a proxy for discharge). Incompleteness of MOC coverage and modification of valley structures limit the precision of the data, but the trend clearly resembles precipitation-fed terrestrial systems.

Sapping Channels. The channel structures in east-central Warrego Valles appear to result from sapping processes; these structures exhibit a distinct linear morphology in comparison to fluvial dendritic systems. The channels have few, if any, tributaries and have stable widths along their length, which are hallmarks of sapping channels [6, 12]. These structures appear to modify and thus post-date the fluvial systems described above.

Sapping has probably been active over a much longer time period than run-off processes, but more precisely constraining ages is difficult with existing geologic data. Channel development post-dates Noachian deformation (fault grabens which provide structural control on channel orientation) and it is clear that some sapping features may be relatively fresh structures, perhaps the result of climate changes due to extreme obliquity variations [20-22].

Conclusions: The basement in Warrego Valles is composed of fractured Noachian units, which evidence the region's complicated tectonic history. The valley networks dissect Noachian materials, which have been extensively modified by eolian processes. The oldest valley structures are the dendritic networks located in central Warrego Valles, which probably began forming as precipitation-fed fluvial systems in the Noachian. The climate system required to sustain the precipitation needed to form dendritic fluvial networks appears to have failed by the end of the Noachian. The sapped outflow channels and debris flows are less well-constrained; they are inferred to have formed episodically following the Noachian. These processes exhibit signs of strong structural control. Eolian processes are active presently in Warrego Valles and are responsible for the most recent degradation in the region.

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