GEOMORPHIC AND CHRONOSTRATIGRAPHIC EVIDENCE FOR EARLY AND LATE-STAGE GROUNDWATER EFFUSION ON EQUATORIAL TERRAINS, MARS . N.H. Warner[1], M. O'Shea[1], S. Eckes[1], S. Gupta[2], E. Noe Dobrea[3]. [1]Department of Geological Sciences, SUNY Geneseo, 1 College Circle, Geneseo, NY 14454; [2]Imperial College London, South Kensington Campus, Earth Science and Engineering, London, SW7 2AZ, UK; [3]Planetary Science Institute, Tucson, AZ 85719. warner@geneseo.edu

Introduction: Multiple fluvial systems cross-cut the highland terrains of the equatorial regions of Mars, including smaller valley networks, single-trunk channels, and larger catastrophic outflow channels. The geomorphic and chronologic data indicate that these features formed over a span of time that includes the Late Noachian up to and including the Amazonian epoch [e.g. 1,2]. While the classic chronostratigraphic paradigm still holds that precipitation-fed valley formation preceded groundwater-sourced flow, focused observations of local terrains illustrate that there is complexity in this model [3,4].

Here, we present a series of observations/chronostratigraphic data of single order to multi-order, theater-headed, fluvial systems at Xanthe Terra, including Hypanis Valles and Nanedi Valles (among others). The data suggest that groundwater flow persisted over a span of time that includes the Late Noachian to Early Amazonian. Our approach to evaluating the age of fluvial systems involves three independent techniques. These include: (1) derivation of model ages using impact crater statistics for ejecta blankets that are cross-cut by or that superpose channels, (2) construction of a crater degradational time series to provide age constraints on individual impact basins that are cross-cut by or superpose channels, (3) buffered crater counting of the networks themselves. Here we report on the results of methods (1) and (2). Results from method (3) are forthcoming.

Methods and Results: Early mapping efforts [3,4] using a near complete Mars Reconnaissance Orbiter Context Camera (CTX) mosaic revealed that many (but not all) fluvial systems in this region cross-cut well-preserved ejecta blankets of impact craters. While in some cases the channels emanate from the ejecta, several systems originate from the highlands. Nanedi Valles for example cross-cuts the continuous ejecta blanket of the ~70 km diameter crater 15N (designation for our analysis). This is indicated by the valley's relatively pristine morphology as it crosses within the crater's continuous ejecta blanket. A north-south trending, broad (~10 km) topographic trough was also identified using High Resolution Stereo Camera (HRSC) digital elevation models (DEMs) along the margins of the incised valley (Fig. 1), implying broader-scale denudation of the ejecta blanket before channel incision. At this distance from the rim of crater 15N, ejecta thickness models [5] indicate that the < 100 m deep

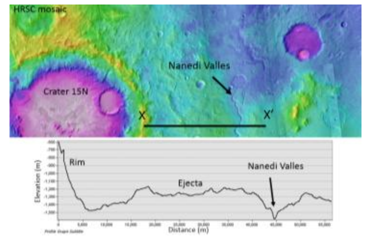

Fig. 1: HRSC DEM of the northern end of Nanedi Valles where the channel crosses and incises through the ejecta blanket of crater 15N.

Nanedi Valles should have been completely buried by continuous ejecta if the valley pre-dated the event.

In contrast, where the headwaters of Hypanis Valles (north and south branches) cross within the range of the distal reach of the continuous ejecta blanket of 15N, the interior channel slopes and overall morphology of the channel become characteristically muted (Fig. 2). Furthermore, secondary craters mapped back to 15N cross-cut Hypanis Valles. These observations suggest that crater 15N is a chronostratigraphic marker that separates the two valley systems.

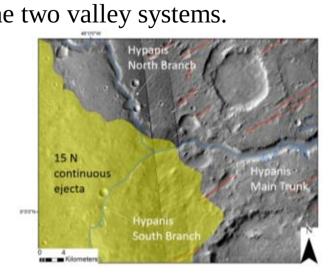

Fig. 2: CTX mosaic displaying the cross-cutting relationships of the ejecta blanket of crater 15N relative to the northern and southern branches of Hypanis Valles. Both branches are superposed here by the ejecta blanket.

Impact crater statistics from the continuous ejecta blanket of 15N suggest a 3.7 Ga Late Noachian to Early Hesperian model age (Fig. 3). However, care was taken to avoid counting impact craters that may be protruding from the basement rock through the relatively thin, distal regions of the ejecta. HRSC DEMs were used to evaluate the thickness of the ejecta of 15N relative to the elevation of the surrounding highland terrain. At a distance of ~ 25 km from the crater rim, the ejecta of 15 N is on average only ~300 m thick. It thins to near zero at a distance of 80 km. As a conservative threshold to consider, older highland craters that are > 1 km in diameter may not have been totally obliterated by the formation of this ejecta blanket beyond the 25 km distance using depth to diameter relationships of pristine, simple and complex impact craters [6,7]. Within 25 km of the rim however, the ejecta is thick enough to have completely buried all craters < 1 km in size. The 3.7 Ga model age is therefore derived from a count of 500 m to 1 km sized craters taken from within the 25 km annulus. Craters < 500 m in size are poorly preserved on the topographically variable ejecta blanket. Their size frequency distribution (SFD) follows a near equilibrium -2 slope [8].

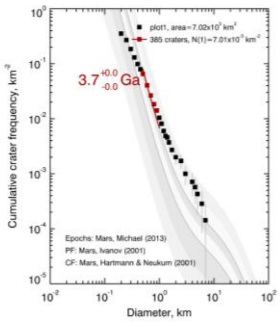

Fig. 3: Cumulative SFD of craters superposed on the continuous ejecta blanket of crater 15N within a 25 km annulus from the crater rim. A resurfacing correction fit was applied only to craters between 500 m and 1 km in diameter.

The second method used to evaluate the age of these systems involves the construction of a degradational time series for all impact basins in the Xanthe Terra region. Using the HRSC DEMs and a 100 m Thermal Emission Imaging System (THEMIS) basemap we mapped all craters with diameters > 2 km. The DEMs were then used to construct topographic profiles across each crater to evaluate depth (d) and diameter (D) relationships.

The craters were sorted by both size and their relative state of degradation. The most pristine craters in our dataset, or Class 1 craters, were classified as those craters where the d/D ratio is 80 to 100% of the empirically-derived model ratios of [e.g. 6,7]. The least pristine class, or Class 5 craters, were those with a d/D that has a value that is 0-20% of the model value. The d/D model of [6] was chosen for relative comparison to our dataset based of the similarity in the power-law distribution of our data to their model.

For each classification we constructed cumulative SFD plots to constrain timescales of degradation. For example, to estimate the age of the most degraded class (Class 5), we plotted the SFD for all craters in all classes (Class 1 – 5). By fitting the data to Mars production and chronology functions [9,10] we not only estimate the age of the terrain but the maximum age of the most degraded crater on Xanthe Terra. To estimate a maximum age of the least degraded class we plotted the SFD for only Class 1 craters. We assume that Class 1 craters represent the youngest craters in the region based on their near pristine morphology. The data indicate that a crater that shows depth-related degradation such that its d/D relationship is 80 – 100% similar to the pristine ratio is at maximum Early Hesperian (3.6 Ga) in age but possibly younger. Likewise, any crater whose d/D is further from the pristine model (< 80%) should be Early Hesperian or older. The chronostratigraphic marker that separates Nanedi from Hypanis Valles, crater 15N, plots almost exactly at ~80% from the pristine d/D model suggesting a maximum age of 3.6 Ga, or Early Hesperian. This age constraint is consistent with the crater statistics of its ejecta blanket.

Discussion and Conclusion: Crater 15N represents a useful Late Noachian/Early Hesperian time marker to constrain the timing of fluvial systems in the region. 15N is also dissected to the west by Tyras Vallis, which ends in a sedimentary fan on the crater floor. However, the Nanedi/Hypanis river systems represent only one example in the Xanthe Terra region of channels that are separated chronologically by large impact crater basins. Other rivers, including Sabrina Vallis and Ochus Valles, are superposed by younger, Hesperian to Amazonian age craters, while other smaller, unnamed rivers (including an apparent tributary to Hypanis Valles) cross-cut similarly well-preserved ejecta blankets. The combined observations indicate that fluvial activity in this broad region of Xanthe Terra both predates and post-dates the critical climate transition of the Late Noachian to Early Hesperian. In all cases, the valleys lack multi-ordered branching tributaries and emanate from single point source locations at full-width headwalls. While these observations imply a groundwater effusion model, the groundwater release had less of a geomorphic impact on the equatorial regions as compared to the nearby larger catastrophic outflow systems. The question remains as to whether the source water reservoirs are related both hydrologically and temporally to the larger outflow systems or how/if these networks relate in any way to the Late Noachian Icy highlands model [11].

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