

Quantitative geomorphic and hydrologic analysis of paleo-lake basins in the Gale Crater region, Mars. M. K. Kanine¹, E. T. Putnam², F. Rivera-Hernandez², and M. C. Palucis², ¹Dartmouth College, Hanover, NH, Melanie.K.Kanine.20@Dartmouth.edu, ²Dartmouth College, Hanover, NH.

Introduction: Deltaic features near the Martian crustal dichotomy in the Gale crater region are used as evidence for a global northern ocean [1], but the timing and extent of standing water is debated [2]. Detailed geomorphic and hydrologic analysis of several deltas and their associated paleo-basins, combined with mineralogical study and crater counts, can be used to estimate the quantity, timing, duration, and chemical composition of water present in the region. These estimates are vital in developing a narrative of Mars's climate evolution. Here we present preliminary results of such an analysis in the Nepenthes Mensae region.

Methods: Geomorphic analyses of the Nepenthes Mensae region were done using standard tools in ArcGIS. Mars Reconnaissance Orbiter Context Camera (CTX) and High Resolution Imaging Science Experiment (HiRISE) imagery was used for visual analysis, such as mapping features' areal extents (including a CTX mosaic [3]). A Mars Orbiter Laser Altimeter (MOLA) digital elevation model (DEM) and a CTX DEM (created using the NASA Ames Stereo Pipeline [4]) were used for spatial analysis and volumetric calculations; Thermal Emission Imaging System (THEMIS) imagery was used to identify degree of consolidation and thus the boundaries of landforms; and Compact Reconnaissance Imaging Spectrometer for Mars (CRISM) imagery was used to investigate mineralogy. Mass balances were conducted by subtracting an interpolated "pre-erosional" or "pre-depositional" surface from current topography.

Past work and new observations from the Nepenthes Mensae paleo-basin:

Deltaic deposit. A pristine Gilbert delta, previously identified by de Pablo [5], is located on the northwest side of one of the Nepenthes Mensae topographic basins. The delta is at the terminus of a 3.9 km long valley mainstem. Its apex is at an elevation of -1820 m, and the bottomset is at -2450 m. For most of the delta, the rollover elevation ranges from -2000 m to -1950 m. Gullying is present on the delta. It has an average topset slope of 3% (0.02°) and a foreset slope of 39.6% (21.6°). The delta's surface area is 38.6 km² and its volume is 15 km³. The delta deposit overlays a finely-bedded, likely finely-grained (determined from HiRISE image analysis [e.g. 6] and hydrologic modelling) fan-shaped feature with convex topographic contours.

Valley. The associated mainstem valley (Fig. 1B) is also relatively pristine. The valley walls make a "V" shape truncated at flat floors. The valley network span-

ning the catchment area is dendritic, approaching sub-parallel. The catchment area for the delta's feeder channel and its tributaries is approximately 8,200 km². It is bounded by a wrinkle ridge (or lobate scarp) to the southwest [7] and a scarp with an elevation ~120 m higher than the enclosed landscape to the west. The catchment area is not an uninterrupted and unified topographic basin enclosed by ridgelines or other topographic highs; rather, there are neighboring and interconnected catchment areas for other outflow channels, as well as sub-catchments created by impact craters. Craters greater than ~1.3 km in diameter were classified as sub-catchments and excluded from the area calculation. The catchment area has an average slope of 2.2% for a long profile bisecting the mainstem valley and the catchment area; the mainstem has a slope of 2%. The mainstem contains an inner channel with a maximum width of ~120 m. The volume of the mainstem valley is ~92 km³.

Basin. The topographic basin (Fig 1A) associated with the delta was recently mapped by García-Arnay et al. (2018) [8]. Here, we extend that mapping based on textural changes and document possible glacial and periglacial features associated with the basin. We observe a change in surface texture from smooth and relatively lightly-cratered terrain within the basin, to rougher and more heavily-cratered terrain outside the basin. There is terracing present near this terrain change. Terracing is also found on sharply-crested hills and shallowly-sloped, dome-shaped mounds within the smooth region. The mounds, which often exhibit a divot or a moat in the center, are also prevalent along the transition between terrain types. The terrain change is closely correlated with the -1900 m contour line in this region. Yet, mapping in nearby basins without deltas (but with similar texture and terracing) suggests water levels were likely previously higher.

Mineralogy. Fe/Mg smectites were observed near the boundary of the basin along the crustal dichotomy, on several of the hills, and proximate to the delta and fan-shaped feature. Hydrated silica deposits are also found in the vicinity of the delta and in several of the hills, and one deposit appears to be fracture fill.

Discussion:

Sources of water and formation timescales. The valley network supplying sediment to the delta is consistent with formation by overland flow (versus groundwater seepage). The V shape of the valley and the presence of an inner channel is indicative of fluvial rather than glacial processes [9]. Mass wasting from

the valley walls can explain the flat floors. Calculated bankfull discharges, when applied over the entire catchment area, approximately match runoff estimates for the Gale crater region [10]. Using our calculated delta volume, estimates of runoff rates, and rock/water ratios for arid fluvial systems [e.g. 11], we find the delta formation timescale is on the order of 10 to 100 ka. The lake into which the delta was forming would have to have been stable at least this long.

Climate. Wave cutting could explain the terracing on the hills and mounds within the mapped lake region. However, perennially ice-covered lakes can also exhibit these or similar features. In addition, many of the mounds are consistent with pingo morphology (Fig. 1C). It is possible that the basin was in a periglacial environment.

Mineralogy. Fe/Mg smectites form from the alteration of basalt in circumneutral water; hydrated silica forms in circumneutral or more acidic waters [12]. The presence of these minerals in the basin supports a history of local liquid water. However, pending further study, it is difficult to discriminate between sources or formation mechanisms of the observed clays: a layer in underlying bedrock, sub-aqueous formation, or formation during diagenesis of sediments or later interaction with groundwater. The fracture-filling silica suggests late-stage aqueous alteration due to groundwater.

Conclusions: As previously suggested [8], it is reasonable to conclude that paleolakes existed in the Neptunes Mensae region of Mars. Even a single one of these basins is comparable in size to Earth's Lake Baikal, and geomorphic analysis suggests the lake systems were active for a minimum of tens of thousands of years. Though there is some evidence of a glacial to periglacial environment (pingos, moraines) in this region, the timing of formation of these features is unclear. The focus of current work is determining whether these paleolakes represent the last remnants of a northern ocean or were isolated from a northern ocean, the relative importance of groundwater versus surface runoff, and the chronology of the local climate evolution.

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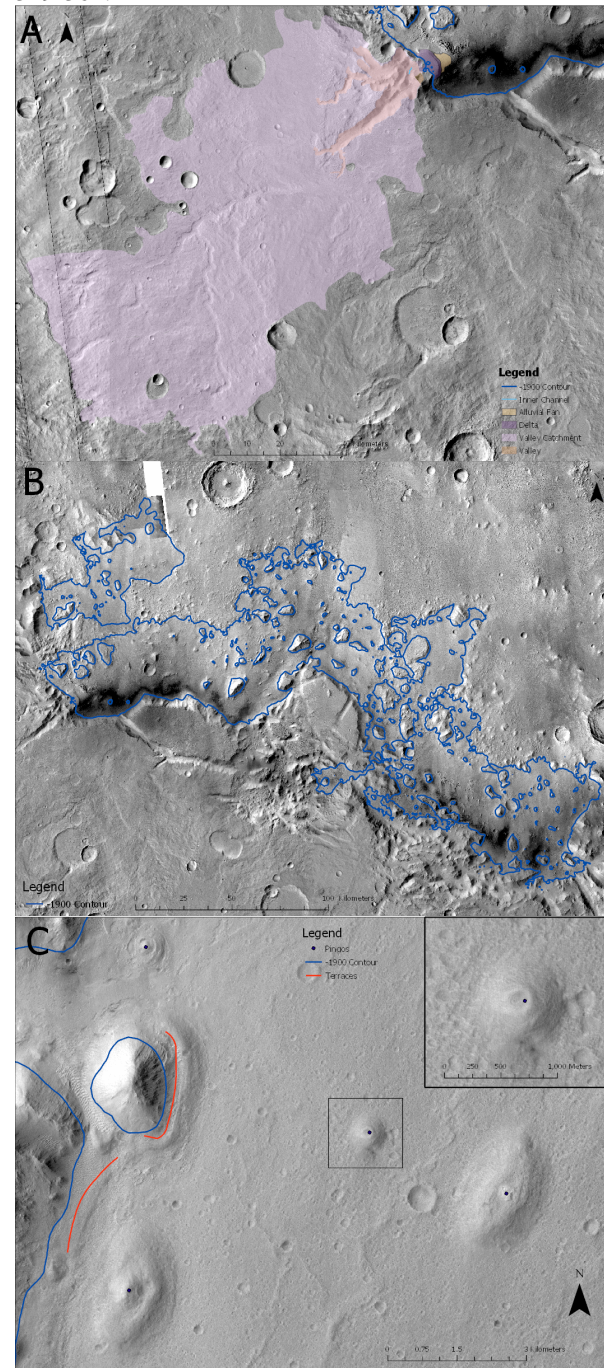


Fig. 1. The fluvio-deltaic system (A); one topographic basin in Neptunes Mensae (B); and putative pingos, along with exemplars of terraces (C).