GEOLOGY AND CHRONOLOGY OF THE MA'ADIM VALLIS-ERIDANIA BASIN REGION, MARS: IMPLICATIONS FOR THE NOACHIAN-HESPERIAN HYDROLOGIC CYCLE.

David M. H. Baker[1], James W. Head[1], [1]Dept. Geological Sci., Brown Univ., Box 1846, Providence, RI 02912, Email: David_Baker@brown.edu

1. Introduction: There is growing evidence that standing bodies of water were common during Mars' early history [e.g., 1]. Analysis of the formation of the 1,000-km long canyon, Ma'adim Vallis, [2] suggest that a ~3,000,000 km^2 Noachian-aged paleolake, herein called Eridania basin, infilled and catastrophically overflowed to carve the channel system. At its highest water level, the lake would have had a volume 562,000 km^3, creating one of the largest lake systems in early Mars.

How is such a large lake maintained? What is the origin and timing of the large water input needed to fill Eridania Basin? What is the ultimate fate of this water as the lake drained? We assess these questions and the hydrologic evolution of Eridania basin by analyzing the stratigraphy, crater chronology, and mineralogy of units on the basin's floor. This analysis places constraints on the environmental conditions during the Noachian/Hesperian boundary and into the Late Hesperian.

2. Stratigraphy and Crater chronology: The study region includes a portion of Eridania basin from 157°E to 196°E longitude and 25°S to 45°S latitude (Fig. 1). We use a THEMIS IR daytime mosaic at 100 m/pixel to map and determine the stratigraphic relationship of three widespread units: Chaos, Ridged Plains, and the Electris units. We also conducted crater counts in subset areas using the THEMIS IR mosaic and CTX images for small count areas. Crater size-frequency distributions are then compared to the Hartmann [3] isochron system to derive best-fit ages; period boundaries are from [4].

2.1. Chaos: Chaos is the oldest unit and occurs as five major fields of flat-topped mesas and rounded knobs concentrated in the central, lowest parts of five highly degraded, 100-130 km diameter craters in Eridania basin (Fig. 1). So-called "chaotic terrains" in this region are rare, as they are more typically found at the heads of Hesperian-aged outflow channels to the east of the Tharsis Rise [5,6,7]. Crater counting on all of the regions of Chaos yields an age near the Late Noachian/Early Hesperian boundary at ~3.50 Ga.

2.2. Ridged Plains: The Chaos unit is embayed by the Ridged Plains unit, which has been previous mapped as volcanically emplaced Hesperian ridged plains (Hr) [5,6]. The Ridged Plains unit covers ~40% of the total Eridania basin floor, creating smooth, low-sloping areas with prominent wrinkle ridges. Surficial contacts with the Chaos unit are often obscured by younger sedimentary layers; however linear boundaries where the Ridge Plains unit was thick enough to cover substantial portions of the Chaos is observed (Fig. 1). Crater retention ages of combined Ridged Plains unit count areas are similar to the Chaos unit at ~3.51 Ga, or near the Late Noachian/Early Hesperian boundary (3.55 Ga).

2.3. Electris: Although we did not map its occurrence explicitly, a 100s of meters thick, relatively higher-albedo unit called the Electris unit covers a substantial portion of the Terra Sirenum region, including the Ridged Plains unit [8,9]. The deposit occurs as isolated plateaus on the Eridania basin floor and is more continuous along the margins of Eridania basin where it is heavily etched and dissected by valley networks. The Electris unit is likely to be airfall material, either altered pyroclastic deposits or remobilized sediment/ash [8,9]. Crater retention ages place the Electris unit at ~3.43 Ga, which is slightly younger than the Ridged Plains and Chaos units, and is consistent with the stratigraphic relationships and previous age dating [8].

3. Mineralogy: Analysis of CRISM hyperspectral images [10] has shown that the walls of mesas and knobs in the Chaos unit have strong Mg- and Al-rich smectite signatures, with weak indications of sulfates. Alteration of original Chaos material to smectities may have occurred during the Eridania lake episode or during subsequent Hesperian-aged aqueous activity. Although a comprehensive survey has not been conducted, CRISM parameter maps suggest that the Ridged Plains unit is spectrally bland with some pyroxene signatures and no phyllosilcates. The Electris unit, however shows strong Fe-phyllosilicate signatures that may have formed in situ or from alteration prior to remobilization and deposition [9].

4. Hydrologic evolution: We now combine our mapping and age dating of floor units with observations of the distribution and morphologies of valley networks on the Eridania floor to construct a scenario for the hydrologic evolution of the Eridania basin region from the Noachian to Hesperian.

4.1. Late Noachian: While dense Noachian valley networks occur in localized regions within the Eridania basin watershed (Fig 2A), major Noachian-aged input channels are sparse [11] (Fig. 1B). The large water volume of Eridania lake and the scarcity of large input channels in its watershed suggest that surface runoff was not a sufficient input. Instead, growing evidence suggest that groundwater was a major water source for Eridania lake, including its large lake area to watershed area ratio [1] and hydrologic modeling [12], which shows Eridania basin to be one of the few locations in the southern highlands where groundwater upwelling occurs. The occurrence of Chaos units in the deepest portions of the Eridania basin [Fig. 1B] may also be related to more catastrophic release of groundwater, similar to occurrences of chaotic terrain at the head of large outflow channels east of Tharsis [7,13]. However, occurrences of similar knob-like units at high elevations outside of Eridania basin suggest that the Chaos unit may instead be an ancient depositional unit, perhaps formed contemporaneously with Eridania lake.

4.2. Early Hesperian: After the Eridania lake drained, the volcanic Ridged Plains unit was emplaced. Complete drainage of the lake must have occurred or lavas were thick, as no evidence of landforms produced by volcano-water interactions (e.g., pseudo-craters) are observed. The Electris unit was emplaced shortly after Ridged Plains, as suggested by their relative crater size-frequency distributions. Valley networks incised into the Electris unit (Fig. 2B) is evidence of a renewed episode of valley network activity during the Early Hesperian. These valley networks are less spatially dense than typical Noachian valleys (Fig 2A), generally lack extensive tributaries, and erode the Electris deposit into wide valleys (Fig. 2B). Electris valleys commonly terminate in low albedo deposits that are concentrated near the margins of Eridania basin and embay Chaos, Ridged Plains, and Electris material (Fig. 2B). These deposits may be eroded Electris material that was fluvial transported and deposited down-gradient. The water source is unclear; however, a volcanically-enduced warming of the climate or melting of volatile-rich material are plausible scenarios.

4.3. Late Hesperian: Late-stage fluvial activity on the floor of Eridania basin is evidenced by small, often braided and intersecting channels <0.5 km wide, which exhibit a few tributaries (Fig. 2C). These channels are incised into Early Hesperian materials, including Ridged Plains, Electris, and deposits at the termini of channels within the Electris unit (Fig. 2B) and have been recently dated to the Late Hesperian to Early Amazonian [14]. Our observations indicate that these valleys are wide-spread on the Eridania basin floor, consistent with previous suggestions [14]. Their small sizes and immaturity suggest relatively low discharges that may have been sourced from melting of local deposits of snow or ice [14].

5. Summary: The floor of Eridania Basin experienced substantial amounts of geologic activity in a relatively short period near the Noachian/Hesperian boundary. This activity included creation of regions of Chaos followed by embayment by volcanic Ridged Plains and emplacement of Early Hesperian Electris airfall material. Different styles of water activity are found within Eridania basin. Groundwater appears to have played an important role in filling and maintaining a large lake that overflowed to carve Ma'adim Vallis. After extensive volcanic activity, a renewed pulse of valley network fromation occurred in the region that incised the Electris and Ridged Plains materials. Later, Late Hesperian-aged small-valley incision in some locations on the basin floor occurred, representing localized surface runoff, perhaps related to meltwater from ice-rich materials [14].

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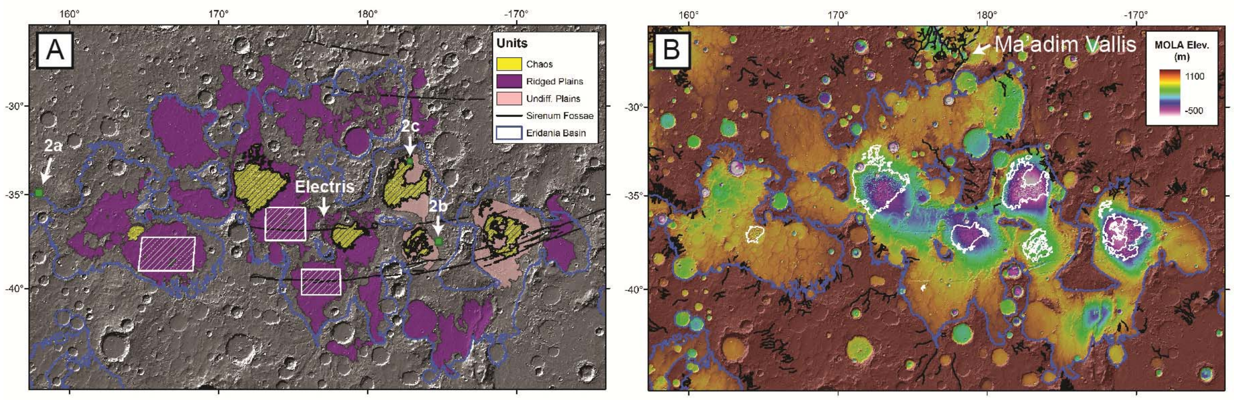

Fig. 1. The Eridania basin study area. A) Mapped units within the Eridania basin, including Chaos (yellow), Ridged Plains (purple), and undifferentiated plains material (pink). The Electris unit is not shown but is widespread in the region. The base map is MOLA gridded hillshade topography. The 1100 m contour (blue line) delineates the extent of Eridania Lake [2]. Hatched areas of Ridged Plains and Chaos and the arrow labeled Electris give the locations of the areas used for crater size-frequency distributions. The locations of panels in Fig. 2 are also indicated. B) MOLA colored gridded topography of the study area superposed on MOLA hillshade, showing the Eridania basin outline (blue), mapped regions of chaos (white lines), and mapped valley networks from [11] (black lines). Ma'adim Vallis is in the top center in each panel.

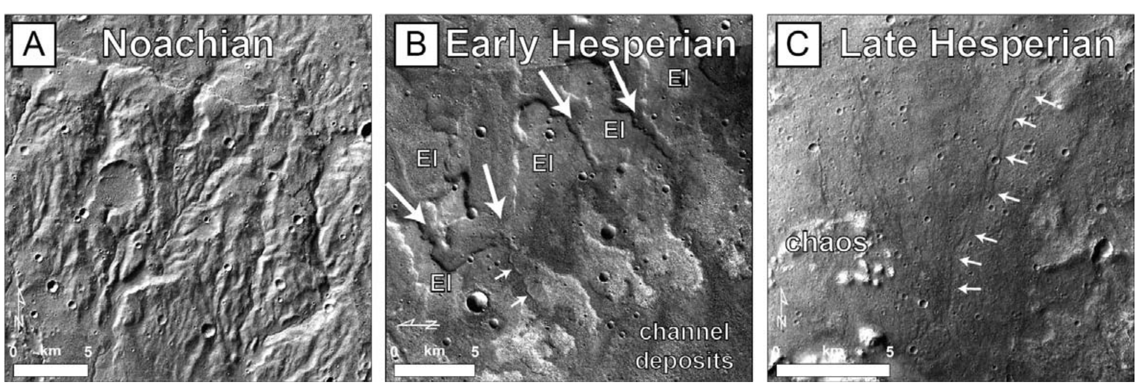

Fig. 2. Evolution of fluvial activity in the Eridania basin watershed. (A) Dense valley networks in Noachian terrain. (B) Wide valleys (large arrows) eroded into Early Hesperian-aged Electris unit (El). Fluvially transported deposits occur at the channels' termini. Small arrows indicate a late-stage channel. (C) Small Late-Hesperian aged channels (one is outlined by arrows) formed in Early Hesperian materials.