NORTHERN LOWLANDS ON MARS: EVIDENCE FOR WIDESPREAD VOLCANIC FLOODING AND TECTONIC DEFORMATION IN THE EARLY HESPERIAN.
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Abstract. Detrended northern lowland topography shows that surface deposits are underlain by an Early Hesperian regional unit with a basin-wide system of sub-parallel wrinkle ridges; the orientation and location of these wrinkle ridges completes a global circum-Tharsis ridge system ~7000 km wide.

Introduction and stratigraphy: The northern lowlands of Mars form the central part of a larger drainage basin that has comprised about three-fourths of the surface for most of its history [1]; the northern lowlands may have contained a large standing body of water in earlier Mars history [2], and could have been the location of plate tectonic activity in its early history [3]. Two fundamental issues remain unresolved: 1) when and how did the distinctive northern lowlands form, and 2) what were the processes involved in their evolution?

In ascending stratigraphic order, the exposed surface units of the northern lowlands [4] include: 1) Noachian-aged remnants including a small unit dissected by channels in Acidalia Planitia, old degraded crater rims, and Scandia Colles, a collection of domes interpreted to be old degraded Noachian crust; 2) the Hesperian-aged Vastitas Borealis Formation, an unusual unit interpreted to be degraded lava flows and sediments, 3) Hesperian-aged channel deposits at the margins of the lowlands in Chryse Planitia, 4) various local Amazonian-aged plains units, 5) Elysium channel deposits, 6) the north polar cap, consisting of Late Amazonian ice and layered terrain deposits, and 7) Amazonian-aged circumpolar mantling material. The predominantly sedimentary nature of many of the northern plains units and modification processes since their formation have obscured the character and age of underlying terrain, and thus its origin and evolution. We analyze these units with newly processed MOLA data to asses the stratigraphy and structure of the northern lowlands.

New MOLA results: The Mars Orbiter Laser Altimeter (MOLA) experiment on board the Mars Global Surveyor mission has provided a new global characterization of the topography and slope characteristics of Mars [1,5]. The combinations of gravity and topography have provided important new insights into crustal structure and thermal evolution [6]. These data have shown that: 1) the northern lowlands are extremely flat and smooth [1]; 2) they are irregular in shape and consist of two basins, the ancient, circular, heavily modified Utopia Basin of impact origin, and the irregularly-shaped North Polar Basin [7]; 3) the dichotomy boundary (the distinctive morphologic and local topographic slope boundary between the southern heavily cratered uplands and the northern lowlands) does not coincide exactly with crustal thickness trends [6]; 4) there is evidence for low-density linear gravity anomalies interpreted to be ancient fluvial channels [6]; and 5) the surface of the northern lowlands is exceptionally smooth at all scale lengths and is characterized by an unusual roughness at about the 3 km scale length [1,5].

As a further step in the analysis of the origin and evolution of the northern lowlands, we have used comprehensive MOLA data to analyze basin topography and surface roughness characteristics, removing regional slopes to detect and assess subtle topographic variations and geologic structure [8]. We find that the northern lowlands are underlain by a regional unit containing a basin-wide system of sub-parallel ridges that we interpret to be wrinkle ridges and arches. This unit also contains highly modified ghost or stealth craters, the number of which suggests an Early Hesperian age [18]. The unit can be traced laterally and is contiguous with Hesperian-aged ridged plains in the southern hemisphere. Mapping of the orientation and location of the ridges completes a global circum-Tharsis ridge system forming a band approximately 7000 km wide, and extending over the whole circum-Tharsis region.

The recognition of this unit and the superposed very degraded craters permits us to assess the stratigraphy and geometry of subsequent units and structure. We find that the present height of wrinkle ridges and geometry of buried craters suggest that the Vastitas Borealis Formation has a minimum thickness of about a hundred meters. The polar layered terrain deposits completely cover the wrinkle ridge system, and the circumpolar deposits obscure it, supporting the interpretation that the circumpolar deposit thickness is of the order of several hundred meters and that wrinkle ridge formation was not as active in the Amazonian as in the Hesperian. The trends of Hesperian-aged channels entering Chryse Planitia are controlled by the orientation and topography of wrinkle ridges deep into the basin. Some Amazonian-aged smooth plains units of volcanic origin in Amazonis Planitia and South Arcadia Planitia further bury and obscure the underlying wrinkle ridges [19]. Fretted terrain, particularly in the Deuteronilus Mensae region, formed subsequent to the Early Hesperian-aged ridged plains [10], and remnants can be seen to extend beneath the Vastitas Borealis Formation. Amazonian-aged Elysium Formation channel deposits are distinctly different in morphology and structure from the Chryse channels and very clearly overlie the wrinkle-ridged plains and Vastitas Borealis Formation in Utopia Planitia [4, 12].

New views of the northern lowlands: The recognition of these units and their stratigraphic relationships permits us to outline a new perspective on the history of the northern lowlands: 1) In the Noachian, little surface record remains but large now-buried channels apparently distributed water and sediments to the northern lowlands [6]; 2) in Early Hesperian, a significant part of the northern lowlands was filled with volcanic plains similar to those presently exposed in Tharsis and much of the southern uplands; 3) these volcanic plains were subsequently deformed by a Tharsis-circumferential, 7000 km wide band of wrinkle ridges, as well as other basin-related systems in Utopia and Isidis (the exact age of wrinkle ridge formation is uncertain [4,9]); 4) slightly later in the Early Hesperian, portions of the basin margins, including the ridged plains, were modified to form the fretted terrain [10], depositing sediments in the basin; 5) circum-Chryse outflow channels formed in the Late Hesperian and once in the basin, formed subdued channels whose course was largely controlled by wrinkle ridge orientation and height, depositing material in the basin; 6) The Vastitas Borealis Formation was emplaced in the Late Hesperian; our analysis supports the idea that this unit represents a veneer on the ridged plains of a minimum mean thickness of ~100 meters and probably a significant part of the sediments forming this unit are from outflow channel emplacement; 7) Amazonian volcanic plains were emplaced, primarily in the Elysium Basin and Amazonis Planitia, further obscuring the Hesperian ridged-plains [11]; 8) channel and flow deposits quite different than those of Chryse were emplaced in Utopia Planitia from the Elysium rise and overlie both the Hesperian ridged plains and the Vastitas Borealis Formation [e.g., 4]; and 9) Late Amazonian polar and circumpolar deposits formed, obscuring the structure of the underlying Hesperian ridged plains; extension of the regional slope of the Hesperian ridged plains beneath these deposits suggests that the circumpolar deposits are relatively thin (less than a few hundred meters), unless significant local polar cap loading and flexure has taken place [e.g., 12].

These data do not bear directly on the presence or absence of a large standing body of water in the northern lowlands in early Mars history, but have the following implications: 1) if an ocean existed in the Hesperian [e.g., 2], the emplacement of the Hesperian ridged plains would have been largely subaqueous, perhaps generating significant amounts of hyaloclastite sediment; 2) the distribution of what appear to be largely sedimentary deposits (Vastitas Borealis Formation) on top of the Hesperian ridged plains is consistent with the presence of a large standing body of water at the approximate level of Contact 2 [2]; 3) the widespread nature of this overlying layer and its sharp contacts are consistent with aqueous sedimentation; 4) evidence for greater thicknesses of these overlying deposits (fewer subjacent craters) in the Chryse region supports other evidence [e.g., 13, 14] for the emplacement of sediment by the outflow channels; 5) the nature of the Elysium channel deposits, and their distinctive contrast in morphology and structure with the Chryse channels, suggests that their emplacement into the Utopia basin [e.g., 15] in the Amazonian on top of the Vastitatis Borealis Formation was in a subaerial environment and that if an ocean existed, it was gone by this time [e.g., 14].

These data support the suggestion that the northern lowlands date back to the Noachian Period [4]. The presence of the ancient and heavily degraded Utopia impact basin, islands of Noachian-aged terrain, and the presence of a significant floor of Early Hesperian ridged plains, all suggest that the northern lowlands looked like much of the southern uplands at this time. Thus, any process producing the lower topography of the northern lowlands must have originated prior to the end of the Noachian.

Outside the northern lowlands there is an observed early planet-wide volcanic emplacement phase of Late Noachian-Early Hesperian age. Late Noachian ridged plains (Nplr) comprise ~3% of the presently exposed surface of Mars and Hesperian-aged ridged plains (Hr) make up another 10%. Thus, if Hesperian-aged ridged plains underlie the northern lowlands, then this would mean that the total percentage of the planet resurfaced by Hesperian-aged volcanic plains would be the 10% presently exposed in the southern uplands and the 20% making up the northern lowlands, for a total of 43.5 x 10^6 km^2 or 30% of the surface of Mars. These new estimates would more than double the area covered by Hesperian ridged plains. If the southern upland plains are typically about 500 meters thick and those in the northern lowlands about 900 meters thick (based on the average thickness of flooding models), then the total volume of Hr would be about 3.3 x 10^7 km^3. These estimates represent an increase in the importance of Hesperian-aged volcanic plains from previous estimates of more than twice the area and almost twice the volume. Estimates of gas exsolution from volcanic effusion and input of volatiles into the atmosphere as a function of time during Mars history [16] shows that the peak input was during the Early Hesperian. These new data suggest that this peak volatile input into the atmosphere may have been significantly more important than previously recognized. These results further emphasize the importance of events occurring during the Early Hesperian. On the basis of a variety of data, it appears that significant volcanic activity, perhaps the peak global flux, occurred during this period and that this was accompanied and followed closely by regional and global contraction to produce the circum-Tharsis and other wrinkle ridge systems [17]. On the basis of our interpretations here, the northern lowlands played a very important role in the Early Hesperian volcanic activity and in the subsequent period of regional and global-scale contraction.

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