AN ANALYSIS OF EVIDENCE FROM MOLA FOR NORTHERN SEAS AND OCEANS IN THE PAST HISTORY OF MARS.

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Introduction: Abundant evidence exists for the presence of water on the surface and in the subsurface in the past history of Mars [1]. Among the most distinctive pieces of evidence are the outflow channels that begin full-size at discrete sources and flow hundreds to thousands of km downslope into the northern lowlands displaying a wide variety of bedforms on their floors. An unusual characteristic of outflow channels is that channel cutting does not continue far into the northern lowlands even though downslope topographic gradients appear to continue. Where did the water go? Did it spread out over the broad smooth lowlands and sink into the substrate, or could it have ponded, creating lakes, seas or oceans? Some investigators have hypothesized that outflow channels had enough volume and occurred with sufficient simultaneity and repetitiveness to produce large standing bodies of water in the northern lowlands (Oceanus Borealis) at several times in the history of Mars [2]. Specifically, Parker et al. [3-4] mapped two contacts near and generally parallel to the highland boundary of the northern lowlands and interpreted these contacts to be shorelines, representing two separate highstands of a north polar ocean. Contact 1 is older and corresponds approximately to the highland-lowland dichotomy boundary. Contact 2 is younger, lies northward of Contact 1, and is more well-expressed by a sharply defined smooth, lobate, or arcuate contact and associated features interpreted to be related to shorelines and basinward deposition and evolution.

The new MOLA data permit us to test this hypothesis in several ways. 1) Are "shorelines" level?: If the mapped contacts are ancient shorelines, then they should also represent the margins of an equipotential surface, and if no vertical movement has occurred subsequent to their formation, the elevation of each contact should plot as straight lines. Preliminary analysis of the first 18 orbits showed that neither Contact plotted as a straight line, but that Contact 2 was a closer approximation than Contact 1 [5]. We have now plotted data from Hiatus phase; SPO1, and SPO2 (science phasing orbits), and produced a topographic map of the northern hemisphere. Contact 1 as presently observed is not a good approximation of an equipotential surface; variation in elevation ranges over several km, an amount exceeding plausible values of post-formation vertical movement. Contact 2 is a much closer approximation to a straight line, and the most significant variations occur in areas where post-formation vertical movement is anticipated (e.g., Tharsis, Elysium, and Isidis). 2) Are volumes consistent with water estimates?: Derivation of the topographic map (Fig. 1) permits us to test for volumes of water that might be contained in topographic basins of various scales. Assuming that the present topography is a reasonable approximation of the topography in Hesperian and Amazonian time, we have measured the volume of the topography below Contact 2 and find that it is about 1.4×10^7 km^3, a value lying between the minimum for all outflow channels (~0.6-0.8×10^7 km^3, [1,2]) and the maximum value for water-containing megaregolith pore space (~5-20×10^7 km^3, [6]). This volume of the area below Contact 2 is equivalent to a global layer about 100 m deep, and is within the range of estimates for available water [1].

3) How would individual flooding events fill the basin?: The northern hemisphere topographic map also permits us to assess what would happen if the lowlands were flooded concurrently or if individual channels emptied into the lowlands at different times. We sequentially flooded the northern lowlands in 500 m increments and observed where the water would pond and how candidate seas and oceans might evolve with increased depth. It is clear from the sequence of maps that there are two distinctive basins in the northern lowlands, the Utopia Basin and the North Polar Basin. Individual channel-forming events may have flooded only one of these basins, and volumes of the order of 1-3×10^6 km^3 are required to fill one of the basins to spill over into the adjacent one (Utopia: 1.2×10^6 km^3; North Polar basin: 2.6×10^6 km^3). Detailed simulations of flooding events from individual channels are underway [7].

4) How are other features correlated with basin topography?: Polygonal Ground: Several other geologic features are thought to have been associated with the presence of bodies of water or residual ground ice remaining from them, and the new topographic data can be used to assess their locations. Lucchitta et al. [8] examined the locations of a variety of features in the northern lowlands using Viking image data in an attempt to identify the location and characteristics of sedimentary deposits that might have resulted from the debouchment of the large outflow channels into the adjacent plains. They brought strong support to the sedimentary layer hypothesis by pointing out that the polygonal ground occurred in close proximity to major channel systems, that the outflow channels and the

fractured plains deposits have similar ages, that Antarctic analogs revealed many similarities to this process, and that polygonal ground occurred elsewhere on Mars in similar situations. We digitized the global map of the polygonally fractured terrain on Mars of Lucchitta et al. (Fig 1a) and superposed it on our MOLA topography map; we found that there is a strong correlation between the location of the polygonal ground and the position of the Utopia and North Polar basins.

5) How are other features correlated with topography?: Impact craters: Martian impact craters in the 2-50 km diameter range commonly have ejecta deposits with distinctive lobe and rampart morphology, interpreted [9] to be due to the presence of ground water or ground ice in the target area which mobilizes the ejecta material. It is also observed that craters on Mars smaller than a few km do not have ramparts, and thus the onset diameter of ramparts may be an indication of the depth where ground water or ground ice is encountered. On the basis of this concept, Kuzmin et al. [10] assessed the onset diameter globally and found that in equatorial regions the diameter was 4-6 km but toward the pole it was 1-4 km. We have digitized the Kuzmin et al. global onset-diameter map and superposed it on our MOLA topographic map (Fig. 1b). We find that there is a strong correlation between the smallest onset diameters and the position of the two large basins.

Summary and conclusions. MOLA data show that the topographic position of Contact 2 [3,4] is consistent with a boundary interpreted as a shoreline: the contact altitude is close to an equipotential surface, topography is smoother at all scales below the contact than above it [5], and the implied ocean volume is within the range of estimates of available water on Mars. In addition, detailed topographic maps of the northern lowlands reveal two major basins (Utopia and North Polar); features thought to be related to the evolution of standing bodies of water (polygons, lobate impact craters) show a high degree of correlation with basin topography. These new data do not prove, but are consistent with the northern lowlands of Mars being occupied by standing bodies of water ranging in scale from seas to perhaps as large as oceans in the Hesperian and Amazonian Eras. We are presently examining evidence for proposed subbasins within the northern lowlands and elsewhere on Mars [11].

References: [1] Carr, M. H., Water on Mars, Oxford U. Press, NY, 229 p., 1996; [2] Baker, V. R., et al., Nature, 352, 589, 1991; [3] Parker, T. S., et al., Icarus, 82, 111, 1989; [4] Parker, T. J., et al., JGR, 98, 11061, 1993; [5] Head III, J.W., et al., GRL, 25, 4401, 1998; [6] Squyres, S., Mars, Univ. Arizona Press, 523, 1992; [7] Thomson, B. & Head III, J.W., LPSC 30, 1999; [8] Lucchitta, B., et al., JGR, 91, E166, 1986; [9] Carr, M., et al., JGR, 82, 4055, 1977; [10] Kuzmin, R., et al., Solar Sys. Res., 22, 195, 1988; [11] Scott, D. et al, USGS MI Map 1-2461, 1995.

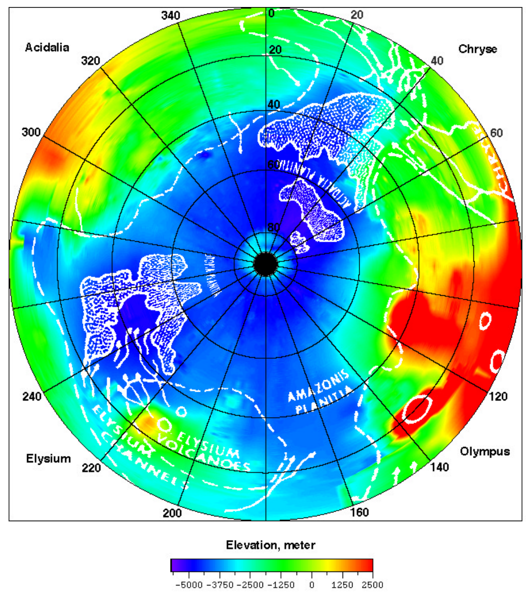

Fig. 1a. Map of Lucchitta et al. [8] superposed on MOLA topography

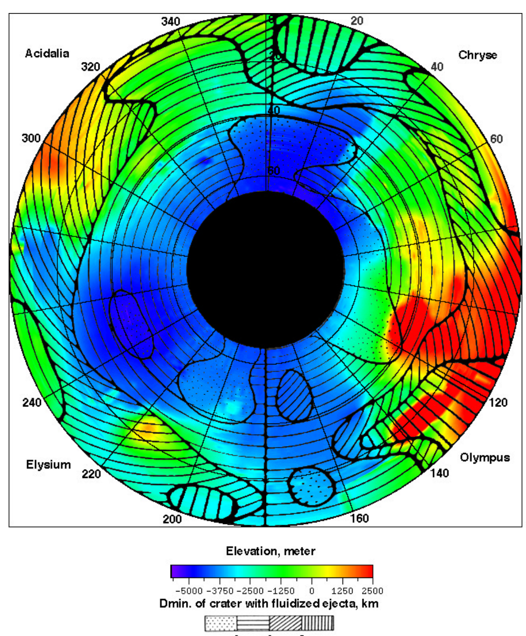

Fig. 1b. Map of Kuzmin et al. [10] superposed on MOLA topography