ANCIENT GIANT BASIN/AQUIFER SYSTEM IN THE ARABIA REGION, MARS, AND ITS INFLUENCE ON THE EVOLUTION OF THE HIGHLAND-LOWLAND BOUNDARY

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Introduction: Ancient geologic and hydrologic phenomena on Mars observed through the magnetic data [1,2] provide windows to the ancient past through the younger Argyre and Hellas impacts [e.g.,3,4], the northern plains basement and the rock materials that mantle the basement [e.g.,5,6], and the Tharsis and Elysium magmatic complexes (recently referred to as superplumes [7,8]). These signatures, coupled with highly degraded macrostructures (tectonic features that are tens to thousands of kilometers long [9]), reflect an energetic planet during its embryonic development (0.5 Ga or so of activity) with an active dynamo and magnetosphere [1,2,6]. One such window into the ancient past occurs northwest of the Hellas impact basin in Arabia Terra. Arabia Terra is one of the few water-rich equatorial regions of Mars, as indicated through impact crater [10] and elemental [11,12] information. This region records many unique characteristics, including predominately Noachian materials, a highland-lowland boundary region that is distinct from other boundary regions, the presence of very few macrostructures when compared to the rest of the cratered highlands, the largest region of fretted terrain on Mars, outflow channels such as Mamers Valles that do not have obvious origins, and distinct albedo, thermal inertia, gravity, magnetic, and elemental signatures [13]. We interpret these to collectively indicate a possible ancient giant impact basin that later became an important aquifer, as it (1) provides yet another source of water for the formation of putative water bodies that occupied the northern plains [14,15], (2) helps explain possible water-related characteristics that may be observed at the Opportunity landing site, (3) identifies a potential contributor to the development of the long-lived Tharsis superplume [7,8], and (4) provides a viable explanation for the unique character of the highland-lowland boundary when compared to other boundary regions of Mars. This primary basin is approximately antipodal to Tharsis and estimated to be at least 3,000 km in diameter (see Fig. 1a,b of [13]).

Discussion: Collectively, the distinct characteristics of Arabia Terra add credence to the following proposed hypothesized sequence of events (from oldest to youngest): (1) an enormous ancient impact basin at least 1.5 times the size of Hellas forms during extremely ancient Mars when the dynamo is active and the lithosphere is relatively thin, (2) sediments and other materials infill the basin during high erosion rates and a productive Noachian aquifer system is established, (3) the basin isostatically adjusts, (4) uplift of basin materials related to the growth of antipodal Tharsis results in differential erosion, exposing ancient stratigraphic sequences, and (5) parts of the ancient basin/aquifer system remain water-enriched [13].

The putative Arabia impact basin should not be unexpected on Mars. During the earliest period of solar system history some 4.2 billion years ago, there were very large impacts on the Moon and terrestrial planets. Impact basins comparable in size and age occur on the Moon. The largest impact basin ever identified is the Procellarum basin, first discovered by Whitaker [16] and confirmed from Lunar Prospector chemical data by Feldman et al. [17]. Based on structural and elemental information, the manifestation of the extremely large impact event recorded on the lunar surface extends for an estimated radius of about 60° or a diameter of about 3600 km. Feldman, et al [17] present evidence, which includes elemental information, of yet another giant impact basin on the lunar far side with a radius of 50° or about 3000 km diameter. Both of these basins have also been heavily cratered by the period of late heavy bombardment as the Arabia basin. The South Pole-Aitken basin (2500 km diameter) is another example of a heavily cratered large basin on the Moon. On Mercury, there is also an old giant impact basin (Borealis Basin) with an estimated diameter of 1500 km, but only 25% of that planet has been observed at sun angles sufficient to detect old basins. Even larger basins may occur on the unexplored side. The surface of Venus is too young to record such extremely large impact basins, and on

Earth the earliest part of solar system history is not preserved.

An old impact basin the size of the putative Arabia should, in fact, be present on Mars. The primary impact basin proposed for the Arabia Terra region is estimated to be at least 3,000 km in diameter, or at least 1.5 the size of Hellas. However, its total deformational extent may approximate or even exceed the estimated total extent of the Procellarum impact event. Whether the proposed Arabia Terra impact basin included multi-ring structures and associated basins is difficult to ascertain due to the observed high degree of erosion and deformation of the region.

Although we do not know how much water the Arabia impact basin/aquifer held, we can get some idea by estimating the water content for a 5 kilometer-thick layer coincident with an approximated 3000 km diameter. The volume of such a layer is about 1.43×10^7 km^3. If the porosity was about 10% then the total volume of water would have been about 1.4×10^6 km^3. This is comparable to about 10% of the volume of the smallest ocean in the Northern Plains based on the interior shoreline dimensions of [15,18]. However, this estimated volume may be much higher if the basin had a greater depth and total extent.

Implications: Implications of the basin hypothesis include: (1) explaining the unique characteristics of the region, (2) providing another source of water for the putative water bodies that occupied the northern plains [15,19-20], (3) providing additional information to assess the water-related characteristics observed at the Opportunity landing site, (4) identifying a potential contributor to the development of the long-lived Tharsis superplume [7-8], and (5) providing a viable explanation for the unique character of the highland-lowland boundary when compared to other boundary regions of Mars.. Furthermore, the existence of an ancient, gigantic basin in the Arabia terra region, especially when taken in conjunction with the smaller yet massive Tharsis basin [21], suggests that rapid obscuration of basins (be they tectonic or impact in origin) and infill with volatile-rich materials was a relatively common phenomena early in martian history. This has profound implications for rates of deposition in the earliest of martian times, and alludes to an environment with vigorous geomorphic processes being driven by a dynamic hydrosphere. The Arabia terra basin also brings into focus the timing of formation for the northern lowlands. Although this manuscript suggests that the formation of the highland-lowland boundary postdates the formation and infilling of the Arabia terra basin, several investigators have suggested that the dichotomy was shaped by geophysical phenomena present as the planet cooled and first formed a crust, such as mantle convection associated with core formation [22]. If so, why were the northern lowlands not also infilled by materials and therefore obscured to the present day? Were rates of deposition somehow different for the polar regions, or was the mechanism that formed the northern plains and global dichotomy longer-lasting, perhaps related to incipient plate tectonism [6-7,9,23]? Although many questions are still left to be answered, the emerging picture is that the topography of extremely ancient Mars was drastically different from what is observed today. In addition, such geologic information should provide the constraints on theoretical models relating to the time-space relations of the formation of the highland-lowland boundary, including geophysical modeling of the planet's interior.

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