REGARDING A WET, EARLY NOACHIAN MARS: GEOMORPHOLOGY OF WESTERN ARABIA AND NORTHERN SINUS MERIDIANI. K. S. Edgett[1] and T. J. Parker[2], [1]Department of Geology, Arizona State University, Box 871404, Tempe, AZ 85287-1404, U.S.A. (edgett@esther.la.asu.edu), [2]Mail Stop 183-501, Jet Propulsion Laboratory, 4800 Oak Grove Drive, Pasadena, CA 91109, U.S.A. (timothy.j.parker@jpl.nasa.gov).

INTRODUCTION AND BACKGROUND. This is a paper about the environment of Mars during the time when heavy bombardment was coming to an end and shortly thereafter. The exact date of this period is not known, but based on the Earth-Moon experience, it can be assumed to be around 4.1 to 3.8 billion years ago. A common assumption made about the early history of Mars is that the surface environment was similar to Earth [*e.g.,* 1]. The common image of Earth during this period is that of an ocean-covered world dotted by islands of volcanic and impact origin [*e.g.,* 2,3]. The oldest rocks on Earth date back to about 3.9 billion years and include many volcanic and immature sedimentary rocks that were deposited in subaqueous environments [2,4].

If early Earth was a "Water World," could the martian surface also have been largely underwater at the same time? Estimates of the amount of water available on Mars relative to Earth ~4 billion years ago range from very little to more than on Earth. A typical assumption is that both planets had the same amount of water in proportion to the planet size [*e.g.,* 5], although Mars could have had more water because it formed at a greater distance from the Sun [6]. If both planets began with the same proportion of water per planet mass, the depth of water on Mars, spread out over the surface, would have been about 1.2 km [5].

There is considerable evidence, largely in the form of valley networks, to suggest that erosion by water was vigorous during the Noachian Epoch [7]. Also, some of the largest impact basins, such as Isidis, Chryse, Argyre, and Ladon, have very deeply-eroded rims [8,9]. Erosion by surface runoff nearly ceased as Mars entered the Hesperian Epoch [7].

Large, ancient seas have been proposed to have occurred at times in the martian past. Most attention is usually focused on the question as to whether the northern plains of Mars filled with water as a result of the formation of the giant Hesperian/Amazonian outflow channels [10], but there might also have been seas in Argyre and Hellas Basins [*e.g.,* 9].

While the case has been made that seas might have once covered vast portions of Mars [10], little attention has been given to the question of seas in the earliest martian environments—seas that could have been larger than those proposed, for example, by Parker *et al.* [10] for the northern plains. Such Noachian seas would have existed at the same time that life was emerging on the ocean-covered Earth.

This paper explores the possibility that a portion of western Arabia and Sinus Meridiani might have been under water at about the same time that heavy bombardment was ending and the valley networks were eroding the cratered highlands of Mars.

OBSERVATIONS. We focus on the region that is mainly between 10°S northward to 30°N, and from 10°W eastward to 330°W. The region includes the three main color units of western Arabia and Sinus Meridiani, identified as "bright red," "dark red," and "dark gray" [11]. The elevation of this region is low (<2 km) compared to other heavily-cratered, Noachian surfaces on Mars [12]. The topography at the kilometer scale is very flat across the region, dropping about 0.7 m per km from east to west over a 3,000 km distance. Frey and Roark [12] called this the "Western Arabia Shelf". While their focus was on the geophysical explanation for the low, flat topography of western Arabia [12], our focus is on the surface geomorphology.

Our observations can be summarized as follows: (1) There are horizontally-bedded sediments in various states of aeolian erosion throughout the region. These include mesas and "white rock"-like landforms on crater floors [13,14], yardangs and pedestal craters [15], and craters buried by bright layered material in Sinus Meridiani. (2) The sedimentary layers overlie most of the large impact craters in the region. (3) Some portion of the sediments must consist of sand, because recent dark streaks and dunes are common among these wind-eroded landforms. (4) There are almost no valley networks in the region (see M. H. Carr's Figure 4–6 in [7]). (5) As noted by Frey and Roark [12], the regional topography is presently low and flat relative to other regions in the martian cratered highlands.

The portion of western Arabia that has a "dark red" surface [11] is characterized by the presence of many large, dark depositional wind streaks that originate at small dune fields on crater floors. In many of these craters there are small mesas and yardang landforms that resemble "White Rock" in Sinus Sabaeus. (Note that "White Rock" has been proposed to be a possible lacustrine deposit [16] with exobiological implications [17]). Also in the "dark red" part of western Arabia, there are many examples of yardangs and pedestal craters in the intercrater plains [15], both of which are characteristic of aeolian erosion of fine-grained, semi-consolidated sedimentary rock. In the northern part of the "pipe bowl" of Sinus Meridiani, craters are buried under sediment that is probably 100–1000 m thick. The sediment appears to be the same as that which is largely wind-eroded in the "dark red" areas to the north. It is interesting to note that some of the sediment that buries craters in Sinus Meridiani appears to be very bright, similar to "White Rock". In the "bright red" portion of western Arabia, there are several craters that contain large mesas of layered sediment; the largest of these is in Henry Crater [14].

DISCUSSION. Western Arabia appears to have been buried by up to 1 km of fine-grained sediment. Some large craters in the region post-date this deposit, thus it is likely that the sediment was deposited during the time when heavy bombardment was ending or had just recently ended. The origin of the sediment is unknown, but a case can be made to suggest that the sediment was deposited in standing water. Moore [18] was confronted with a similar dilemma regarding wind-eroded mantle deposits in northeastern Arabia. The primary difference between the western Arabia region discussed here, and the northeastern Arabia region discussed by Moore [18], is elevation. The region described by Moore [18] lies at modern elevations between 2 km and 5 km. If not for the great elevation, Moore [18] said that "a reasonable conclusion would be that it is [a].water-laid sedimentary deposit." Moore [18] then discussed the merits and difficulties with interpreting the mantle in terms of tephra airfall *vs.* aeolian dust deposition.

The elevation problem confronted by Moore [18] for northeastern Arabia does not apply in western Arabia and Sinus Meridiani. In addition, northeastern Arabia has valley networks, while western Arabia does not. The entire region lies below the present-day 2 km contour, and a portion of this region is lower than the 0 km datum. With a low, broad slope, the region could easily be inundated by water if enough water were present to fill the northern plains up to the 2 km contour level. The fact that the entire western Arabia region has almost no valley networks may be an important clue that this may have been the case. This observation is most easily explained if the region was underwater at the same time that valley networks were eroding the martian highlands.

CONCLUSION. The low, relatively flat expanse of western Arabia and northern Sinus Meridiani bears evidence of a post-heavy bombardment event in which layered sediments of up to 1 km thick were deposited in and surrounding the older impact craters. The sediments have subsequently been eroded by wind. The region, with its low elevation and relative lack of valley networks, could very plausibly have been under water early in martian history. Our scenario assumes the regional elevation has been about the same for 4 billion years—however, it is equally possible that the region has been up-warped (toward eastern Arabia) over time.

If western Arabia and northern Sinus Meridiani were underwater during the (perhaps appropriately named) Noachian Epoch, the observed layered sediments might include carbonate and evaporite deposits, as well as airfall from volcanic eruptions and meteorite impacts. The summary presented here is a framework in which future observations can be made and the origin of the sedimentary layers can be ultimately determined.

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