GEOLGY AND HYDROLOGY OF THE ARGYRE BASIN, MARS BASED ON MOLA AND MOC DATA

H. Hiesinger, J.W. Head III
Dept. of Geological Sciences, Brown University, Providence, RI, 02912; Harald_Hiesinger@brown.edu

Introduction
Argyre, located in the southern highlands southeast of Tharsis, is one of the largest impact basins on Mars and formed in Early Noachian time [e.g., Hiesinger and Head, 2002]. It has been proposed that meltback of a south polar ice cap during the Noachian completely filled the basin with water, that the outflow channel in the north drained the basin, and that the water eventually entered the northern lowlands [Parker, 1994].

Two models of the hydrologic evolution
Several channels, Surius Valles, Dzigai Valles, and Palacopas Valles, breach the southern rim and empty into the Argyre basin [e.g. Parker, 1989, Parker et al., 2000; Head, 2000c, d; Head and Pratt, 2001]. Most of these channels can be traced back to the distal portions of the Dorsa Argentea Formation, which was interpreted to represent the extent of a formerly larger south polar ice cap. Numerous authors (e.g., Parker et al., 2000; Head, 2000c, d, Head and Pratt, 2001) argued that melting of the ice cap releases significant amounts of water and that this water would pond in the Argyre basin. However, there are some differences in the amount of available water and the timing of the lake in Argyre.

In Parker’s model the basin is interpreted to have been completely filled in the Noachian because he found evidence for two flood events in the outflow channel, Uzboi Valles, which is of Noachian age [Parker, 1994, 1996a, b]. Parker et al. [2000] proposed that once the basin was completely filled, water could have left the basin through Uzboi Valles, a channel in the north of the basin and flowed down the Chryse trough [e.g., Saunders, 1979; Phillips et al., 2001] towards the northern lowlands.

A second model involving water in the evolution of Argyre basin was proposed by Head [2000c]. On the basis of their investigation of the present south polar ice cap and its related geologic units, Head [2000c] and Head and Pratt [2001] concluded that a much larger polar cap existed during the early Hesperian for which they presented evidence of ice retreat in middle Mars history [Head and Pratt, 2001; Head, 2000c]. They proposed that meltwater produced by this ice retreat would pond in the Argyre basin

Testing the models
Clifford and Parker [2001] presented a model for the evolution of the Martian hydrosphere. This model is based on the assumption that permeability and porosity of the Martian crust are high enough to allow the distribution of water to be governed by the effort to reach hydrostatic equilibrium, by flowing from regions of elevated hydraulic head to saturate the regions with the lowest geopotential. Clifford and Parker [2001] concluded that the existence of a primordial ocean that covered the northern lowlands on Mars was inevitable, given the thermal and hydrologic conditions during the early Noachian.

Parker et al. [1989, 1993] mapped several “shorelines” of such an ocean, i.e. Contact 1 and 2. Provided that the distribution of water during the Noachian is governed by the effort to reach hydrostatic equilibrium, that the ocean in the northern lowlands existed at these times, and that Argyre was filled with water at these times, then we might expect to find “shorelines” in the Argyre basin at about the same elevation as Contact 1 and 2. MOLA data indicate that at –3760 m (elevation of Contact 2) only crater Hooke would have contained water, and that at –1680 m (elevation of Contact 1) the water level in Argyre basin is well below the elevation where the entire basin would have been filled and water would have flowed through Uzboi Valles. We conclude that all of the investigated shoreline positions are below the elevation of the outflow channel of Argyre basin. If the distribution of water in the martian crust is correctly modeled by the hydrostatic model of Clifford and Parker [2001], water would flow underneath the surface toward lower regions rather than accumulating in Argyre to a level where flow through Uzboi Valles could occur. In Viking images we did not identify morphologic features which would be evidence for a shoreline at the level of drainage through Uzboi Valles. From our observations we conclude that either a complete fill of Argyre basin during the Noachian is unlikely, or alternatively, that the model of Clifford and Parker [2001] needs some revision.

The ages of the channels are not well constrained and vary in the literature from early Noachian to Hesperian. However, the age of the channels is crucial in order to address the hydrologic history of the basin. There are three possible scenarios: (1) the channels are early Noachian to Noachian in age [Parker et al. [2000]; (2) the channels are Hesperian in age but occupy valleys formed in the Noachian [Parker, 1996a, b]; (3) the channels are Hesperian in age [Scott and Tanaka, 1986; Tanaka and Scott, 1987].

If the channels, Surius, Dzigai, and Palacopas Valles, are Hesperian in age, then this is inconsistent with the model of Parker [1994] that suggests a complete fill of the Argyre basin in the Noachian by water flow through these three large southern channels. The channels can be traced down to the floor of the basin and this is consistent with the channels postdating the proposed complete fill. If the channels are early Noachian to Noachian, we face the problem of where the water came from. Parker et al. [2000] proposed meltback of a Noachian polar ice cap but Head and Pratt [2001] only found evidence for a Hesperian retreat of the ice cap. In addition, if the channels are early Noachian to Noachian in age, and the basin was completely filled at this time, then the channels should not be traceable down to the basin floor because they would have encoun-
tered a base level at a much higher elevation. If the channels are Hesperian in age but occupy Noachian valleys, this could explain the presently observed channel morphology and would leave the possibility of a complete fill of the basin during the Noachian. However, this scenario does not solve the problem of the Noachian water source.

How much water is actually necessary to initiate spill-over? Flooding models indicate that at ~3760 m, the global mean elevation of Contact 2, Argyre basin contains 3310 km³ of water and at ~1680 m, the elevation of Contact 1, Argyre holds as much as 5.71 x 10⁶ km³ of water. We conclude that (1) the basin has to be filled with at least 2.1 x 10⁶ km³ of water before flow through Uzbobi Valles could occur, and (2) once this hypothetical spillover through Uzbobi Valles stopped, one would be left with an enclosed lake approximately half the volume of the Mediterranean. We argue that such a lake or sea should have left morphologic evidence that can be interpreted as shorelines or terraces, but such evidence has not been observed.

Parker et al. [1989, 1993] postulated a north polar ocean and argued that the formation of such an ocean should be accompanied by sedimentation, smoothing submarine terrain below the shoreline. Head et al. [1999] tested the northpolar ocean hypothesis and showed that the average surface below the shoreline is indeed smoother at all scales than the surface above. On the basis of our observations of the roughness of individual geologic units, we find that all investigated Argyre units (Hpl, Hr, Nple, and Nph) are on average systematically rougher at all baselines than units Hvm and Hvk, which are exposed in the northern lowlands [Kreslavsky and Head, 1999, 2000].

Head and Pratt [2001] found evidence for extensive melting and retreat of a Hesperian-aged southpolar cap. Assuming that the entire area of the Dorsa Argentea Formation was once covered with a maximum of 3 km of ice, Head and Pratt [2001] estimated a maximum volume of ~8.82 x 10⁶ km³. If we subtract the volume of the present-day ice cap, which is of the order of 2.19 x 10⁶ km³ [Head and Pratt, 2001], the volume of the removed polar deposits would be ~6.63 x 10⁶ km³. This is a maximum estimate as it is rather unlikely that the ice cap had a constant thickness of 3 km over the entire surface area of the Dorsa Argentea Formation. If we further assume sediment/volatile ratios between one third and one half [e.g., Komar, 1980; Thomas et al., 1992; Herkenhoff, 1998], the amount of water that could be produced by melting would be of the order of 2.21-3.32 x 10⁶ km³, a volume sufficient to entirely flood the Argyre basin. However, it has to be kept in mind that this is a maximum estimate because the ice cap certainly becomes thinner towards its margins, and that only a portion of the meltwater would flow across the surface in order to pond in the Argyre basin. Significant amounts would enter the groundwater system, would remain in the pore space of the present Dorsa Argentea deposits [Head and Pratt, 2001], and large portions of the ice cap’s volatiles would go into the atmosphere. In addition, not all of the melt water would flow into the Argyre basin, but some portion would end-up in the Hellas basin [Head et al., 2001].

From numerous terrestrial and planetary examples it is well known that emplacement of thick basaltic lavas, large bodies of water or ice sheets cause subsidence of the floor of a basin or crater [e.g., Strom et al., 1975, Schultz, 1976, Solomon and Head, 1979]. We argue that flooding of the entire Argyre basin with a lake several kilometers deep would have depressed the floor, probably hundreds of meters, hence making it even harder to initiate spill over in the past compared to today.

Conclusions

In summary, we found numerous evidence for water playing an important role in the geologic history and evolution of the Argyre basin. However, this evidence does not necessarily point to a complete fill of the basin. Evidence for water in the Argyre basin are the formation of channels which can be traced to the basin floor, the morphologies at their mouths which suggests a fluvial origin, and the availability of large amounts of water generated by the meltback of the south polar ice cap. In order to initiate flow through Uzbobi Valles, the basin has to be completely filled with at least 2.1 x 10⁶ km³ of water and this is not consistent with current hydrologic models. If there was such a complete fill, probably more than 3 b.y. ago, it is not easily tested for because subsequent modification of the basin would have destroyed most of the evidence. Based on the evidence that is left, we propose that the Argyre basin was partly filled with a frozen lake during the Hesperian. In our model, Hesperian meltback of the south polar ice sheet released water, which entered the Argyre basin. The meltwater partly filled the basin floor to form a lake, which froze over. Ice thickness increased with time until the entire lake was frozen to the ground or at least until the ice became grounded in the shallower regions of the lake (i.e., close to the incoming channels). Meltwater or incoming water formed subglacial channels in which esker-like ridges were deposited. After the deposition of eskers, continued sublimation and migration of water into the substrate removed the water/ice in the basin and the eskers became visible. Eolian activity contributed to the evolution of the Argyre basin throughout its entire geologic history, mantling or exhuming morphologic features, influencing sublimation rates, and contributing to the present day morphology.

References