WATER ON MARS; M. Carr* and H. Wänke**, *United States Geological Survey, Branch of Astrogeology, Menlo Park, CA 94025, USA; **Max-Planck-Institut für Chemie, Saarstrasse 23, D-6500 Mainz, F. R. Germany.

Geological evidence for large amounts of water at the martian surface appears to be in conflict with geochemical evidence from SNC-meteorites, which indicates that the Mars mantle is dry and that Mars should have lost almost all of its initially large water inventory during accretion. We suggest here possible ways that this apparent conflict may be reconciled.

The effects of water and ice on the surface have been recognized since the early nineteen seventies (1-3). Features formed by water and ice include valley networks, large flood features, debris flows, softened terrain at high latitudes, various types of patterned ground, and layered deposits at the poles and elsewhere. While the evidence for water and ice action is clear, quantifying the amount of water present at the surface from the geologic evidence has proved more difficult. The polar layered terrain and ice caps could contain as much as 20 m of water averaged over the whole planet, and a few more meters could be contained in the weathered debris on the surface, but most of the outgassed water is probably hidden from view as groundwater or ground-ice. Carr (4) attempted to estimate the amount of water outgassed from the amount of erosion performed by the large floods. He estimated that at least the equivalent of 45 m planet-wide had flowed down the large flood channels in the Chryse region alone. Much of this water may still remain as ice deposits in low areas of the northern plains. The almost ubiquitous presence of valley networks in the old cratered terrain suggests that groundwater was not restricted to the Chryse region. Extrapolating from the Chryse region to the whole planet, Carr suggested that at least 500 m of water had outgassed from the planet, and possibly as much as 1 km. Recently much larger volumes of water have been postulated (5). Most floods and valley networks begin in old cratered terrain. This led Carr (4) to suggest that Mars may have a water-rich primitive crust that is now partly overlain by younger, relatively dry, mantle-derived volcanics.

In contrast to the geologic evidence, the geochemical evidence suggests that Mars is very dry. The SNC-meteorites, which are widely assumed to represent martian rocks ejected into free space by impact of large bodies are extremely dry. In Shergotty meteorite, for example, a H_2O content of 180 ppm was measured (6), compared to the about 2000 ppm H_2O in ocean ridge basalts. Using the Shergotty data, Dreibus and Wänke (7) estimated a concentration of 36 ppm H_2O for the martian mantle. Exactly the same figure was derived by these authors earlier in very indirect way using the halogen concentrations in SNC-meteorites and the solubilities of HCl and H_2O in silicate melts. A mantle concentration of 36 ppm water would correspond to an ocean covering the whole planet to a depth of 130 m. According to all estimates, the degassing efficiency on Mars is thought to be small and so that outgassing of the interior is likely to have provided no more than about 10 m of water to the surface.

This apparent contradiction of a very dry mantle and considerable amounts of water in the crust of the planet points towards a scenario, in which the water was added to the planet at the very last stage of accretion. Such a scenario has been proposed previously for both Earth and Mars (8). Dreibus and Wänke (7) have argued that on Earth the amount of water in the crust corresponds to a veneer of only 0.4 % of the Earth's mass, assuming a C1-composition. In light of their inhomogeneous accretion model, these authors suggested that of the total amount of H_2O added to the Earth only that portion remained, which was in excess of the amount of metallic iron available for the reaction $Fe + H_2O \rightarrow FeO + H_2$. Such an excess can only have been established at the very end of accretion at a time when most of the Earth's metal had segregated into the core. It may be interesting to note that the amount of Ir observed in mantle xenoliths corresponds also to about 0.4 % C1-material. Obviously, only that portion of Ir had the chance to remain in the mantle, which was added after metallic iron was no longer stable. Even small amounts of metal would on segregation extract all Ir from the mantle due to its highly siderophile character.

The SNC-meteorites suggest that the Mars mantle is in geochemical equilibrium with the core. Chalcophile elements such as Cu, Ni, and Co are depleted in the mantle, presumably as a result of partitioning between silicates and sulfides during core formation. This led Dreibus and Wänke (9,10) to suggest that Mars accreted homogeneously, and that its initially large water inventory was lost during core formation as the water was reduced by metallic iron to hydrogen, which was subsequently lost. If Mars did acquire a water-rich veneer in the last stages of accretion, it was not mixed deep into the mantle as in the case of the Earth, otherwise we would see higher concentrations of H_2O in the SNC-meteorites.

Why should late accretion events have affected Earth and Mars differently? There are several possibilities. The smaller size of Mars with respect to the Earth, would have resulted in proportionately less energy of accretion and core formation, less vigorous internal convection and earlier formation of a rigid crust. A significant fraction of the water-rich oxidized component could consequently have been added after a crust had formed.

It has been pointed out recently that the lack of plate tectonics on Venus might be coupled with its poverty of water making the lithosphere less deformable (11). Hence, another possibility could be that all three planets Venus, Earth and Mars did originally not drastically differ in the amount of water added as a last veneer, but only the Earth managed to keep substantial amounts of this water. The high H/D ratio of Venus (12) might indicate a large loss of water after accretion due to the reduction of H_2O to H_2, transforming FeO to Fe_2O_3 furthered by high surface temperature on Venus. Was it, that on Earth the water originally confined to the surface gradually found its way into the interior and made plate tectonics possible? Or was it a very special event which on Earth brought some water into the mantle so that plate tectonics could start? Could this event have been the collision which formed the Moon, or did the Earth actually gain its present water from the collision partner?

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