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Water on Mars: clue to accretional history. Carr, M. H., U. S. Geological Survey, Menlo Park, CA

Geological evidence for large amounts of water at the martian surface appears to be in conflict with geochemical evidence from SNC meteorites that suggests that Mars that the Mars mantle is dry and should have lost almost all of its initially large inventory of water during accretion. Several possibilities are suggested here as to how the apparently conflicting data from two sources may be reconciled.

The effects of water and ice on the martian surface have been recognized since the early nineteen seventies[1-3]. Features ascribed to the action of water and ice include valley networks, large floods, debris flows, softened terrain at high latitudes, various types of patterned ground, and several characteristics of impact craters. While the evidence for water and ice action is clear, quantifying the amount of water from the geologic evidence has proven more difficult. The polar layered terrain, ice caps, and weathered debris could contain as much as 20 m averaged over the whole planet, but most of the outgassed water is probably hidden from view as ground-ice or groundwater. Carr[4] attempted to estimate the amount of water outgassed from the amount of erosion performed by large floods. He estimated that at least the equivalent of 45 m planet-wide of water had flowed down the large flood channels around the Chryse basin. Most of this water may still remain as ice deposits at the ends of these channels. The presence of flood channels elsewhere, and the almost ubiquitous presence of valley networks in the old cratered terrain suggests that groundwater was not restricted to the Chryse region. More probably, floods were more common in Chryse because the conditions required for massive release of water were more commonly met there. Extrapolating from Chryse to the entire planet, Carr suggested that at least 500 m of water had outgassed. This may be a conservative estimate, since all the groundwater in the Chryse region is unlikely to have been brought to the surface. However, the estimate could be in error if the water that participated in the floods was recycled.

In contrast, the geochemical evidence suggests that Mars is very dry. Estimates of the outgassed water inventory from ^{15}N, ^{36}Ar and D/H in the atmosphere range from 3-130 m, with the lower values being preferred. These estimates have been critically reviewed elsewhere[6], and are suspect because of the possible loss of atmospheric gases through hydrodynamic escape and impact erosion, and because of the rapid evolution of D/H in the atmosphere, as a result of limited exchange of water with the surface. The SNC meteorites, which are widely assumed to represent martian rock ejected into free space by impact of large bodies are extremely dry. Shergotty, for example contains only 180 ppm H_2O[7] as compared with an average of 2100 ppm in terrestrial ocean ridge basalts. From this value Dreibus and Wanke[8] estimated that the mantle contained 36 ppm water. They also estimated water in the martian mantle from Cl in SNC meteorites. By comparing the relative solubilities of Cl and H_2O in silicate melts, and assuming that no water was left on the martian surface at the end of accretion, they estimated that the Mars mantle contained 36 ppm H_2O, fortuitously the same value they had derived from direct measurements of water in the meteorites. Thus the geochemical evidence suggests that the Mars mantle is dry relative to the Earth's.

A dry martian mantle is consistent with other geochemical reasoning. The Earth and Mars are both thought to have accreted from two different components: component A, a highly reduced, volatile poor, metal-bearing component, similar in composition to enstatite chondrites, and component B an oxidized, volatile rich component similar to carbonaceous chondrites[9]. During accretion, most of the water in the volatile rich component would have reacted with metallic iron in the volatile poor component to form FeO and H_2 which would have escaped. On Earth, chemical disequilibrium between the upper mantle and core suggests that part of the volatile rich component was added late, after the core formed. The SNC meteorites suggest that Mars had a higher proportion of the volatile rich component, but the Mars mantle, in contrast to the Earth's, is in equilibrium with the core. There is no evidence of the volatile rich veneer. Most of its water should, therefore, have been lost by reaction with metallic iron. Thus the low estimates of water in the Mars mantle are consistent with geochemical models for how the planet accreted.

The apparently conflicting evidence of a wet surface with a dry mantle may be reconciled in various ways. The Mars mantle may be dry, in part, because of the lack of plate tectonics. It is not known to what extent the water in the Earth's mantle has been derived from the surface. Jambon and Zimmerman[10], suggest that there are two sources of mantle water, subducted crust, and juvenile mantle sources, which they estimate contain 200-300 ppm. Thus, although their estimates of the water content of juvenile mantle sources is still higher than the estimates for the martian mantle, part of the contrast between the mantles of Earth and Mars is probably due to plate tectonics.

Mars, like the Earth, may have acquired a late volatile rich veneer, but the mantle contains no evidence of this veneer because the volatile-rich near-surface materials have not been folded into the mantle by plate subduction. If one percent of Mars accumulated late, after core formation, then the equivalent of 2.7 km of water would have been added. Because of the lack of plate tectonics, this could still remain close to the surface and not have affected the chemistry of SNC meteorites, with magma sources deep within the planet. Thus Mars would have been left with a volatile rich crust and a dry mantle, in chemical equilibrium with the core.

The accretional history of the two planets may have contributed to their contrasting water distributions. Modelling of accretion by Matsui and Abe[11] suggest that as the Earth accreted water started to accumulate at the surface by impact degassing by the time the planet had reached about one fifth of it present radius. Ultimately, a steam atmosphere formed, thereby insulating the surface. Surface temperatures rose, the surface melted, and water in the atmosphere was able to dissolve in the surface melts and become distributed through the mantle. As the accretion rate tapered off, the surface cooled and the water condensed to form the oceans. However, much of the water in the steam atmosphere was lost by hydrodynamic escape and by impact erosion of the atmosphere. For Mars, the models give very different results. Impact degassing begins at roughly two fifths the present radius, but for plausible accretion rates, a steam atmosphere never develops. The degassed water remains condensed on the surface, and the surface never melts, so water does not dissolve into surface melts and become distributed through the mantle. On Mars, because a steam atmosphere never develops, loss of water by hydrodynamic escape and impact erosion of the atmosphere should have been suppressed. At the end of accretion Mars could have had a dry mantle but a water-rich surface.

These considerations indicate that there are several plausible explanations for the apparent conflict between the geochemical evidence of little water on Mars and geologic evidence of abundant water. The contrast is a reflection of the contrasting accretional histories of the two planets and their contrasting tectonics. One possible conclusion is that Mars has a primitive volatile-rich crust that has been partly overplated with young, dry, mantle-derived volcanics of which we have samples in the SNC meteorites.

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