

MARS 89 - 10822

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WATER ON MARS . H. Wänke and G. Dreibus, Max-Planck-Institut für Chemie, Saarstrasse 23, D-6500 Mainz, F.R.Germany.

With the assumption that the SNC-meteorites are indeed Martian rocks, these meteorites allow very definite conclusions about the bulk composition of Mars. Figs. 1 and 2 show correlations of the moderately volatile K and of the volatile Br with the refractory element La. As to a first approximation one can assume C 1-abundances for the refractory elements for all terrestrial planets, these correlations clearly indicate higher abundances of moderately volatile and volatile elements on Mars as compared to the Earth. In the case of Br, the difference may actually be smaller as on the Earth the oceans represent such an ideal reservoir for Cl and Br that today the major portions of the whole terrestrial inventory of Cl and Br reside in the oceans.

According to the two component model for the formation of terrestrial planets as introduced by Ringwood (1,2) and slightly modified by Wänke (3), the composition of these planets can successfully be described as mixtures of: Component A: Highly reduced and free of all elements with equal or higher volatility than Na, but containing all other elements in C 1-abundance ratios. Fe and all siderophile elements and even Si partly in metallic form. And Component B: Oxidized and containing all elements - including the volatiles - in C 1-abundances. Fe, all siderophile and lithophile elements as oxides.

From the analytical data of SNC-meteorites (4,5), Dreibus and Wänke (6,7) concluded that the mixing ratio of component A/component B for Mars is 60:40, compared to a ratio of 85:15 for the Earth. They further concluded that Mars accreted almost homogeneously contrary to the inhomogeneous accretion of the Earth, as proposed by Jagoutz et al. (3) and in more detail by Wänke (3).

On Mars because of the homogeneous accretion almost all H₂O added (from component B) reacted with metallic Fe (and, of course, with other metallic phases like Si of component A) and was reduced to H₂ which escaped. The huge quantities of H₂ will not only have greatly accelerated the extraction of gaseous species from the interior of the planet but also have furthered the removal of these species from the gravity field of the planet due to hydrodynamic escape by keeping the mean molecular weight of the atmosphere low. Hence, in their estimate of the amount of H₂O left on Mars after accretion, Dreibus

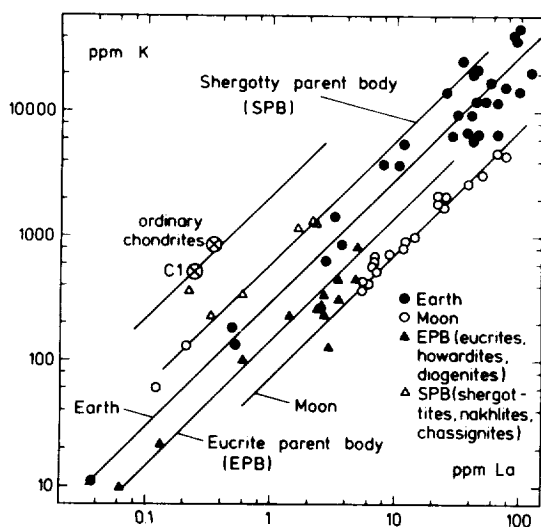


Fig. 1
Morgan and Anders, 1979 (19); Morgan and Anders, 1980 (20); Wänke, 1981 (3)

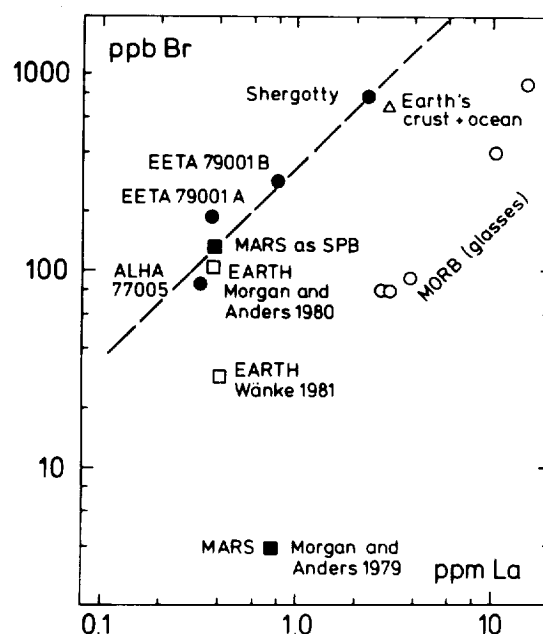


Fig. 2

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and Wänke (7) assumed that at the end of accretion the concentration of H_2O and other volatiles at the surface of the planet was zero. From the Br/La concentration (Fig. 2), they could calculate the absolute amounts of Cl, Br and I on Mars using C 1-abundance ratios of Cl/Br and I/Br. In this way, they found for Mars an absolute Cl concentration of 34 ppm. Assuming the composition of component B to be identical to that of C 1-meteorites, 320 ppm Cl were actually added to the planet, of which all except the 34 ppm was lost during the accretion process together with H_2 and other gases, yielding a depletion factor for Cl of 0.11.

During accretion even the relatively small Mars was heated to temperatures which probably led to partial melting of the silicates (9). Nevertheless we have to expect that the solid or liquid phases of the planets' interior were in solubility equilibrium with the temporary atmosphere during the accretion process. The solubility of HCl in basaltic melts exceeds that of H_2O by about a factor of 200 (10), yielding for H_2O a depletion factor of $0.11:200 = 5.5 \times 10^{-4}$. C 1-chondrites contain about 20% H_2O , however, the preterrestrial H_2O content is only 4.5% (11), the rest is mainly terrestrial contamination. Hence, in order to find the composition of component B which we assume to be identical to C 1-chondrites, we divide the C 1-values by 0.85. During accretion the hydrogen of the hydrocarbons of the C 1-material will at an intermediate stage also be present in form of H_2O . For the following, we will therefore use a C 1-concentration of 7.1% H_2O as deduced from the H abundance of 7900 ppm (12). With this value we find that 3.3 % H_2O was added to Mars during accretion. Together with the depletion factor of 5.5×10^{-4} , we find that a total of 18 ppm H_2O was retained in the interior of the planet corresponding to 23 ppm H_2O in the mantle. Making the unrealistic assumption of a 100% release, this would yield a water layer of 80 m covering the whole planet.

From SNC-meteorites a value of 247 ppm K for bulk Mars is obtained (6,7), leading to a total of $1840 \times 10^{-8} \text{ cm}^3/\text{g}$ ^{40}Ar produced in 4.5×10^9 years. The observed amount of ^{40}Ar in the Martian atmosphere corresponds to $48 \times 10^{-8} \text{ cm}^3/\text{g}$. Hence, if we neglect a possible loss of ^{40}Ar from the atmosphere into space, we find a release factor for ^{40}Ar of 0.026. Assuming the release factor of H_2O to be identical to that of ^{40}Ar , we derive at a water layer of 2.1 m or a total of $0.3 \times 10^6 \text{ km}^3$. The low ^{40}Ar concentration in the Martian atmosphere leading to the very low release factor may be in part due to removal of ^{40}Ar from the atmosphere by energetic impacts in geologic time (13). Hence the release factor would in fact be higher than 0.026 and consequently the amount of water at the surface of Mars would become higher, too.

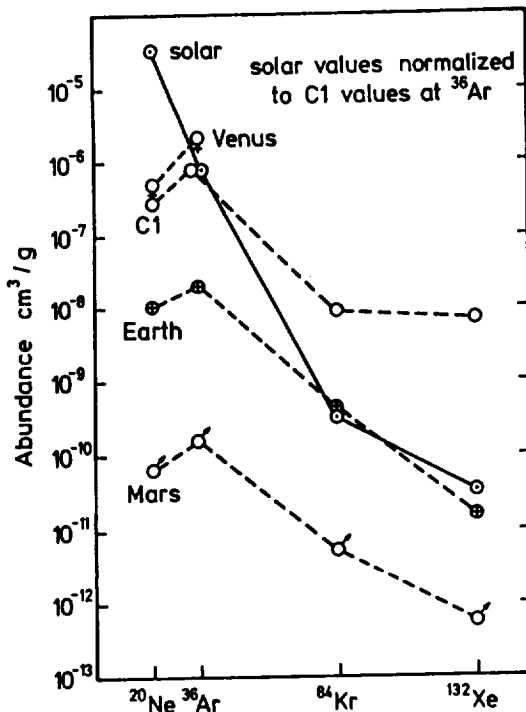
The assumptions made above may not be as unrealistic as they might sound at first sight. Because of the even smaller Cl abundance on Earth compared to Mars only a small fraction of the total H_2O of the Earth could be explained in this way. However, the Earth probably accreted inhomogeneously. According to the model of Wänke (3), the accretion of the Earth started with the highly reduced and volatile-free material of component A. After the Earth had reached about 60% of its present mass more and more of the oxidized component B was added. However small amounts of metal still present were responsible for the extraction of highly siderophile elements (Ir, etc.). Towards the very end of accretion metal became unstable, hence, even the highly siderophiles remained in the mantle in their C 1-abundance ratios. The concentration of 2.8 ppb Ir in the Earth's mantle equal to 1.9 ppb Ir for the whole Earth, corresponds to 0.39% C 1-material. With a C 1 H_2O content of 7.1%, we find that 280 ppm H_2O were added to the Earth after metallic iron respectively Ni became unstable. These 280 ppm remained in form of water while of the much larger amounts of the water (~1%) added before metal became unstable almost all was converted

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to H₂. Hence, we would expect a total H₂O content of the Earth of about 300 ppm. The contribution of the crust (mainly the oceans) to the bulk Earth H₂O content is already close to 300 ppm so that very little would remain for the contribution of the mantle. However it seems likely that this contribution is indeed much smaller as generally assumed. Of the total halogen inventory of the Earth more than 90% were found to be concentrated in the crust. A similar distribution is expected for water.

The large amounts of H₂ generated during accretion may have removed most of the primordial rare gases delivered by component B so that even these gases were contributed predominantly by the 0.39% C 1-material added at the very end of accretion. The 0.39% C 1-material would bring $0.29 \times 10^{-10} \text{ cm}^3/\text{g}$ ¹³²Xe to the bulk Earth compared to $0.16 \times 10^{-10} \text{ cm}^3/\text{g}$ ¹³²Xe present in the atmosphere. Most of the Earth's ¹³²Xe inventory is certainly in the atmosphere, nevertheless a surprisingly good agreement, considering the large uncertainties in our exercise. In the case of ³⁶Ar only 16% of the $210 \times 10^{-10} \text{ cm}^3/\text{g}$ ³⁶Ar in the Earth atmosphere could be derived by 0.39% C 1-material. However we have the strong suspicion that in respect to rare gases the C 1-chondrites of today do not represent the material actually added at the accretion stage of the terrestrial planets. As about 90% of the radiogenic ⁴⁰Ar produced during the 4.5×10^9 yrs was obviously lost from C 1-chondrites by diffusion a similar loss of ³⁶Ar may be inferred. Preferential diffusion loss of Ne, Ar, and Kr relative to Xe would also explain the striking difference of Kr/Xe-ratios in Earth and Mars as compared to that in C 1-chondrites (Fig. 3). In this way, the "Xe problem" might be solved (14-18).

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(Fig. 3)