ACCRETION OF THE EARTH'S WATER BUDGET AND ATMOSPHERIC CRATERING;

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Cameron (1983) pointed out on the basis of the present variability among the terrestrial planetary atmospheres, $^{36}Ar/^{40}Ar$, D/H, and other noble gas isotopic ratios, that a large fraction of initial planetary volatile inventories may have been lost during accretion via infall of planetesimals in a process he named "atmospheric cratering." We examine this process by applying: (1) the results of shock devolatilization experiments on both pure hydrous and carbonate minerals (Lange and Ahrens, 1982b; Lange et al., 1985; Lange and Ahrens, 1985) which occur in carbonaceous chondrites, and carbonaceous chondrites (Frisch and Ahrens, 1984; Frisch et al., 1985), and (2) calculations of the energetic and dynamics of large body impact onto silicate- and water-covered planetary surfaces (O'Keefe and Ahrens, 1977a, b, 1982, Ahrens and O'Keefe, 1983). In order to explore the accretion of water and silicate and avoid the complication of the water-iron reaction (Ringwood, 1979; Lange and Ahrens, 1982a, 1984) we consider accretion of serpentine-bearing planetesimals forming a mantle about a 3000 km core. Infall (escape) velocities of 3.6 km/sec allow the onset of impact volatilization of the hydrous-bearing minerals in the planetesimals. Partial devolatilization takes place until the earth reaches a radius ~ 5000 km and impact pressures of > 600 kbar. The partial pressure of water in equilibrium with serpentine (Robie et al., 1978) is described in terms of post-impact temperature. At this stage the earth's interior retains some 30 ocean masses of H_2O. Surface temperature is calculated by assuming the primordial atmosphere is in radiative equilibrium with its uppermost layer at 252K (Goody and Walker, 1972). Continued infall, without atmospheric erosion, will release some 18,000 optical thicknesses of water and surface temperature will rise to 2940 K at 1 earth mass (Fig. 1). We employ an optical constant of 0.1 cm^2/g (Ingersoll, 1969), as compared to 0.01cm^2/g assumed by Matsui and Abe (1984) in a similar calculation. Taking into account an atmospheric cratering model in which M_e, is the mass of escaping atmosphere which results from accretion of a planetesimal of mass M_p, yields

$$\log_{10}(M_e/M_p) = -1.8 + 0.81\log_{10}(V, \text{km/sec})$$

where V is the infall velocity. We calculate that ~ 600 ocean masses of H_2O are eroded from the H_2O primordial atmospheres during accretion of the earth (Fig. 2). Although some 3000 optical thicknesses of H_2O remain in the primordial atmosphere at the end of accretion, the final surface temperatures achieved are only 1890 K (Fig. 1).

Atmospheric cratering can easily account for huge losses of volatile inventories by factors of 10^2 to 10^3 during the accretion of the terrestrial planets.

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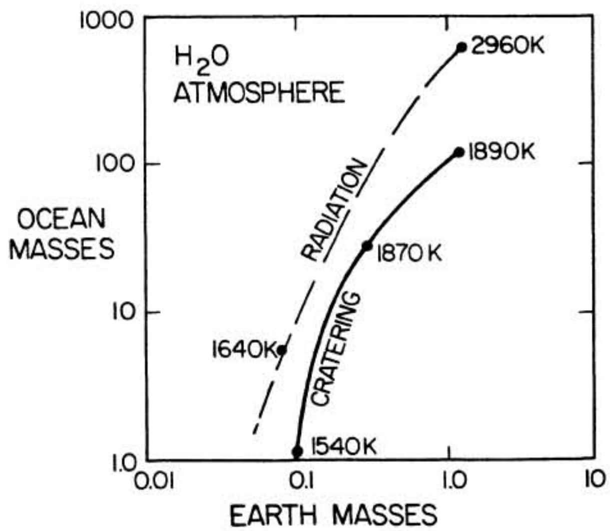

Figure 1. Accumulation of primordial atmosphere by impact of serpentine-bearing planetesimals. Temperatures indicated are surface values. "Radiation" curve indicates only radiative removal of heat, whereas "Cratering" curve takes both radiation and atmospheric cratering into account.

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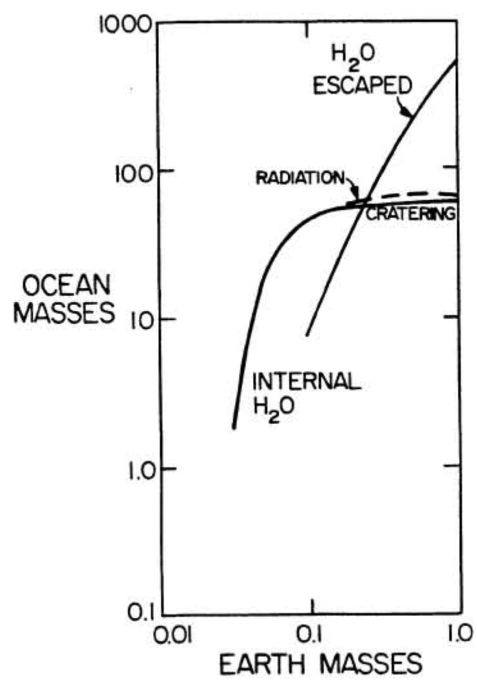

Figure 2. Internal earth water budget and total water escaped via atmospheric cratering versus planet mass. Internal water budget is insensitive to atmospheric model and depends critically on shock devolatilization of hydrous phases.

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