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Preliminary isotopic hints for the role of early micrometeorites in the formation of the Earth's hydrosphere:

EMMA (Early MicroMeteorite Accretion) is a scenario developed to account for various effects of large interplanetary dust particles ("micrometeorites") in the inner solar system during the period of heavy bombardment (*PHBomb*) that occurred just near the end of the formation time interval of the Earth of about 100Ma [see ref. 1 and 2, and all previous useful references herein].

Micrometeorites suffer a frictional heating during their short aerodynamically braking which is essentially effective in the thermosphere (between ≈90 and ≈150 km of elevation) where they release their volatile species. EMMA can be assimilated to a new type of "cosmic-diffuse-global" volcanism anchored in the thermosphere, with fall-out products settling down to the Earth's surface to form the hydrosphere. In conventional models the hydrosphere is formed either from classical volcanism originating from the upper mantle or from a late veener of an ad-hoc mixture of planetesimals exploding like TNT upon impact.

The average isotopic composition of neon in micrometeorites ($^{20}Ne/^{22}Ne$ ≈11.8), which is now defined from both our measurements and those of our Japanese colleagues [3], is rather similar to that deduced for solar energetic particles (SEP), and consequently would fit the "solar" composition postulated for neon on the early Earth [4]. Moreover, the D/H ratios of the constituent water of the hydrous silicates of micrometeorites are very similar to the SMOW value measured for the terrestrial oceans [see figure 4 in reference 1]. These observations already suggested that early micrometeorites were involved in the formation of the Earth's hydrosphere.

But we had to estimate the total amount , $\mathbf{M_A}$, of the volatile species, **A** (at least neon and water), released upon frictional heating of micrometeorites during the peak of the *PHBomb* (between 4,45 et 4,35 Ga ago). The major problem was to deduce the variations of both the composition and the huge mass flux of early micrometeorites with time. This took us about a decade of work.

Early micrometeorites during the period of heavy bombardment: assessment of their origin, mass flux and composition:

To both assess the origin of early micrometeorites and compute their mass flux as a function of time, we learned how to exploit the exponential decay with time of the lunar cratering rates, **K(t),** as given in fig.6.6 of Hartmann [5]. This decay yields the half-life, • , of the population of impactors that bombarded the lunar surface, of about 100Ma. This value can be compared with the half-lifes computed by the group of Alessandro Morbidelli (Observatoire de Nice, France) for asteroids and comets from the Edgeworth-Kuiper belt, of ≈1 and ≈100 Ma, respectively. Consequently, the impactors of the *PHBomb* were comets. They were generating interplanetary dust (i.e., the future early micrometeorites) by the process also effective to day, the sublimation of their dirty ices. Our basic assumption is that the flux of early cometary micrometeorites was directly proportional to the number of comets. It thus suffered a similar relative amplification and decay, which is thus scaled directly by the **K(t)** curve of Hartman.

If Antarctica micrometeorites are indeed cometary dust particles [see recent arguments in ref. 6] it is very likely that the composition of the micrometeorites flux was invariant with time, because the comets we see to day are similar to the juvenile comets that did craterize the Moon. Indeed juvenile and contemporary comets have been formed at the same time, in the same zone, with similar ingredients. Measurement of Ge/Ir vs Au/Ir ratios in the lunar soil 76] as well as the discovery of microclasts of hydrous-carbonaceous materials in HED meteorites [8] indicate that the composition of early micrometeorites was also dominated by an hydrous-carbonaceous material (CM2 and CR2 types) up to at least 4.2 Ga, thus being similar to the material we collect to day. We can thus extrapolate to early micrometeorites the chemical and isotopic compositions of volatile species measured in Antarctic micrometeorites, in order to compute $\mathbf{M_A}$.

The elementary arithmetic's of accretion: formation of the hydrosphere:

In the first two versions of EMMA [1, 2] we did use a very simple formula which is still valid as a first approximation: $\mathbf{M_A(g) \approx A(\%) \times Ø_0 \times K_{max} \times \lambda}$, where $\mathbf{M_A(g)}$ is the total mass of species A injected in the atmosphere by micrometeorites; **A(%)** is the average content (in wt %) of species **A** in micrometeorites; $\mathbf{Ø_0}$ the contemporary flux of micrometeorites of about 40,000 tons per year for the whole Earth [9]; $\mathbf{K_{max}}$ the average value of the amplification factor (≈10^6) of the micrometeorite mass flux relative to the present day value during the peak of the *PHBomb*; **$\lambda \approx$100 Ma** the duration of this peak , approximated by the half-life of the population of juvenile comets. More recently, one of us [10] reported a more analytical computation, which integrates the contribution of the micrometeorite flux alongl the K(t) curve of Hartman between 4.45 and 3.9 Ga. This integration yields a simpler formula:

$$\mathbf{M_A\ (g) \approx A(\%)\ x\ 5{,}6.10^{24}\ g}$$

In table I we reported: - in column 1 the four volatile species considered in this paper; - in column 2 the values of $\mathbf{M_A}$ estimated with our simple arithmetic's; - in column 3 the corresponding values measured in the present day atmosphere and oceans of the Earth. In this table the amount of CO_2 was transformed into carbonates, with the present day value corresponding to an initial pressure of CO_2 on the early Earth of ≈60 bars.

For neon we give a minimum and a maximum values, corresponding respectively to the average value measured in all type of micrometeorites dominated by a fine-grained material ($\approx 10^{-5}$ cc STP/g), and to the higher average value (x3) measured in the most retentive "crystalline" micrometeorites constituted of a few single crystals of olivine and pyroxene.

For water we reported again a minimum and a maximum values, considering first the water content of the hydrous silicate of micrometeorites (about 10% wt), and then adding the maximum quantity of water that would be released during the full oxidation of the carbonaceous material.

For nitrogen we use a value of its concentration (A ≈0.1%) which corresponds to the limit of sensitivity of our technique of electron energy loss spectroscopy associated with a TEM, which allowed to see very weak nitrogen peaks just above background in EELS spectra.

About CO_2 , that will finally end up as carbonates in sea sediments, we bracketed its mass between the minimum value produced during the decrepitation of the constituent carbonates of micrometeorites (1/3 rd of the total carbon) and the maximum value obtained by adding the quantity of CO_2 that would be produced during the full oxidation of the carbonaceous material (2/3 of the total carbon).

Preliminary implications:

The similarity between the predictions and the observed values for neon, nitrogen and the carbonates is amazing and unexpected (see table I). But for water we observe a slight deficit by up a factor of 2. So, with a simple model which don't rely on any adjustable parameter we account for the very heteroclite mixture of Ne , N_2 , H_2O and carbonates observed on the Earth's hydrosphere to day, even so the contents of neon and water in micrometeorites differ by a factor of about 10^7 !

Such a similarity confirms that the planetesimals that did form the Earth were made of a very dry material. Otherwise too much material would have been injected by conventional volcanism in the Earth's hydrosphere as to offset the delicate balance predicted by EMMA. In other companion papers [11, 12, 13] we present several astonishing implications of EMMA, considered as a kind of early cosmic volcanism "falling from the sky".

A significant result about the neon and nitrogen contents is the extreme depletion of the Earth atmosphere in ^{20}Ne, as illustrated by the $^{20}Ne/N_2$ ratio, which is about 100,000 times smaller than the solar value of ≈0.5. The paradox of this extreme depletion is that only micrometeorites with both their high Ne content and their low N content yield the <u>highest ratio</u> on the Earth, which only fits <u>the very small ratio</u> measured in the present day atmosphere.

Tableau I: Volatiles in the Earths'hydrosphere
$\mathbf{M_A\ (g) \approx A(\%)\ x\ 5.6.10^{24}}$

Gas, water and carbonates	M_A	Hydrosphere
Ne	$(5.6\text{-}17).10^{16}$	6.10^{16}
N_2	$\approx 5.6.10^{21}$	4.10^{21}
H_2O	$(0.5\text{-}1.4).10^{24}$	$1.4.10^{24}$
$CO_2 \Rightarrow$ carbonates	$(0.6\text{-}1.7).10^{24}$	$0.75.10^{24}$

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