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An Early Meteoroid Veneer for the Formation of the Earth's Atmosphere

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Abstract

The predicted burden of meteoroid sulfur released upon atmospheric entry as SO_2, since the formation of the Moon, well matches that measured in the Earth's upper mantle. This match strengthens the meteoroid origin of the Earth's atmosphere, and yields new hints about the onset of a benign Earth's climate since ~4.3 Ga ago.

The Meteoroid "Purity" of the Earth's Atmosphere

A Meteoroid "shooting star" volcanism

Meteoroids with sizes ~50–200 µm represent the dominant mass fraction of the extraterrestrial material accreted by the Earth. Upon atmospheric entry, along their deceleration ranges around the mesopause, meteoroids produce ~10 km–long trails of hot gases and "smoke" particles, which generate a meteoroid shooting star "volcanism", erupting from the mesopause. Those that survive upon atmospheric entry can be recovered as hydrous–carbonaceous micrometeorites from Antarctica ices and snows (*AMMs*). We already discussed the meteoroid origin of the "global" Earth's atmosphere [1, 2], which referred to all conventional volatiles in surface reservoirs, including air, water and sedimentary rocks (carbonates), in which early CO_2 is trapped. This definition has now been extended to SO_2 [2, 3], which is now stored as "base-metal" sulfides in the primitive upper mantle [4].

Comparison of relative abundances

The composition of any atmosphere can be defined by the mass mixing ratios (relative abundances), **R**(A) = **M**(A)/**M**(N_2), of its known species, A, relatively to N_2 (just excluding O_2, which appeared ~2 Ga later on the Earth). Moreover, for a pure meteoroid atmosphere, **R**(A) is given by the ratio of the mean wt.% concentrations of A and N_2 in *AMMs* (*c.f.*, the accretion equation in Ref. 3). These concentrations have been directly measured for Ne (2 x 10^{-6} %), N_2 (0.07%), C (2.5%) and S (5%). CO_2 and SO_2 have been produced during a kind of full "in–situ" oxidation of meteoroid C and S at high temperatures (*c.f.*, Ref. 5, 4th section). The concentration of H_2O (~10%) in *AMMs* has been inferred from the identification and the abundance (~20%) of the major hydrous silicate of *AMMs* (saponite). One finally gets the relative abundances that characterize a "pure" meteoroid atmosphere (*c.f.*, second line in Table 1). The measured values of **R**(A) reported for the Earth's atmosphere (third line) have been deduced from the available **M**(A) values measured for: **Ne** and **N_2** in the air; **H_2O** mostly stored in the oceans; **CO_2** trapped as carbonates in the crust [6]. We just added **SO_2** corresponding to the *PUM* sulfur [3].

Table I: Relative abundances, **R**, relatively to ***N_2***

Type	Ne	H_2O	CO_2	SO_2
Meteors	3 x 10^{-5}	140	130	143
EARTH	**1.6** x **10^{-5}**	**350**	**83**	**127**
# 3	?	380	21	1.1
# 4	?	2000	6.6	1.2
# 5	?	10	4	4.4
# 6	?	17	2.6	0.06
# 7	10^{-8}	78	50	1.5

Table I also shows the relative abundances of the same species in 5 other types of model atmospheres, including: **#3**, the classical average volcanic outgassing of Rubey [7], which was popular during ~30 years; **#4**, geysers and fumaroles [8]; **#5**, Hawaiian volcanoes [8] that would also yield a model for the Tharsis bulge volcanism on Mars; **#6**, the impact of comets [9]; **#7**, the impact of CI–type asteroids [10]. The critical Ne mixing ratio was not previously reported for models **#3** to **#7**. The very low value

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quoted for model **#7** (about 100–1000x smaller than the measured value), which invalidates it right away, was derived in Ref. 1 (section 8.3). The meteoroid atmosphere (line 2) best fits the measured composition of the Earth's atmosphere (line 3), which thus shows a meteoroid "purity". This is further supported by the average D/H ratio measured by C.Engrand for the constituent water of 67 AMMs, which best fits the measured "SMOW" value of the oceans (*c.f.*, Ref. 1, Fig. 22). The compositions of the 5 other atmospheres reveal severe misfits, especially when the Ne/N_2 and SO_2/N_2 ratios are considered.

The Onset of a CO_2 "Greenhouse–Control" of a Benign Hadean Climate

Rather similar giant input rates of meteoroid H_2O, CO_2 and SO_2 (~5,000 Mt/yr) are predicted on the Earth, during the first ~100 Ma of the post–lunar early Eon. They define a very long duration *super–eruption*, like that of Toba, which produced a severe volcanic winter during ~5 years [11]. But the meteoroid volcanic winter lasted ~100 Ma and not 5 years! How could liquid water appear on a likely frozen Earth, at the time of the "faint" early Sun? Hot water vapour released along the meteoroid deceleration range in the coldest zone of the upper atmosphere (mesopause), likely formed tiny ice crystals. The resulting clouds were probably related to the "noctilucent" clouds, also made of ice crystals, which are observed today around the mesopause. They likely nucleated sulfate aerosols (inherited from meteoroid sulfur released as SO_2), which did rain on the Earth (either as liquid droplets or dirty hail stones). They were constantly replenished by meteoroid outgassing during the first 100–200 Ma of the post–lunar period. Gradually, the greenhouse effect of CO_2 took over as to melt the acidic hail stones that formed highly acidic oceans.

The low (pH ~0) of the nascent oceans inhibited the precipitation of CO_2 into carbonates. It also triggered the heavy weathering of the early sialic crust, required for the birth of old zircons, around 4.3 Ga ago [12]. But the warming due to CO_2 had to stop, as to avoid a hot Venusian fate. It was probably regulated through the gradual scavenging of meteoroid sulfur in the upper mantle altogether with refractory highly siderophile elements (*c.f.*, Ref. 3, this issue). The pH of water steadily increased up to the critical value (~6) when CO_2 starts precipitating as carbonates. Simultaneously, the meteoroid delivery of SO_2 and CO_2 was sharply decaying by a factor of ~100 during the first 200 Ma of the post–lunar period, while following the decay of the Hartmann–Neukum lunar cratering rates (*c.f.*, Ref. 1, Fig. 1). This likely initiated the long–term CO_2 "greenhouse" control of the benign Earth's climate required for the birth of life. Oddly enough, the contemporary climatic changes also involve similar ingredients, now engineered by man, and present as trace constituents in our "thin" 1 bar atmosphere.

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