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Primordial Degassing of Earth

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Abstract

Primordial Degassing of Terrestrial Planets: the Case for Reduced Carbon Compounds on the Early Surface.

A multiplicity of potential sources, degassing processes and events, and physical-chemical conditions leads to a bewildering array of scenarios and models for the outcome of degassing of the early atmospheres of terrestrial planets. For more than five decades geological, theoretical and experimental evidence seem to have converged on the conclusion that initially surviving terrestrial atmospheres were dominated by CO_2-N_2. Consideration of the chemical nature of the materials most likely to have been major contributors of planetary volatiles suggests not only the likelihood of substantial loss of the earliest atmosphere, but that most of the extant atmosphere probably resulted from the last 1-2% of planetary accretion. Detailed examination of the processes and physical-chemical conditions associated with late accretion suggest that Earth's earliest permanent atmosphere contained highly reduced carbon (and nitrogen?) species. The instability of methane and ammonia under ultraviolet radiation would have rapidly produced a large pool of condensed C-H-N-O compounds, rained out into a primordial ocean. Such a scenario inevitably leads to the production of pre-biotic compounds in concentrations especially favorable for the quick emergence of life. A large, early organic carbon reservoir at Earth's surface leads naturally to models of surface and near-surface chemistry more consistent with the geologic record than an atmosphere dominated by CO_2-N_2.

Volatiles on and near Earth's surface

Volatiles on Earth. Sizes of various surface reservoirs of volatiles and other important components on Earth, including some important rates of transfer of components significant to photosynthetic activity.

H_2O in hydrosphere	**1.4×10^{24}g**
H_2O in sediments	**1.5×10^{23}g**
Total C in crust	**7.0×10^{22}g**
Carbonate rocks in crust (equiv. C)	**6.0×10^{22}g**
CO_2 in atmosphere	**4.5×10^{18}g**
CO_2 production from volcanoes	**1.0×10^{14}g/yr**
Oxygen in atmosphere	**1.2×10^{21}g**
Nitrogen in atmosphere	**4.0×10^{21}g**
Nitrogen in crust	**1.4×10^{21}g**

The CO_2 hypothesis is supported by:

1) Rubey's analyisis of geology
equilibria during magmagenesis (after core forms)
2) Chemical
3) Shockwave experiments - Impact degassing
4) Venus and Mars - mostly CO_2 atmospheres

BUT...

What *were* the prevailing conditions during early degassing?

And, just *what* was being degassed?

The source of the volatiles

Antarctic meteorites. (Grossman, 1994).

- Stony-irons are not included separately, as they comprise only about 1% of the total mass. Achondrites are lumped as stony meteorites. Carbonaceous chondrites are listed separately because of the importance of their volatile components.

Type	Mass (g)	% by mass
Stony meteorites	2306214	85.1
Irons	370779	13.7
Carbonaceous Chondrites	32537	1.2

Volatiles in meteorites

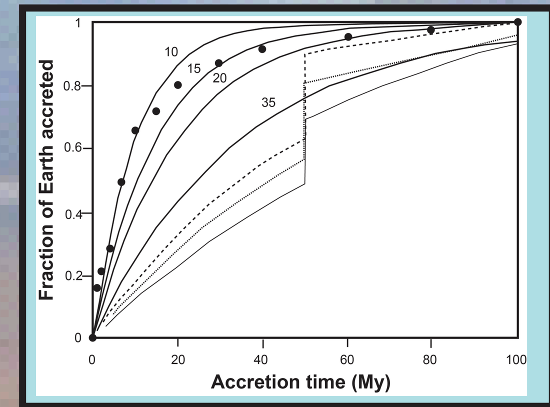
Meteorite	H	C	N
C1 (Orgueil)	2.02	3.22	0.32
CM chondrite		0.35	
H chondrite	0.32	0.12	34 ppm
L chondrite	0.34	0.16	34 ppm
LL chondrite	0.6	0.235	50 ppm

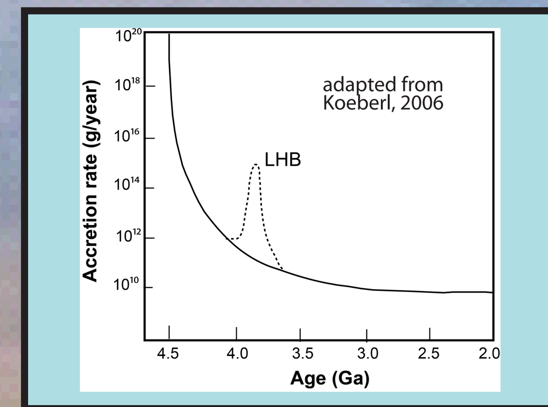
In wt% except as indicated. (Palme and O'Neill, 2003; Bradley, 2004; Schaefer and Fegley, 2007).
H for last three as water.

There was certainly metal in the late impacting material.

And, there was certainly metal in the "late veneer".

Conditions during and after impacts

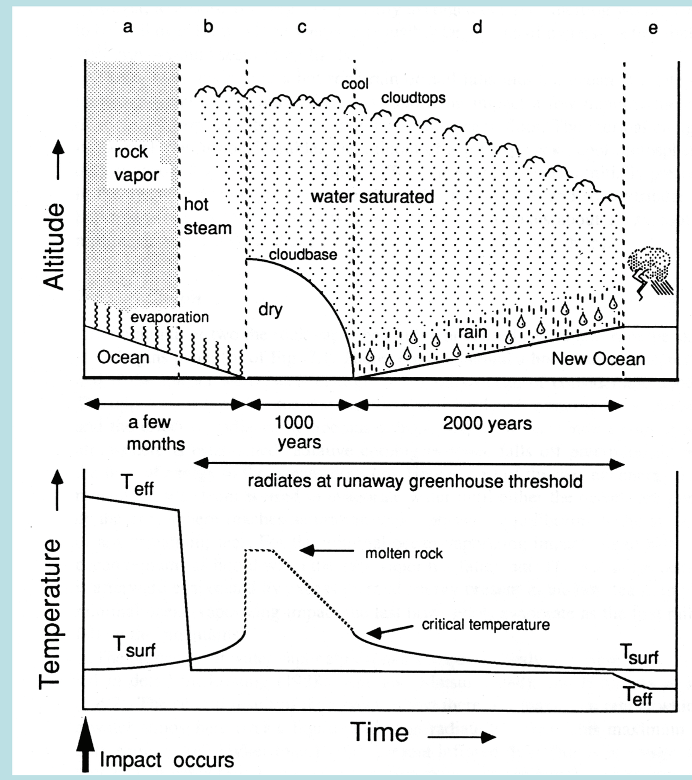




The late accretionary tail can account for all of the known surface volatiles on Earth. The volatiles in 1-2% of Earth's total mass from an average meteorite mix are sufficient.

Post-impact conditions for large impacts.

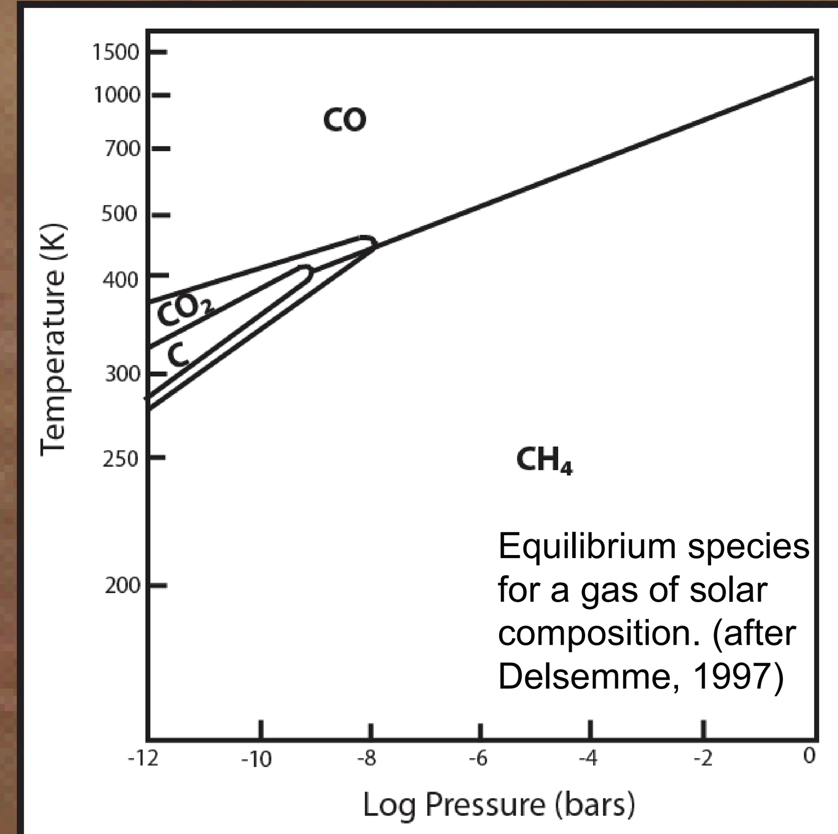
(after Zahnle & Sleep,1997)



High temperature conditions in the post-impact atmosphere do not persist long enough to result in a CO_2-rich atmosphere!

Post-large-impact atmosphere scenarios

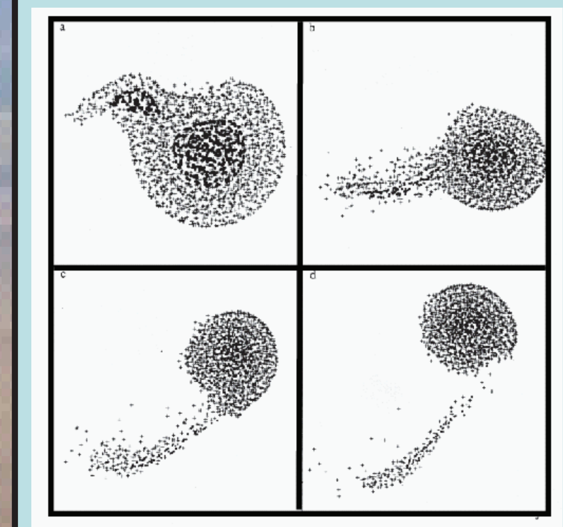
Impactor diameter (km)	Impactor mass (gm)	Possible H_2 Produced (gm)	H_2 pressure (bar)	T (K)	Time until T drops to 650 (years)	H_2 loss while T drops (gm)
ca. 3000	ca. 4×10^{25}	4×10^{23}	120	2500+	2500+	10^{17} +
500	2×10^{23}	2×10^{21}	.6	2000+	1000-	4×10^{16}
50	2×10^{20}	2×10^{18}	.0006	?	1-10?	4×10^{14}

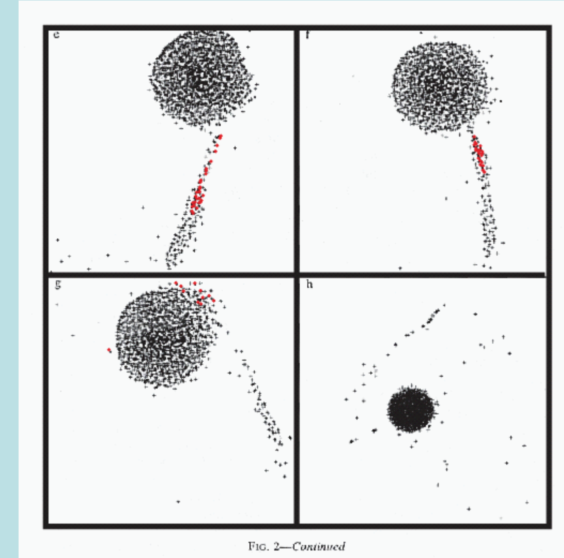


Equilibrium species for a gas of solar composition. (after Delsemme, 1997)

Conditions attending late veneer degassing

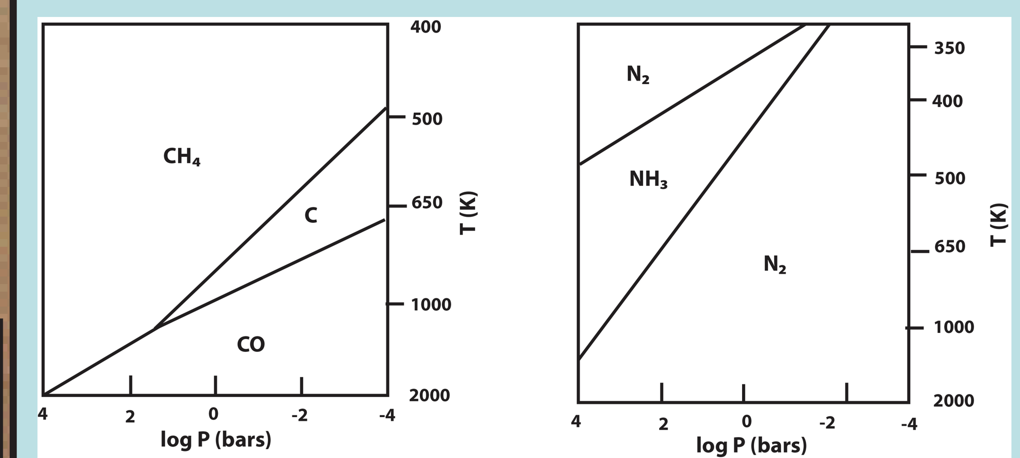
Large impact aftermath. (after Benz, Cameron and Melosh, 1989)





Even for very large impacts the newly accreted "surface" material will contain large amounts of metal.

Carbon and Nitrogen species in equilibrium with ***chondritic*** solids in near-surface environments.
(After Schaefer and Fegley, 2007)



Conclusions:

1) Geological observations do NOT support an early or massive CO_2 atmosphere.

2) Likely circum-accretional conditions favor production of reduced gases, either in the atmosphere or by degassing of a mostly silicate "veneer".

3) Early atmosphere chemistry yields large surface reservoirs of gaseous and condensed organic compounds.

4) This provides conditions (especially high concentrations of organic compounds) suitable for the emergence of life.

5) Large reduced carbon-compound reservoirs ARE consistent with geological observations.