The early Earth Carbon Cycle

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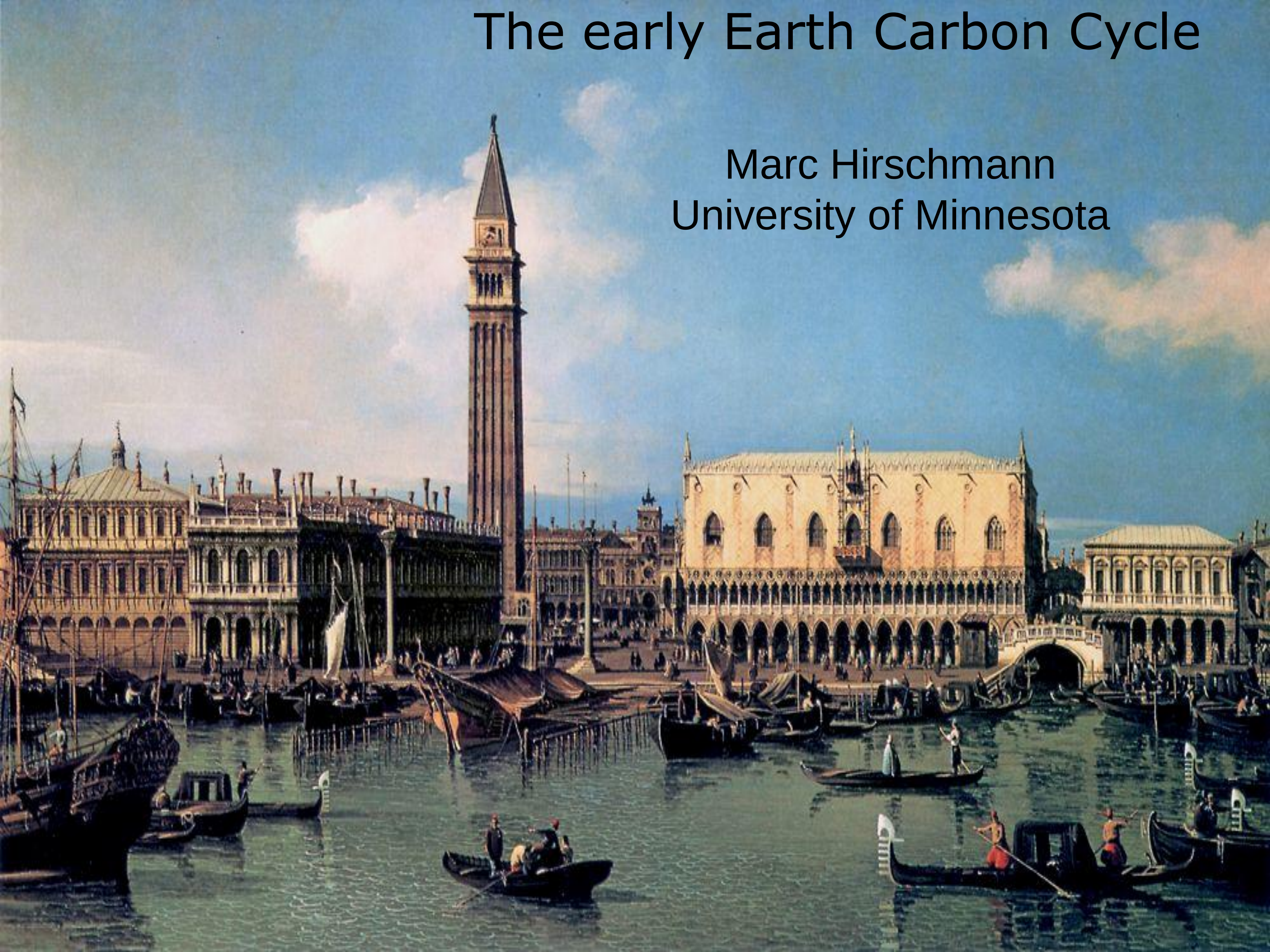
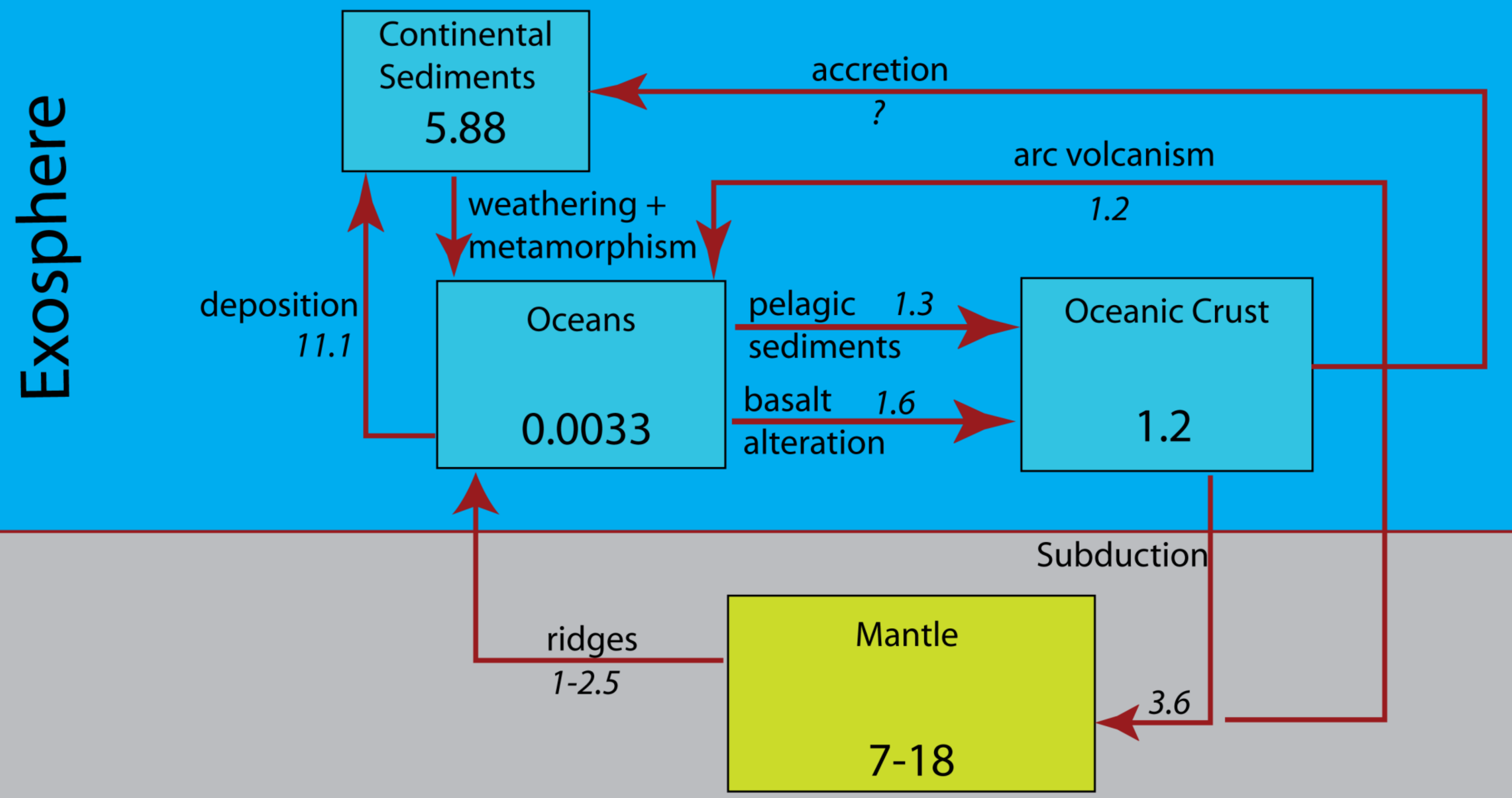


DEEP EARTH CARBON CYCLE



Reservoirs (X 10^{21} mol/year)

Fluxes (X 10^{12} mol/year)

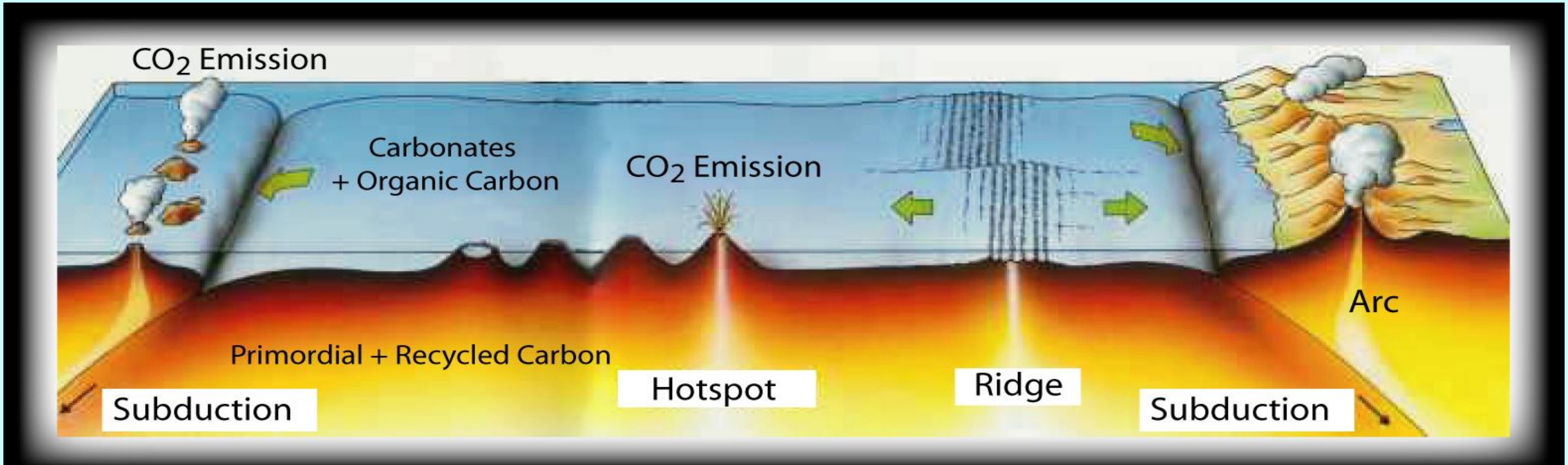
Simplified after Sleep &Zahnle, 2001

What is the Influence of Modern Tectonics on the Deep Earth Carbon Cycle?

- Net Outgassing, Net Ingassing, or Quasi-steady state?
- Does the distribution of Carbon on Earth “remember” Ancient Processes?

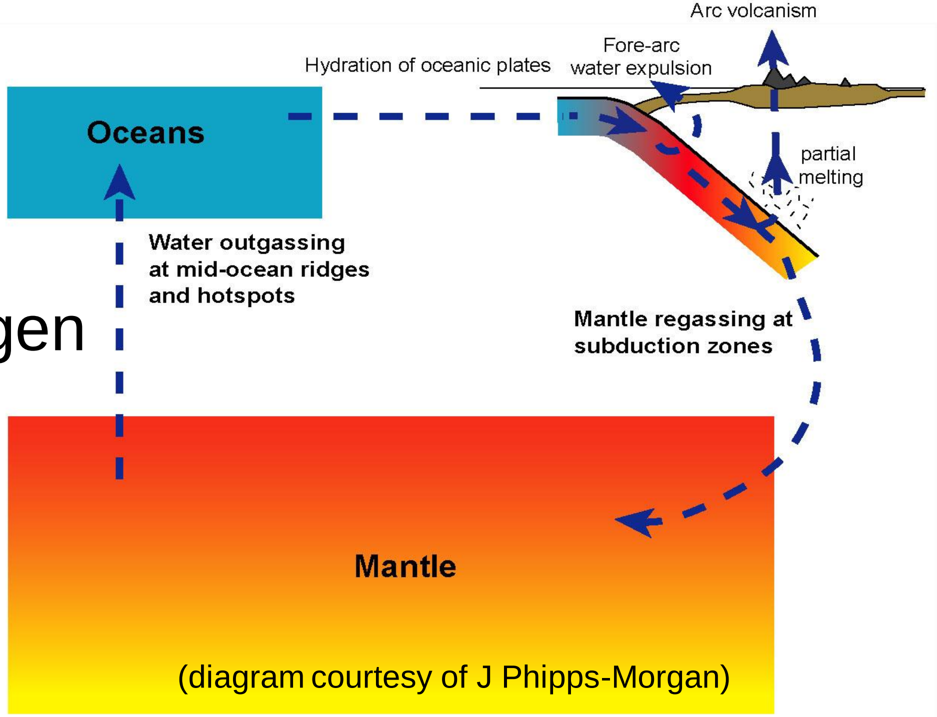
Earth's Deep

Carbon Cycle

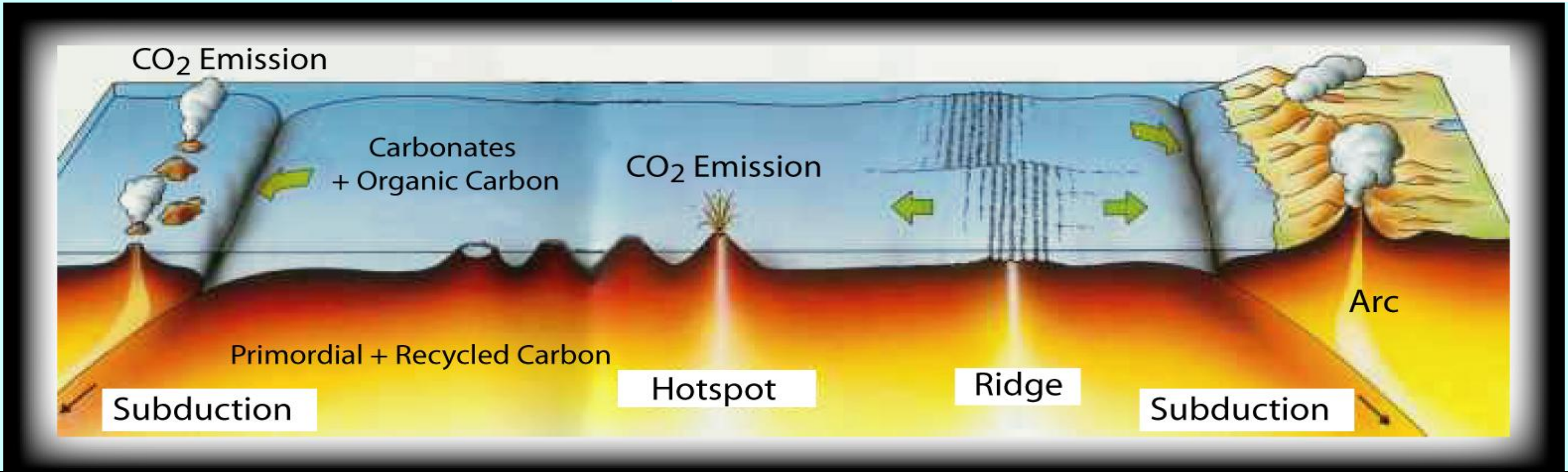


Earth's Deep Volatile Cycles

Hydrogen



Carbon



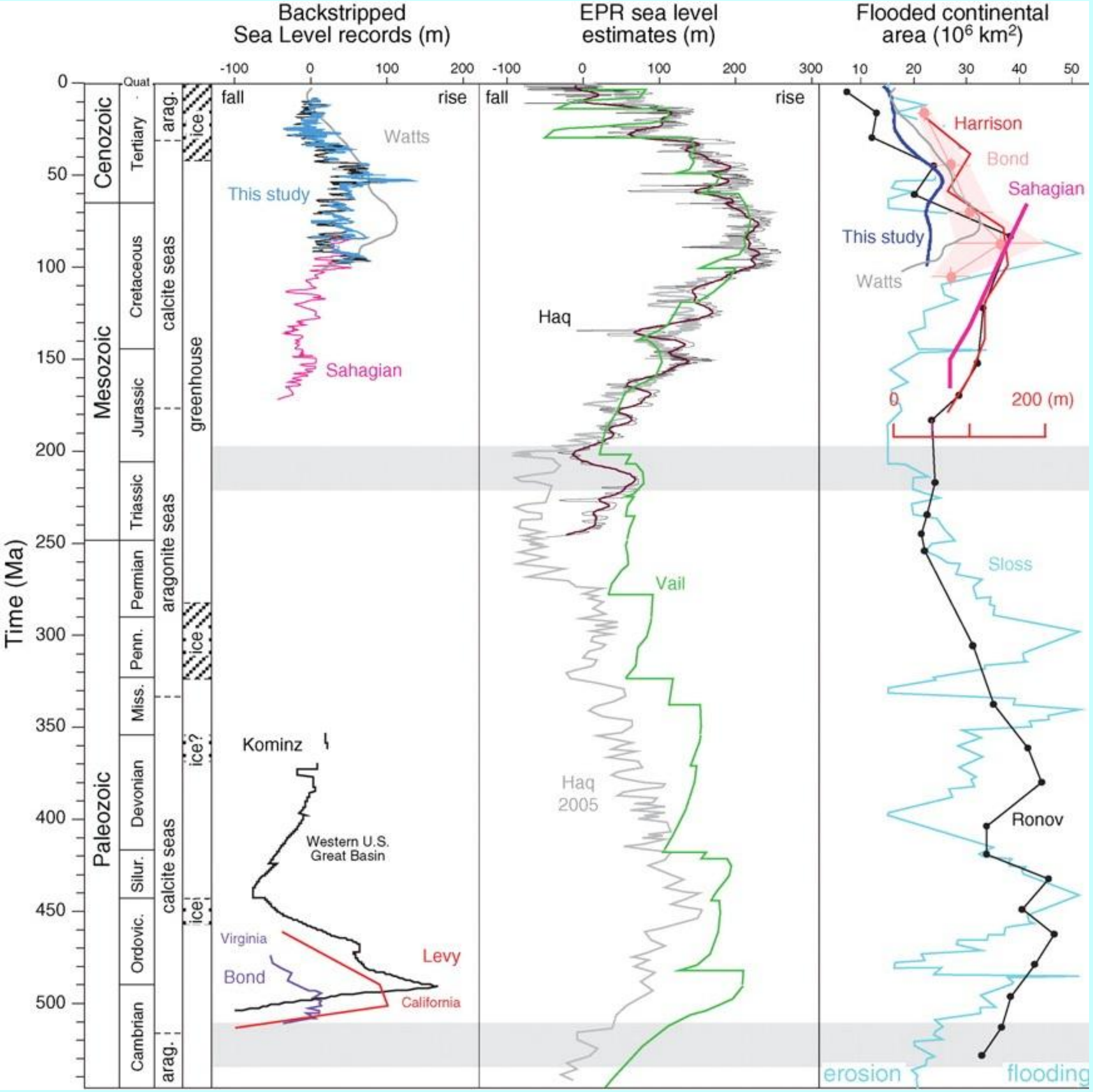
Hydrogen in the Exosphere

(Exosphere=everything above the Moho)

(Lecuyer et al. 1998)

	Grams H_2O	Grams H
Oceans	1.4×10^{24}	1.56×10^{23}
Other	2×10^{23}	2.22×10^{22}
Total	1.6×10^{24}	1.78×10^{23}

Phanerozoic sea level variation

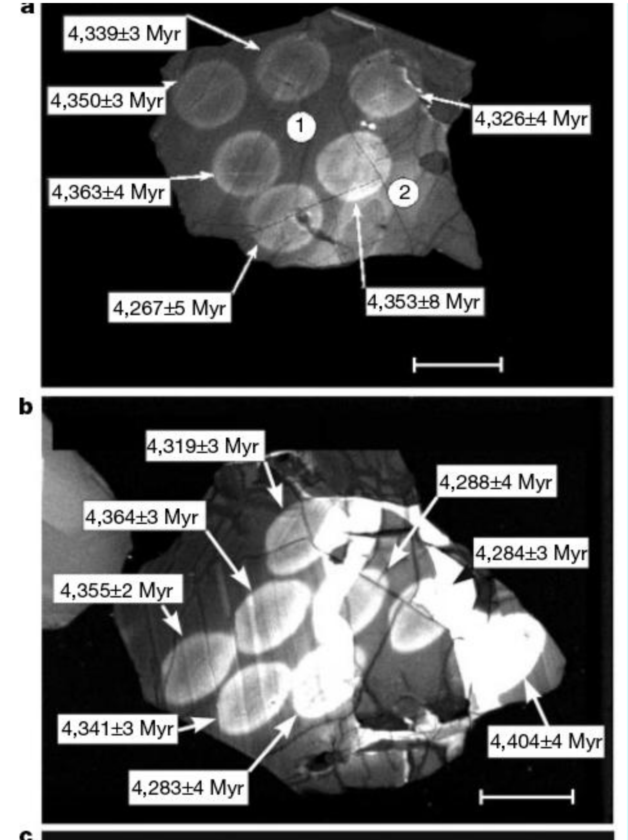


Miller et al., *Science* 2005

H_2O must be near steady state

Evidence from detrital zircons for the existence of continental crust and oceans on the Earth 4.4 Gyr ago

Simon A. Wilde*, John W. Valley†, William H. Peck†‡ & Colin M. Graham§



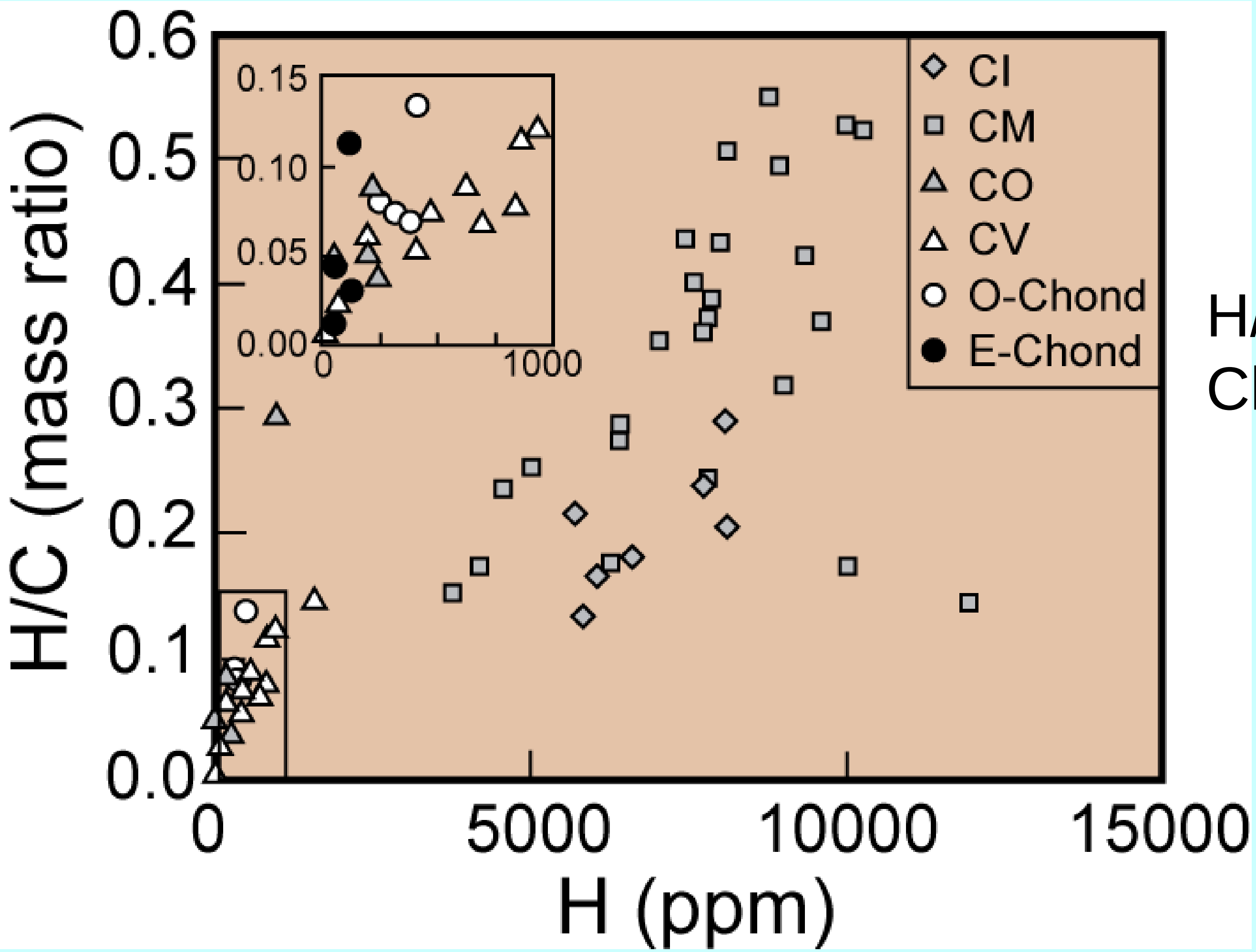
Exosphere Carbon	Moles CO_2	Grams C
Sleep&Zahnle Ô02		
Sediments	5.88×10^{21}	7.06×10^{22}
Oceans	3.31×10^{18}	3.97×10^{19}
Oceanic Crust	1.20×10^{21}	1.44×10^{22}
Total	**7.08×10^{21}**	**8.50×10^{22}**
Hayes&Waldbauer Ô06	**8.50×10^{21}**	**1.02×10^{23}**
Holser Ô89	**7.64×10^{21}**	**9.17×10^{22}**
Average		**$9.29 \pm 0.86 \times 10^{22}$**

H in Exosphere (grams) **1.78×10^{23}**

C in Exosphere (grams) **$9.29 \pm 0.86 \times 10^{22}$**

H/C ratio of Exosphere **1.95 ± 0.15**

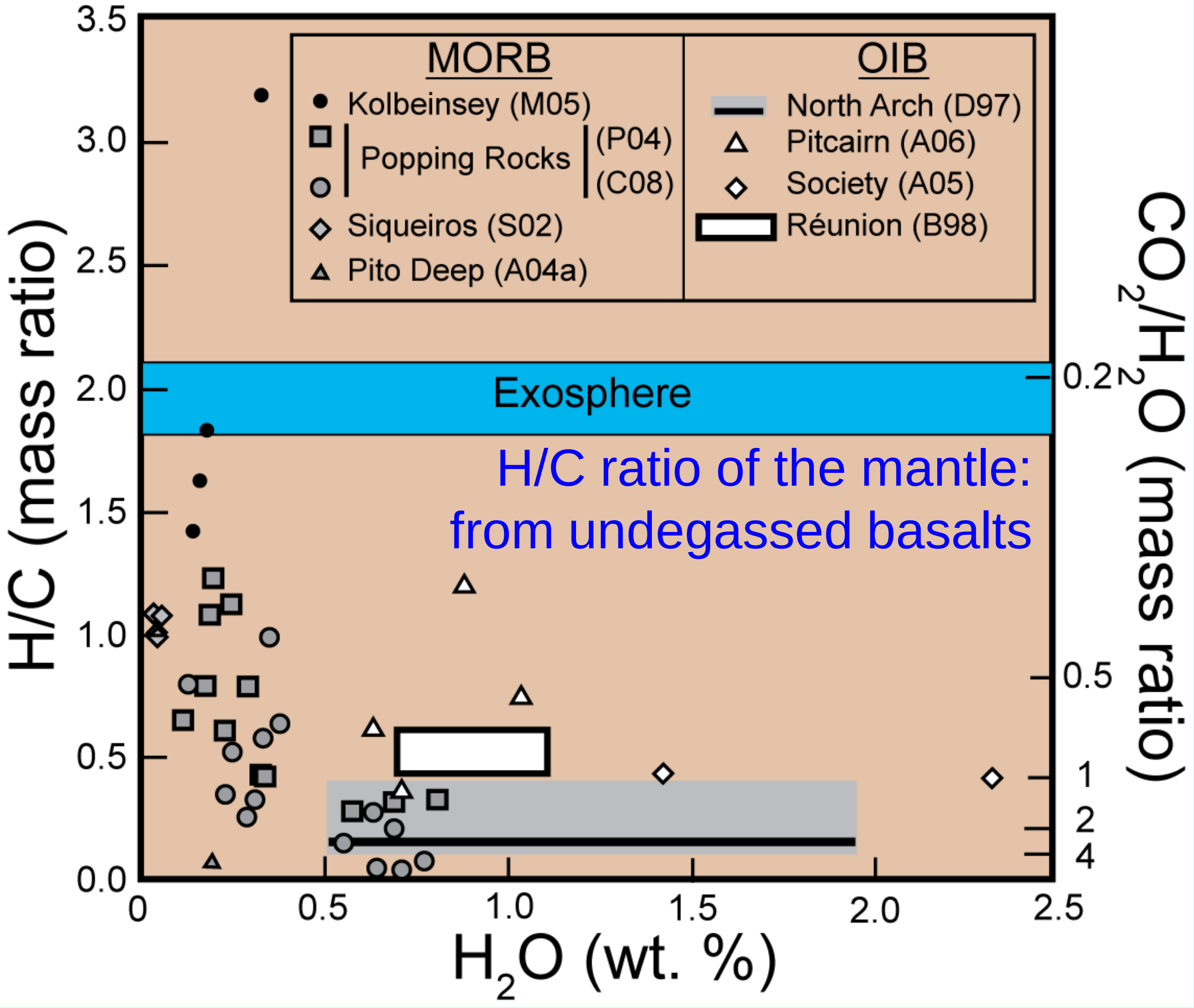
The H/C ratio of the Exosphere is fractionated compared to cosmochemical ingredients



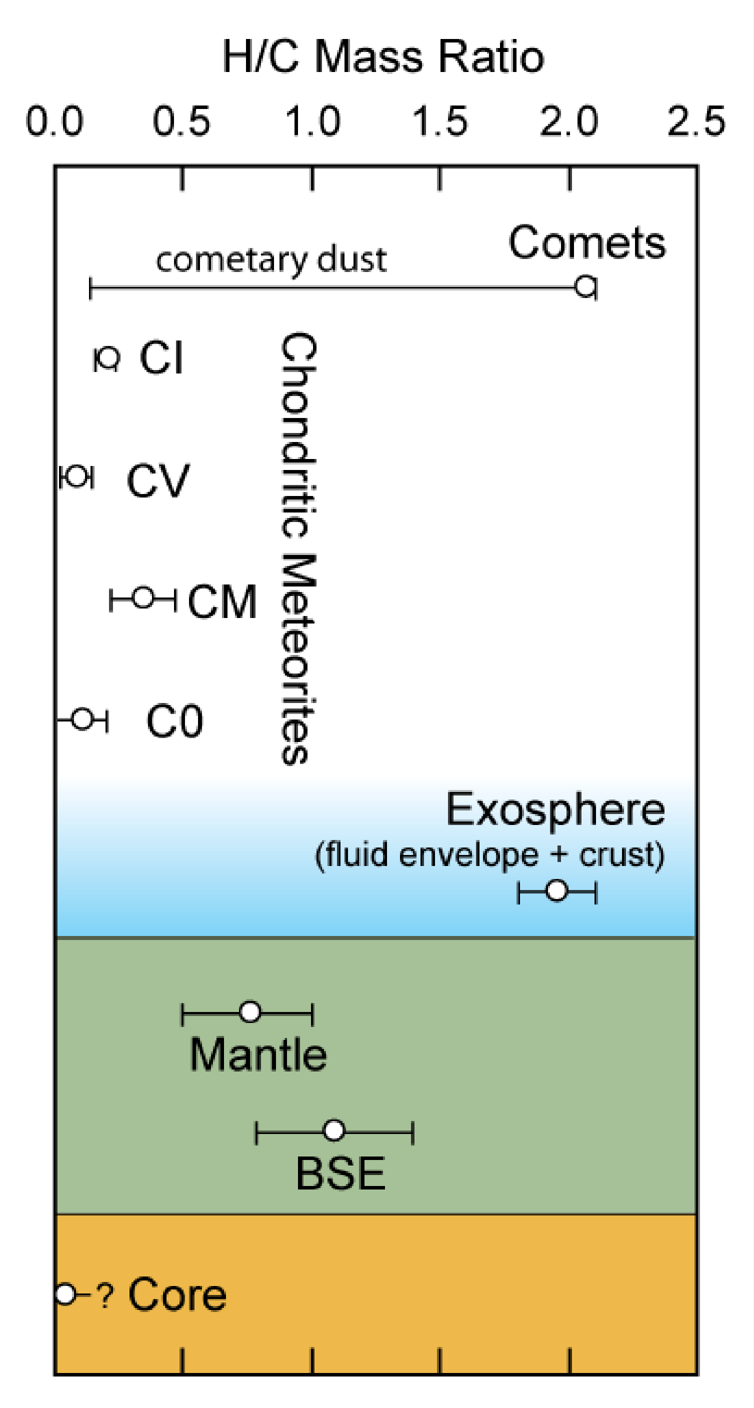
H/C Ratios of Chondritic Meteorites

Kerridge, 1985; Robert+Merlivat, 1979; McNaughton et al. 1981; Grady et al., 1989; Javoy, 1998

The H/C ratio of the exosphere is higher than the mantle H/C ratio.



H/C ratios of principal Earth and cosmochemical materials



Why is the H/C Ratio of the Exosphere Much Greater than the Mantle H/C Ratio?

Volcanic outgassing has the opposite effect

$(C_{outgassing} > H_{outgassing})$

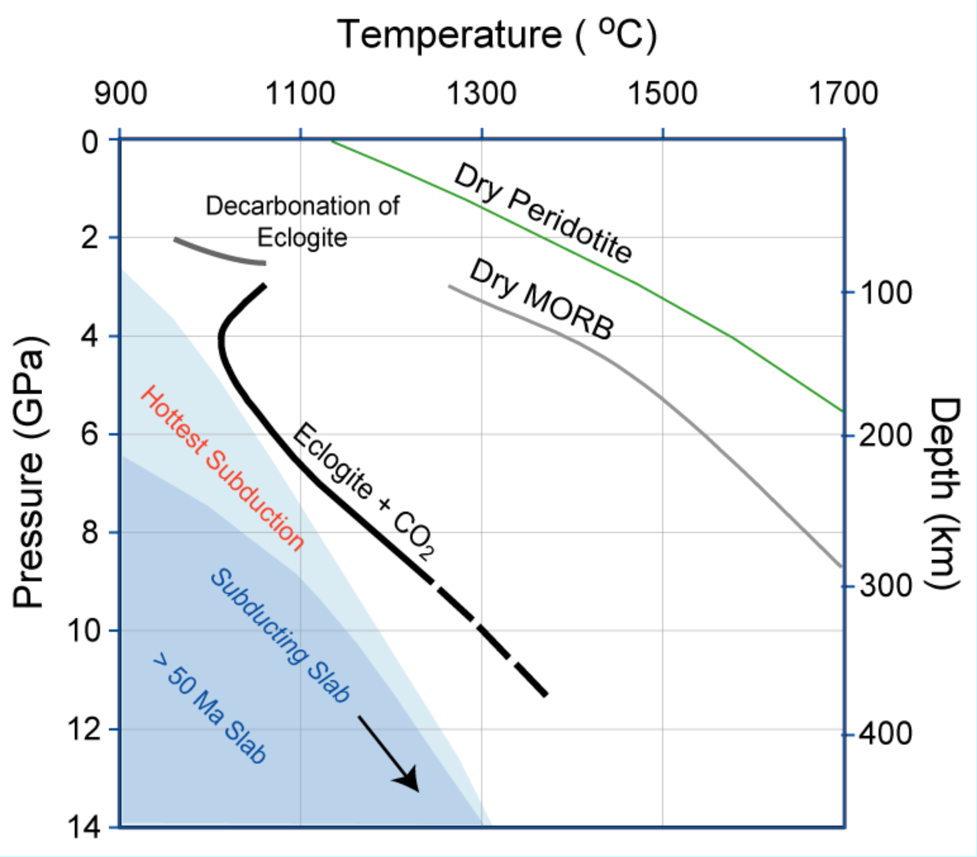
Loss of volatiles to space has the opposite effect

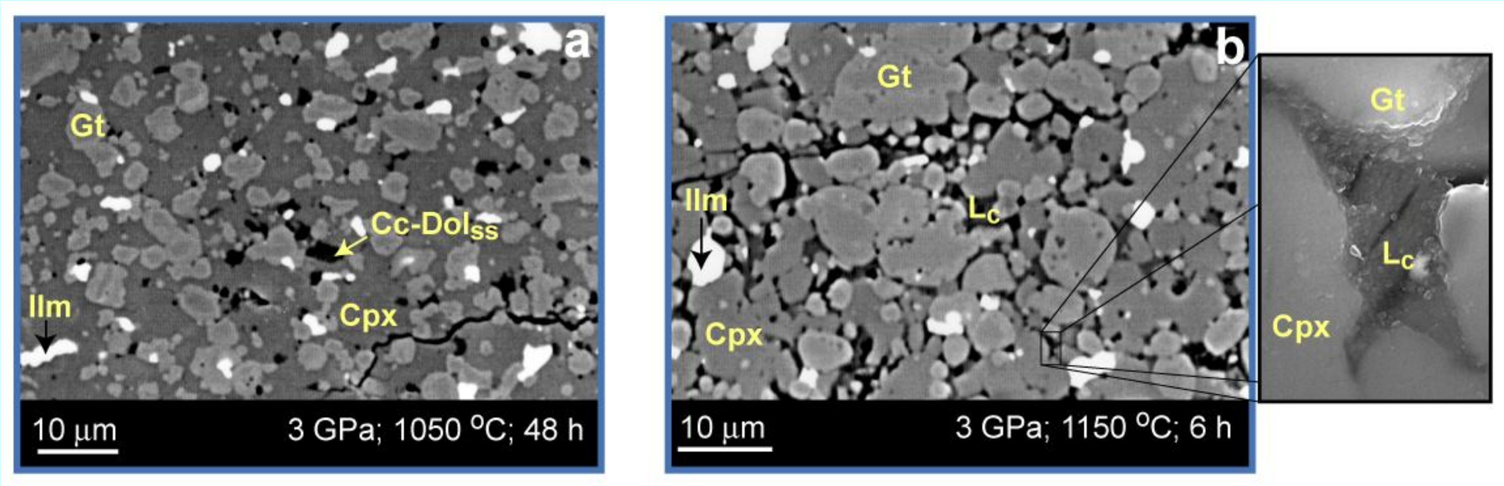
$(C_{escape} < H_{escape})$

*Preferential Subduction of Carbon

*Remnant of events in Deep Time

- Loss of massive CO_2-rich atmosphere
- Early massive return of C to mantle
- Retention of C in reduced mantle or magma ocean

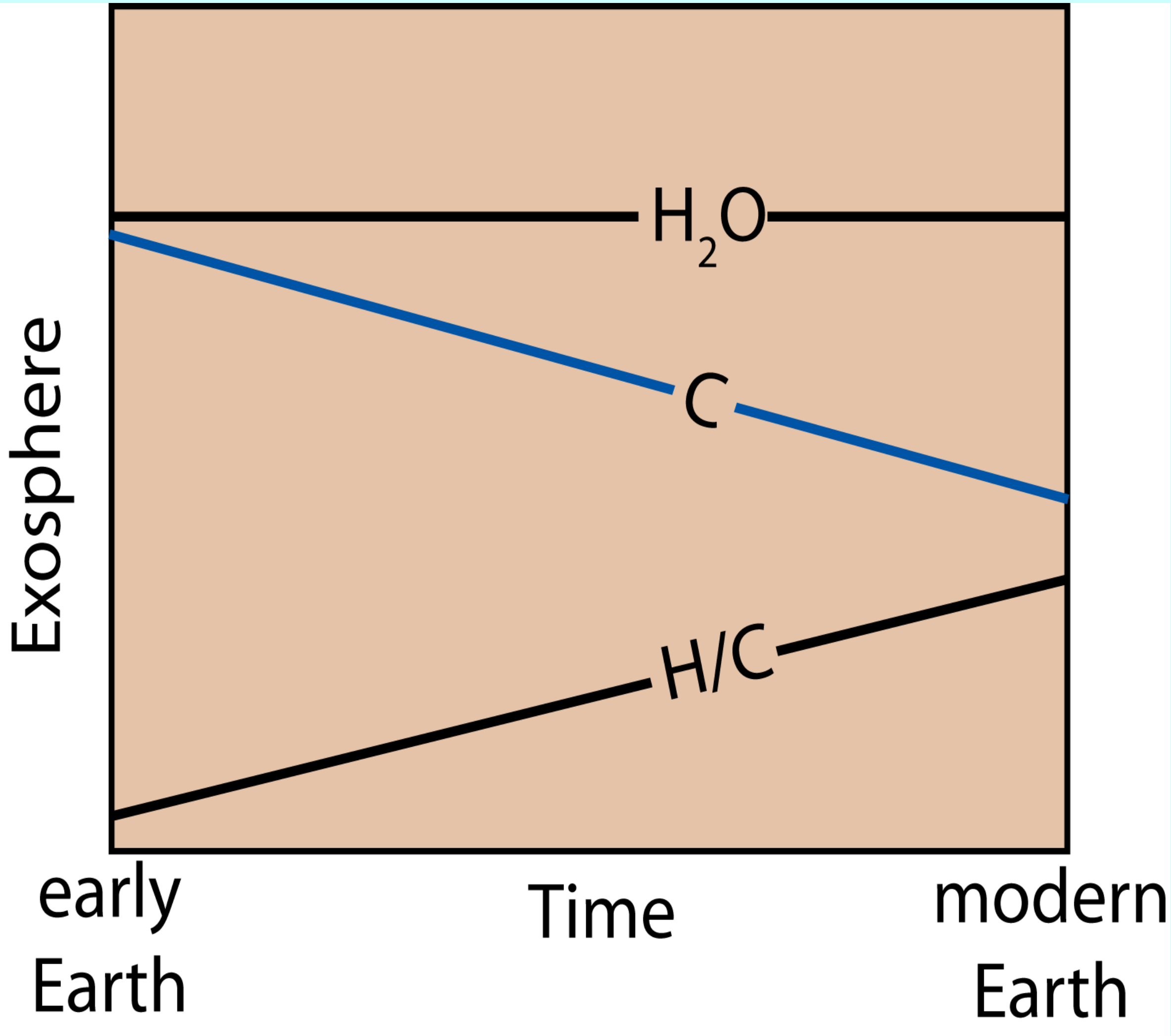




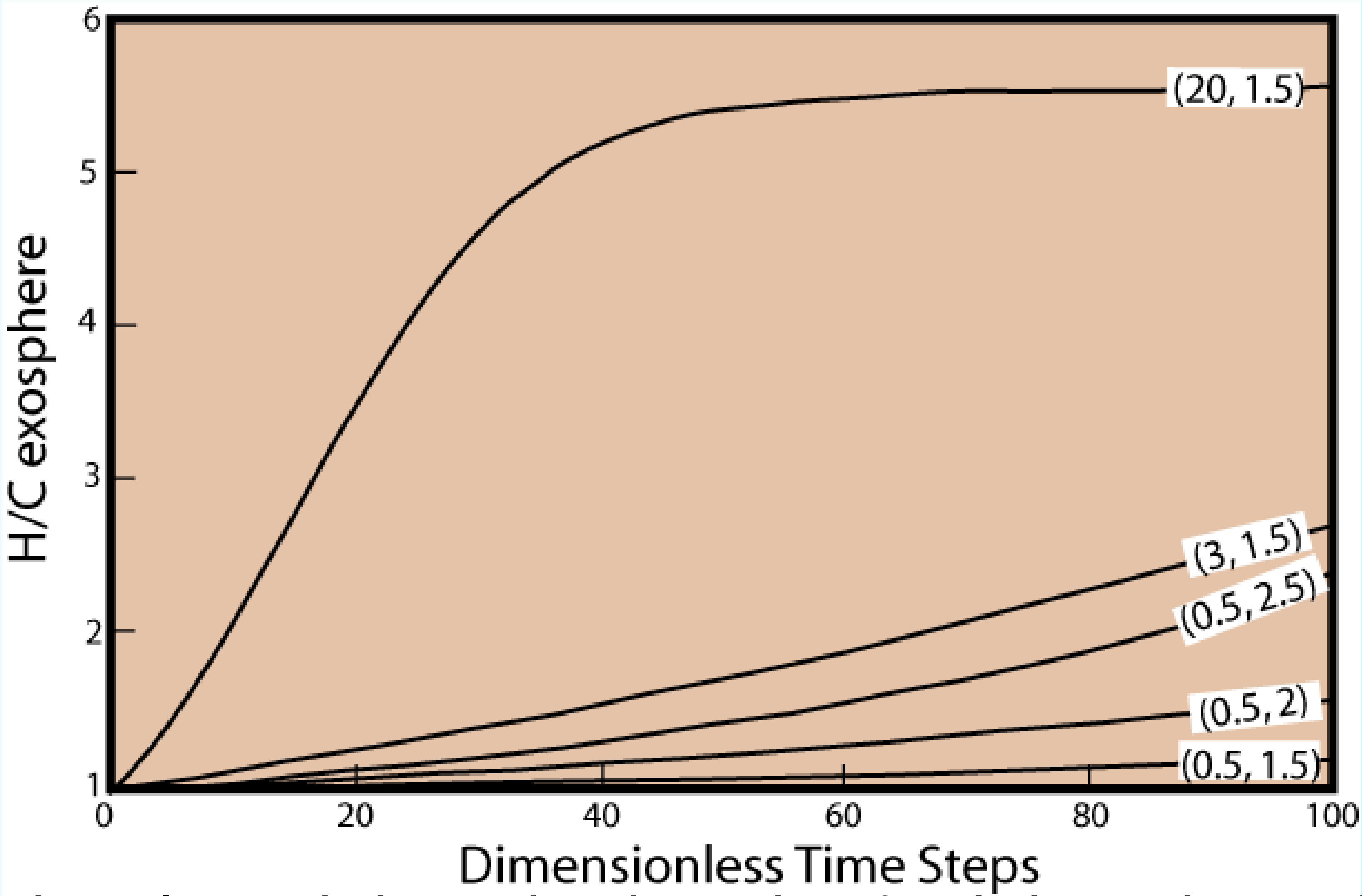
(2004)

Dasgupta et al. 2004

If the H_2O budget of the exosphere is near-constant, and subduction caused the high H/C ratio of the exosphere, then the C budget of the exosphere must have diminished through time.

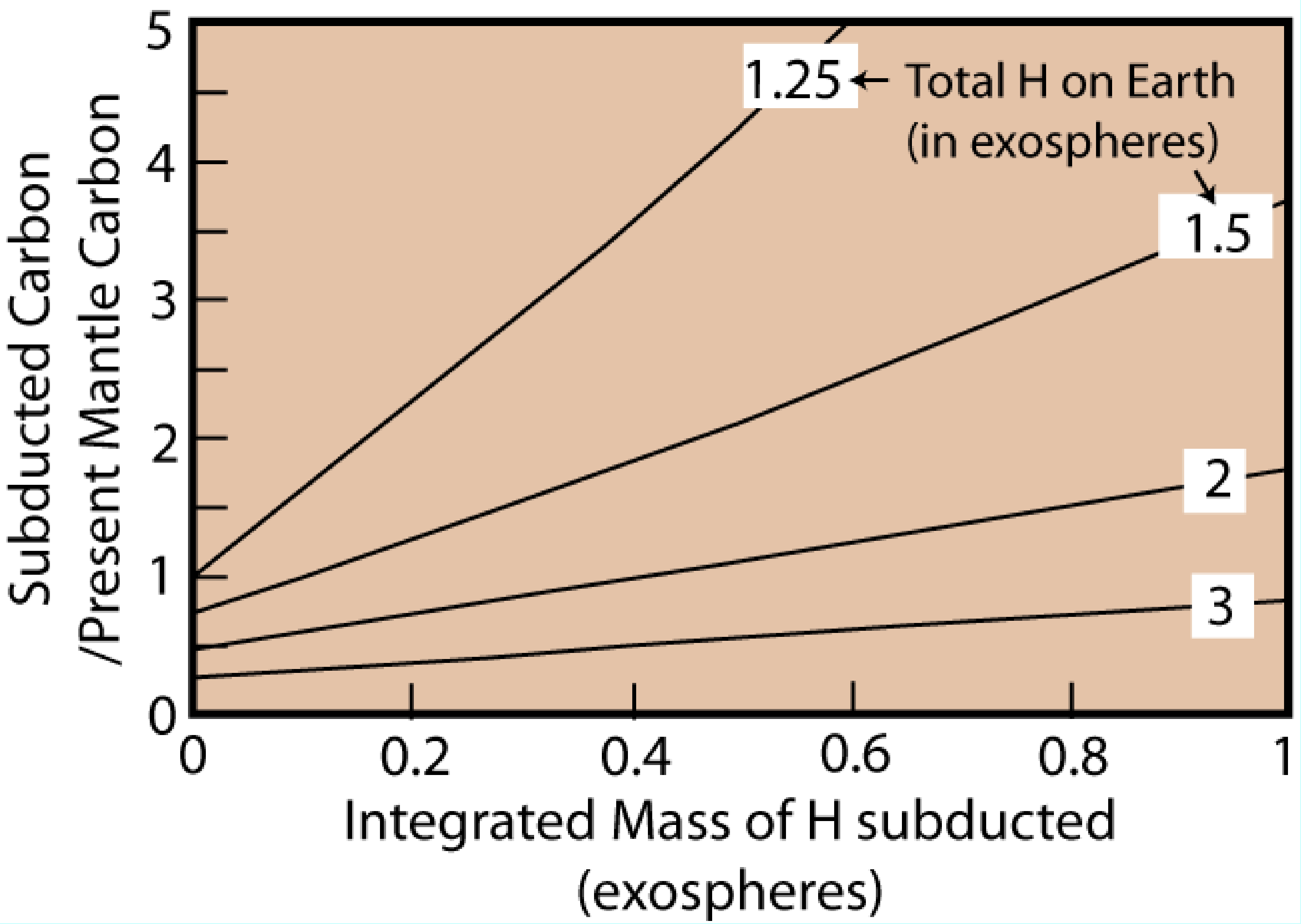


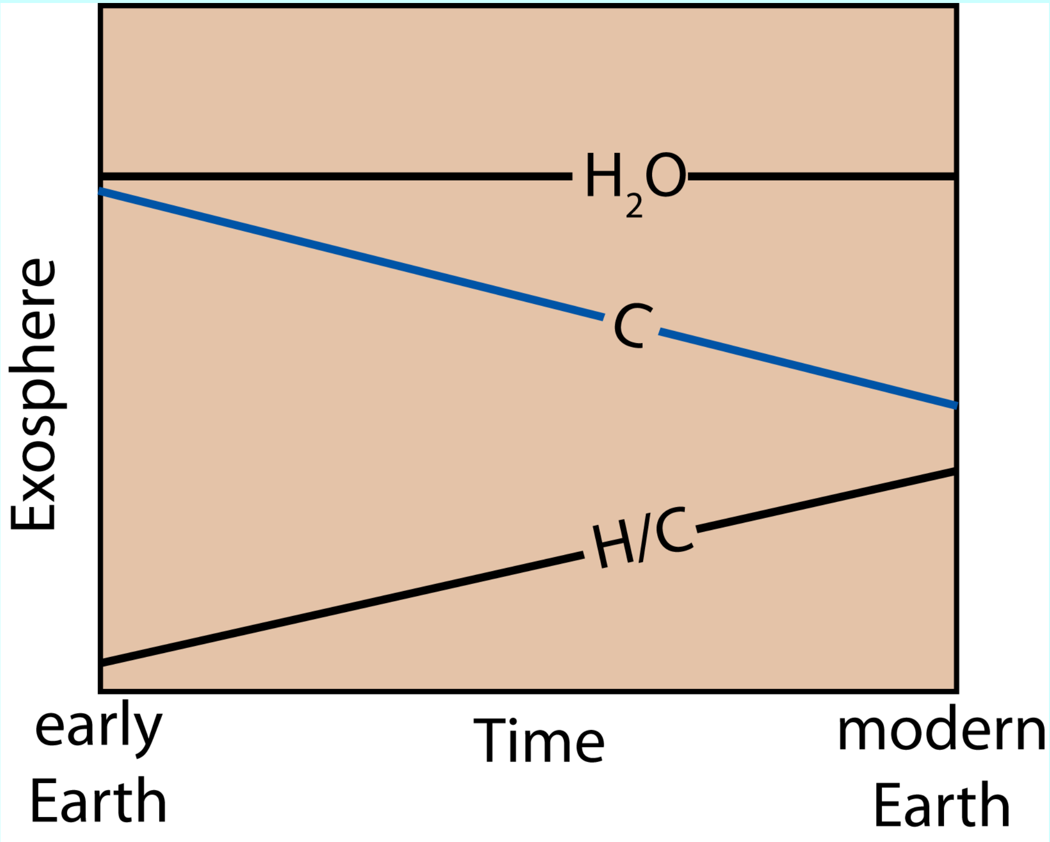
Evolution of exosphere by preferential subduction of C



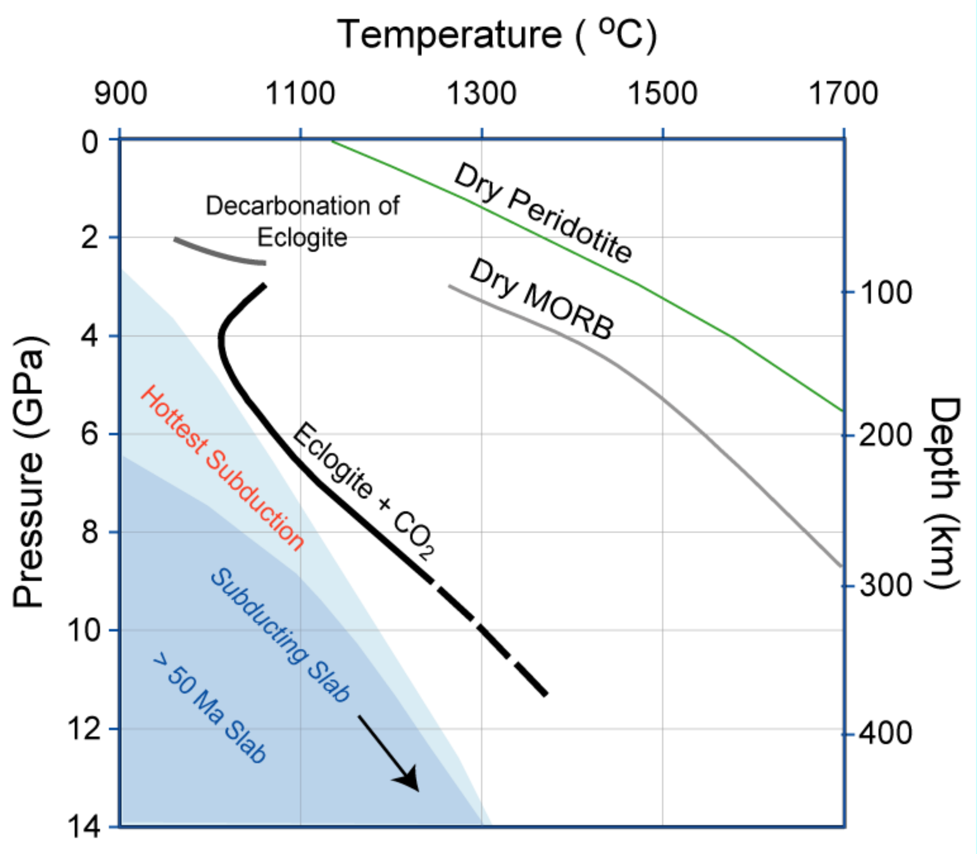
(Total H subducted, C/H ratio of subducted mass)

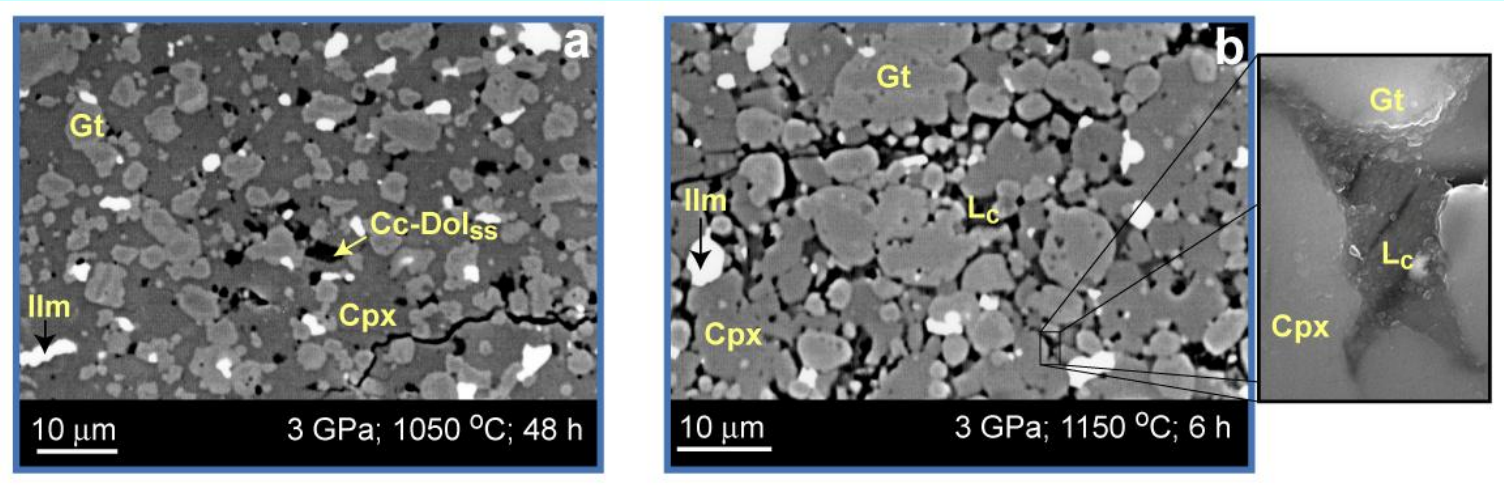
Evolution of exosphere by preferential Subduction of C





H2O
C
H/C
Exosphere
early Earth
Time
modern Earth





Dasgupta et al. 2004

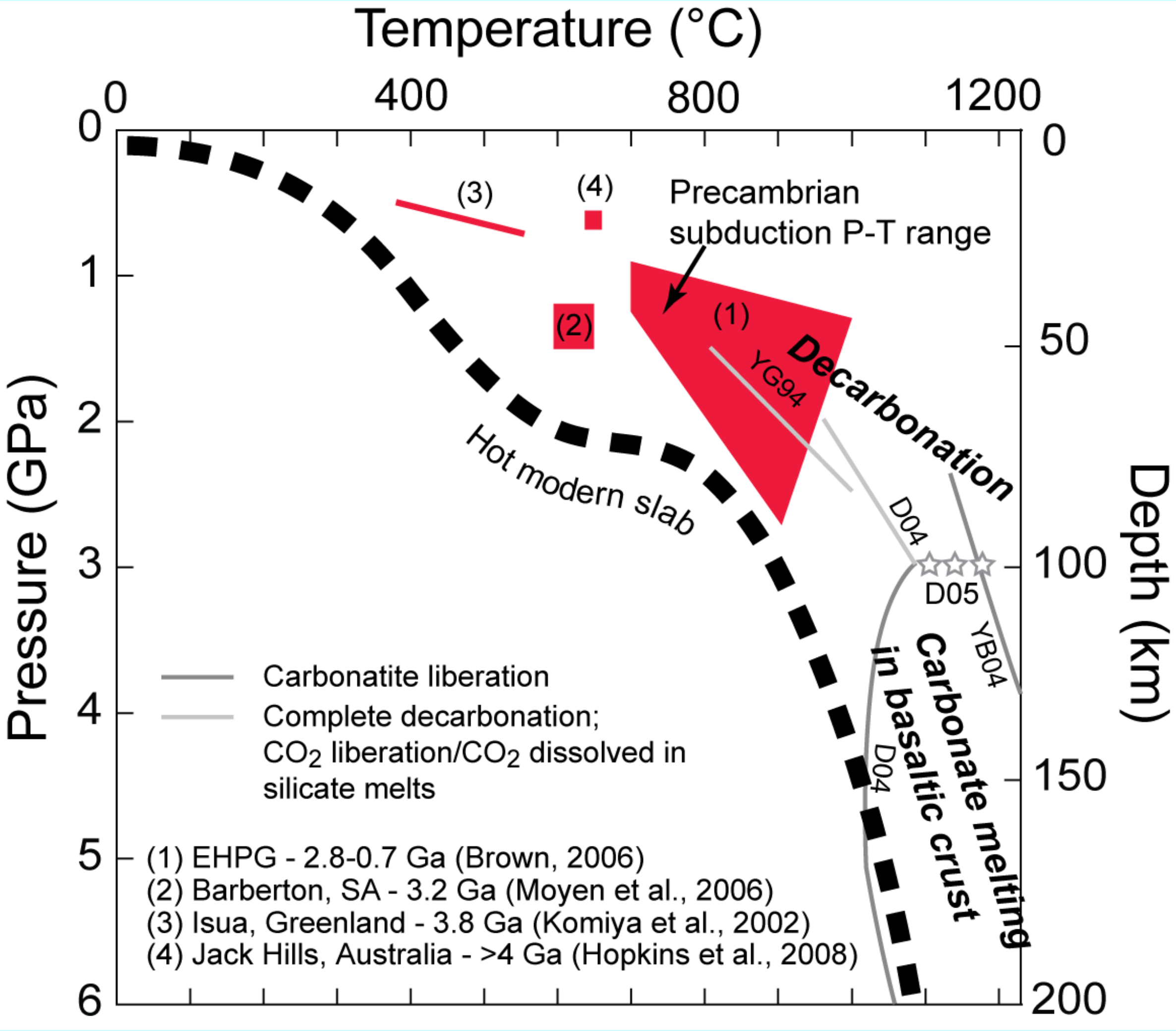
Blueschists are confined to Phanerozoic and very late Proterozoic. Earlier “subduction” geotherms are much hotter

QuickTime?and a
decompressor
are needed to see this picture.

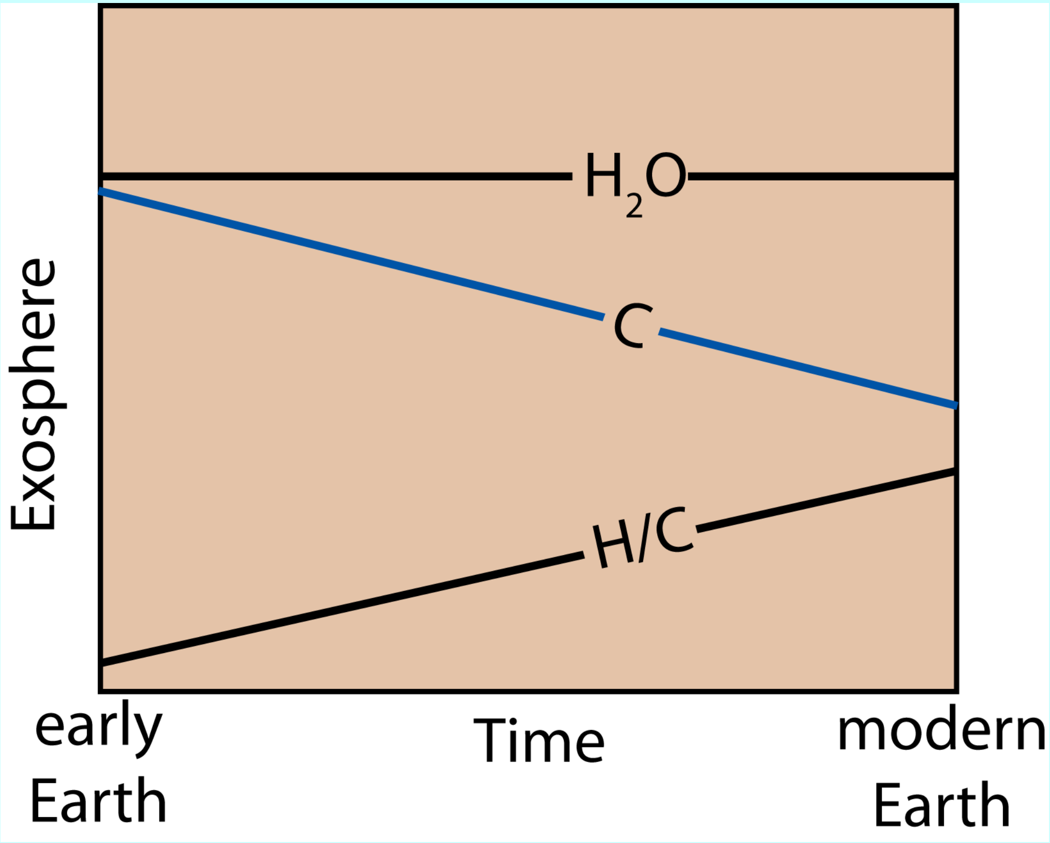
EHPGM=Eclogite/High Pressure Granulite Metamorphism

Brown, 2006

For much of geological time, subduction geotherms have been too hot to allow carbonate subduction

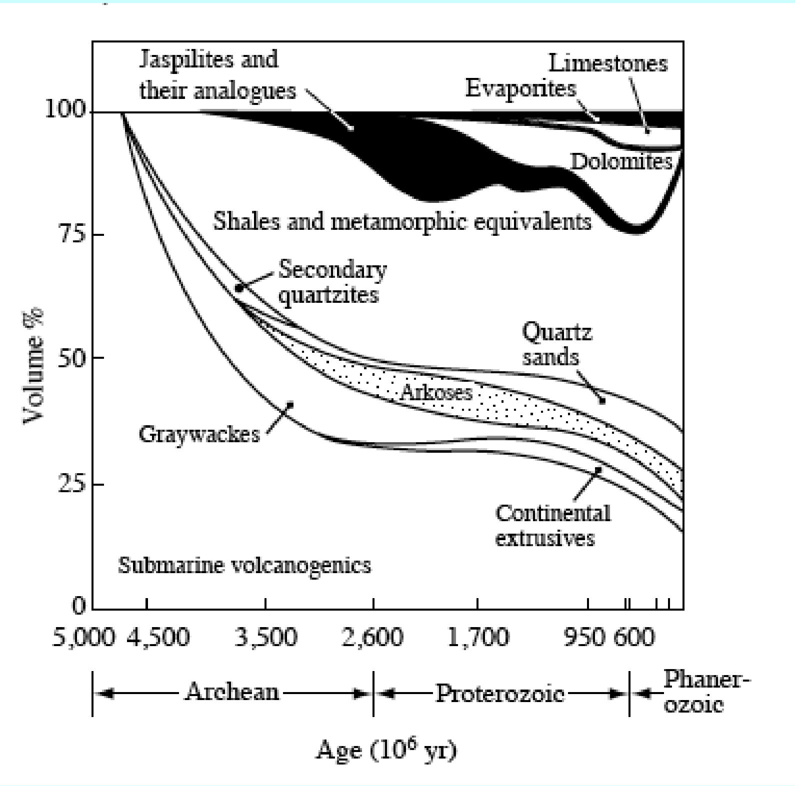


Dasgupta & Hirschmann, submitted



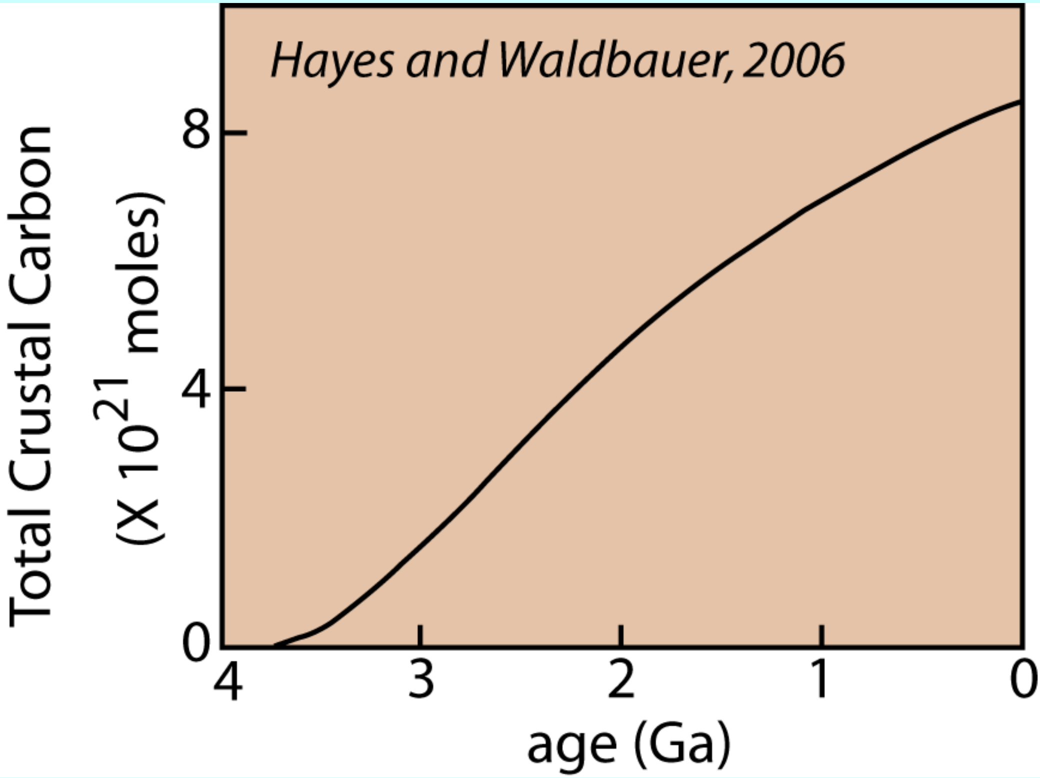
H_2O
C
H/C
Exosphere
early Earth
Time
modern Earth

The exosphere carbon reservoir is dominated by continental sediments……



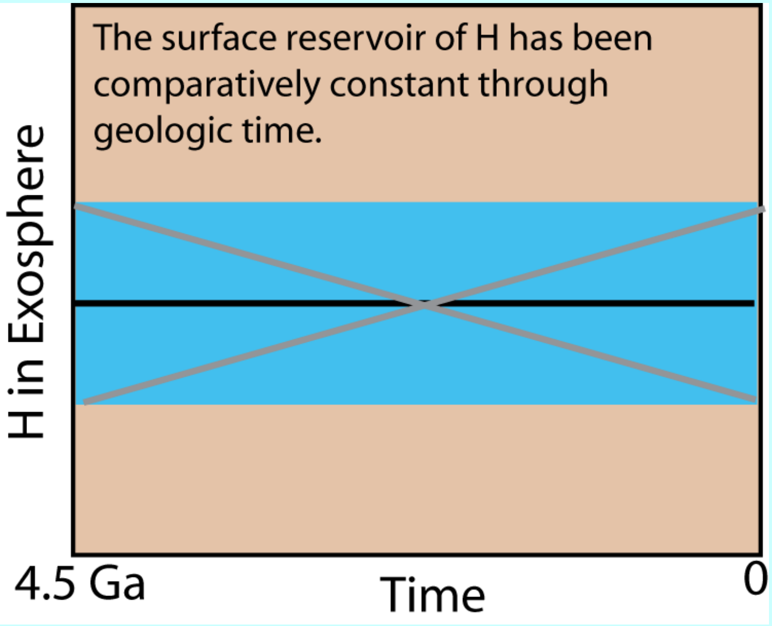
Age distribution of present-day continental sediments

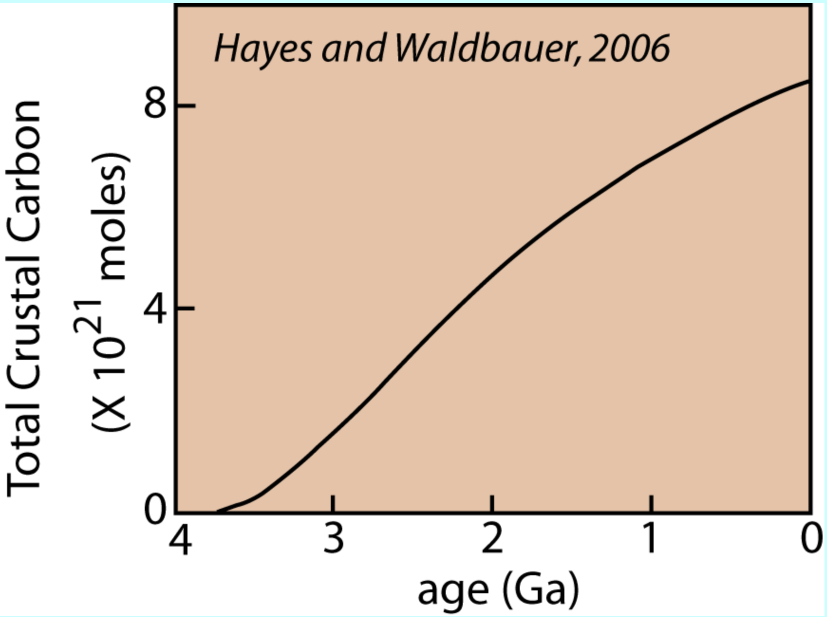
Veizer and Mackenzie, 2004



…and so the surface carbon reservoir grows with the continents.

If the H surface reservoir has not increased greatly, but the C surface reservoir HAS increased, how did the exosphere end up with such a high H/C ratio?





If not by subduction, how did the high H/C ratio of the exosphere develop?

- Catastrophic loss of a thick CO_2 atmosphere.
- Catastrophic early subduction of CO_2
- Degassing of a reduced mantle or magma ocean.

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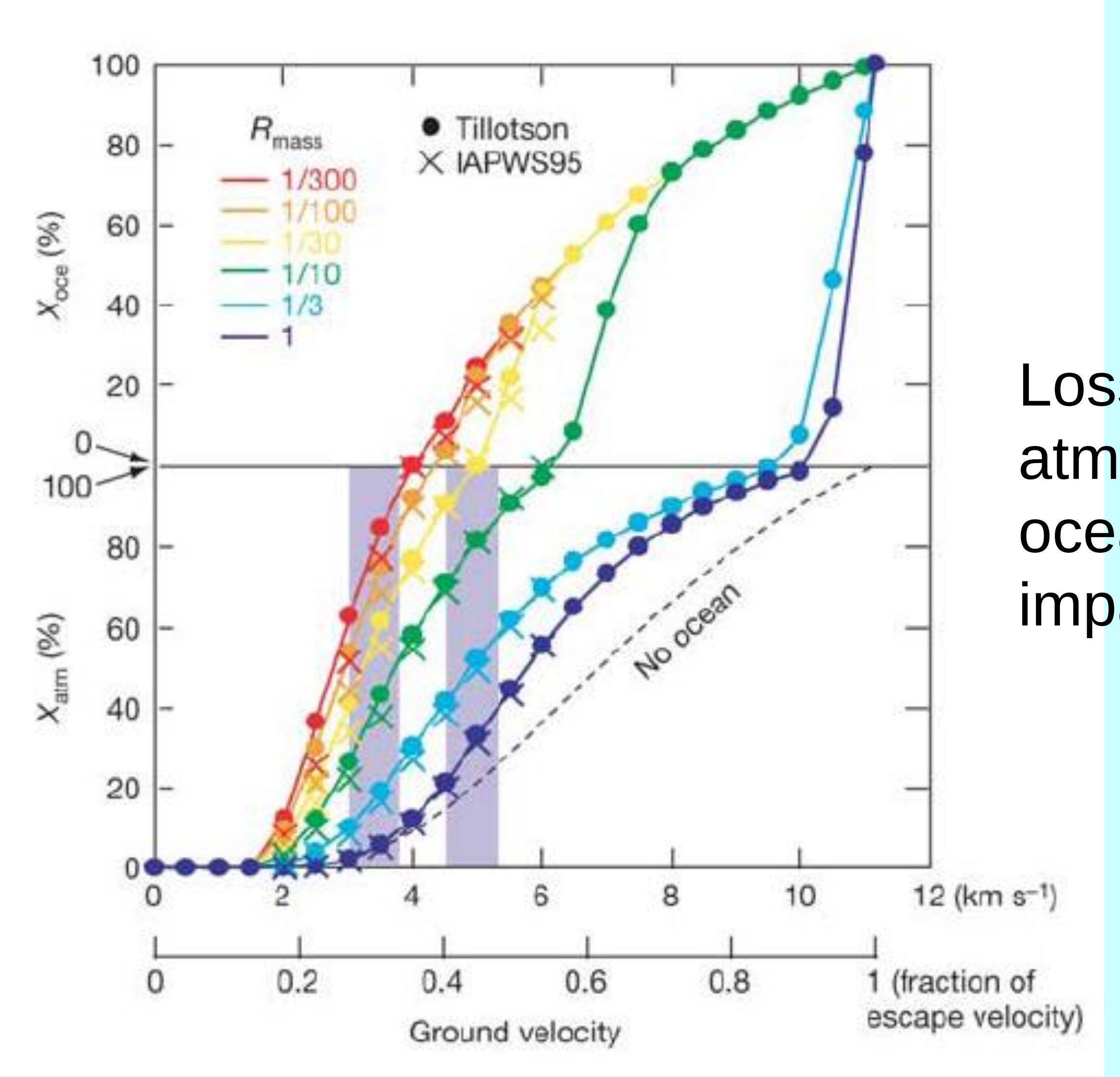

Loss of a massive CO_2 atmosphere, but not the oceans, during a giant impact?

Genda&Abe, 2005

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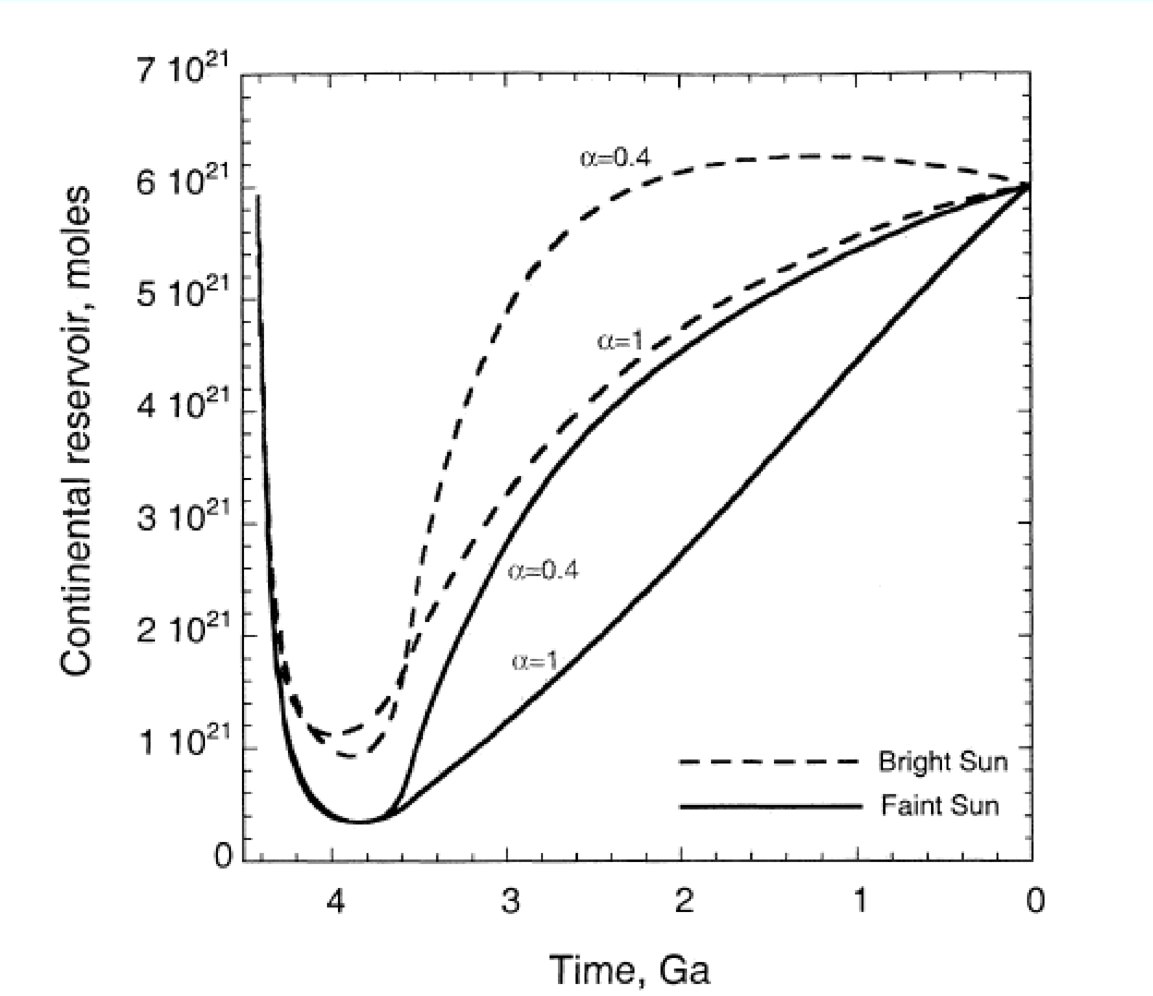
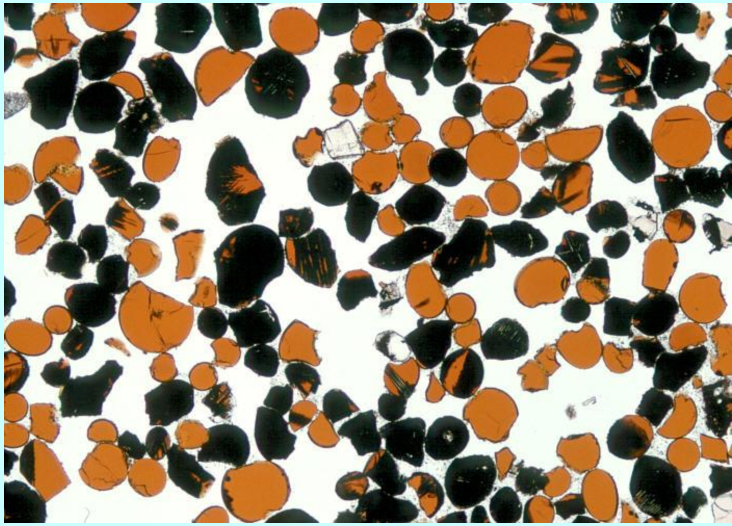


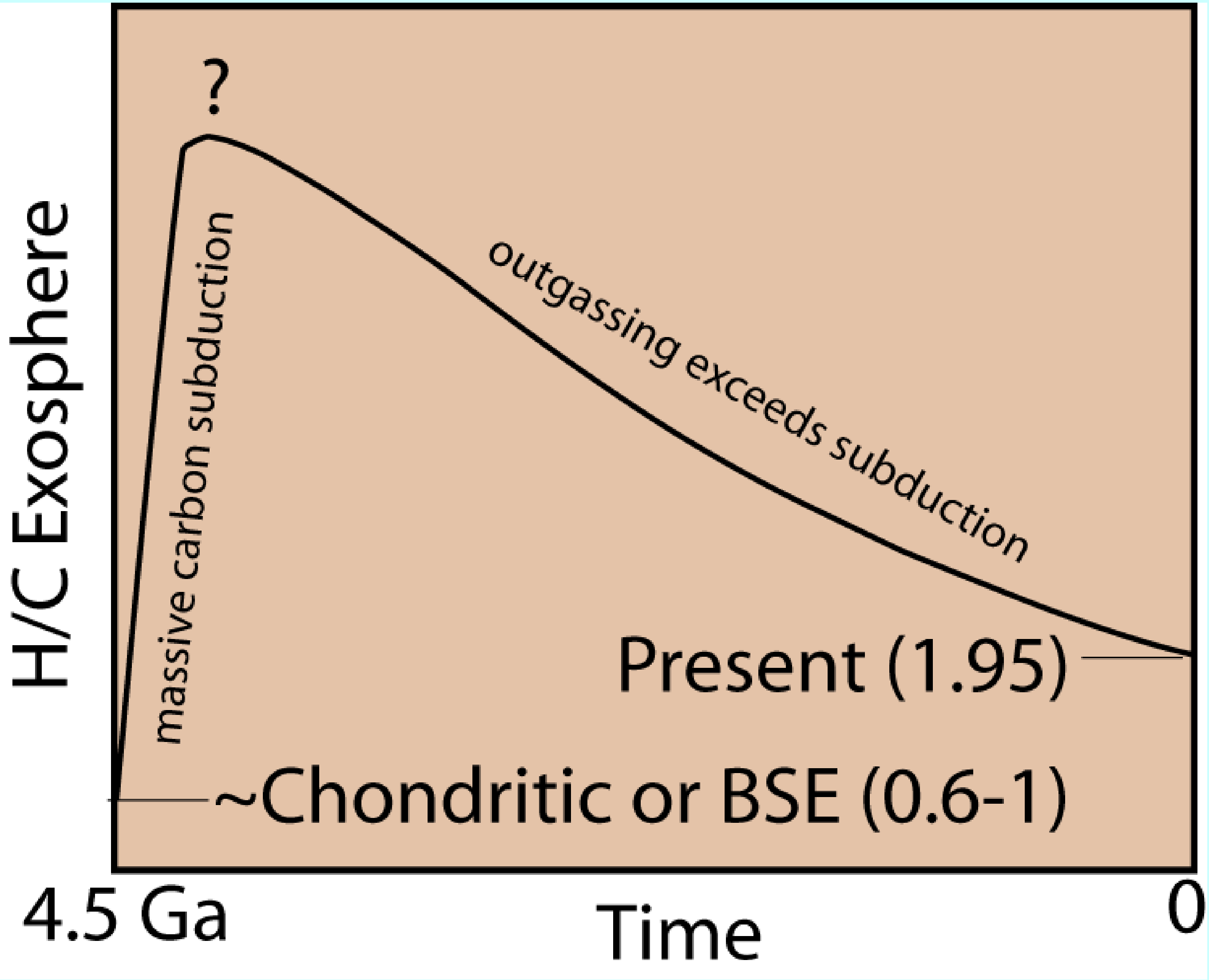
Impact Ejecta
(lunar glass beads)



(highly susceptible to reaction with atmospheric CO_2)

Sleep and Zahnle, 2001

One possible scenario for the H/C evolution of the Exosphere



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Conclusions

- The surface inventories of H and C place important constraints on the deep Earth carbon cycle
- The Deep Earth Carbon Cycle was profoundly influenced by events on the Early Earth. It is not sufficient to study the modern cycle.

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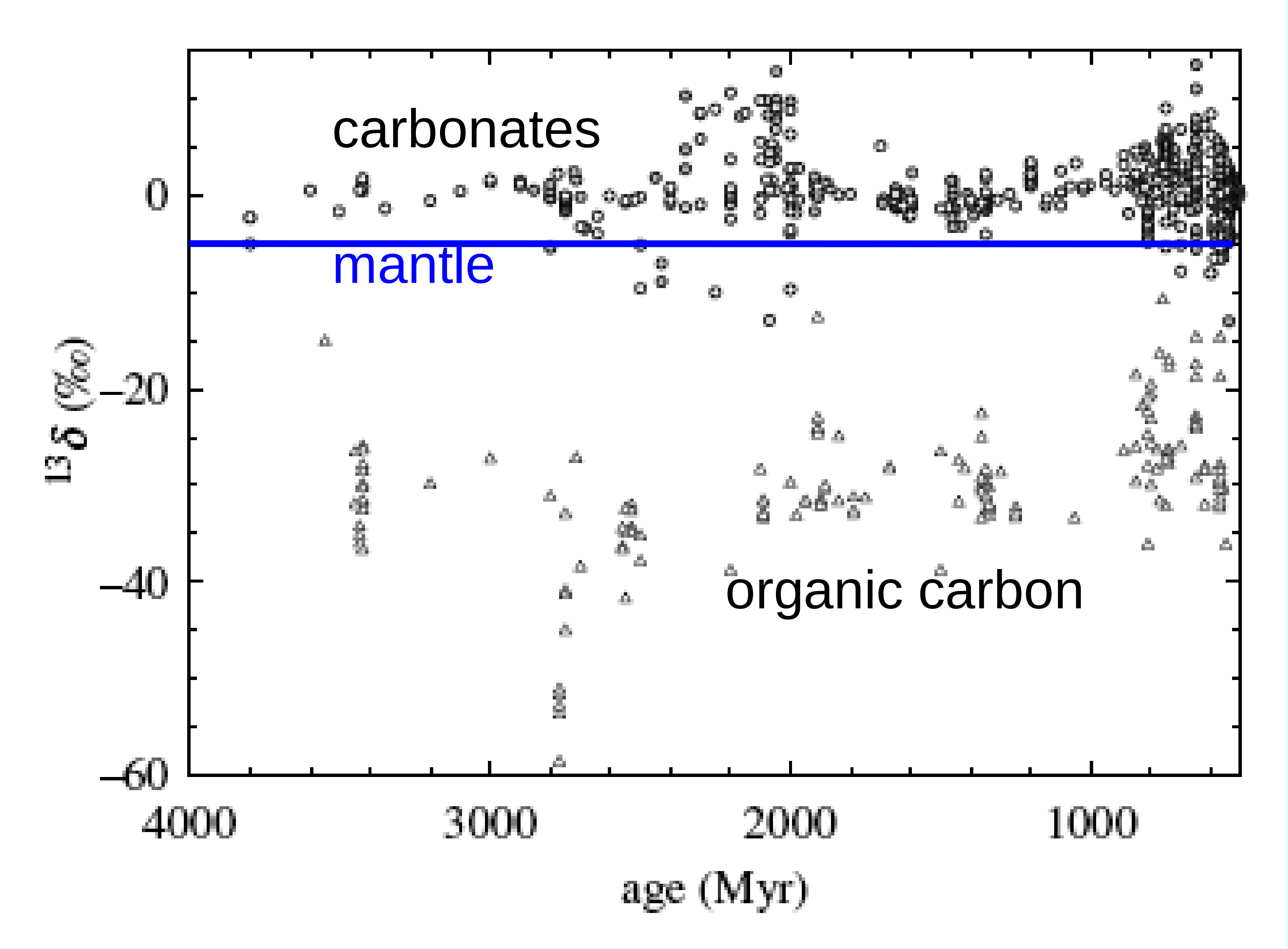
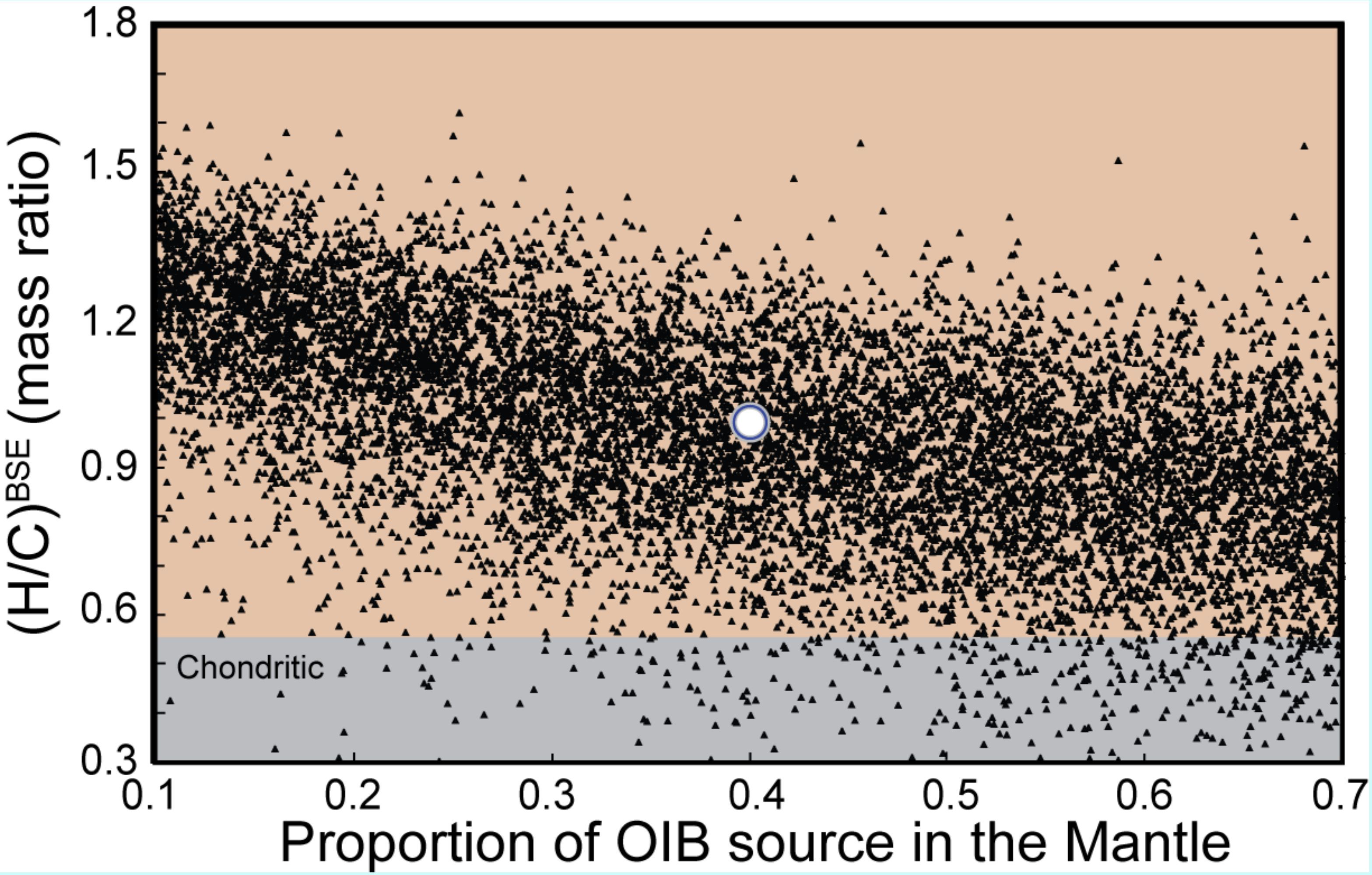


Hayes and Waldbauer, 2006

Simple Model for H and C in the Bulk Silicate Earth (BSE)

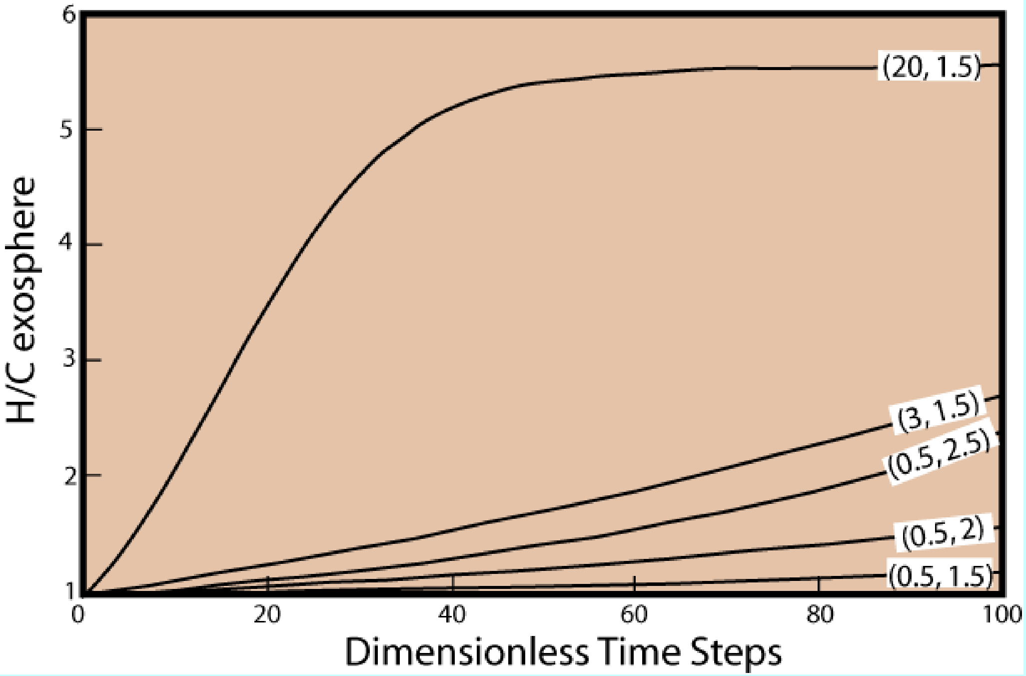
- H/C of exosphere=1.95 $\pm$ 0.15
- H/C of MORB source=0.75 $\pm$ 0.25
- H/C of OIB source=0.5 $\pm$ 0.3
- H_2O in MORB source=100 $\pm$ 50 ppm
- H_2O in OIB source=600 $\pm$ 300 ppm
- OIB source=10 to 70% of mantle
- *No hidden volatile-rich reservoirs*
- Sum these in a Monte Carlo simulation to give H/C of the mantle and the BSE.

H/C ratio of the Bulk Silicate Earth



H/C evolution of the Exosphere

Net C ingassing



Net C outgassing