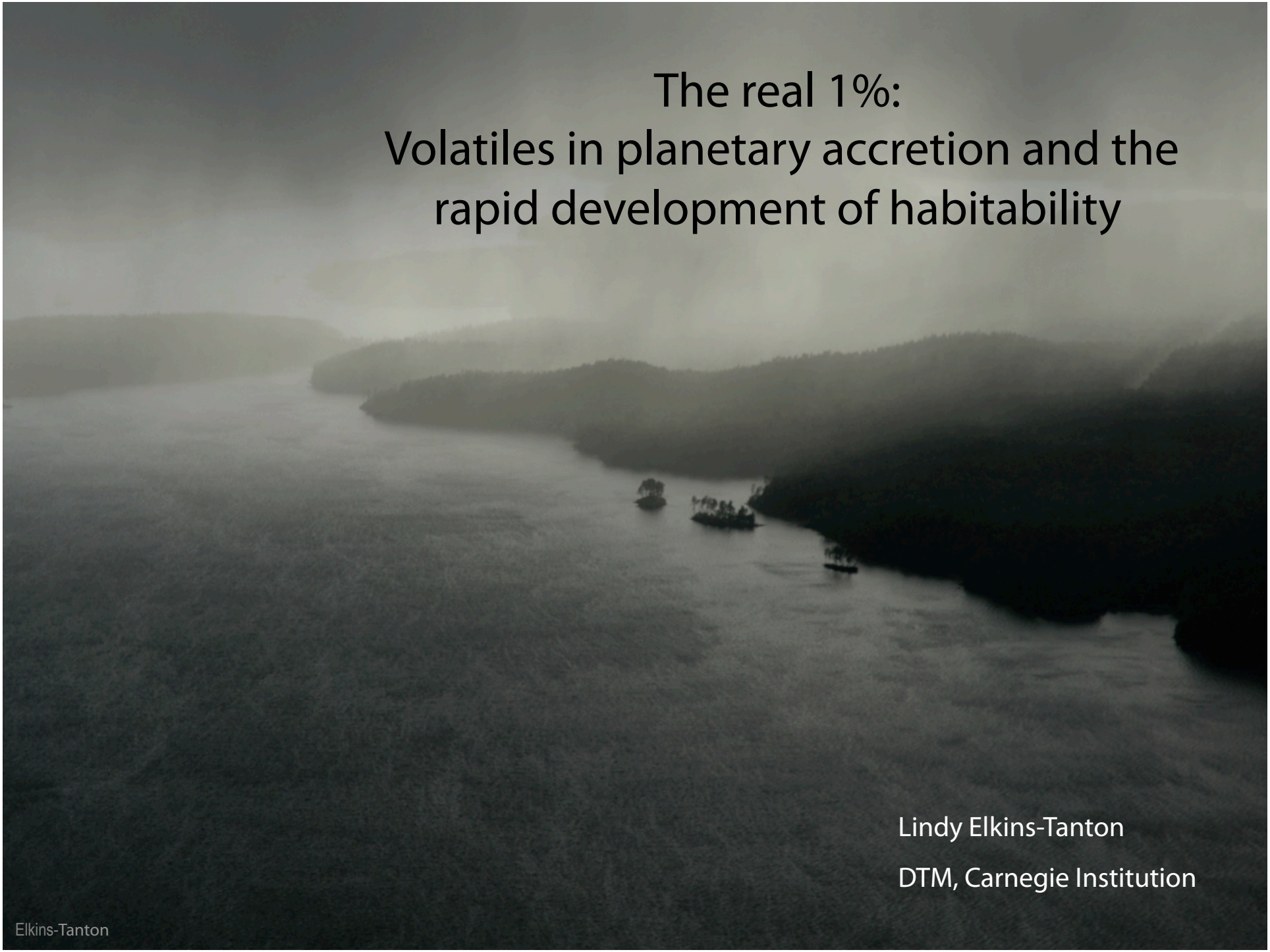
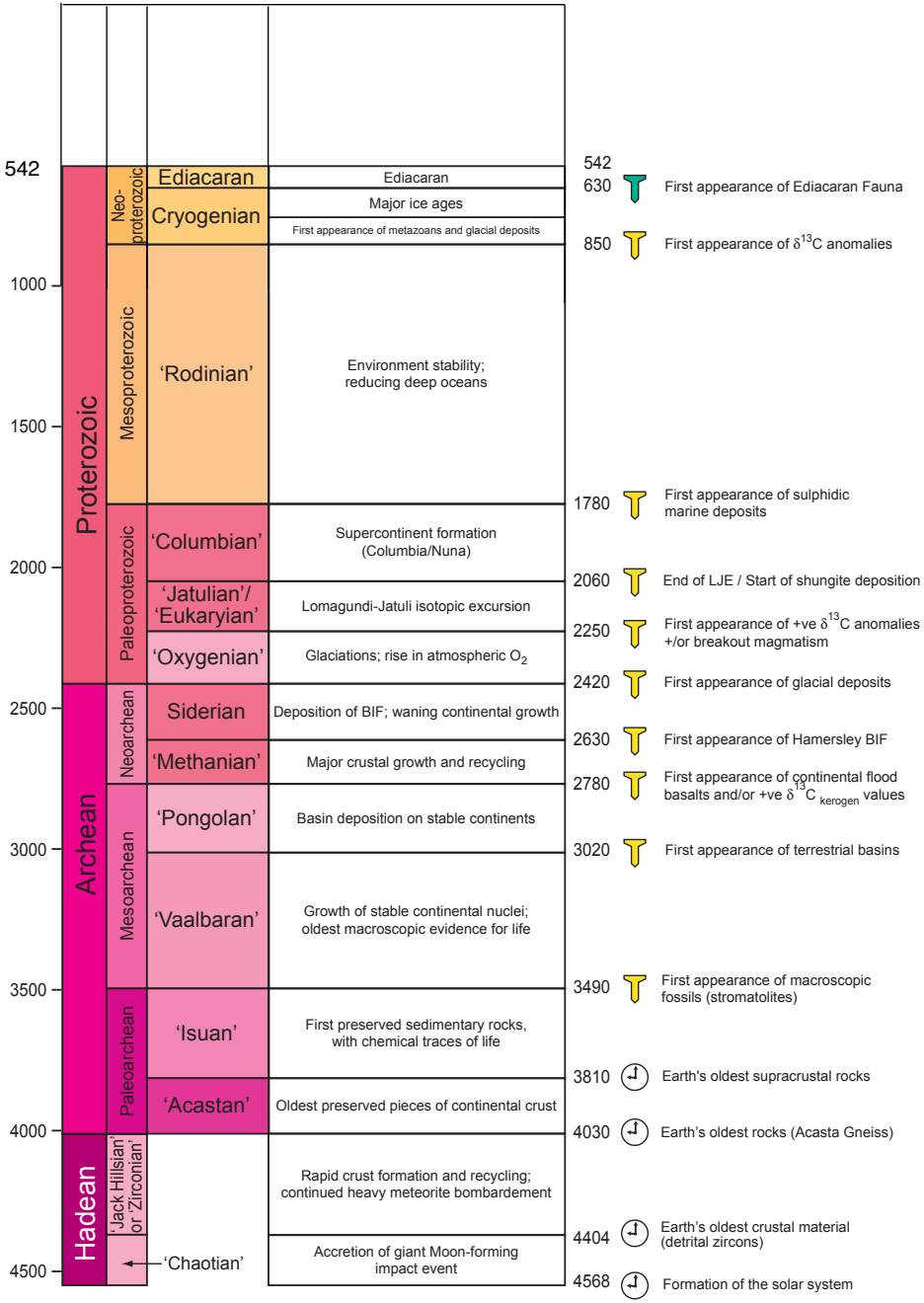


The real 1%:
Volatiles in planetary accretion and the rapid development of habitability

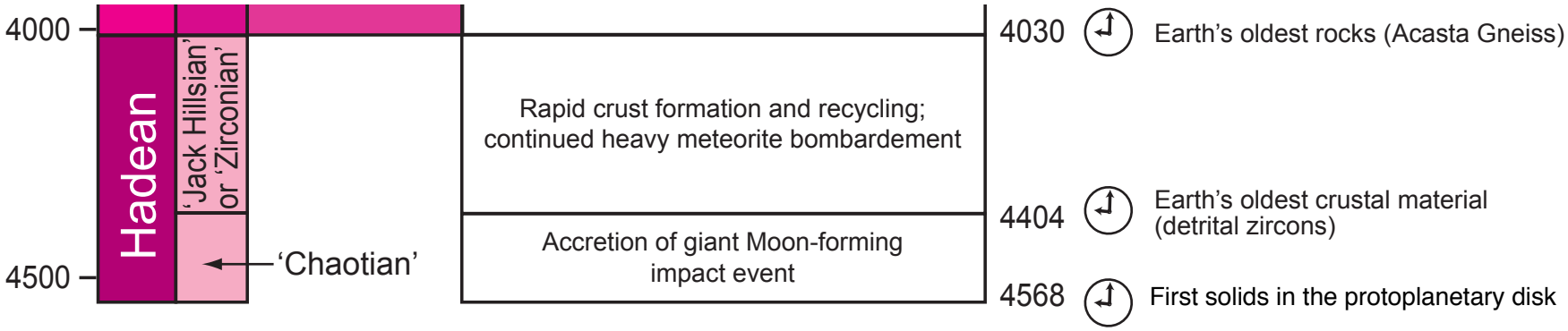
Lindy Elkins-Tanton

DTM, Carnegie Institution

What period of time are we talking about?



Van Kranendonk



Van Kranendonk

How do rocky planets obtain atmospheres?

1. Capture of nebular gases
2. Degassing from the interior
3. Later surface impacts

What material are we working with?

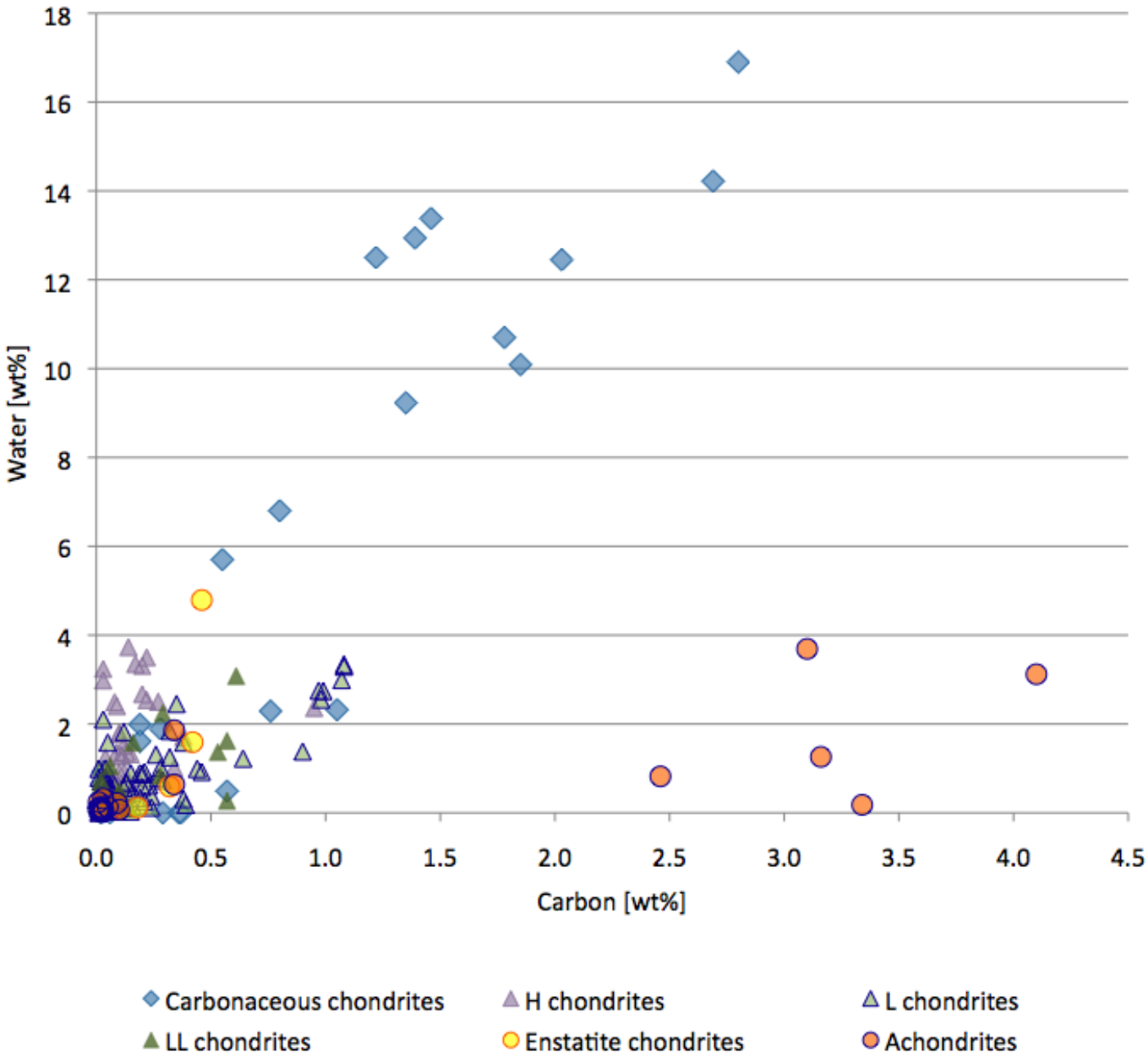
TABLE 5

PHOTOSPHERIC Z/X IN ELEMENTAL ABUNDANCE COMPILATIONS

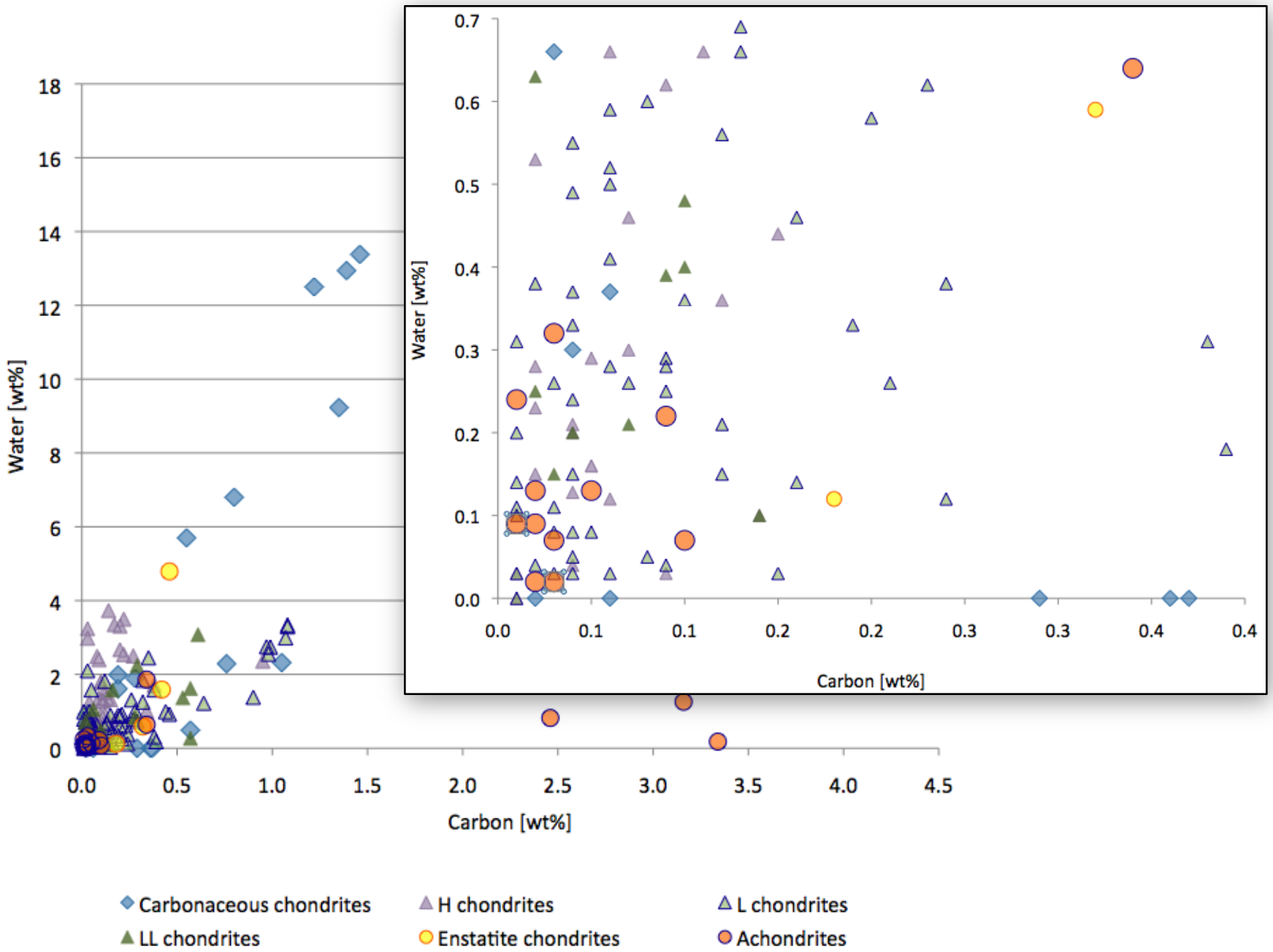
Z/X	Year	Reference
0.0270	1984	1
0.0267	1989	2
0.0245	1993	3
0.0244	1996	4
0.0229	1998	5
0.0208	2002	6
0.0177	2003	7

REFERENCES—(1) Grevesse 1984; (2) Anders & Grevesse 1989; (3) Grevesse & Noels 1993; (4) Grevesse et al. 1996; (5) Grevesse & Sauval 1998; (6) Grevesse & Sauval 2002; (7) this work.

Lodders (2003)

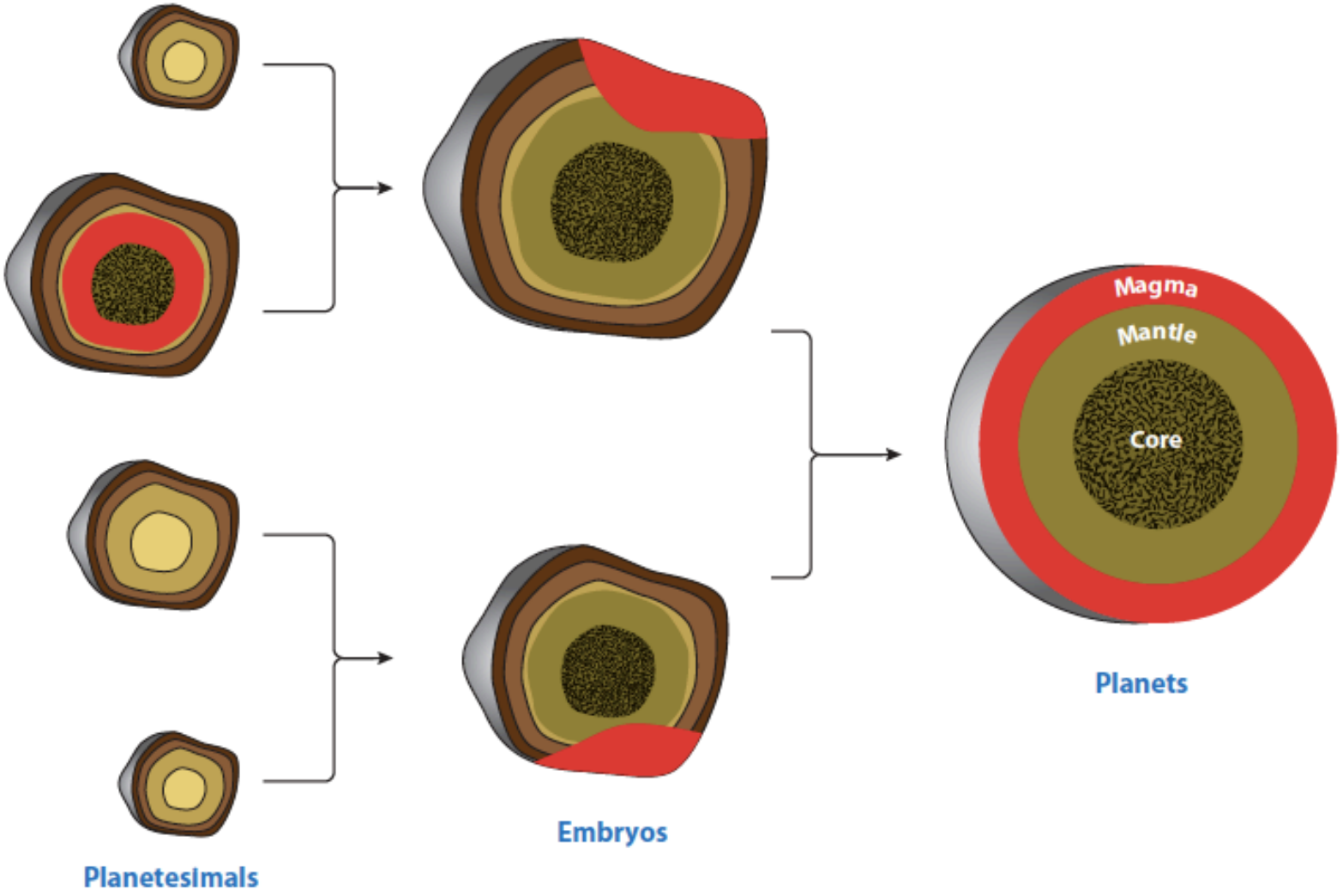


Data from Jarosewich (1990)



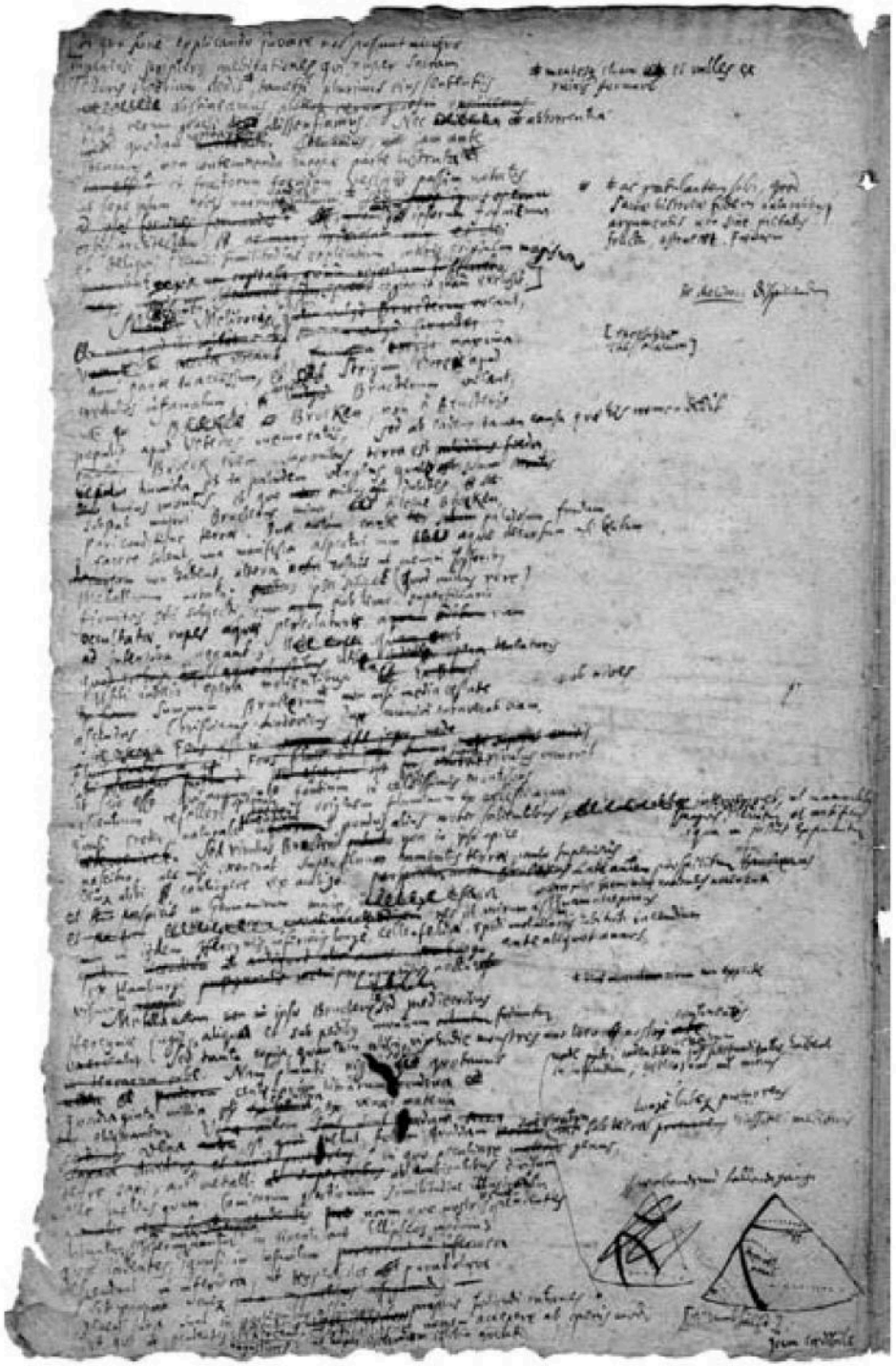
Data from Jarosewich (1990)

What processes make planets?



Elkins-Tanton (2012) Ann.Rev.

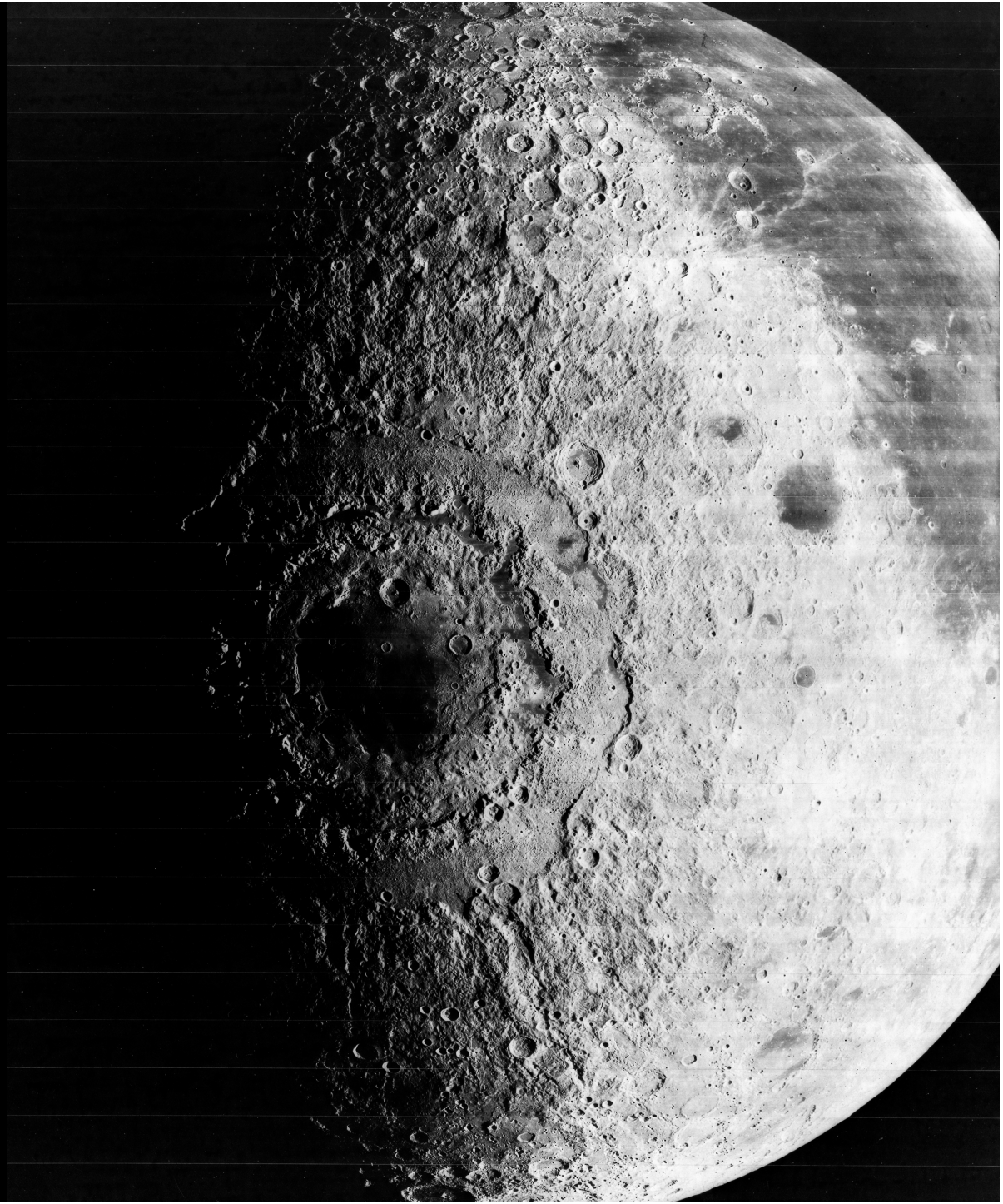
1693: Leibniz suggests in his book *Protogaea* that the Earth was once molten



Gottfried Wilhelm Leibniz Bibliothek, Hannover

Planets retain volatiles during accretion

- Moon, Mars, Mercury
- Water, carbon, …, helium!

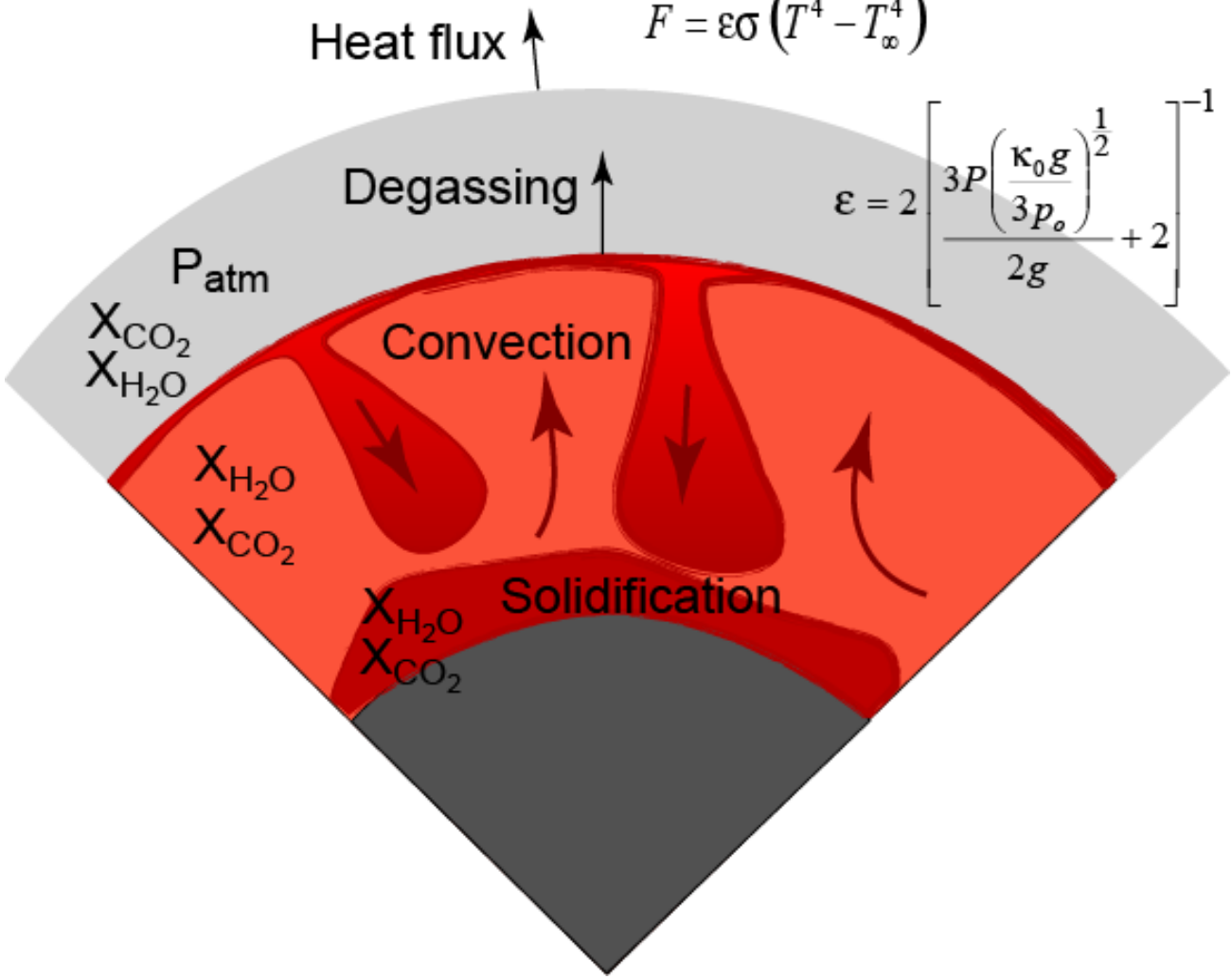


NASA

$$4\pi R^2 F = V\left[\rho H 4\pi r^2 + \rho C_p \frac{dT}{dr}\frac{4}{3}\pi\left(R^3 - r^3\right)\right]$$

$$F = \varepsilon\sigma\left(T^4 - T_\infty^4\right)$$

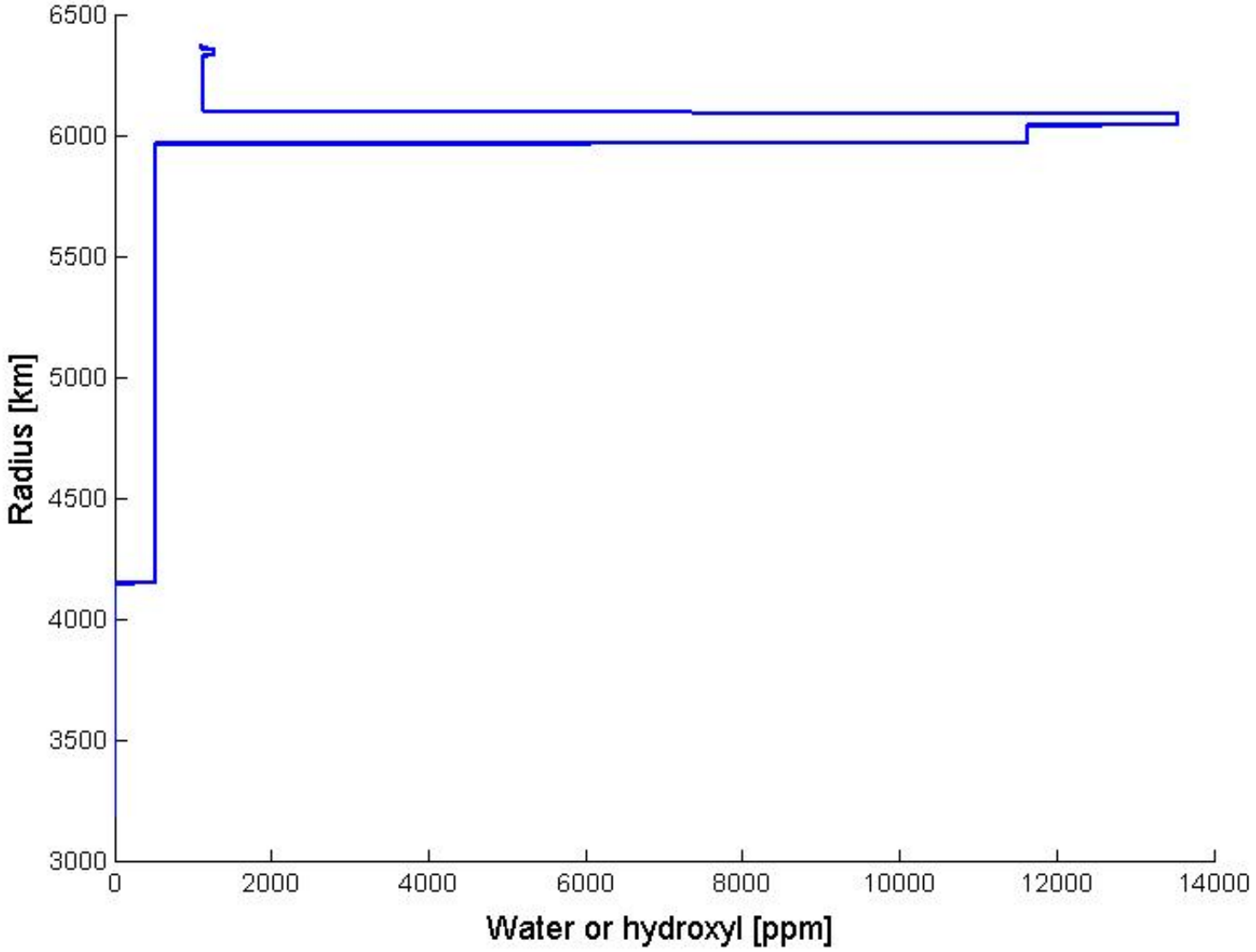
$$\varepsilon = 2\left[\frac{3P\left(\frac{\kappa_0 g}{3p_o}\right)^{\frac{1}{2}}}{2g} + 2\right]^{-1}$$



Elkins-Tanton.

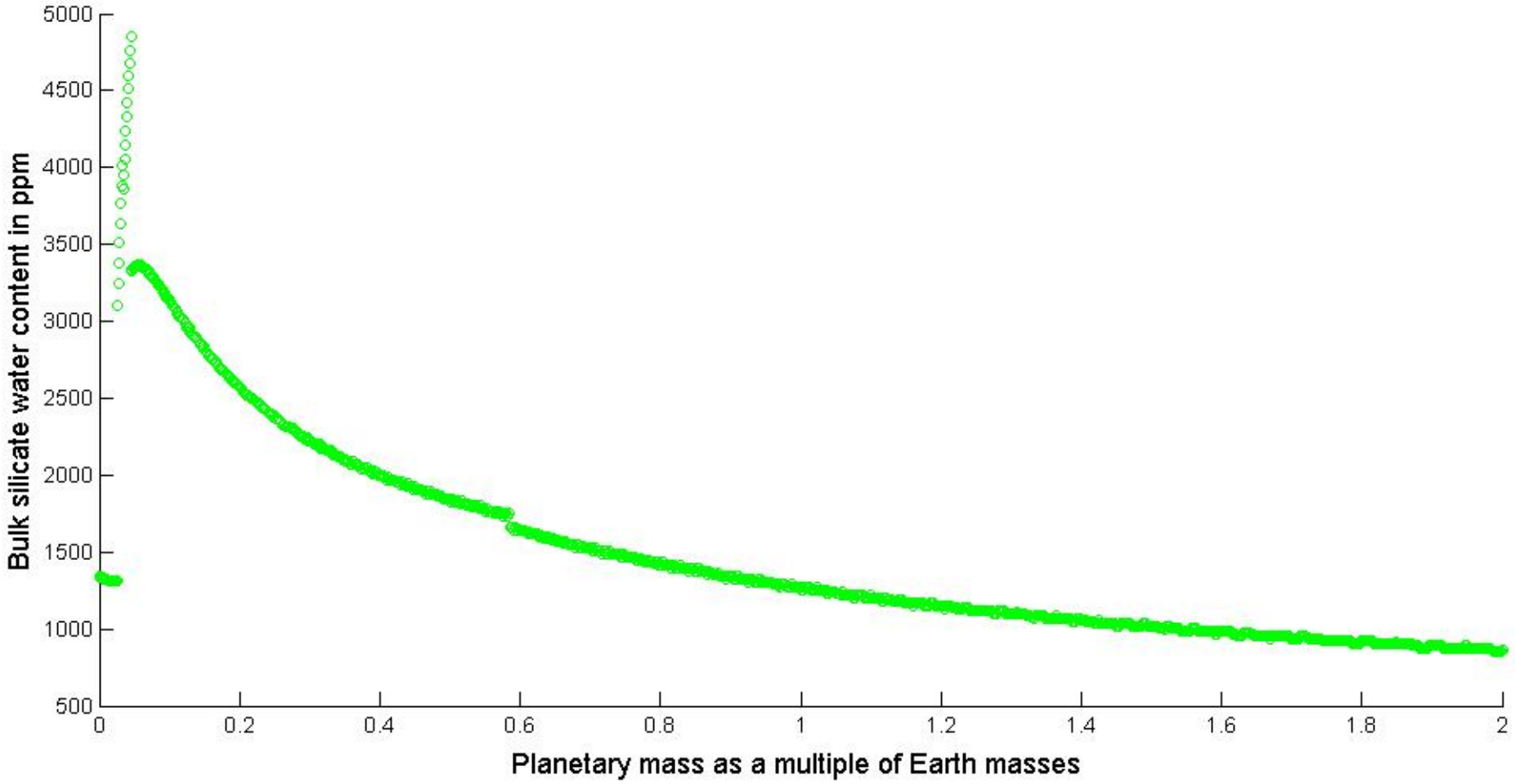
Some volatiles inside, some volatiles outside.

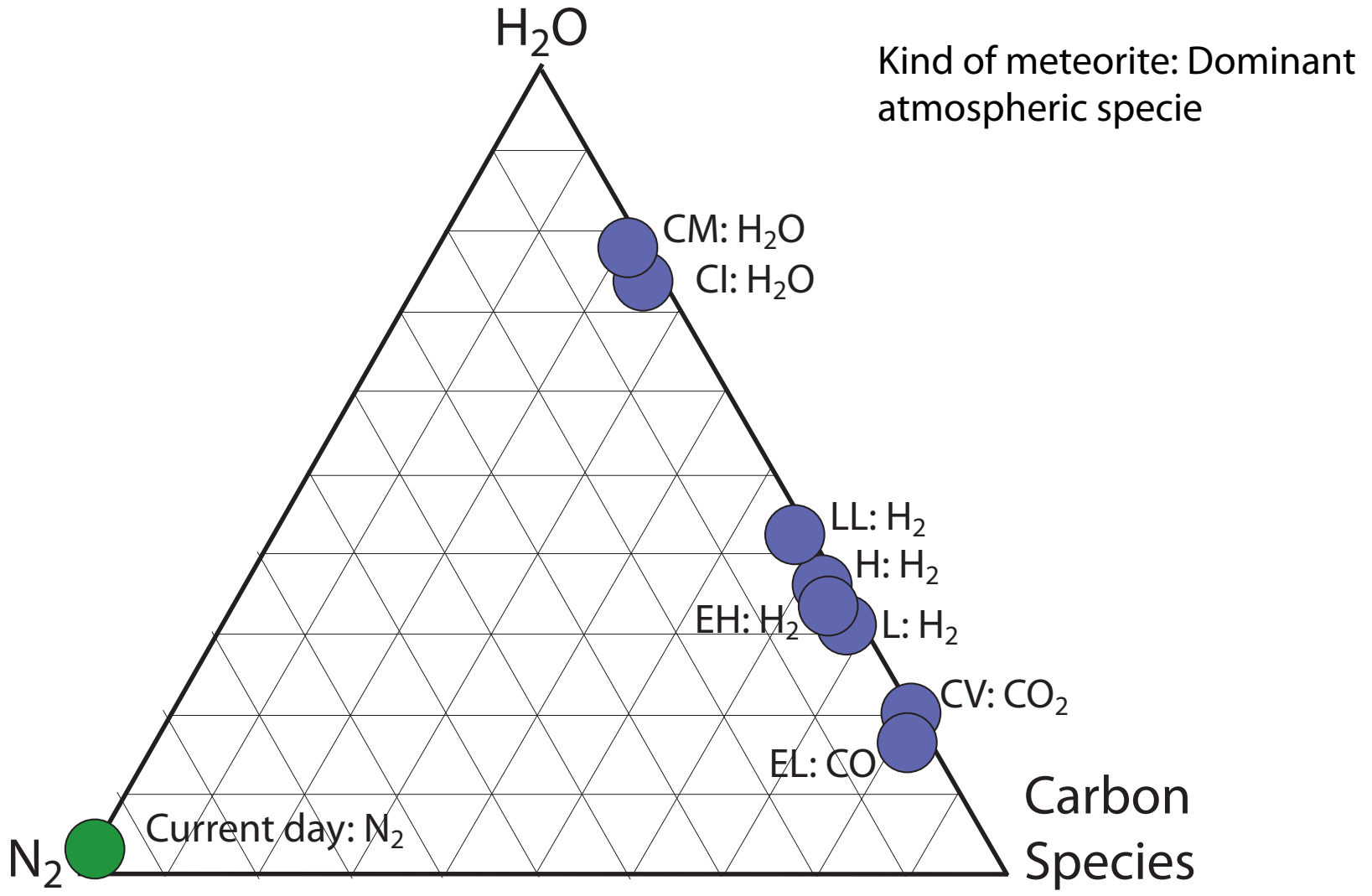
The maximum water capacities of mantle minerals vary widely



Elkins-Tanton

Maximum bulk water content retained in planetary mantle



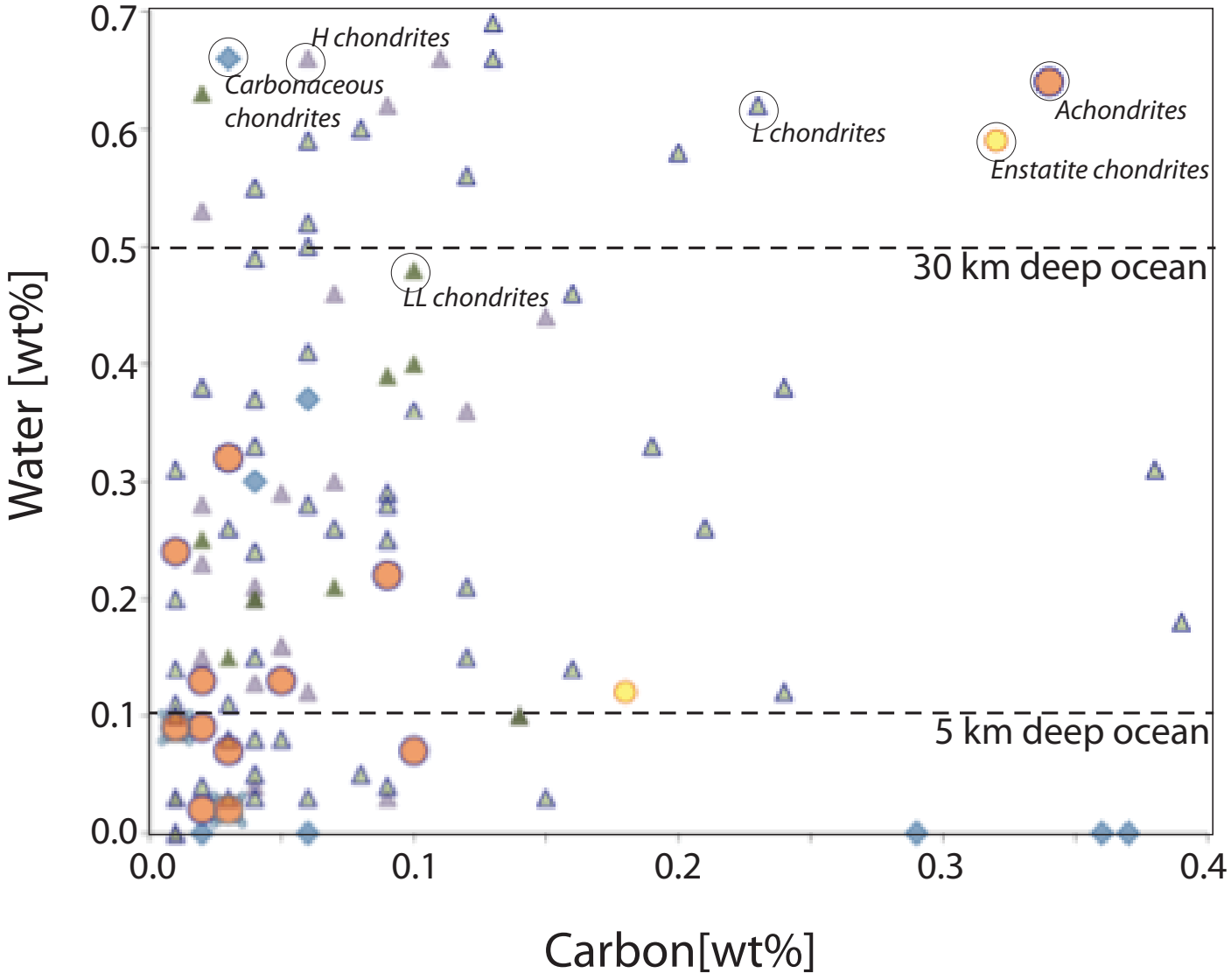


Earliest degassed atmospheres vary with oxidation state, and all are a long way from current day

DATA from Schaefer and Fegley (2010), Hashimoto et al. (2007), Elkins-Tanton and Seager (2008)

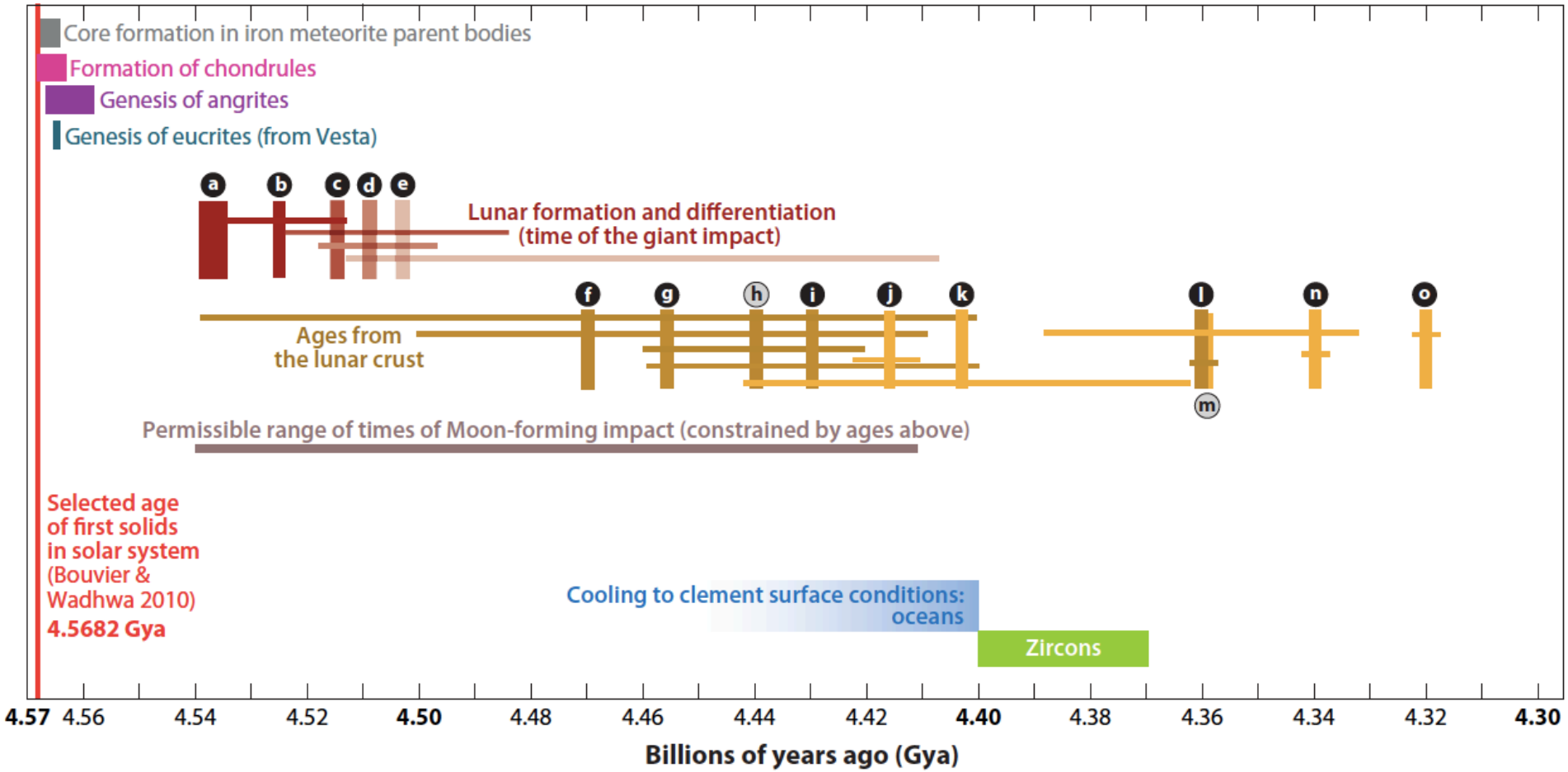
Life (1952)

New York Times (2008)

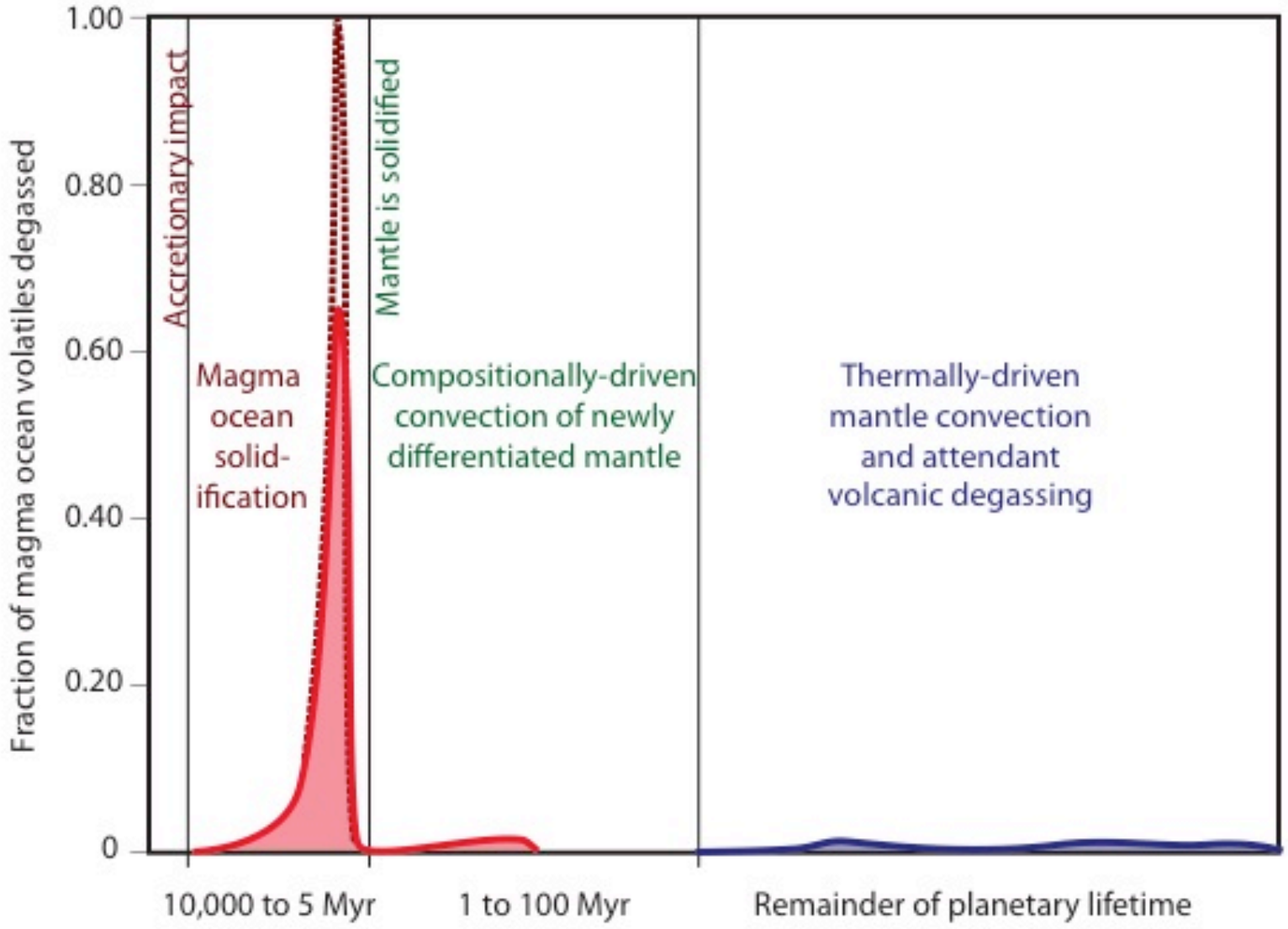


Earth starting with 100 ppm bulk water produces dense atm that collapses upon cooling into global ocean 100s m deep

Elkins-Tanton ; Data from Jarosewich (1990)



Elkins-Tanton (2012) Ann.Rev.



Elkins-Tanton (2010)