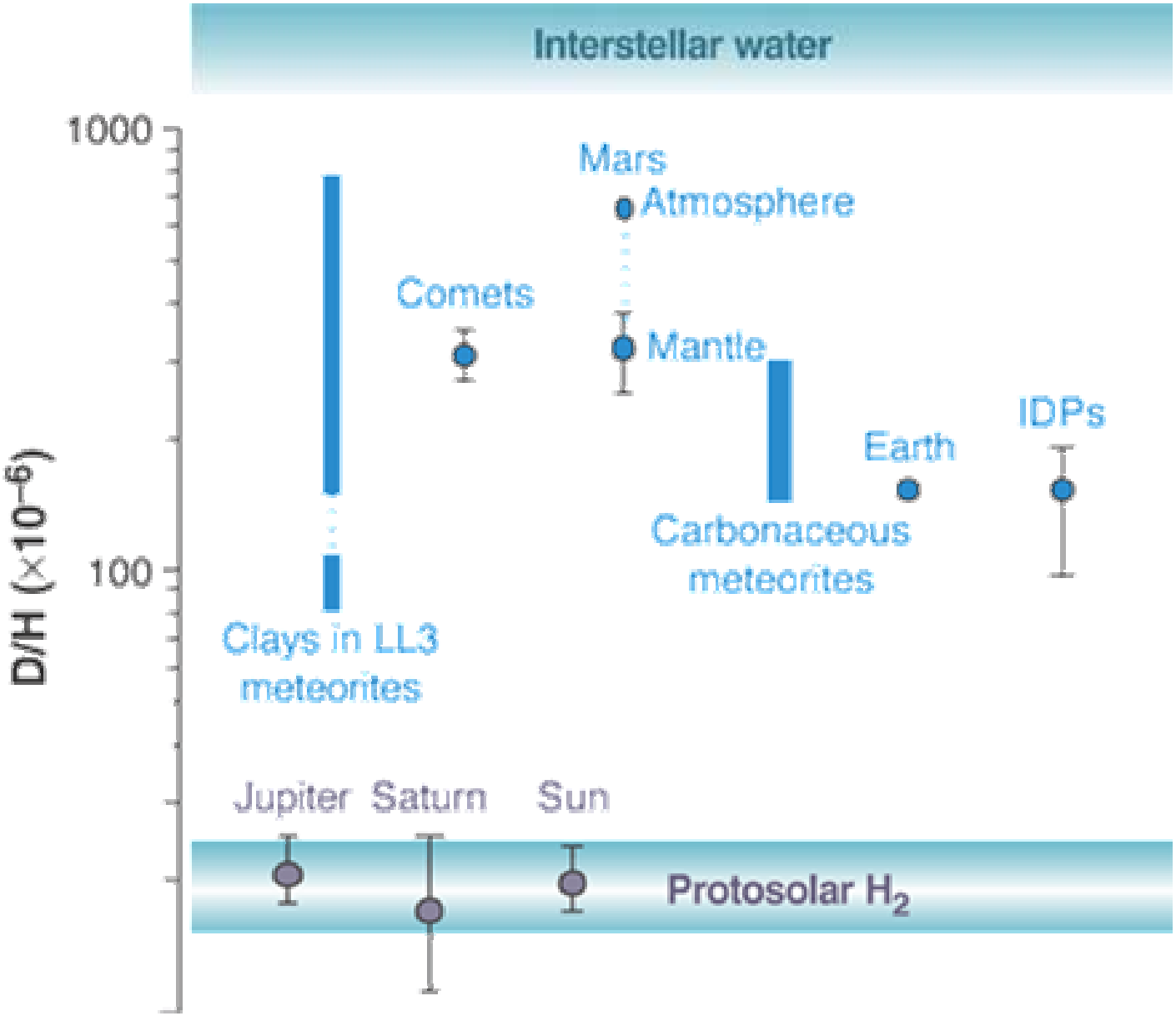
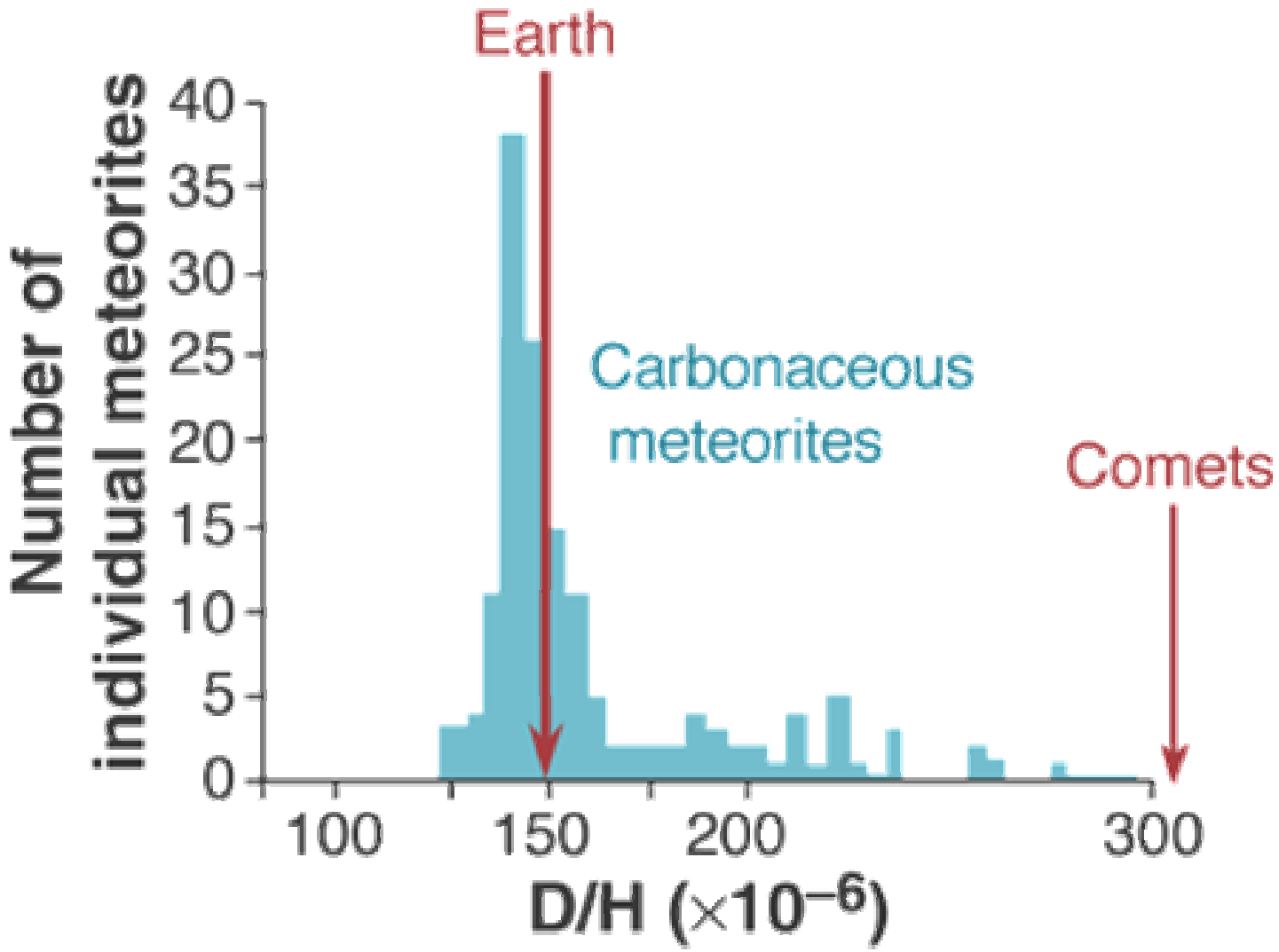
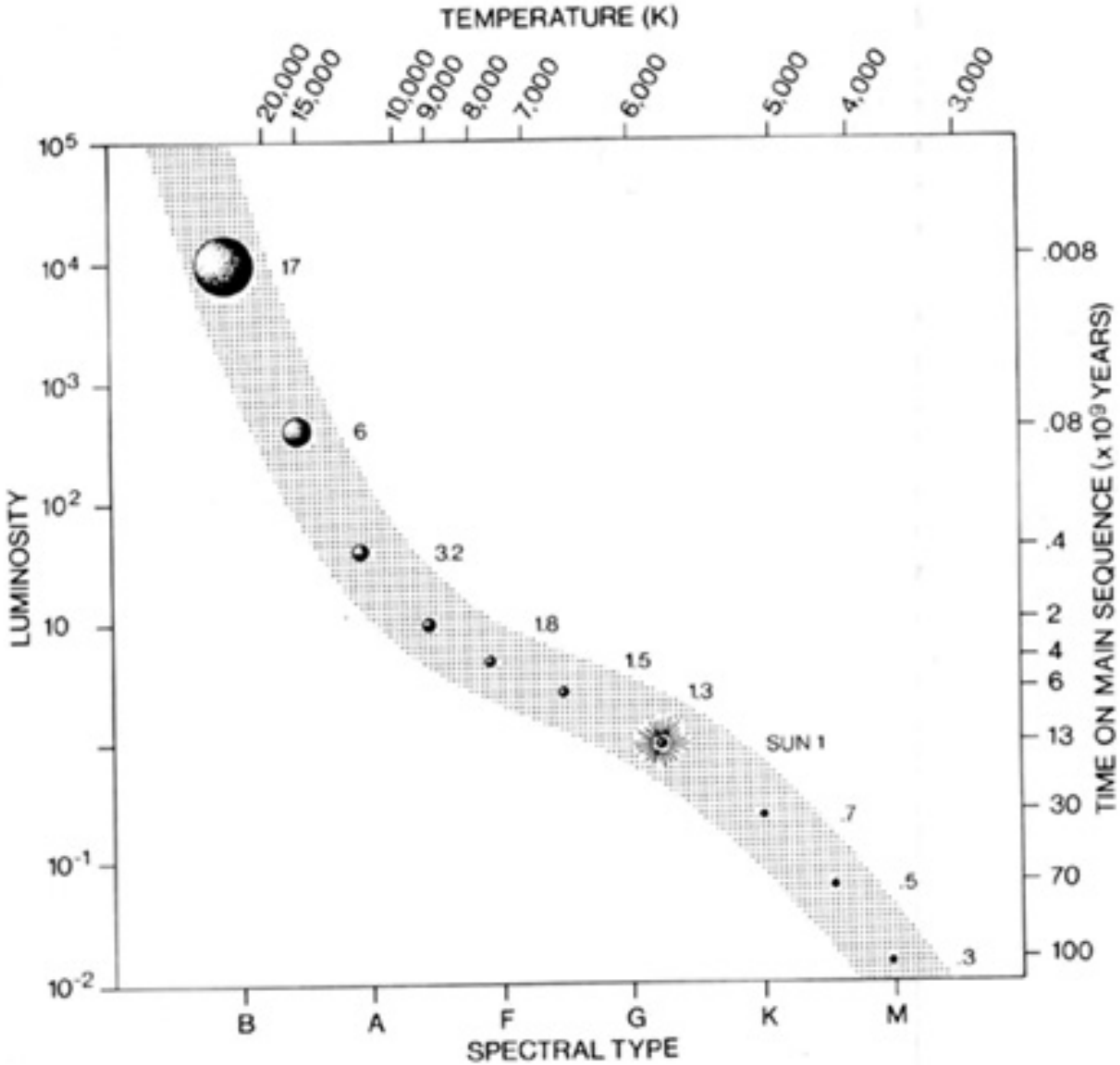

Interstellar water
1000
100
D/H (×10⁻⁶)
Mars
Atmosphere
Comets
Mantle
IDPs
Earth
Carbonaceous meteorites
Clays in LL3 meteorites
Jupiter
Saturn
Sun
Protosolar H2


Earth
Carbonaceous meteorites
Comets
Number of individual meteorites
0
5
10
15
20
25
30
35
40
100
150
200
300
D/H (×10⁻⁶)



Residence time of stars of different mass on the main sequence.
Numbers next to spheres indicate the mass relative to the mass of the Sun (= 1).
Surface temperatures of the various stellar objects are indicated (after Huang, 1970).

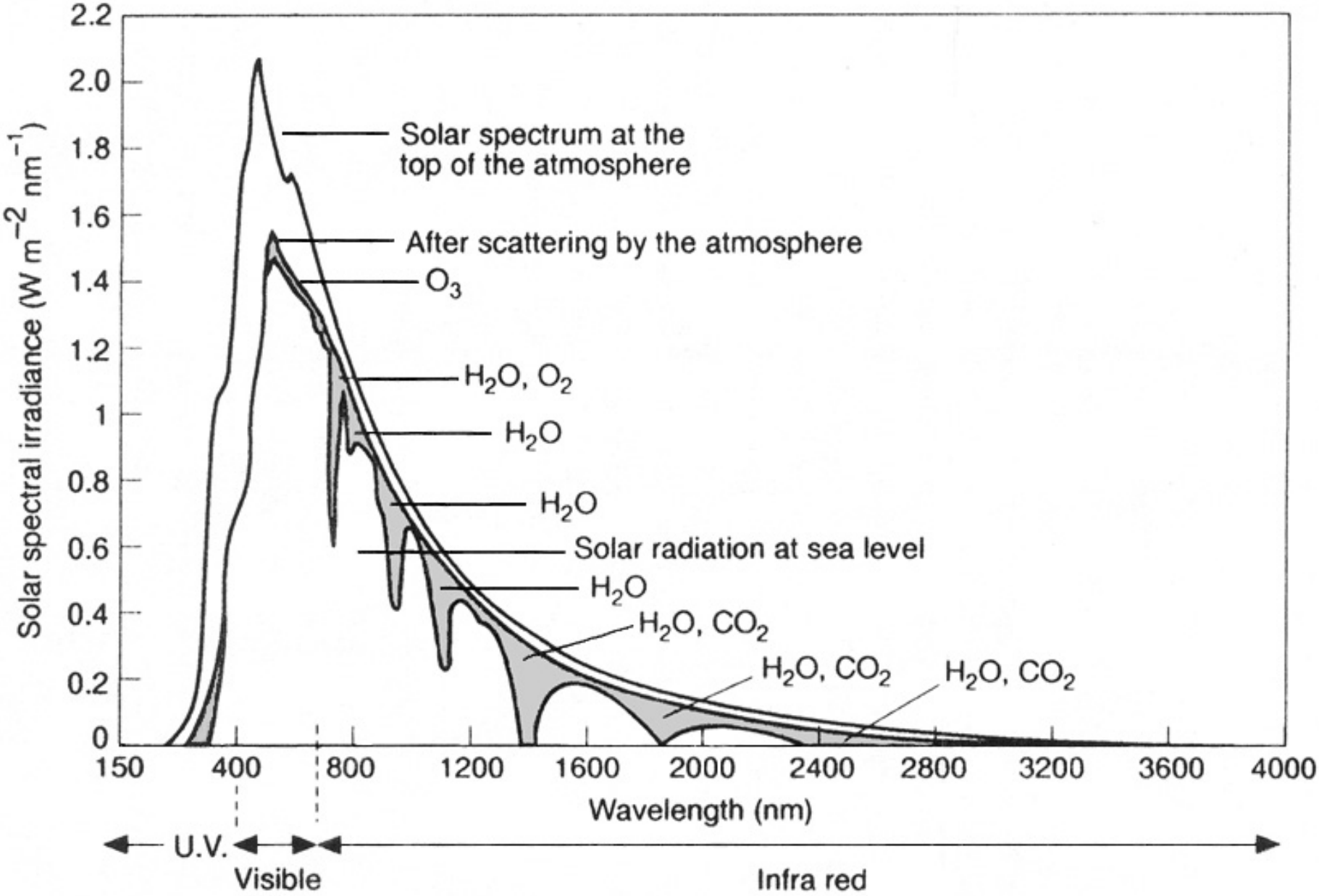

Solar spectral irradiance (W m^{-2} nm^{-1})
2.2
2.0
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
Solar spectrum at the top of the atmosphere
After scattering by the atmosphere
O_3
H_2O, O_2
H_2O
H_2O
Solar radiation at sea level
H_2O
H_2O, CO_2
H_2O, CO_2
H_2O, CO_2
150
400
800
1200
1600
2000
2400
2800
3200
3600
4000
Wavelength (nm)
U.V.
Visible
Infra red

Table 8.7 Summary of data on the probable chemical composition of the atmosphere during stages 1, 2 and 3*

Stage 1 (early Earth)	Stage 2 ($\sim 2 \times 10^9$ years ago)	Stage 3 (Today)
Major components ($p > 10^{-2}$ atm)		
CO_2 (10 bar)		
N_2 (1 bar)	N_2	N_2
CH_4		O_2
CO		
Minor components ($10^{-2} < p > 10^{-6}$ atm)		
H_2 (?)	O_2 (?)	Argon
H_2O	H_2O	H_2O
H_2S	CO_2	CO_2 (10^{-3} bar)
NH_3	Argon	
Argon	(CO?)	
Trace components ($p < 10^{-6}$ atm)		
He	Ne	Ne
Ne	He	He
	CH_4	CH_4
	NH_3 (?)	CO
	SO_2	NO
O_2 (10^{-13} bar)	H_2S (?)	

* We are able to give a good account of stage 3 (Section 8.6.1) and a good estimate of stage 1, but the evolutionary period, stage 2, is hard to describe with any accuracy.

Table 8.8 The characteristics of the early ocean and of today

Proto-ocean (?)

pH = 2.0 (initial); $T = 80°C$
CO_2 and SO_2 not very soluble
HCl gives the acidity
Initially weak content of cations, but increasing to Ca^{2+}, 115 mM; Mg^{2+}, 95 mM; Na^+, 120 mM; K^+, 60 mM
Redox potential around −0.5 to 0.0 volts

Early ocean

pH = 8.0; $T = 55°C$
HCO_3^- (CO_2) high; SO_4^{2-} low; H_2S high
$Ca^{2+} \geqslant 10$ mM
Fe^{2+}, 1 mM; $Zn^{2+} \leqslant 10^{-10}$ M
Redox potential >0.0 rising to <0.4 volts

Late ocean (today)

pH = 8.0; $T = 25°C$
HCO_3^- (CO_2) high, and SO_4^{2-} (not H_2S) present
Average concentrations of cations are Ca^{2+}, 10 mM; Mg^{2+}, 105 mM; Na^+, 470 mM; K^+, 10 mM
Redox potential up to 0.80 volts at surface (O_2)
Fe^{3+}, 10^{-17}M; Cu^{2+}, etc., see Fig. 8.15

Table 8.9 Some trace elements in the early sea*

Elements present

Fe^{2+}, Mn^{2+}, (Mo^{6+}), V^{4+}, (Ni^{2+}), W^{6+}, (Co^{2+}), Se as H_2Se

Elements largely absent

Cu^{2+}, Cd^{2+}, Zn^{2+}, Cr^{3+}, Ti^{3+}

* The assumption is that the pH $\geqslant 5$ and the amount of H_2S kept the sea as a reducing medium (see Fig. 8.11). The concentration of Mo^{6+} may have been lower than that of W^{6+} as Mo is precipitated as MoS_2 at low pH

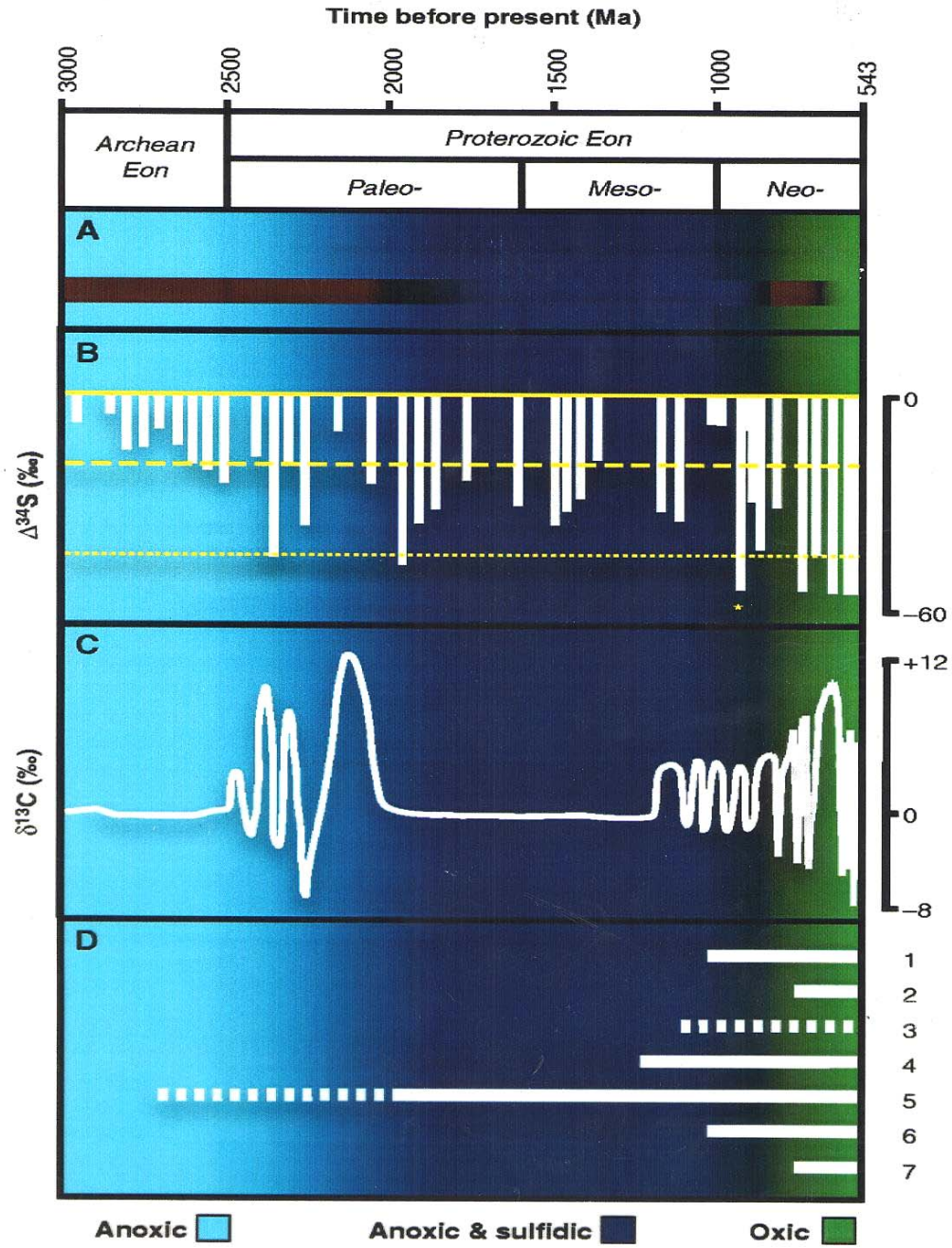
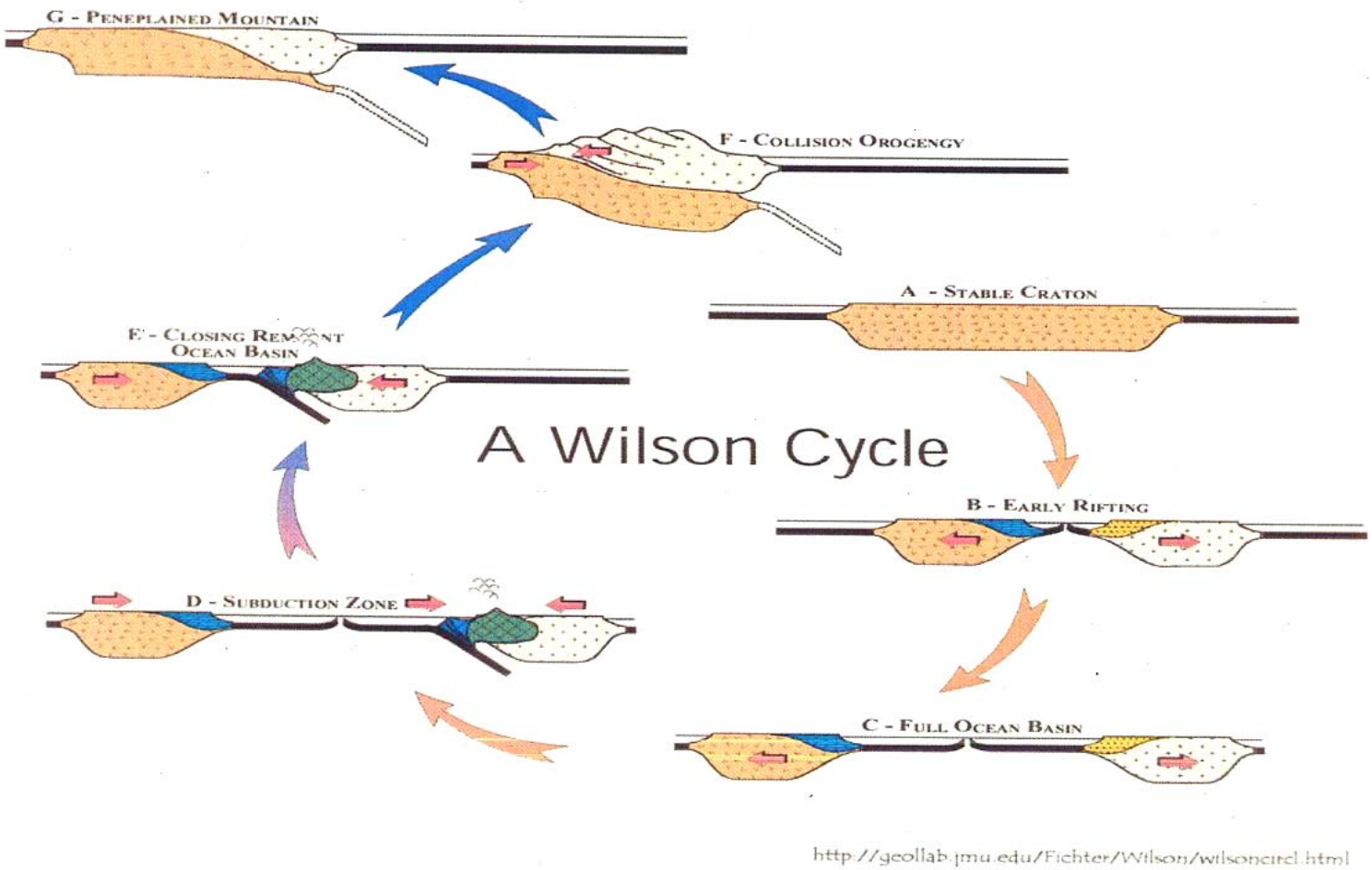

Time before present (Ma)
3000
2500
2000
1500
1000
543
Archean Eon
Proterozoic Eon
Paleo-
Meso-
Neo-
A
B
C
D
$\Delta^{34}S$ (‰)
$\delta^{13}C$ (‰)
0
–60
+12
0
–8
1
2
3
4
5
6
7
Anoxic
Anoxic & sulfidic
Oxic

Table 1.1 Major Chemical Constituents of the Earth's Crust, Sediments, Ocean Water, and Atmosphere

	Crystal ionic charge and radius[a]		Continental crust		Oceanic crust		Average sediments		Ocean water		Atmosphere	
Element		r(Å)	(wt %[b])	(vol %)	(wt %[b])	(vol %)	(wt %[c])	(vol %)	(wt %[a])	(vol %)	(wt %)	(mol % or vol %[a])
O	−2	1.32	46.40	93.04	43.80	92.57	47.61	91.32	86.0	99.0 as H_2O	23.15	20.95 (O_2)
Si	+4	0.42	28.15	1.04	24.00	0.93	24.40	0.86				
Al	+3	0.51	8.23	0.56	8.76	0.63	6.03	0.40				
Fe	+3 +2	0.64 0.74	5.63	0.46	8.56	0.74	3.79	0.30				
Ca	+2	0.99	4.15	1.40	6.72	2.39	7.86	2.54	0.04	0.025		
Na	+1	0.97	2.36	1.31	1.94	1.13	1.36	0.72	1.08	0.11		
Mg	+2	0.66	2.33	0.38	4.5	0.78	2.44	0.39	0.13	0.04		
K	+1	1.33	2.09	1.75	0.83	0.73	2.00	1.61	0.04	0.062		
Ti	+4	0.68	0.54	0.05	0.90	0.09						
Mn			0.095		0.15							
H			0.14		0.2				10.7	(see O)		
P	+5	0.35	0.105		0.14		0.16	0.003				
S	+6	0.30	0.026		0.025		0.62	0.007	0.09	0.0002		
C	+4	0.16					2.91[d]	0.013	0.28	0.002	0.046	0.03 (CO_2)
Cl	−1	1.81					0.83	1.85	1.94	0.833		
N											75.53	78.09 (N_2)
Ar											1.28	0.93 (Ar)

[a] Weast (1974).
[b] Taylor (1964).
[c] From Garrels et al. (1975, p. 61).
[d] Inorganic C, 2.4; organic, 0.5.

The Wilson "Cycle"



http://geollab.jmu.edu/Fichter/Wilson/wilsoncircl.html