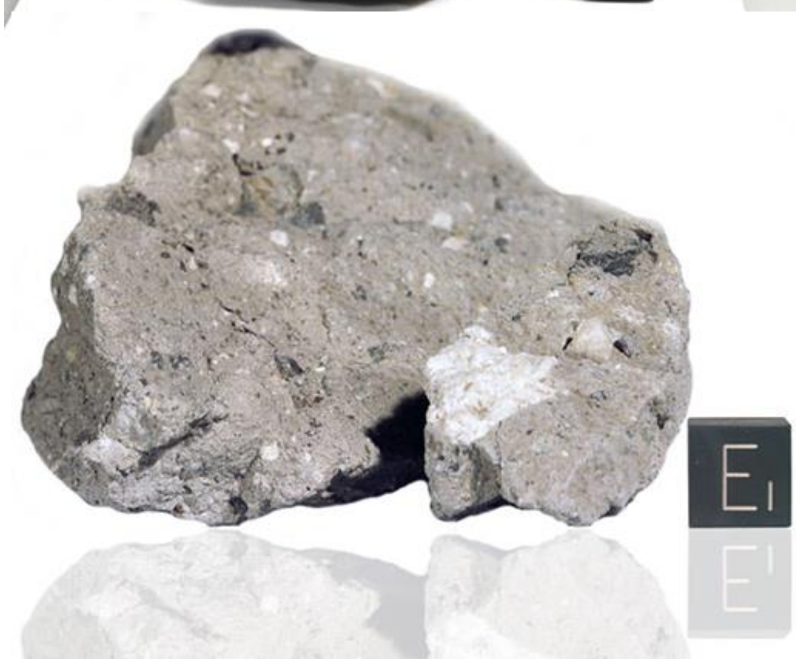
ASTR/GEOL-2040: Search for life in the Universe: Lecture 16

- Rock dating
- Carbon 13 record
- Midterm

Axel Brandenburg
(Office hours: Mondays 2:30 – 3:30 in X590 and Wednesdays 11-12 in D230)

How do we know ages of rocks?



Most abundant elements

Table 1.1 The ten most abundant elements in the Universe, Earth and life (expressed as atoms of the element per 100 000 total atoms).

Order	Universe		Whole Earth		Earth's crust		Earth's ocean		Humans	
1	H	92 714	O	48 880	O	60 425	H	66 200	H	60 563
2	He	7 185	Fe	18 870	Si	20 475	O	33 100	O	25 670
3	O	50	Si	14 000	Al	6 251	Cl	340	C	10 680
4	Ne	20	Mg	12 500	H	2 882	Na	290	N	2 440
5	N	15	S	11 400	Na	2 155	Mg	34	Ca	230
6	C	8	Ni	1 400	Ca	1 878	S	17	P	130
7	Si	2.3	Al	1 300	Fe	1 858	Ca	6	S	130
8	Mg	2.1	Na	640	Mg	1 784	K	6	Na	75
9	Fe	1.4	Ca	460	K	1 374	C	1.4	K	37
10	S	0.9	P	140	Ti	191	Si	–	Cl	33

- H and He in the Universe
- Nobel elements He, Ne, Ar, … highly unreactive (inert)
- Rest in Universe O, N, C, Si
- Human body H, O, C, N

1% (so what?)

Right & left of K

Group→ ↓Period	1	2	3		4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1	1 H																		2 He
2	3 Li	4 Be												5 B	6 C	7 N	8 O	9 F	10 Ne
3	11 Na	12 Mg												13 Al	14 Si	15 P	16 S	17 Cl	18 Ar
4	19 K	20 Ca	21 Sc		22 Ti	23 V	24 Cr	25 Mn	26 Fe	27 Co	28 Ni	29 Cu	30 Zn	31 Ga	32 Ge	33 As	34 Se	35 Br	36 Kr
5	37 Rb	38 Sr	39 Y		40 Zr	41 Nb	42 Mo	43 Tc	44 Ru	45 Rh	46 Pd	47 Ag	48 Cd	49 In	50 Sn	51 Sb	52 Te	53 I	54 Xe
6	55 Cs	56 Ba	57 La	*	72 Hf	73 Ta	74 W	75 Re	76 Os	77 Ir	78 Pt	79 Au	80 Hg	81 Tl	82 Pb	83 Bi	84 Po	85 At	86 Rn
7	87 Fr	88 Ra	89 Ac	**	104 Rf	105 Db	106 Sg	107 Bh	108 Hs	109 Mt	110 Ds	111 Rg	112 Cn	113 Nh	114 Fl	115 Mc	116 Lv	117 Ts	118 Og
				*	58 Ce	59 Pr	60 Nd	61 Pm	62 Sm	63 Eu	64 Gd	65 Tb	66 Dy	67 Ho	68 Er	69 Tm	70 Yb	71 Lu	
				**	90 Th	91 Pa	92 U	93 Np	94 Pu	95 Am	96 Cm	97 Bk	98 Cf	99 Es	100 Fm	101 Md	102 No	103 Lr	

18 Ar Argon
19 K Potassium
20 Ca Calcium

3rd most element in atmosphere

Order	Universe		Earth's crust		Earth's ocean		Dry air		Humans	
1	H	92714	O	60425	H	66200	N	78100	H	60563
2	He	7185	Si	20475	O	33100	O	20920	O	25670
3	O	50	Al	6251	Cl	340	Ar	950	C	10680
4	Ne	20	H	2882	Na	290	C	32	N	2440
5	N	15	Na	2155	Mg	34	Ne	1.8	Ca	230
6	C	8	Ca	1878	S	17	H	1.2	P	130
7	Si	2.3	Fe	1858	Ca	6	He	0.5	S	130
8	Mg	2.1	Mg	1784	K	6	Kr	0.1	Na	75
9	Fe	1.4	K	1374	C	1.4	–	–	K	37
10	S	0.9	Ti	191	Si	0.3	–	–	Cl	33

Why?

A. Nobel gas, so primordial?
B. Radioactive decay of K?
C. Delivered through comets?
D. H-bomb tests in the 1950?

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^{40}K decay
→ Radioactive heat in Earth core

Potassium: mostly ^{39}K 6.73% is ^{41}K (stable)

- ^{40}K is only 0.012% of all K
- Contributes to geothermal heat
- Huge ½ life! (1.251 Gyr)
- Can be used for dating of rocks
- ½ life of C is only 5730 yr

Right & left of K

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β decay and e capture

$$p + e \rightarrow n + \nu_e$$

neutrino

anti-neutrino

$$n \rightarrow p + e + \bar{\nu}_e$$

$$p \rightarrow n + e^+ + \nu_e$$

Two decay products

- ^{40}Ca and ^{40}Ar
  - ^{40}Ca is most common → difficult
- Advantage with Ar?

Two decay products

- ^{40}Ca and ^{40}Ar
  - ^{40}Ca is most common → difficult
- Advantage with Ar
  - it's a gas, trapped in rocks!
  - inert

Which one is $^{40}K \rightarrow {}^{40}Ca$

A. … $n \rightarrow p + e + \bar{\nu}_e$

B. … $p + e \rightarrow n + \nu_e$

C. … $p \rightarrow n + e^+ + \nu_e$

D. … both B and C possible

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5	37 Rb	38 Sr	39 Y	40 Zr	41 Nb	42 Mo	43 Tc	44 Ru	45 Rh	46 Pd	47 Ag	48 Cd	49 In	50 Sn	51 Sb	52 Te	53 I	54 Xe

Which one is $^{40}K \rightarrow {}^{40}Ar$

A. … $n \rightarrow p + e + \bar{\nu}_e$

B. … $p + e \rightarrow n + \nu_e$ ←

C. … $p \rightarrow n + e^+ + \nu_e$ ← 0.001%

D. … both B and C possible

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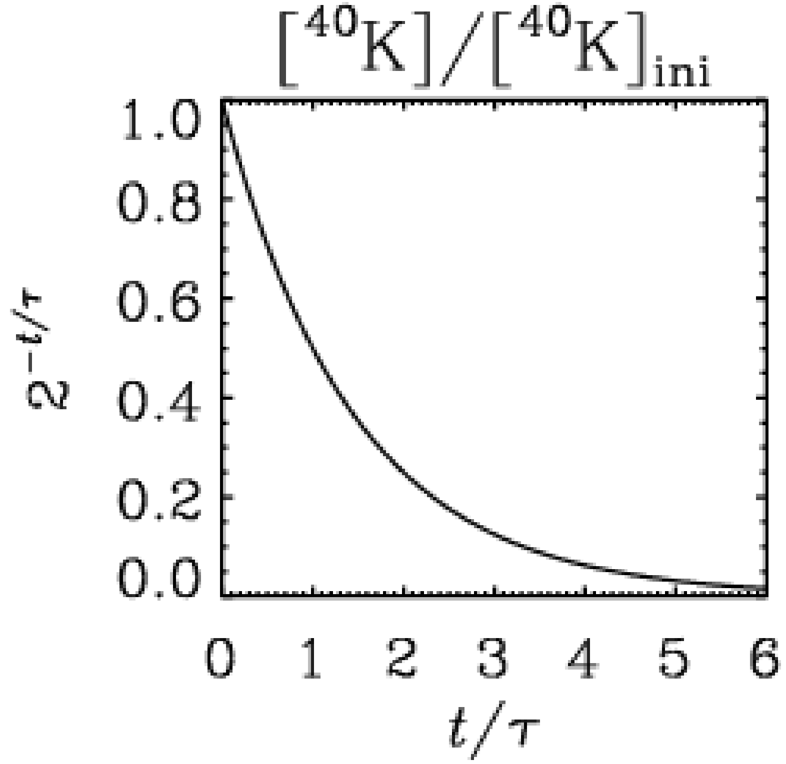
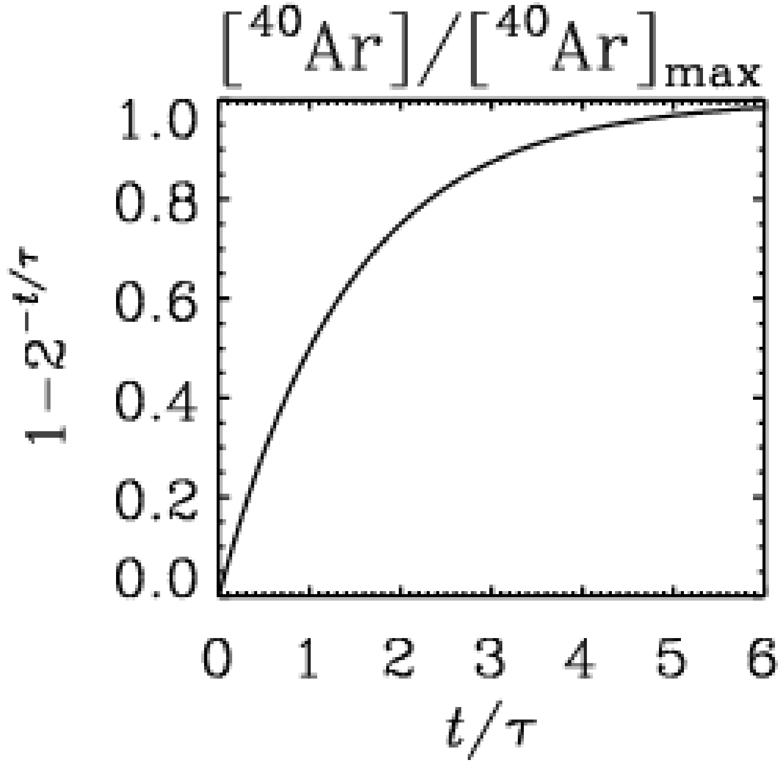
Decay & growth

$$t/t_{1/2}=\log_2(1+[^{40}Ar]/0.109\ [^{40}K])$$



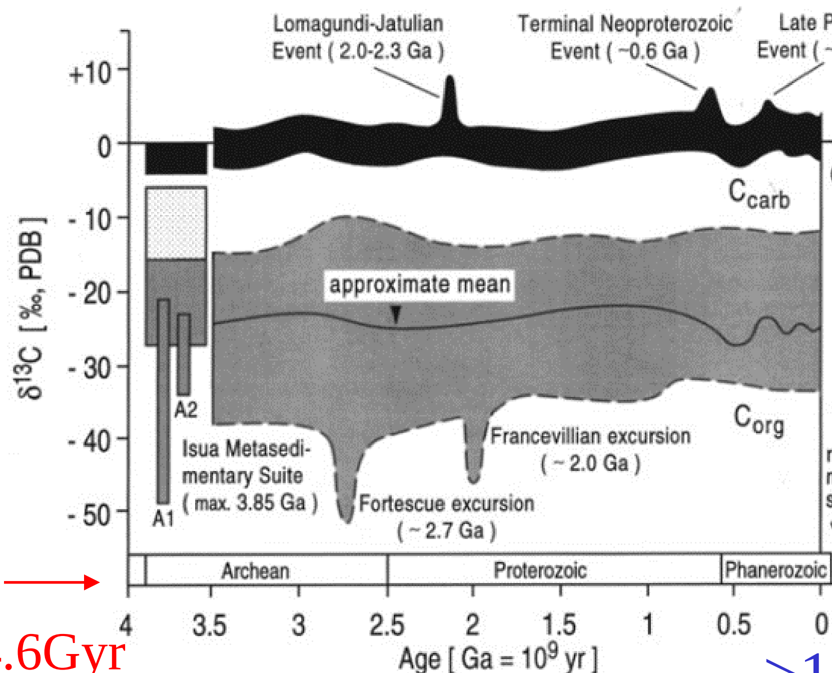


Carbon isotropes: $^{14}C \rightarrow {}^{14}N$

^{14}C decay into ^{14}N: half life 5700 yr

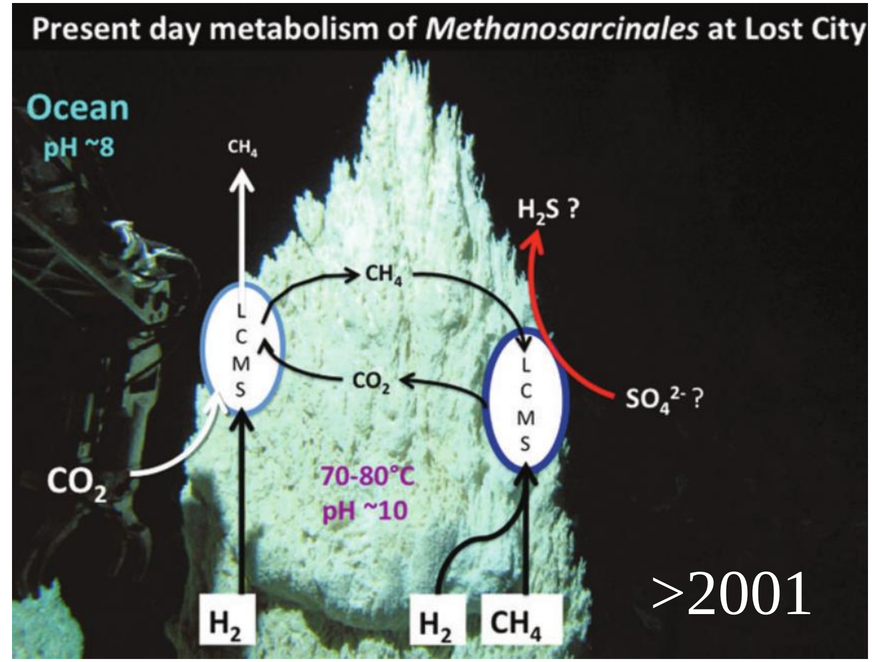
- Most (98.9%) C is ^{12}C
- Some (1.1%) is ^{13}C
- Only traces of ^{14}C
- Chemically same, but ^{13}C commonis heavier: less in biochemistry

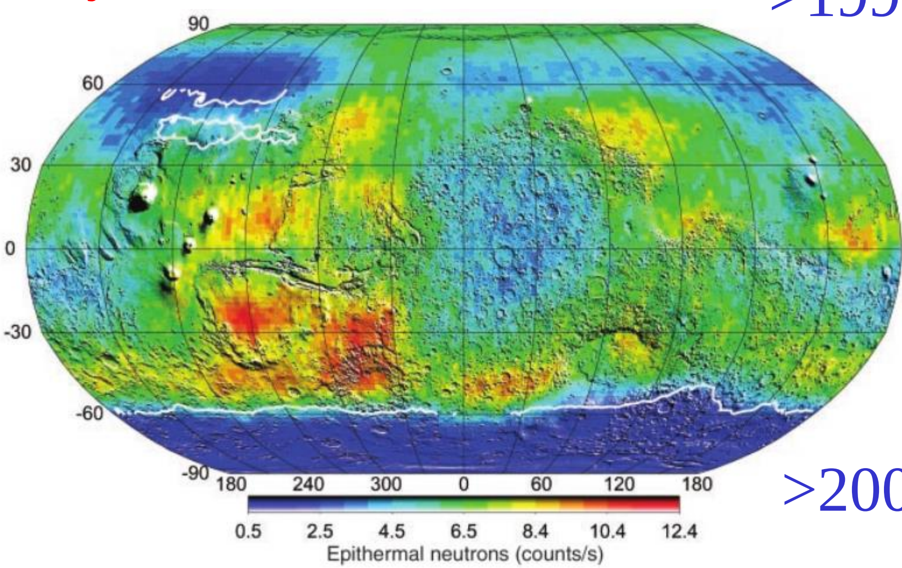
Cornerstones of astrobiology (Lect 1)



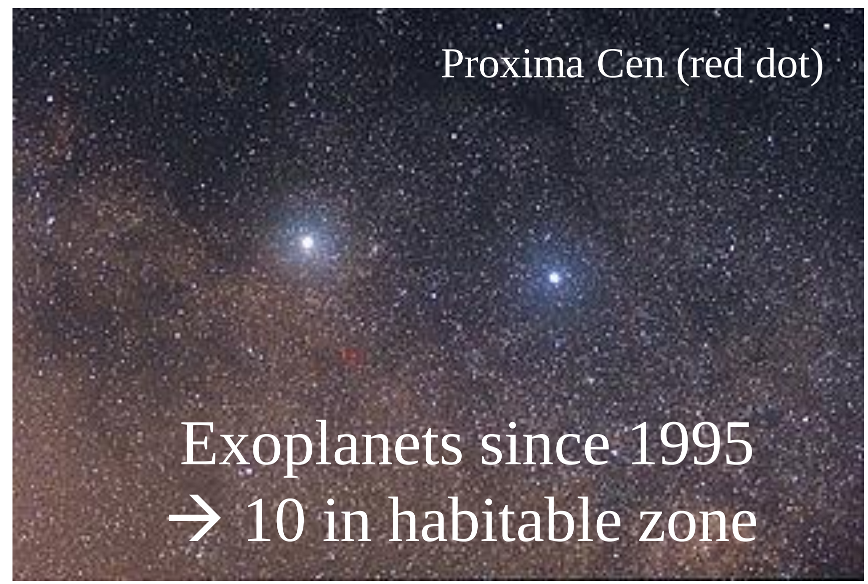
4.6Gyr

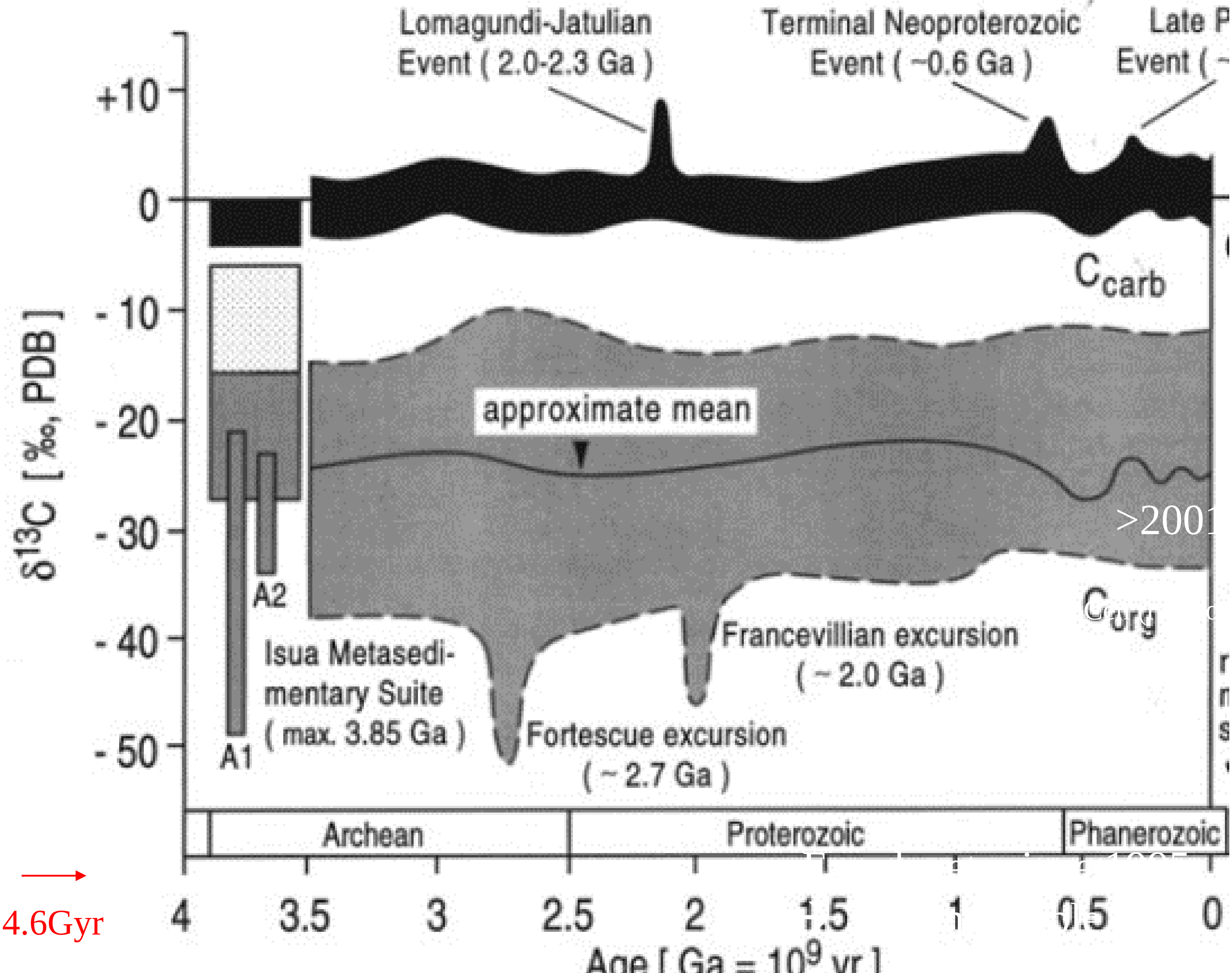
>1996





>2003



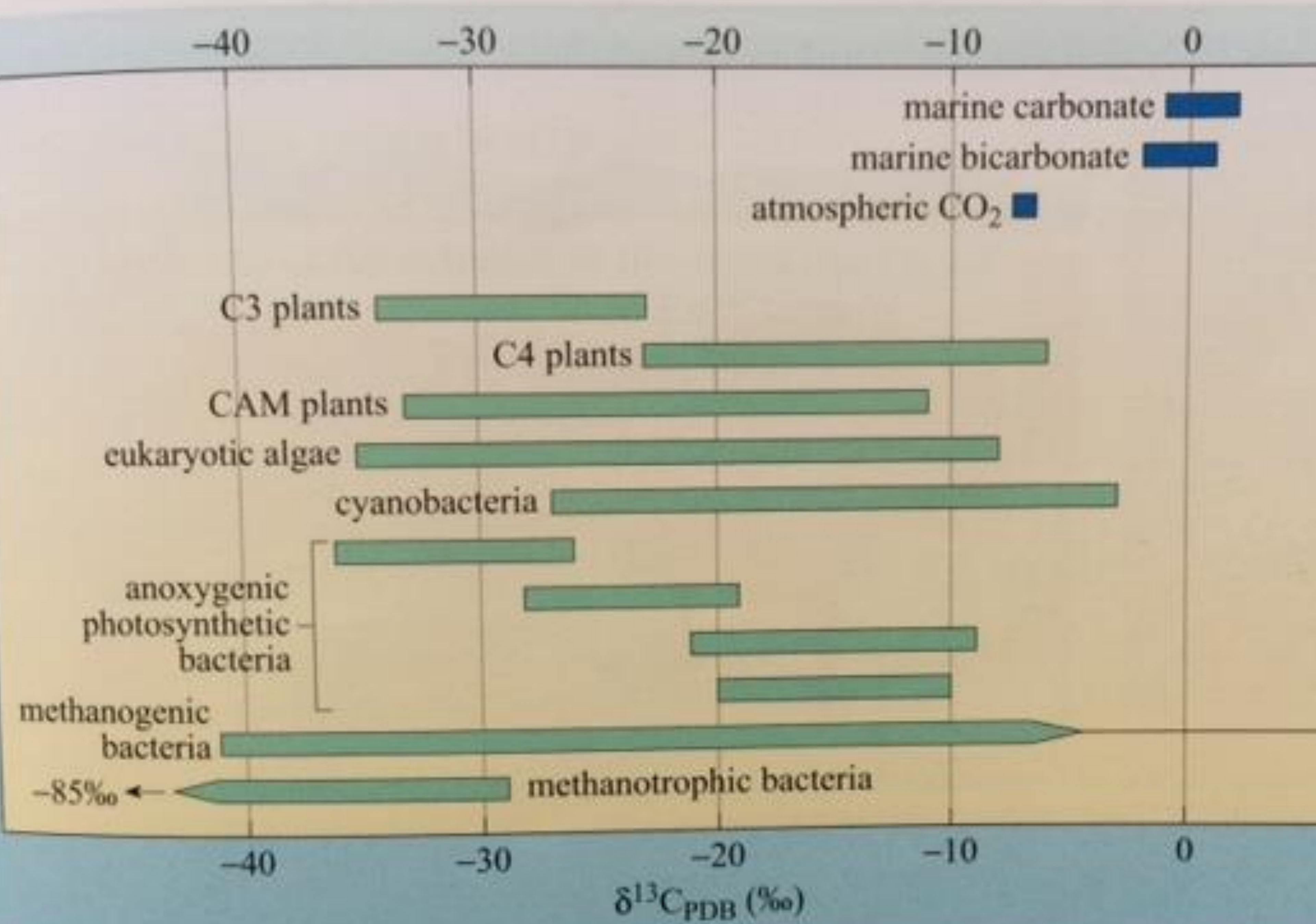

Lomagundi-Jatulian
Event (2.0-2.3 Ga)
Terminal Neoproterozoic
Event (~0.6 Ga)
Late P
Event (~
+10
0
- 10
- 20
- 30
- 40
- 50
$\delta^{13}C$ [‰, PDB]
C_{carb}
approximate mean
>2001
C_{org}
A2
A1
Isua Metasedi-
mentary Suite
(max. 3.85 Ga)
Fortescue excursion
(~ 2.7 Ga)
Francevillian excursion
(~ 2.0 Ga)
Archean
Proterozoic
Phanerozoic
4
3.5
3
2.5
2
1.5
1
0.5
0
Age [Ga = 10^9 yr]
4.6Gyr

On the traces of early life

- Traditionally: fossils
  - subjective
- Oldest carbon deposits
  - Isotopic fingerprint: low $^{13}C/^{12}C$

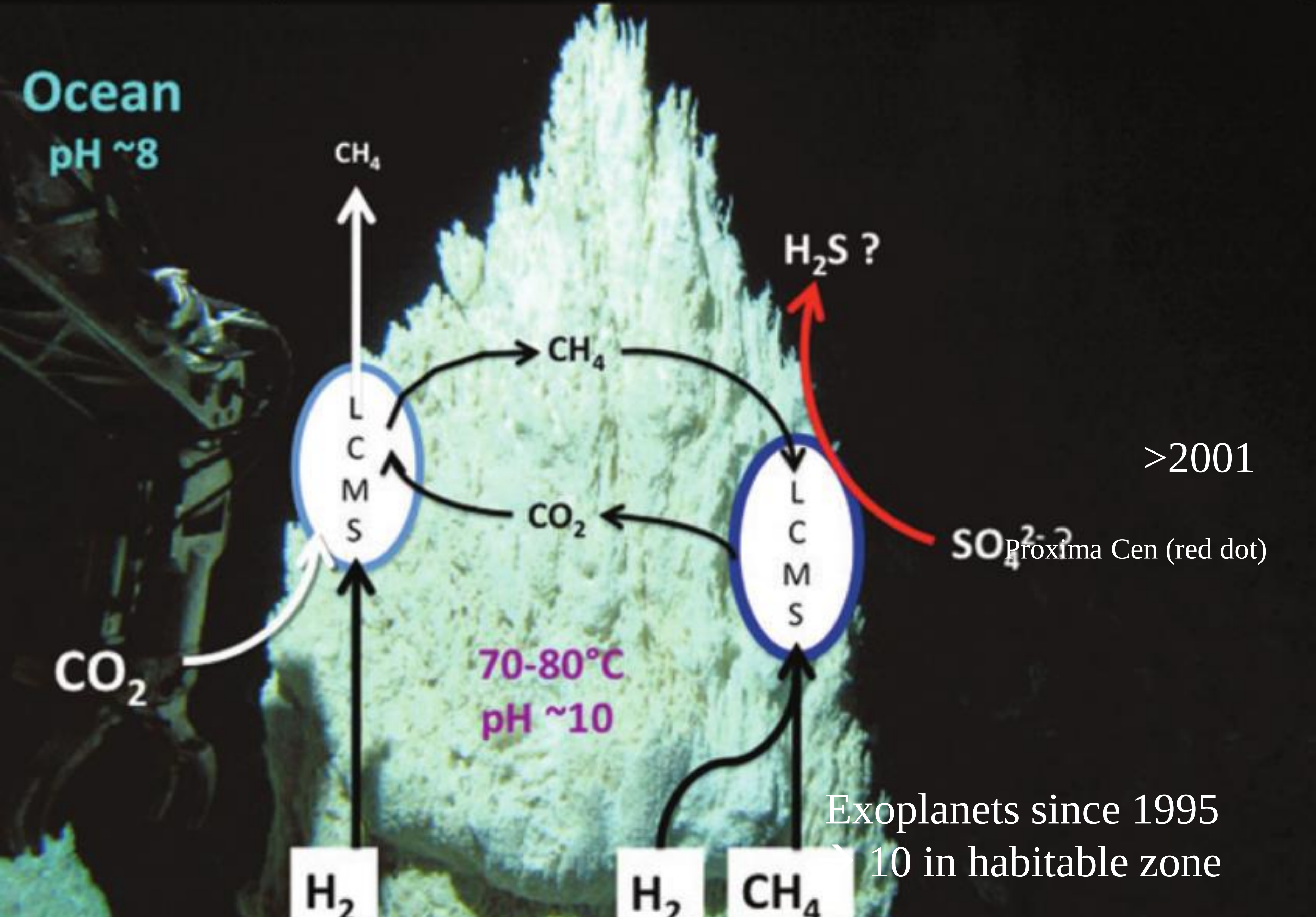
Measurements of $^{13}C/^{12}C$

- Again: work with *ratios* $^{13}C/^{12}C$
  - Vienna PeeDee Belemnite (marine carbonate)
  - $^{13}C/^{12}C = 0.01124$
- Lower values in organic carbons
  - $^{13}C/^{12}C = 0.01096$
  - Ratio: 0.975, ratio minus 1 is -0.025
- $\delta^{13}C = -25^{o}/_{oo}$ (per mil)



−40
−30
−20
−10
0
marine carbonate
marine bicarbonate
atmospheric CO_2
C3 plants
C4 plants
CAM plants
eukaryotic algae
cyanobacteria
anoxygenic photosynthetic bacteria
methanogenic bacteria
−85‰
methanotrophic bacteria
$\delta^{13}C_{PDB}$ (‰)

Present day metabolism of *Methanosarcinales* at Lost City



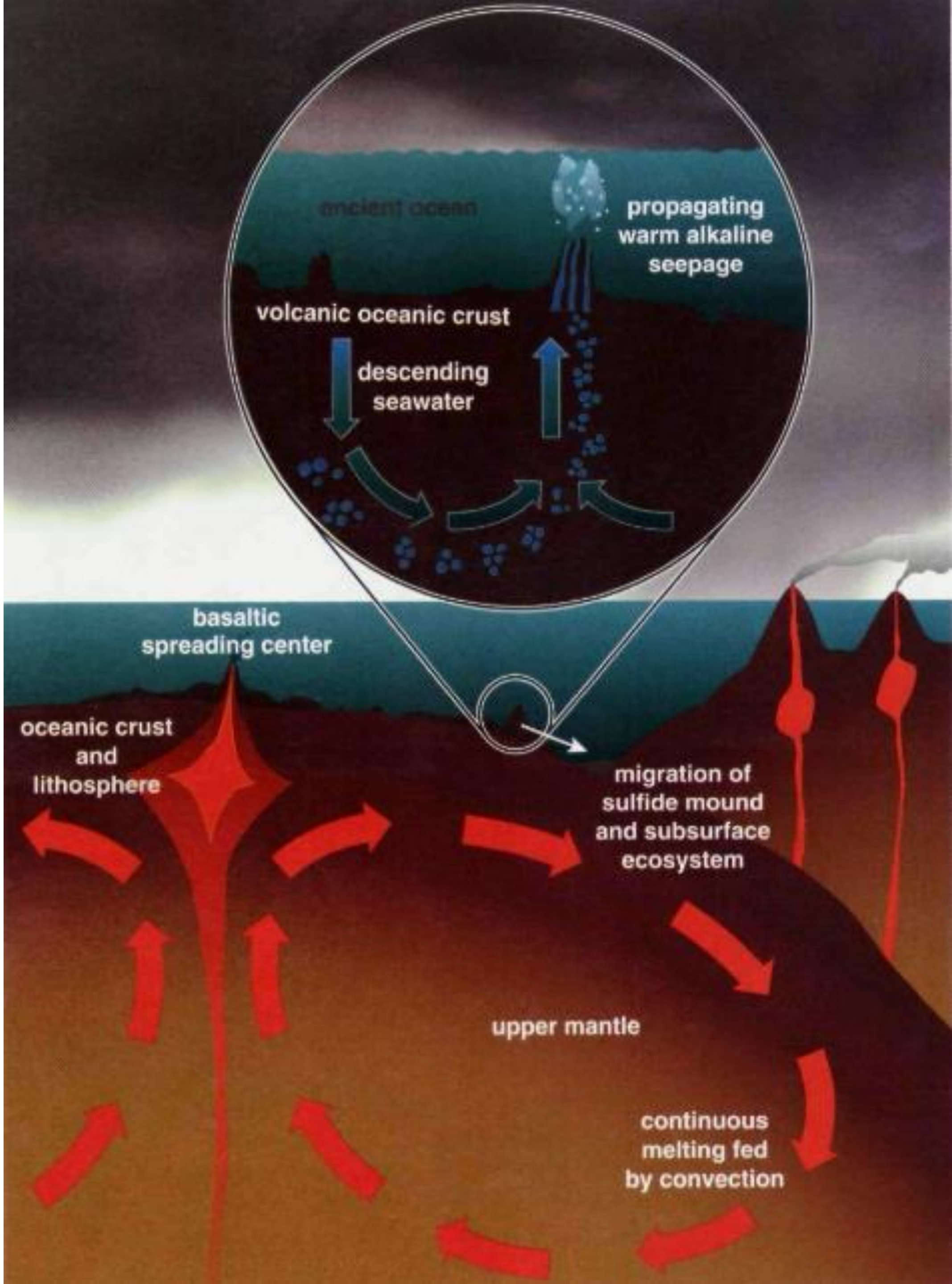
>2001

Proxima Cen (red dot)

Exoplanets since 1995
` 10 in habitable zone

Hydrothermal vents

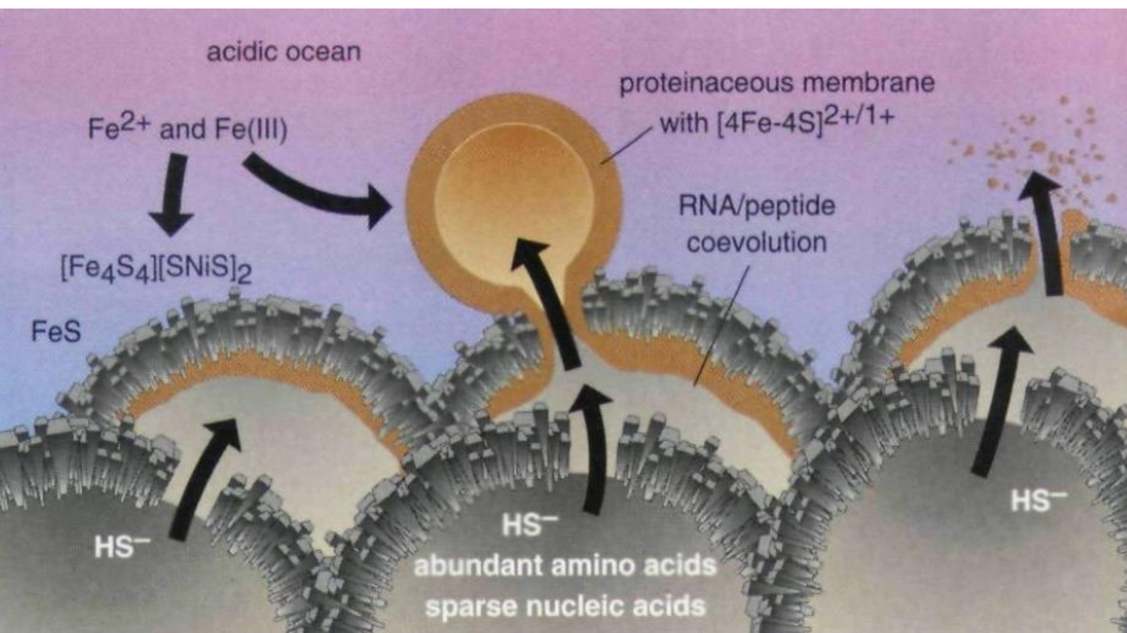
- Black smokers
  - Short-lived
  - Acidic, pH 3-5
  - CO_2, H_2S
- Alkaline vents
  - Long-lived (x10)
  - Lost City
  - H_2, CH_4, ...

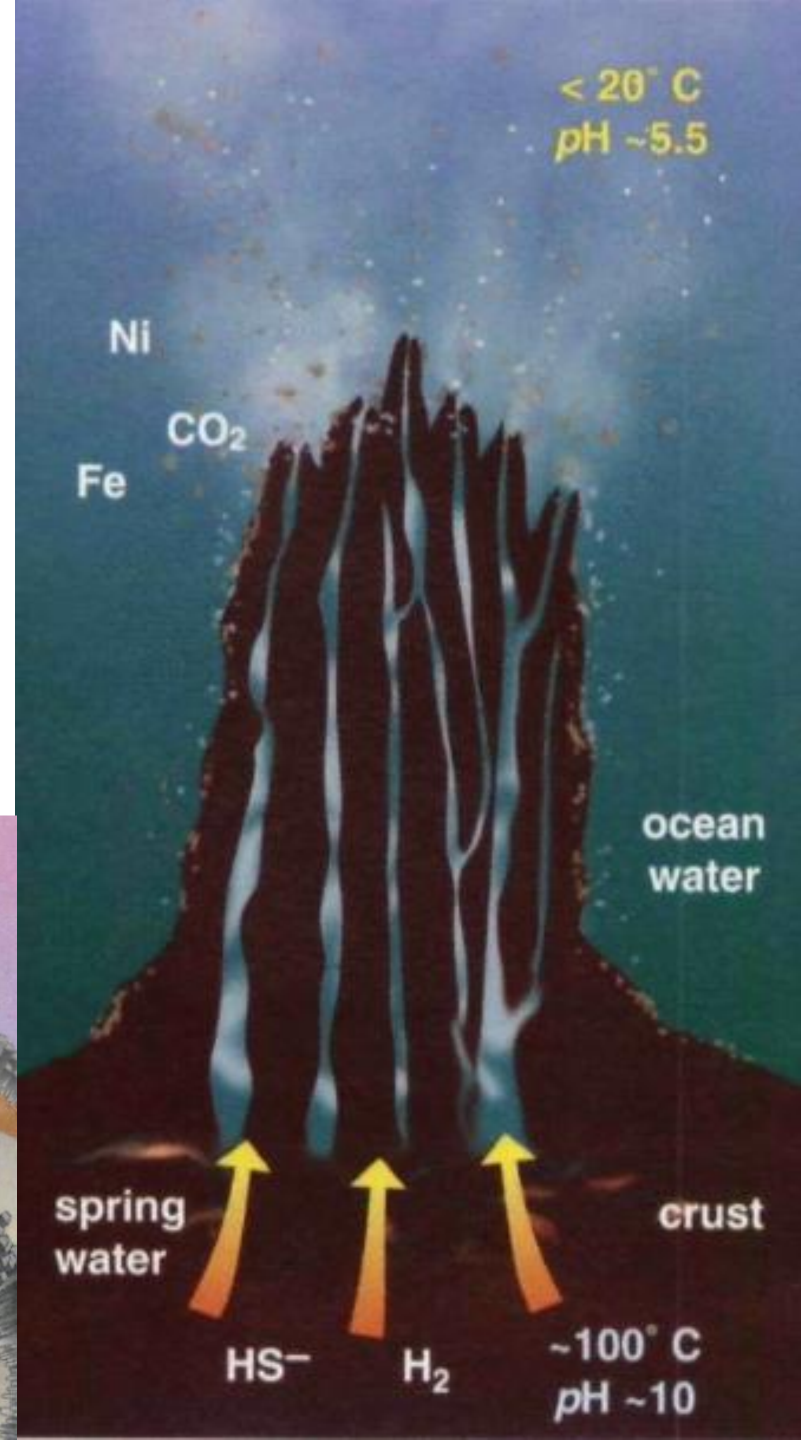


MJ Russell (JPL)

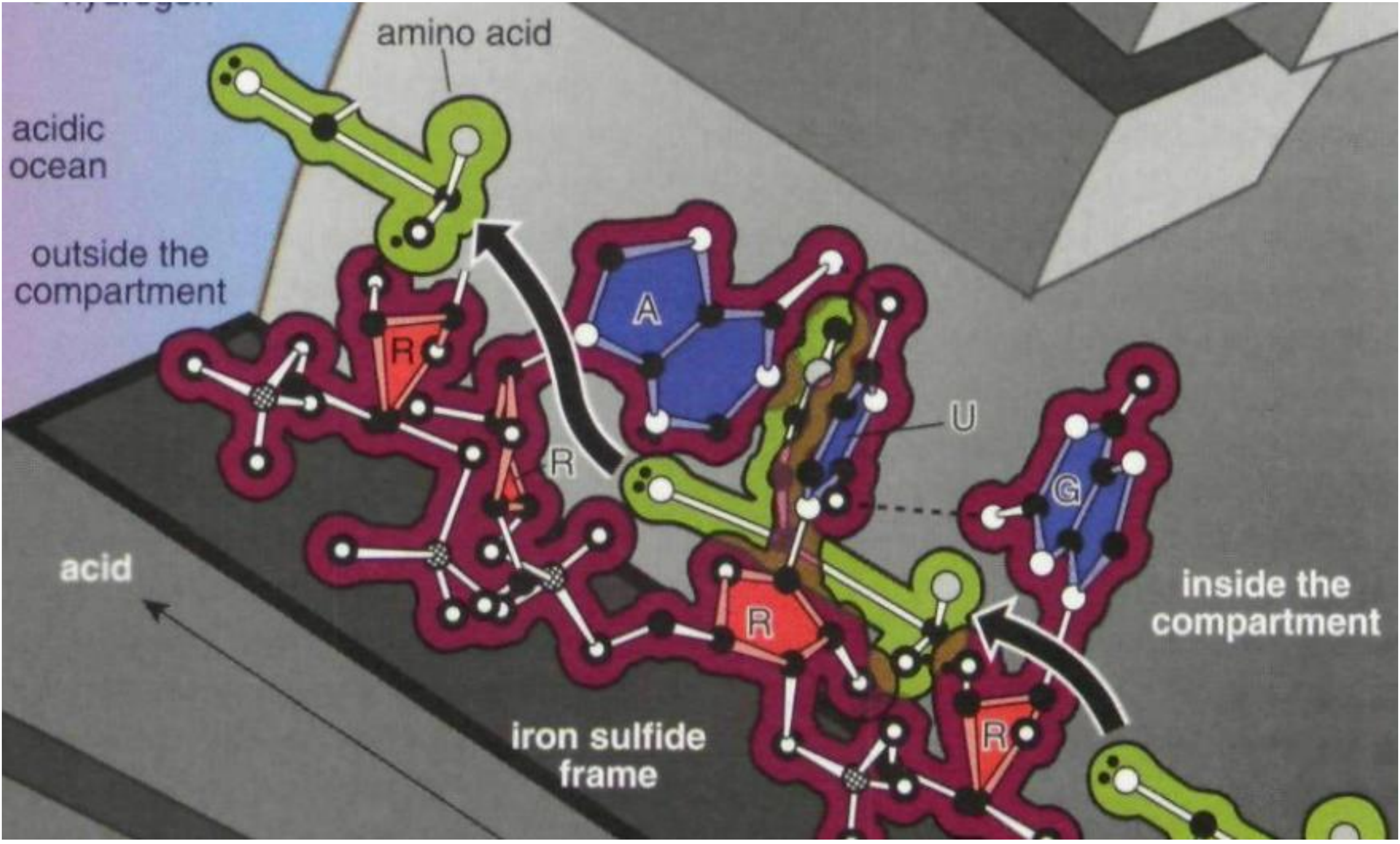
Am. Sci. 94, 32 (2006)

- Pyrite FeS_2 precipitates
  - Early cells: temperature gradients: → polymerization
  - Iron-nickel catalysis
  - RNA, proteins





Protein synthesis on FeS_2 frame



Midterm exam

- On Friday
- Check all lectures: def of life, order/disorder,
- Away from equilibrium
- Natural selection
- Carbon & Water, polar molecules
- Lipids and other building blocks
- Genetic code, A-T, G-C
- Biomarkers, meteorites, Miller/Urey, ...

Midterm exam

- Metabolism first versus replication first.
  - The RNA world.
  - Autotrophs and hydrothermal vents.
- The three domains of life.
  - LUCA, the last common universal ancestor.
- Greenhouse gases. Habitable planet?
  - The carbon cycle on Earth.
  - Plate tectonics and volcanism.
  - Comparison with Venus.
- The great oxidation event.

What is a peptide?

A. a single amino acid
B. a short polymer of amino acids
C. a protein
D. an oxidized amino acid
E. an achiral amino acid

Half life 5700 yr

160 g initially, what is left after 5700 yr

A. 160
B. 80
C. 40
D. 20
E. 10

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Half life 5700 yr

160 g initially, what is left after **11400** yr

A. 160
B. 80
C. 40
D. 20
E. 10

Half life 5700 yr

160 g initially, what is left after 11400 yr

A. 160
B. 80
C. 40
D. 20
E. 10

Half life 5700 yr

160 g initially, what is left after 22800 yr

A. 160
B. 80
C. 40
D. 20
E. 10

Half life 5700 yr

160 g initially, what is left after 22800 yr

A. 160
B. 80
C. 40
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E. 10

Half life 5700 yr

160 g initially, what is left after 17100 yr

A. 160
B. 80
C. 40
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$^{14}C \rightarrow {}^{14}N$

160 g ^{14}C initially, how much ^{14}N after 5700 yr

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On Monday

- Extremophiles
- Life on the edge
- RGS pp. 74 - 84

Metabolic reactions

In the reaction $CH_4 + H_2SO_4 \rightarrow H_2CO_3 + H_2S$; the energy comes from: (sunlight/molecules),

A. sunlight
B. molecules

Metabolic reactions

In the reaction $CH4 + H2SO4 \rightarrow H2CO3 + H2S$; so the elevant prex is (photo/chemo)

A. photo
B. chemo

Metabolic reactions

In the reaction $CH_4 + H_2SO_4 \rightarrow H_2CO_3 + H_2S$;

the electron donor is: ....,

which is (organic/inorganic), so (organo/litho),

A. organic
B. inorganic

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so

A. organo
B. litho

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