5th Workshop of the Italian Astrobiology Society:
Life in a Cosmic Context

Mind the gap: from the primitive soup to the root of universal phylogenies

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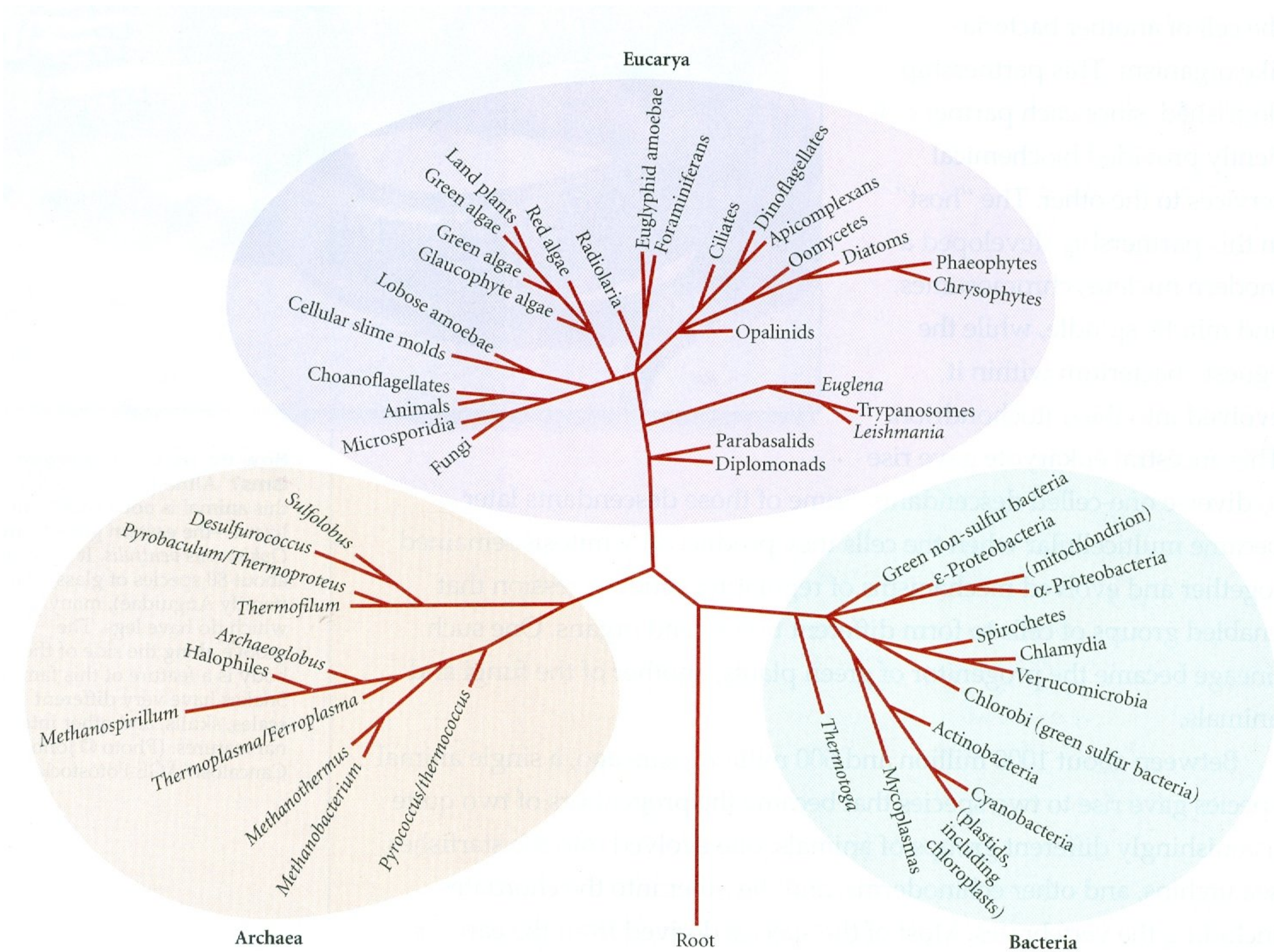
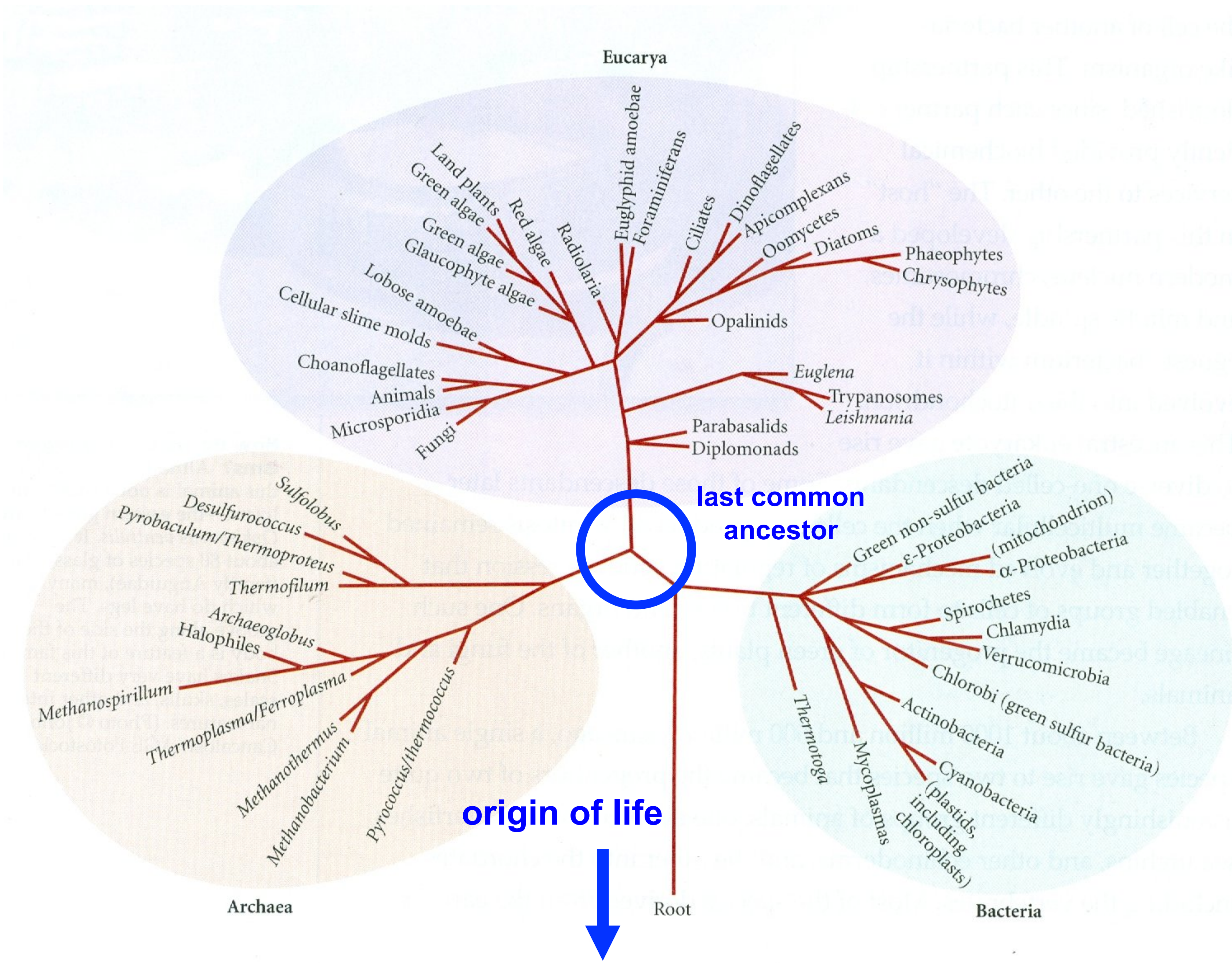


Futuyma (2006) *Evolutionary Biology* (Sinauer, Boston)



Modified from Futuyma (2006) *Evolutionary Biology* (Sinauer, Boston)

The heterotrophic theory of the origin of life: a contemporary reassessment

reducing atmosphere

↓

synthesis of organic compounds & formation of the primitive soup

↓

coacervates

↓

anaerobic heterotrophic bacteria

synthesis & accumulation of organic compounds

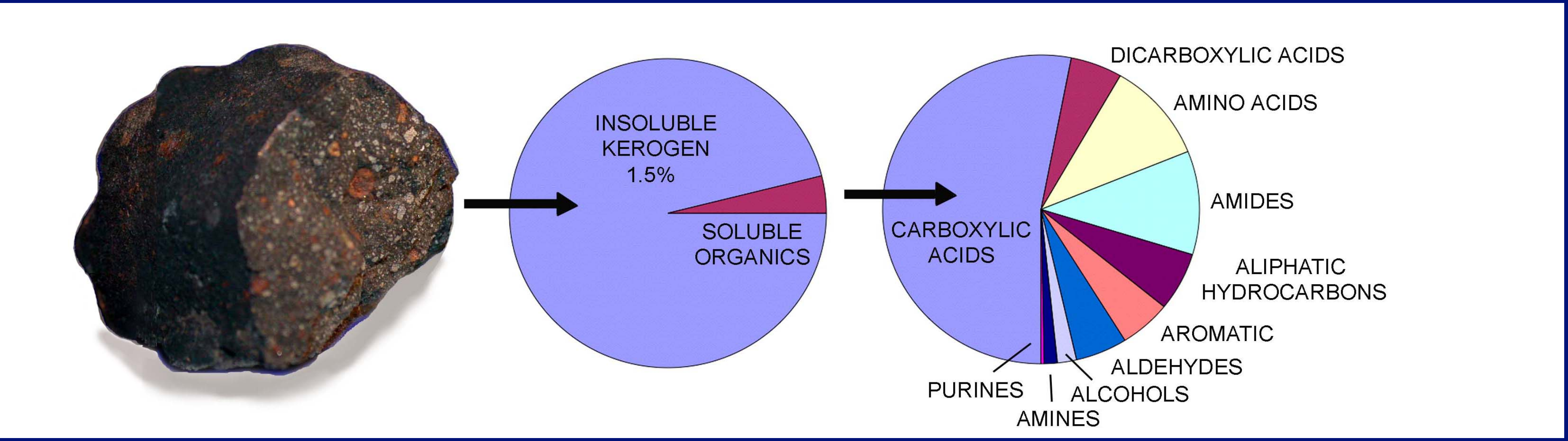
↓

RNA World

↓

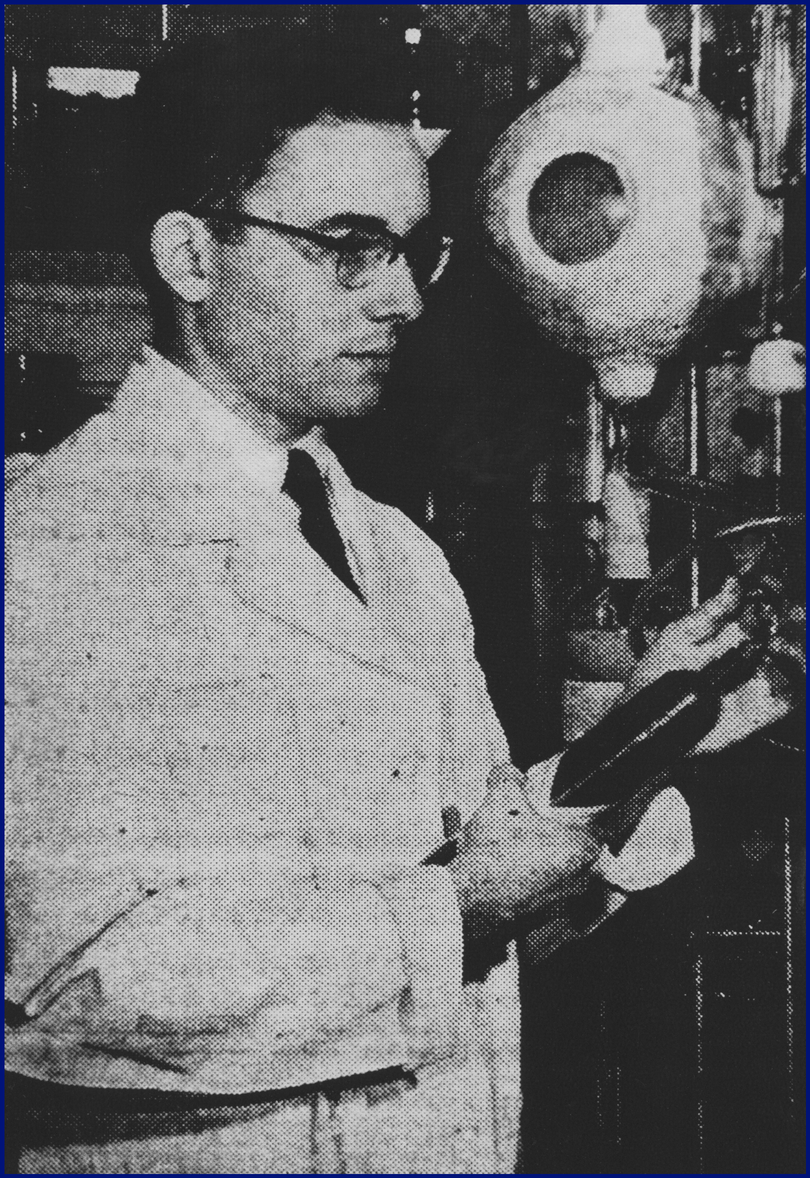
DNA/RNA/protein cells

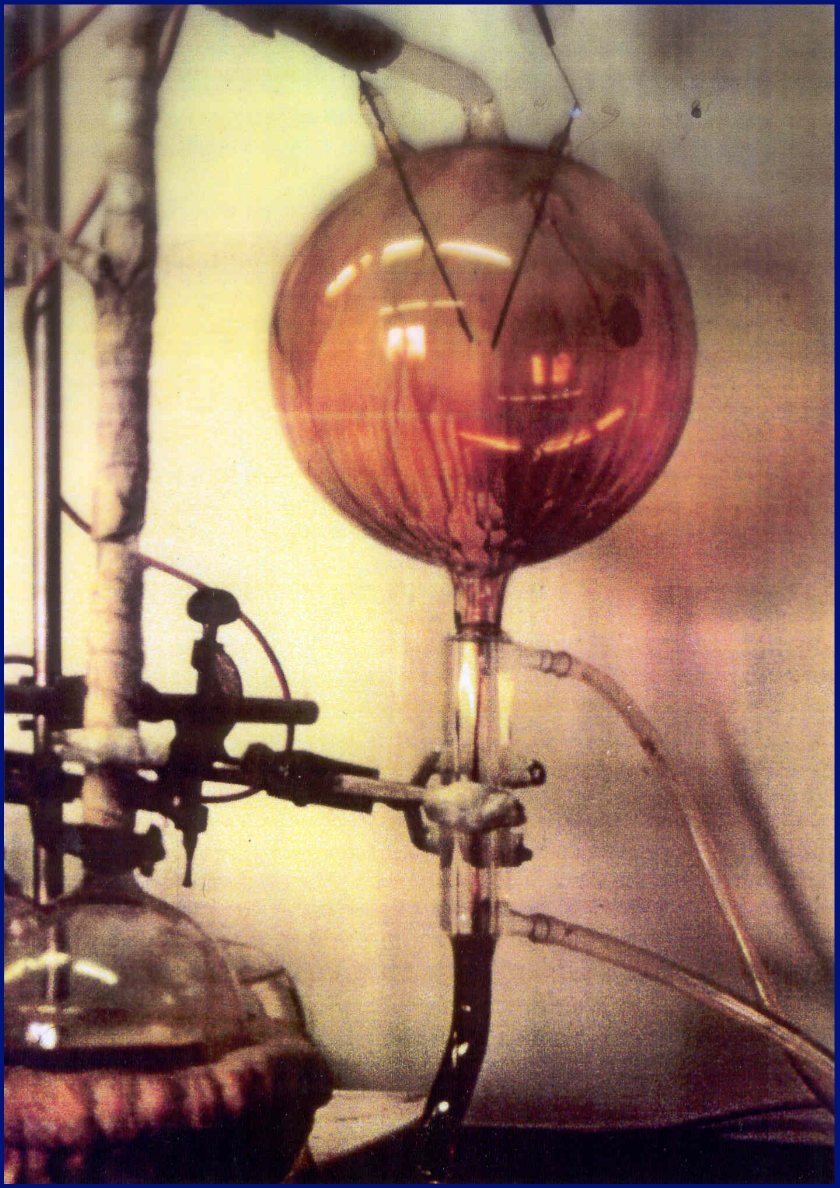
Organic compounds in the 4.6 x 10^9 years-old Murchison meteorite



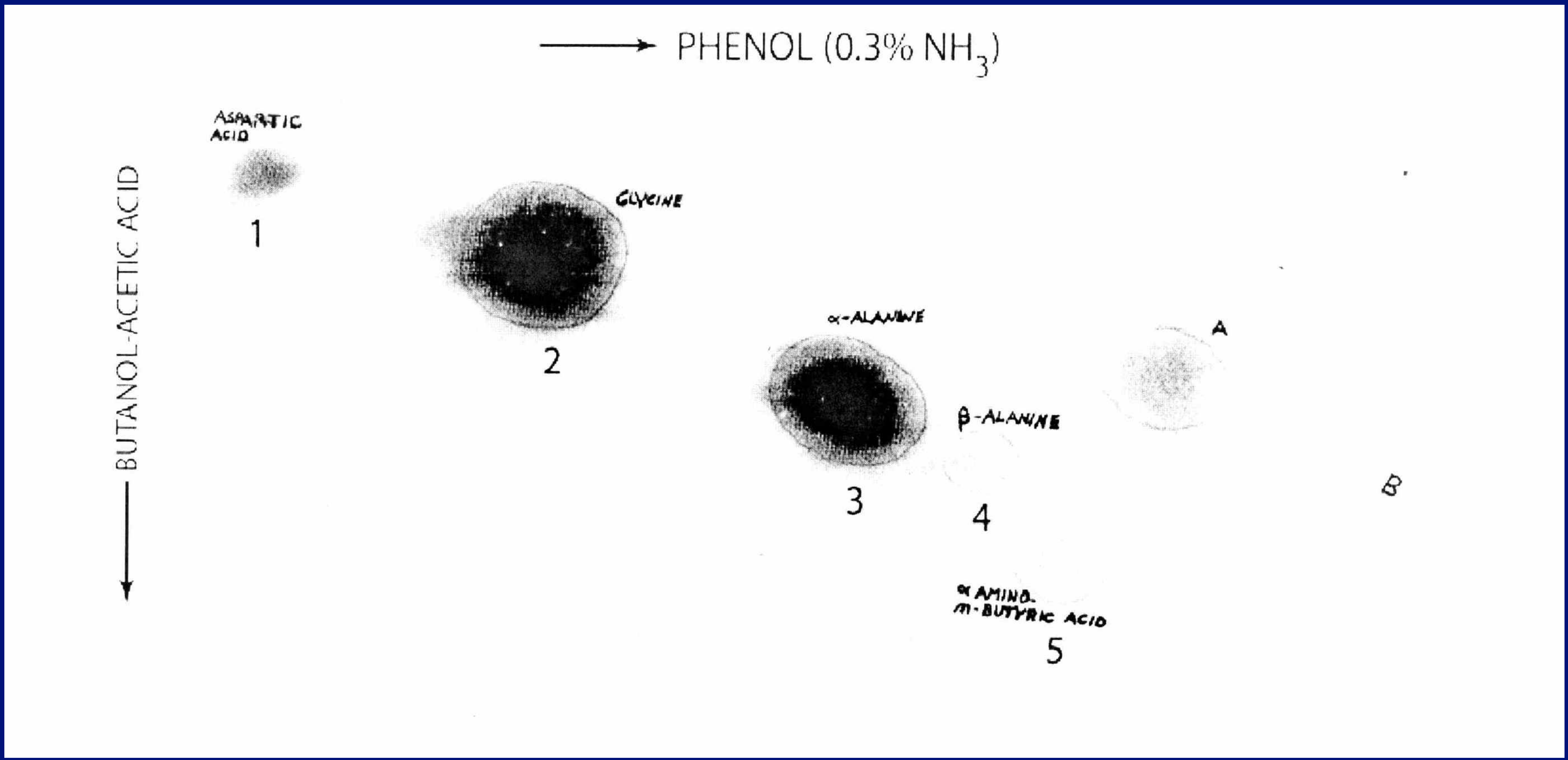
Deamer 2011

The 1953 Miller-Urey experiment



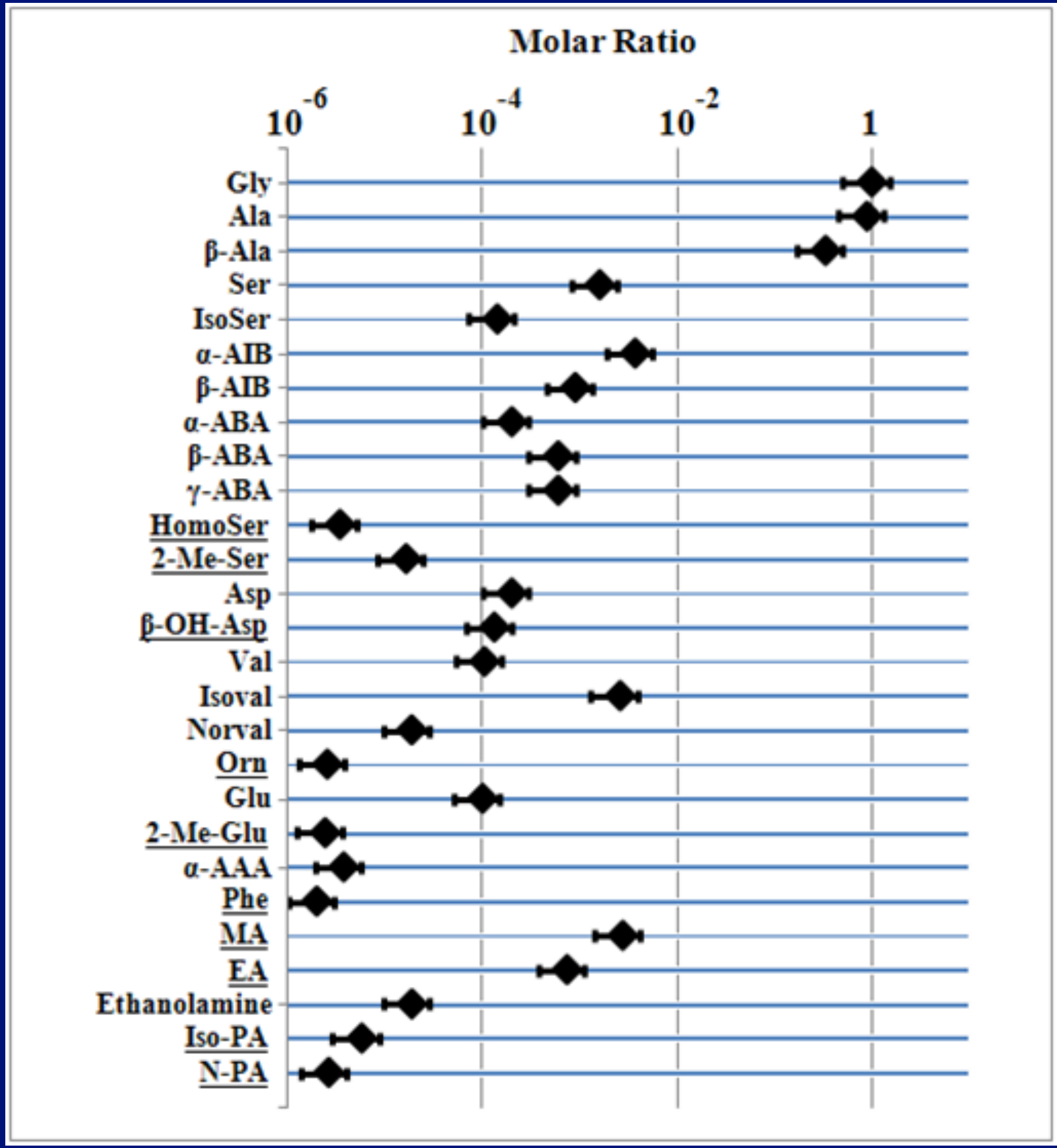


Abiotic synthesis of amino acids



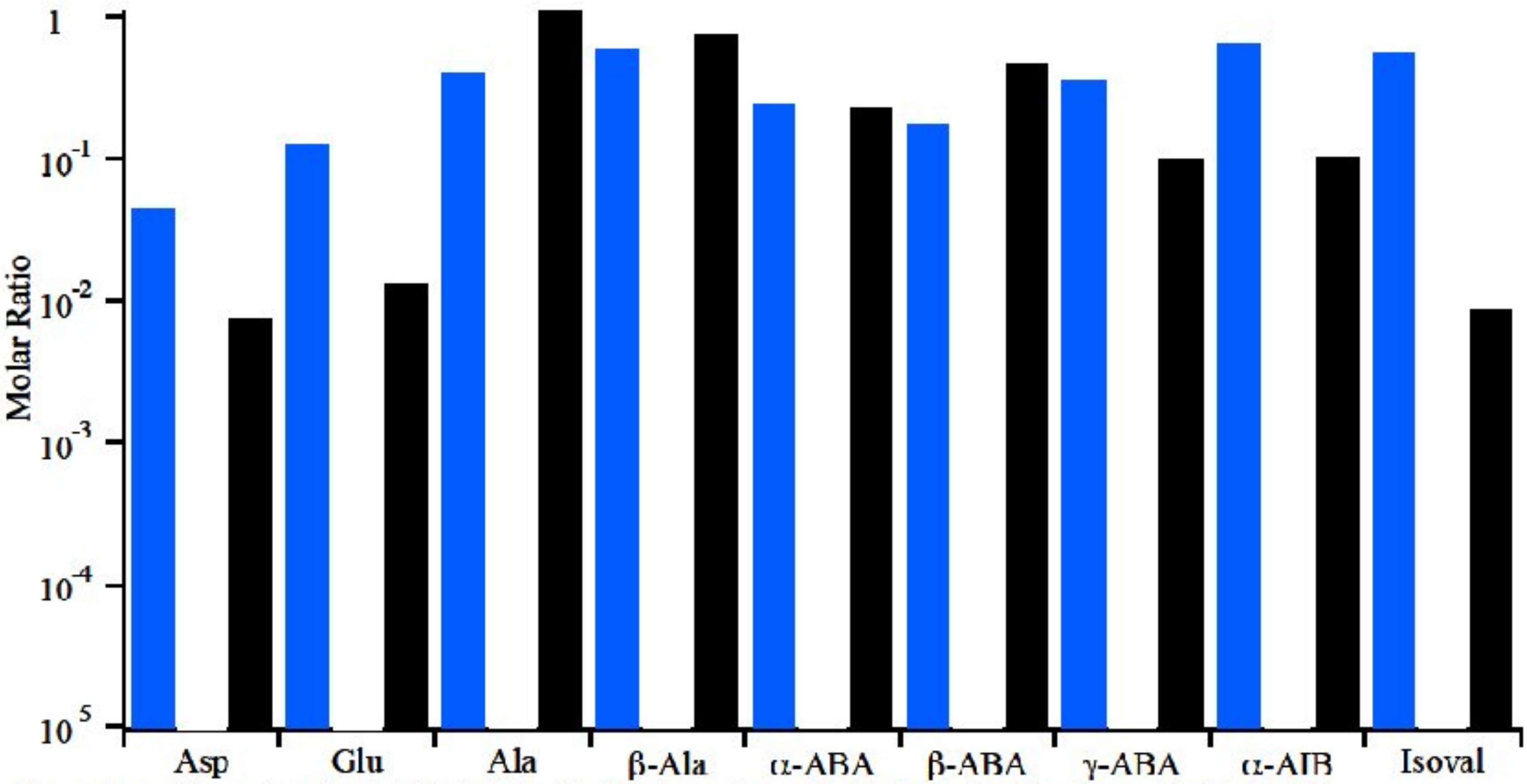
Miller, 1953

Revisiting the Miller's experiments



Johnson, Cleaves, Dworkin, Glavin, Lazcano & Bada (2008) *Science* **322**: 404

Aliphatic amino acids in the Murchison meteorite (blue bars) and synthesized in a CH_4, CO_2, NH_3, H_2O & H_2S atmosphere (black)



Comparison of the molar ratios (relative to Gly = 1) of various amino acids detected in the Murchison meteorite (■), and H_2S (■) spark discharge experiments.

Parker, Cleaves, Dworkin, Glavin, Audrey, Lazcano & Bada (2011)

Amino acids in meteorites

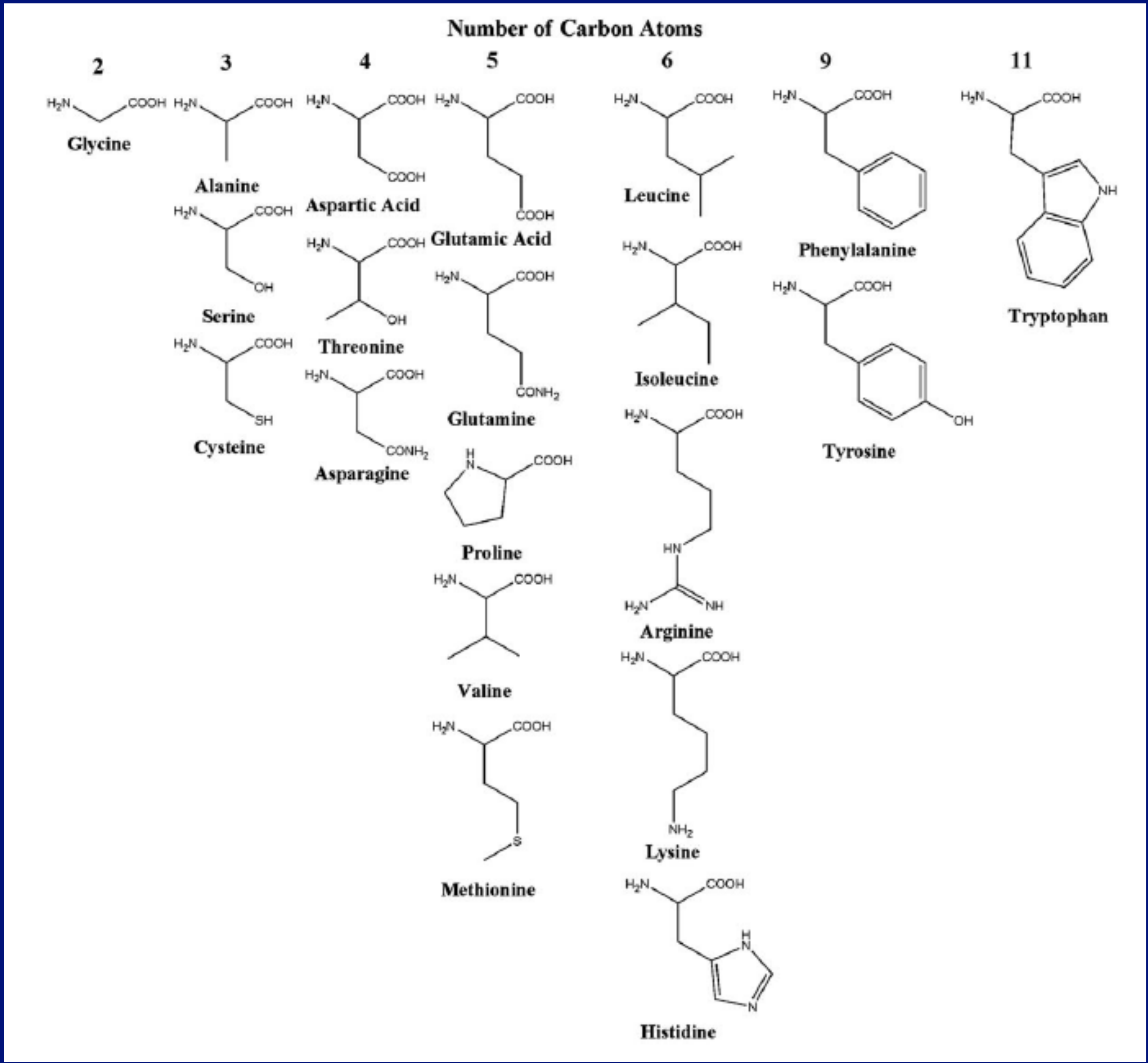
Table 2 Amino acids that have been detected in meteorites[4,5,8,9]

C2
Glycine
C3
Alanine
β-Alanine
Serine
Sarcosine
C4
Threonine
allo-Threonine
α-Aminobutyric acid
β-Aminobutyric acid
α-Aminoisobutyric acid
β-Aminoisobutyric acid
N-Ethylglycine
N,*N*-Dimethylglycine
N-Methylalanine
N-Methyl-β-alanine
Aspartic acid
2,3-Diaminobutanoic acid
2,4-Diaminobutanoic acid
3,3′-Diaminoisobutanoic acid
C5
Valine
Norvaline
Isovaline
3-Aminopentanoic acid
3-Amino-2-methylbutanoic acid
allo-3-Amino-2-methylbutanoic acid
3-Amino-2,2-dimethylpropanoic acid
3-Amino-2,2-dimethylpropanoic acid
3-Amino-2-ethylpropanoic acid
4-Aminopentanoic acid
4-Amino-2-methylbutanoic acid
4-Amino-3-methylbutanoic acid
5-Aminopentanoic acid
Glutamic acid
2-Methylaspartic acid
3-Methylaspartic acid
allo-3-Methylaspartic acid
N-Methylaspartic acid
4,4′-Diaminoisopentanoic acid
C6
Leucine
Isoleucine
allo-Isoleucine
Norleucine
Pseudoleucine
Cycloleucine
2-Methylnorvaline
Pipecolic acid
2-Amino-2-ethylbutanoic acid
2-Amino-2,3-dimethylbutanoic acid
3-Amino-2-ethylbutanoic acid[a]
3-Amino-2,3-dimethylbutanoic acid[a]
3-Methylamine-pentanoic acid[a]
4-Aminohexanoic acid
4-Amino-3,3-dimethylbutanoic acid[a]
4-Amino-2-methylpentanoic acid[a]
4-Amino-3-methylpentanoic acid
4-Amino-4-methylpentanoic acid
6-Aminohexanoic acid
α-Aminoadipic acid
β-Aminoadipic acid
2-Methylglutamic acid
other isomers detected, but not identified
C7
2-Amino-2,3,3-trimethylbutanoic acid
2-Amino-2-ethyl-3-methylbutanoic acid
2-Amino-2-ethylpentanoic acid
2-Amino-3-ethylpentanoic acid
2-Amino-2,3-dimethylpentanoic acid
2-Amino-2,4-dimethylpentanoic acid
2-Amino-3,3-dimethylpentanoic acid
2-Amino-3,4-dimethylpentanoic acid
2-Amino-4,4-dimethylpentanoic acid
allo-2-Amino-2,3-dimethylpentanoic acid[a]
allo-2-Amino-3,4-dimethylpentanoic acid
2-Amino-2-methylhexanoic acid
2-Amino-3-methylhexanoic acid
allo-2-Amino-3-methylhexanoic acid[a]
2-Amino-4-methylhexanoic acid
allo-2-Amino-4-methylhexanoic acid[a]
2-Amino-5-methylhexanoic acid
2-Aminoheptanoic acid
α-Aminopimelic acid
1-Aminocyclohexanecarboxylic acid
other isomers detected, but not identified
C8
Isomers detected but not identified
C9
Phenylalanine
Tyrosine
other isomers detected, but not identified

[a] Denotes compounds that were only tentatively identified.

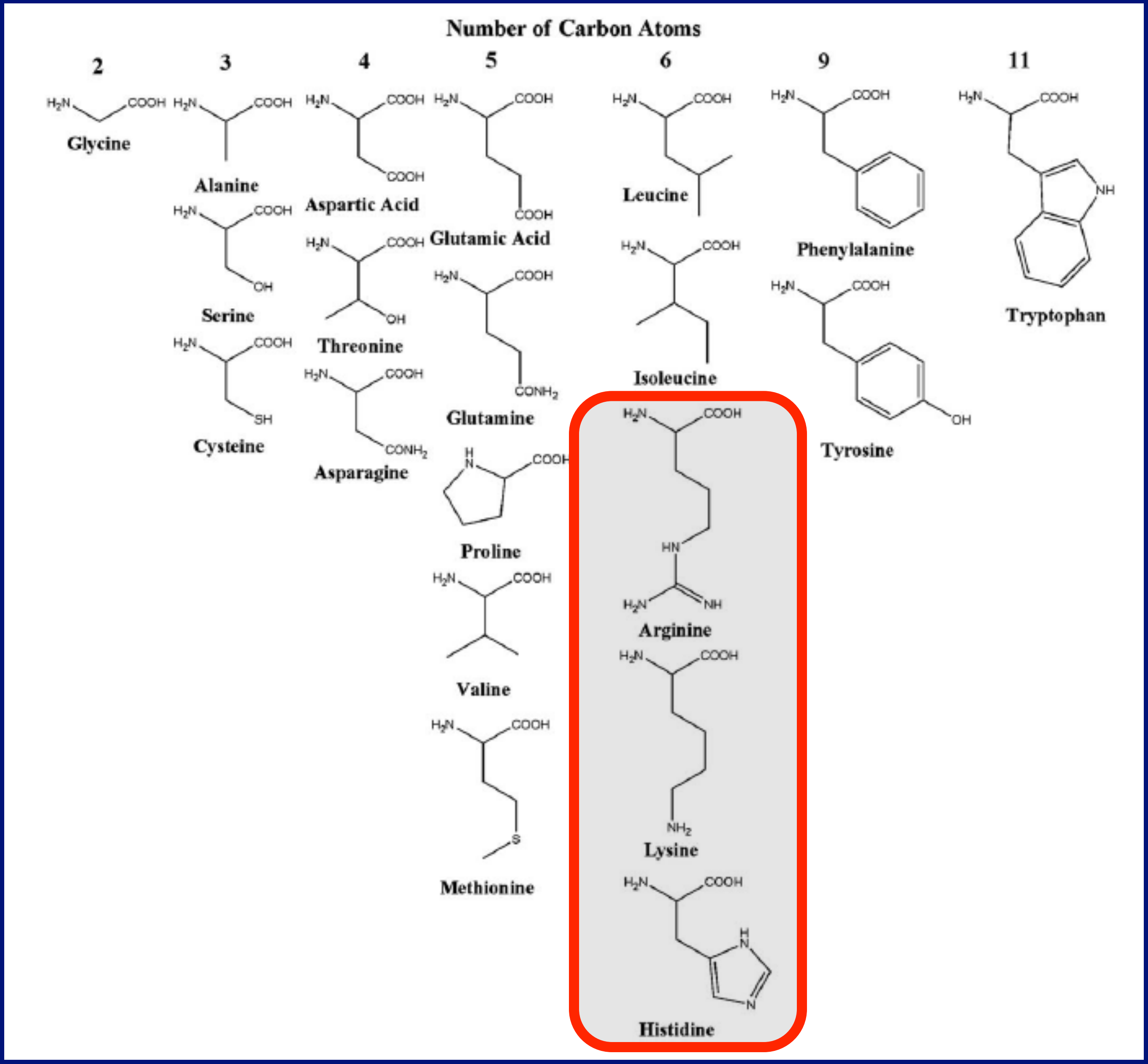
Burton et al 2013

Genetically-encoded amino acids



Cleaves 2010

Genetically-encoded amino acids



Cleaves 2010

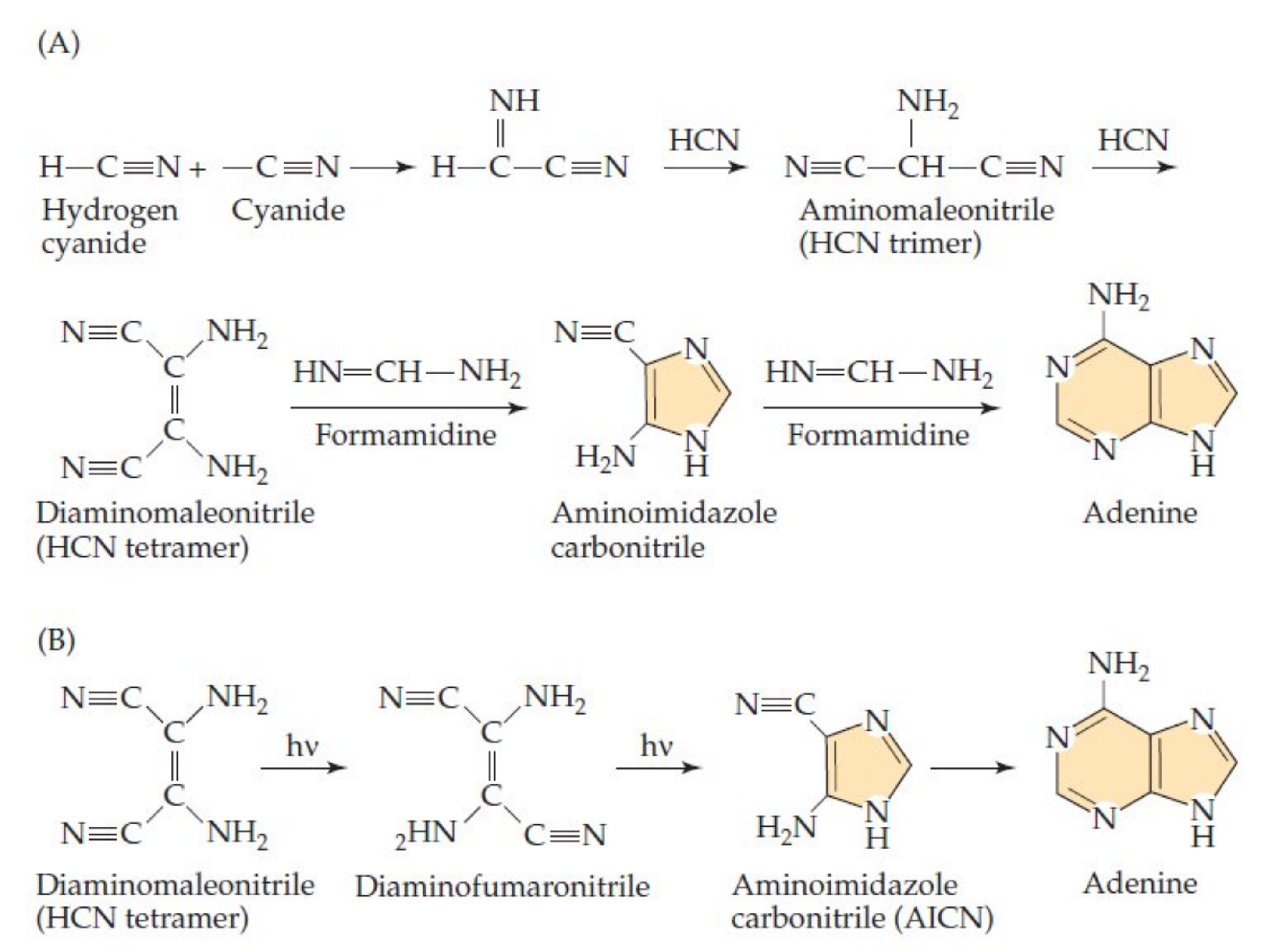
Amino acids are abundant in chondritic meteorites and are readily formed in model prebiotic reactions.

This is not true of:

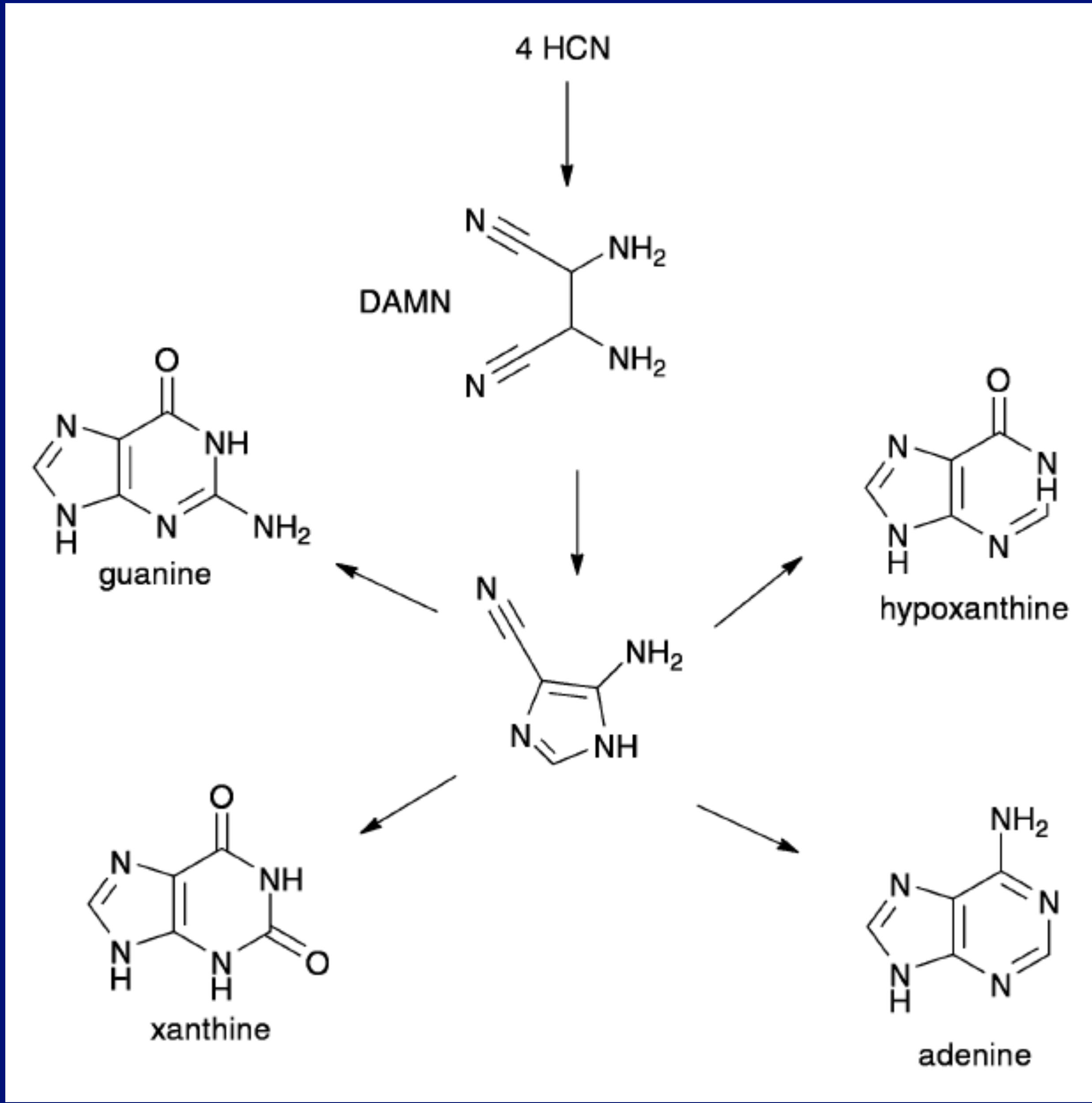
a) lysine & arginine (perhaps)

b) histidine

Molecular biology and the origins of life: the prebiotic synthesis of adenine

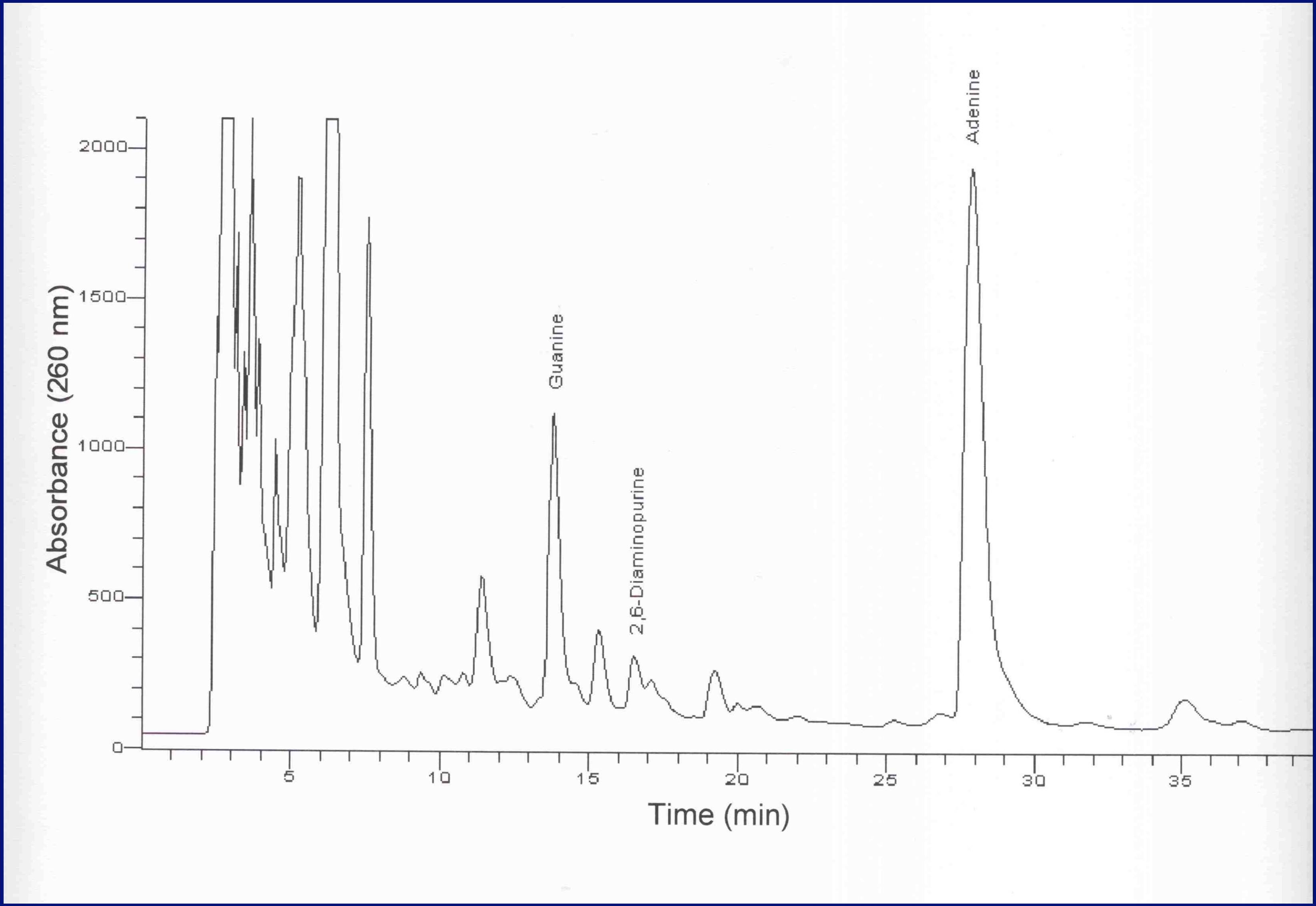


Oró, 1960; Ferris & Orgel, 1966



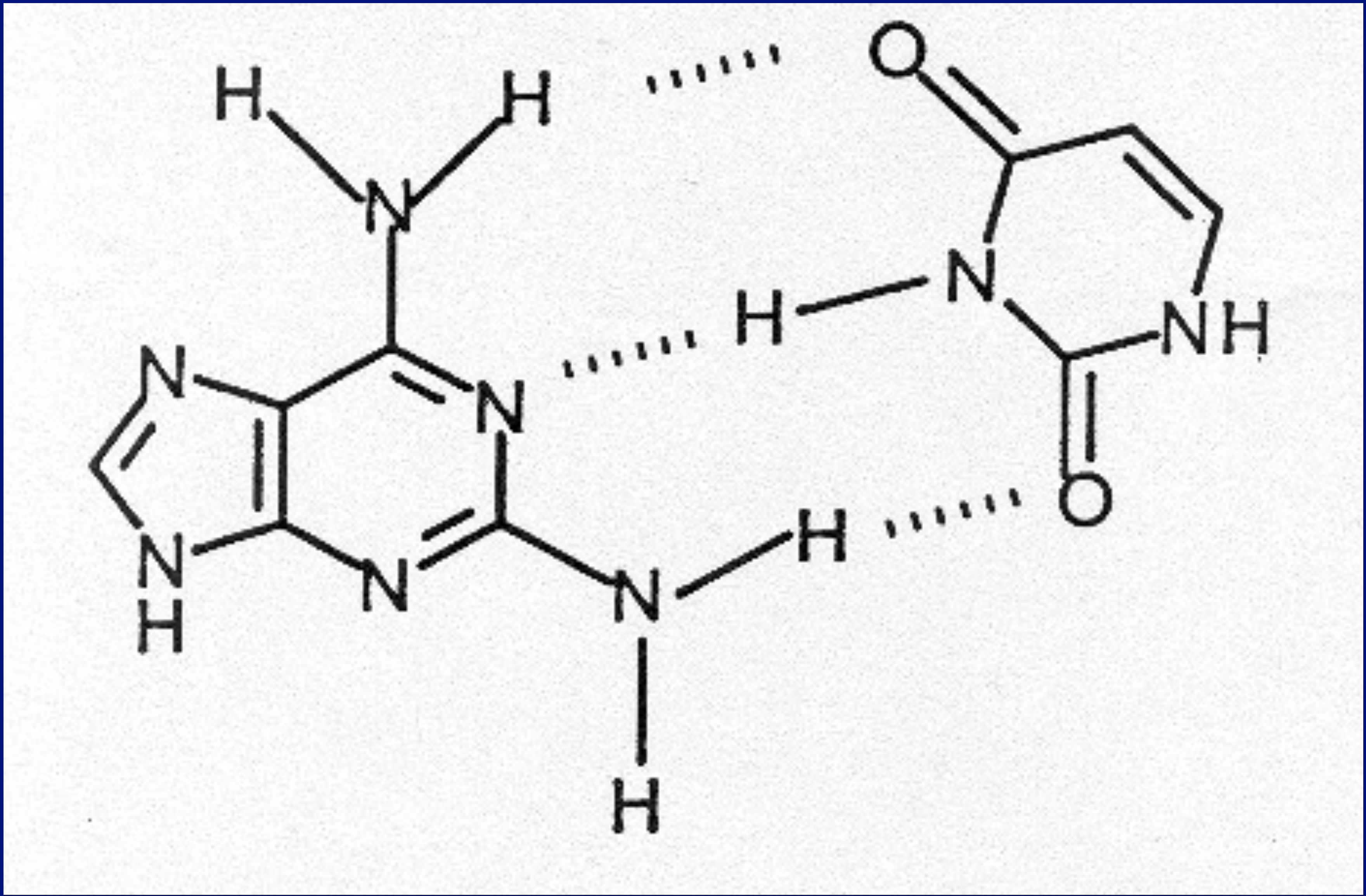
Lazcano, Miller & Oró,1990

Chromatogram of NH_4CN polymerization at 80 °C



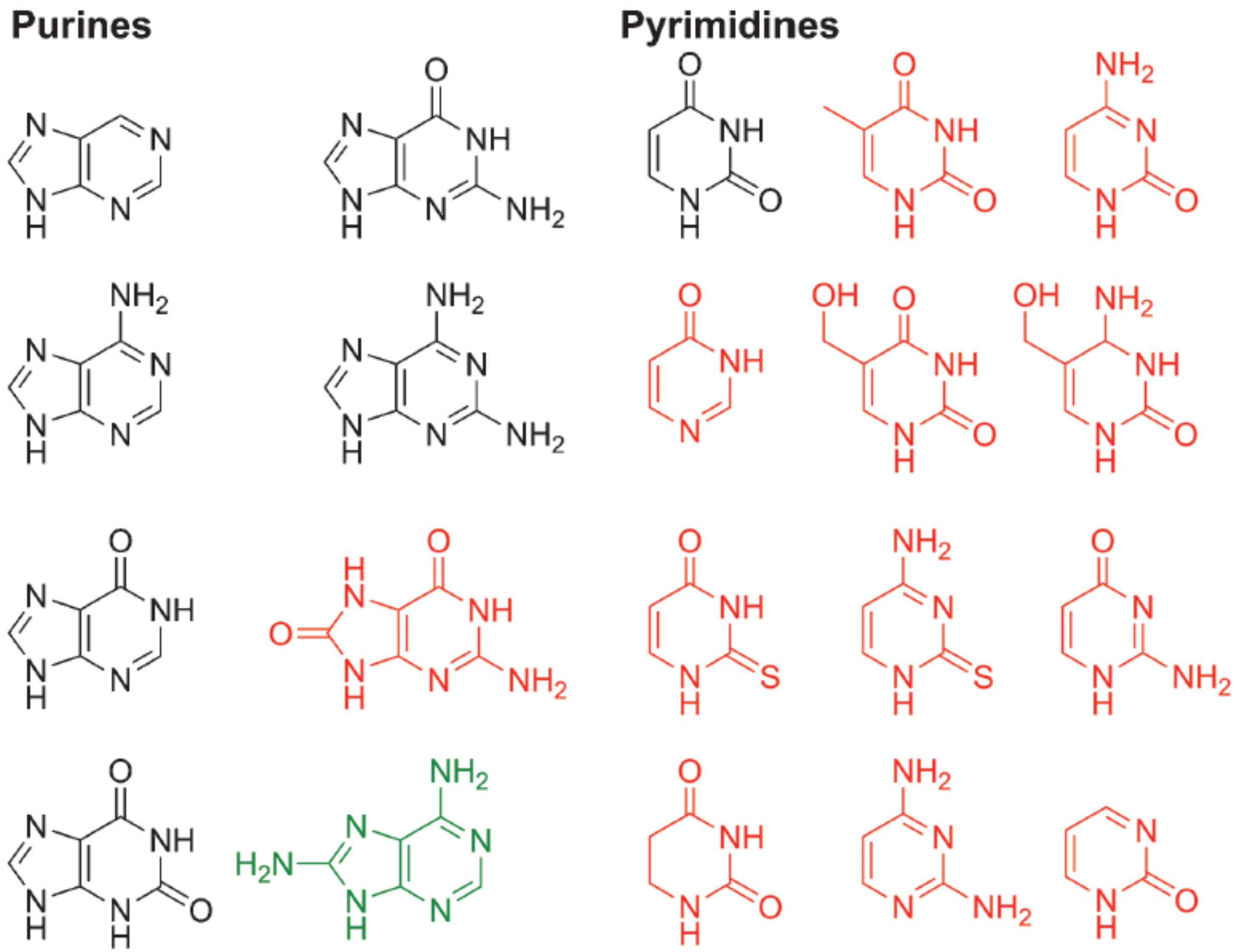
Borquez, Cleaves, Lazcano & Miller (2005) *Origins Life Evol. Biosph.* 35:79

2,6 diaminopurine base pairs with uracil



Borquez, Cleaves, Lazcano & Miller (2003) *Origins Life Evol. Biosph.* 35: 79

Nucleobases of abiotic origin. Red, in prebiotic simulations; black, meteorites and prebiotic simulations



Rios & Tor (2013)

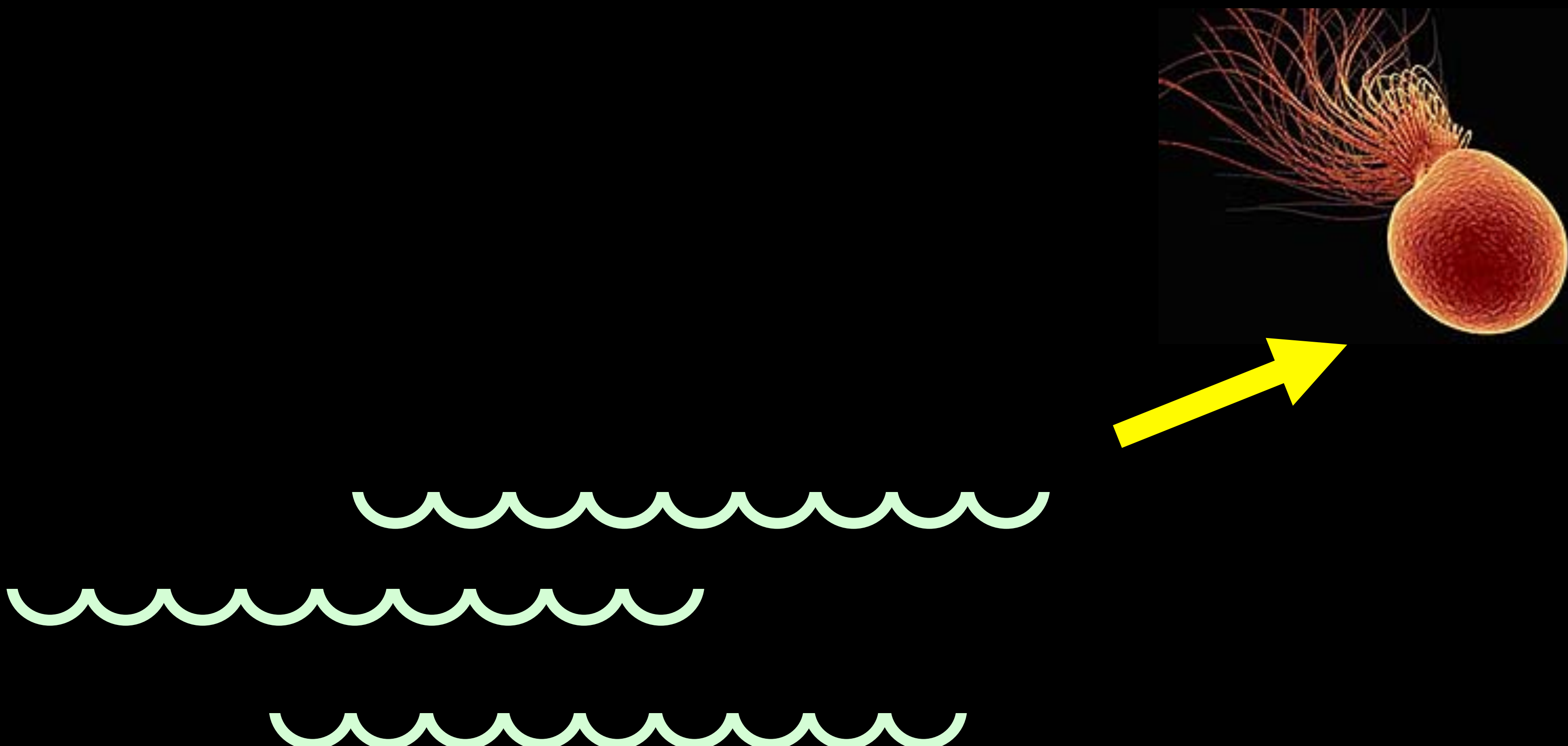
The evidence suggests that prior to the origin of life the primitive Earth already had:

- a wide array of organic compounds of biochemical significance
- many inorganic & organic catalysts
- purines & pyrimidines (the potential for template-directed polymerizations)
- membrane-forming compounds

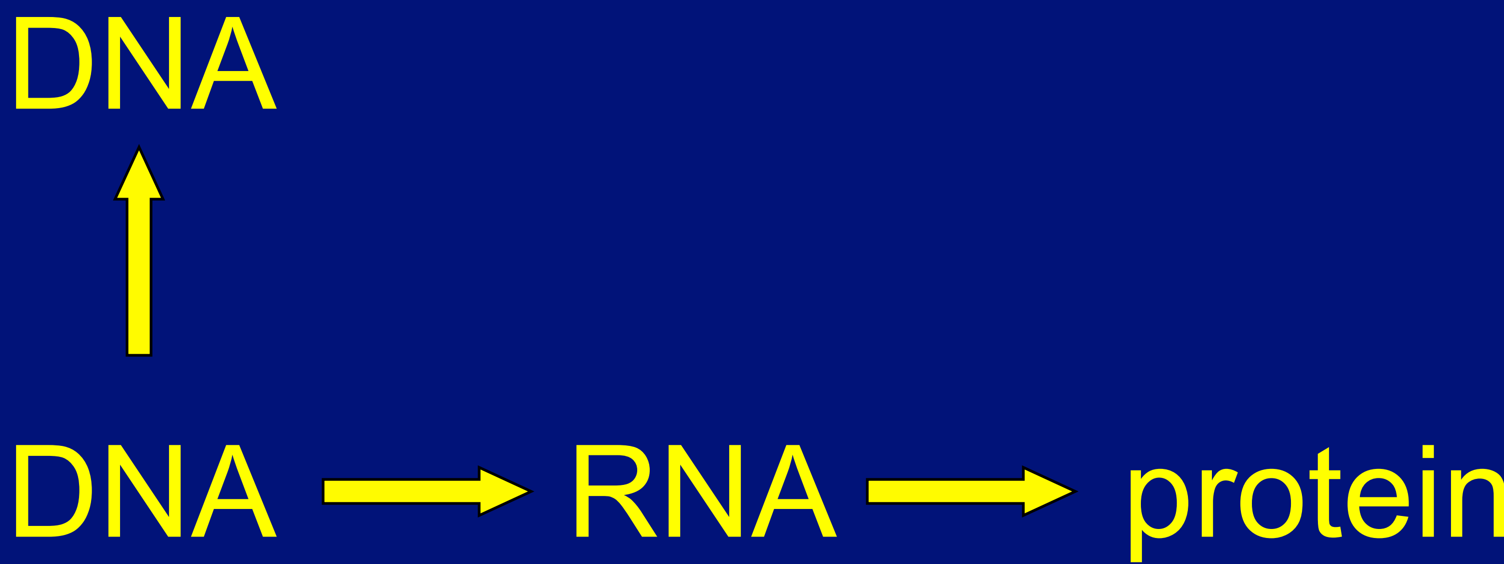
The presence of organic compounds is not evidence of biological activity. For all we know, organic molecules are a necessary but not sufficient condition for the origin of life;

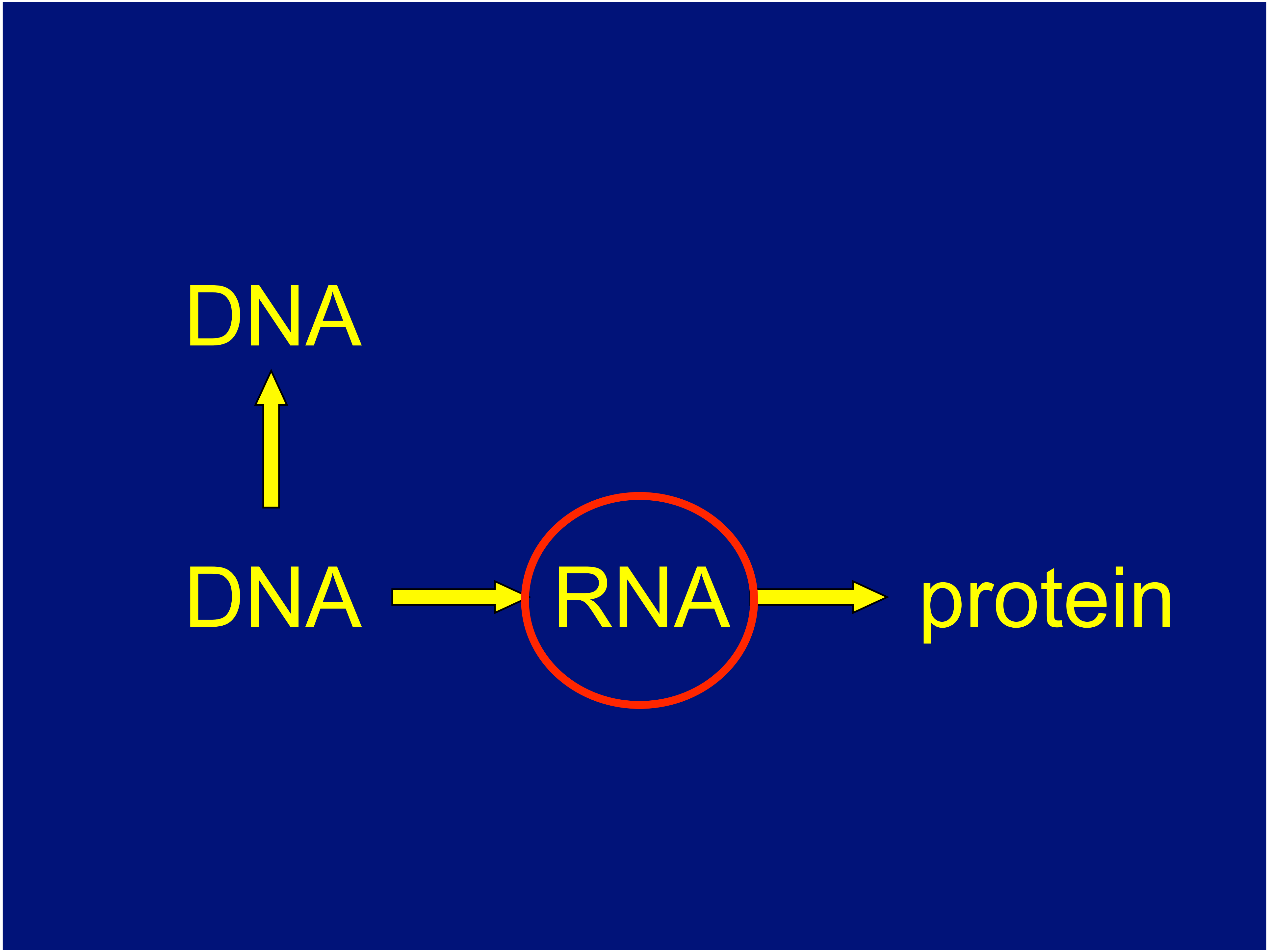
The presence in meteorites of a large array of non-protein amino acids and non-biological nucleic acid bases suggests that there was a period during which the extant components of life were selected due to a variety of chemical (and perhaps biological) mechanisms.

The first life forms were not the direct outcome of the primitive soup: we are beginning to recognize intermediate stages

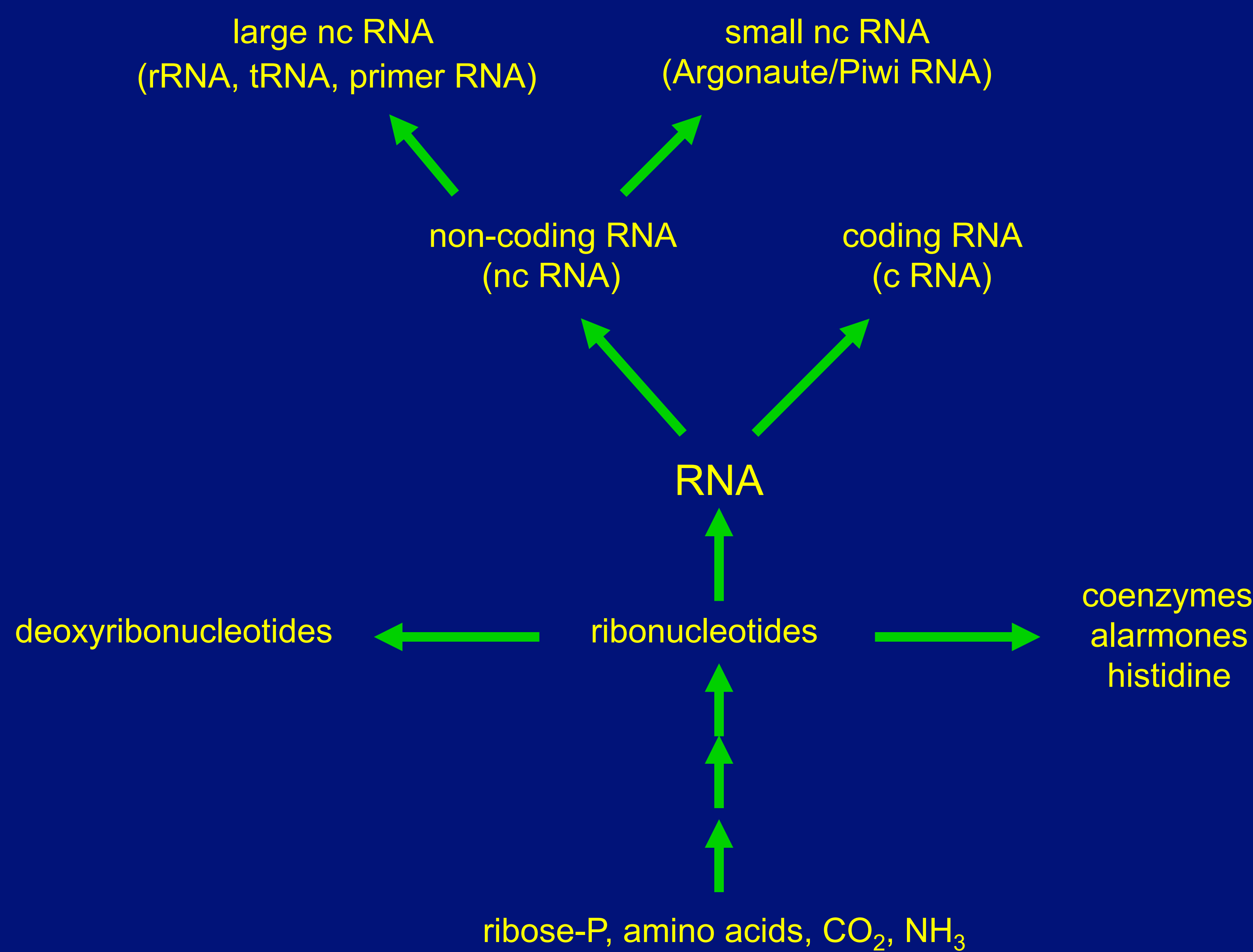


primitive soup


DNA
DNA
RNA
protein

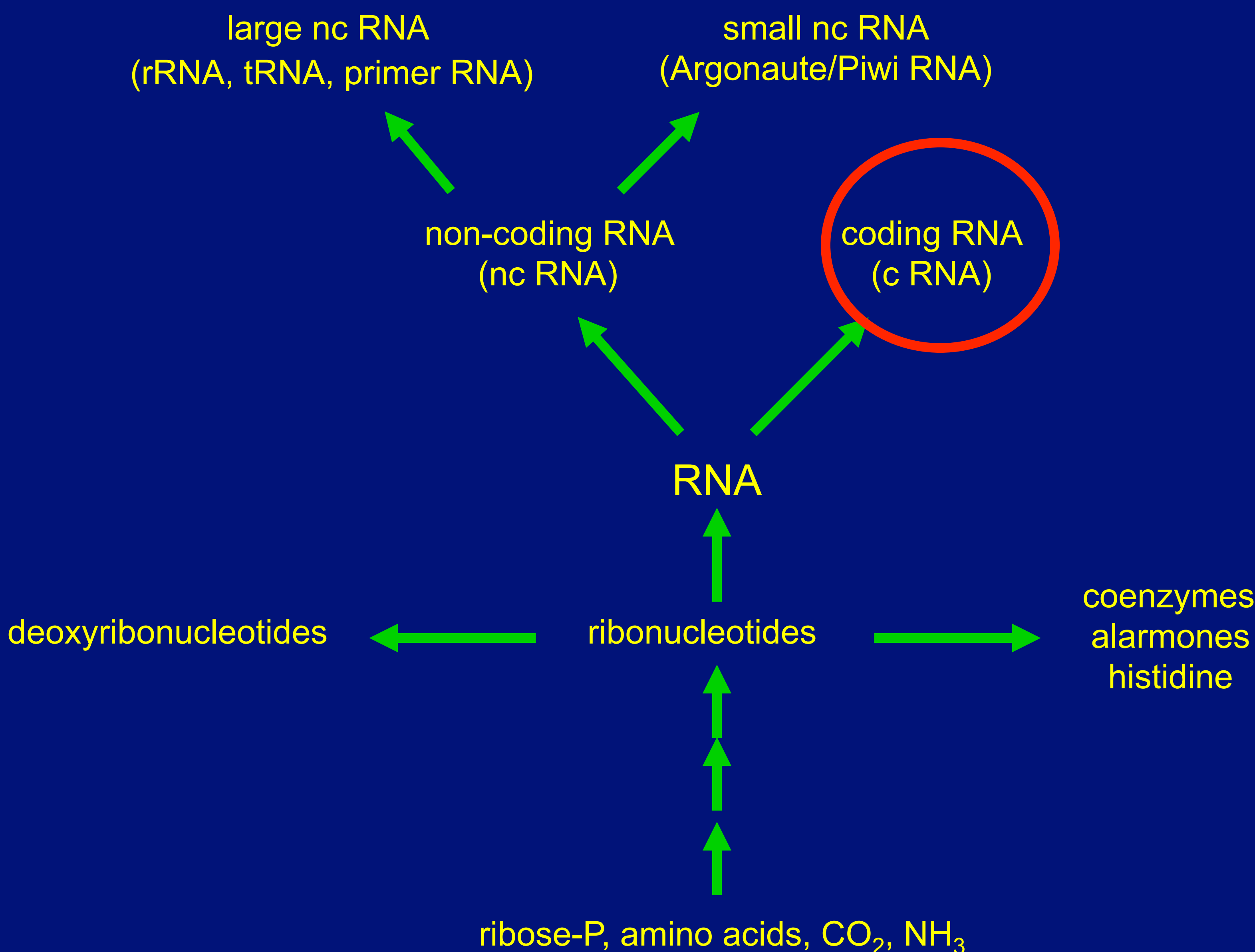

DNA
DNA
RNA
protein

RNA and ribonucleotides: stepping out of the shadows



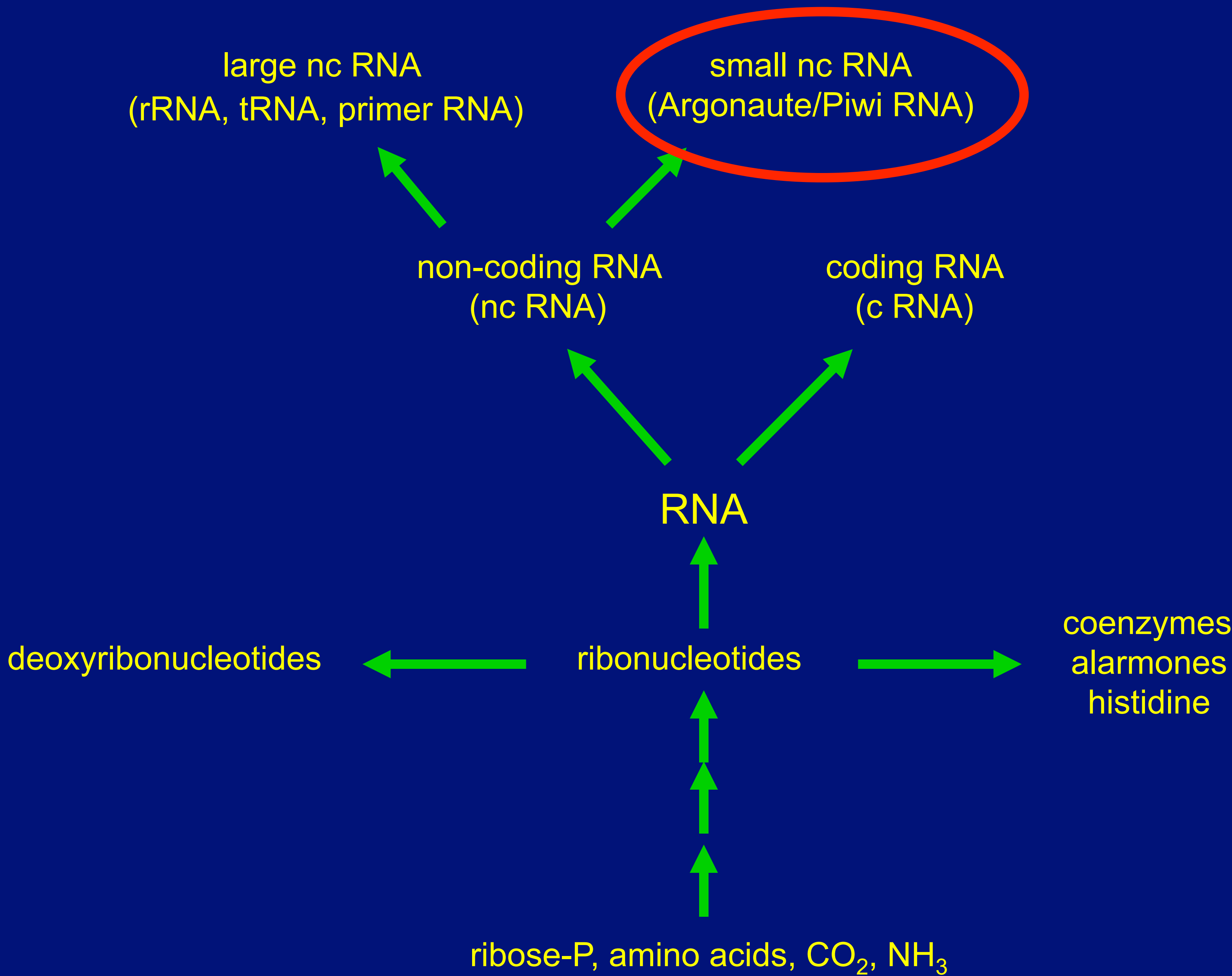
Lazcano (2014)

RNA and ribonucleotides: stepping out of the shadows

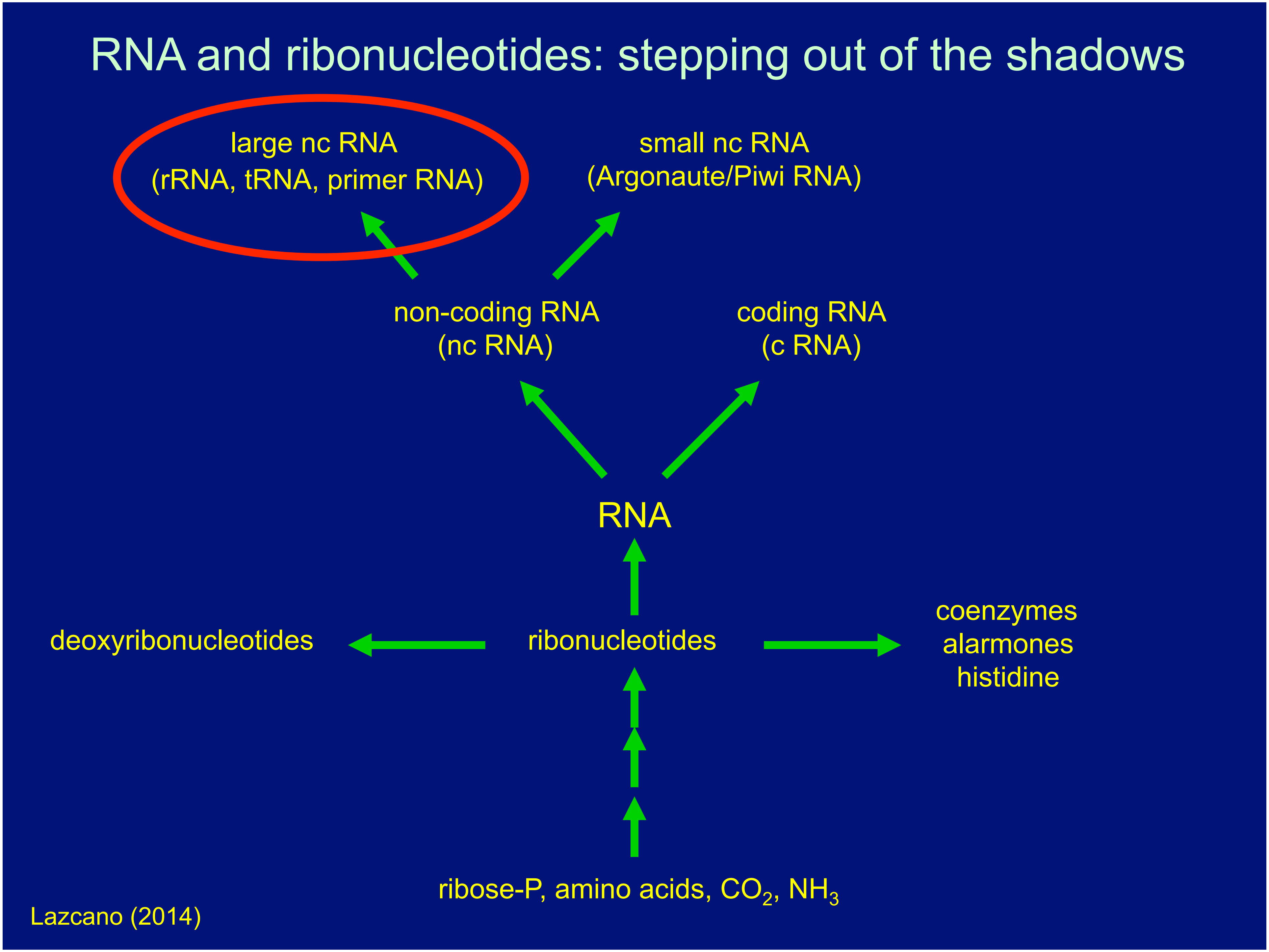


Lazcano (2014)

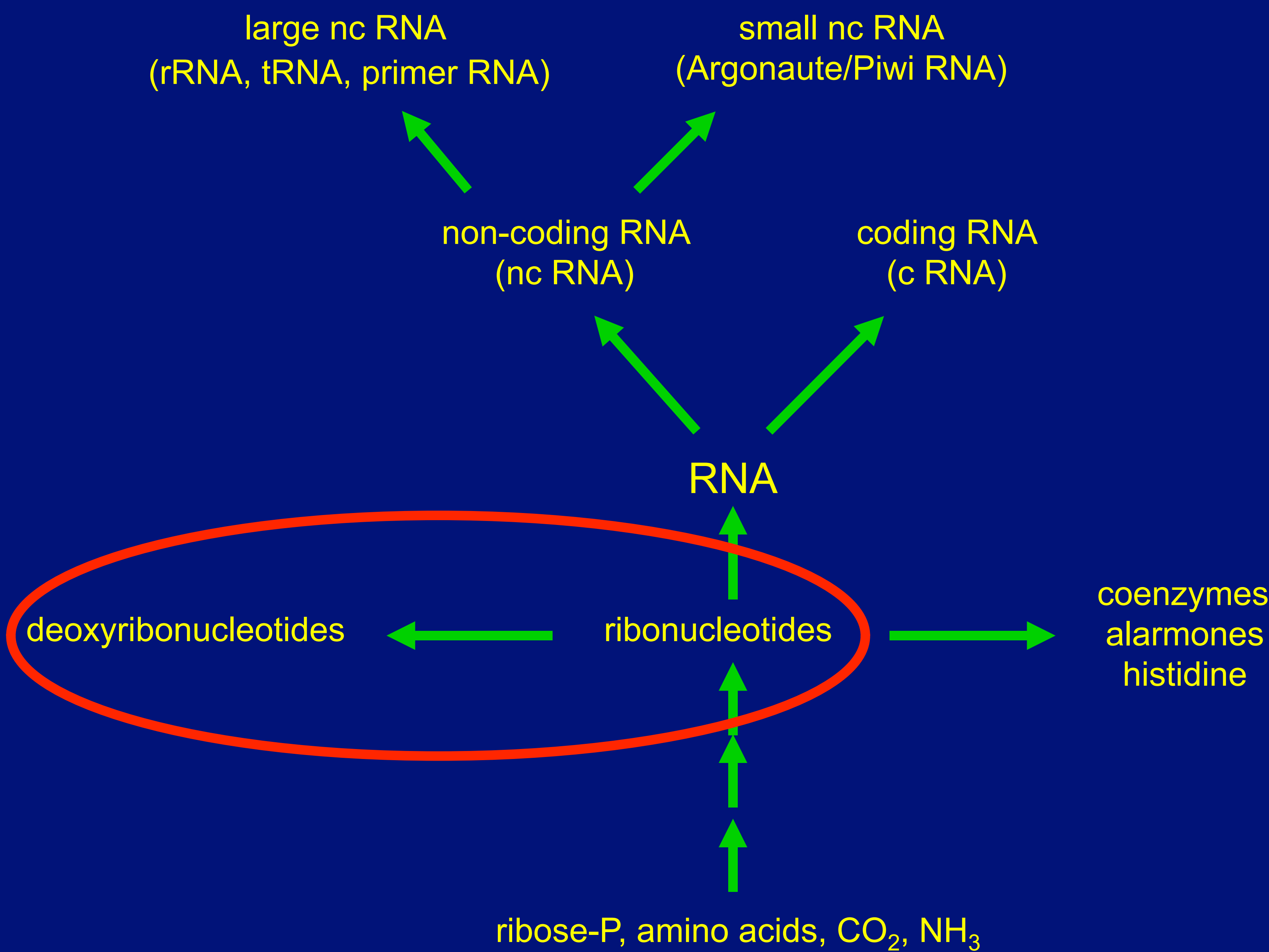
RNA and ribonucleotides: stepping out of the shadows



Lazcano (2014)

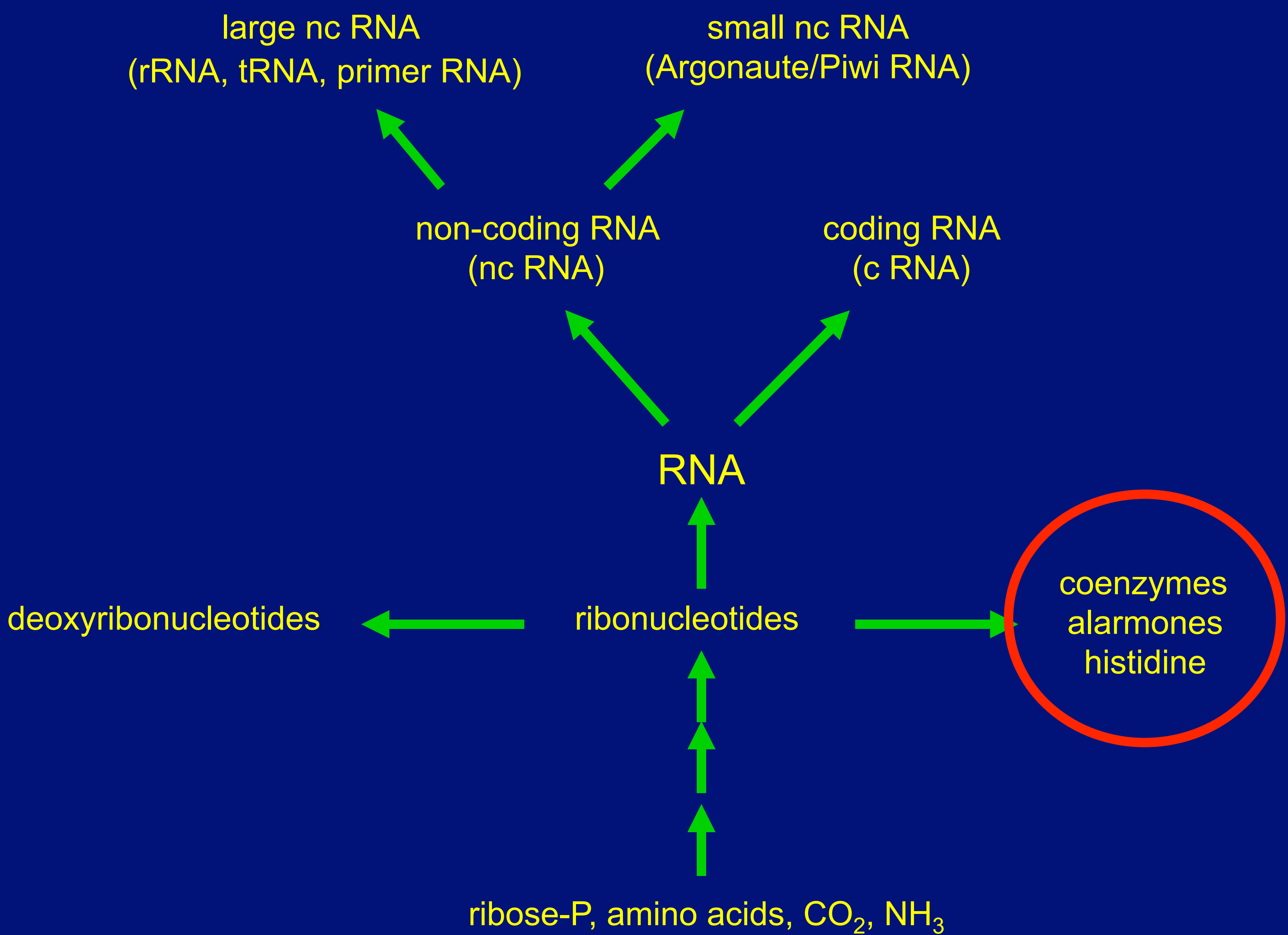

RNA and ribonucleotides: stepping out of the shadows
large nc RNA
(rRNA, tRNA, primer RNA)
small nc RNA
(Argonaute/Piwi RNA)
non-coding RNA
(nc RNA)
coding RNA
(c RNA)
RNA
deoxyribonucleotides
ribonucleotides
coenzymes
alarmones
histidine
ribose-P, amino acids, CO_2, NH_3
Lazcano (2014)

RNA and ribonucleotides: stepping out of the shadows



Lazcano (2014)

RNA and ribonucleotides: stepping out of the shadows

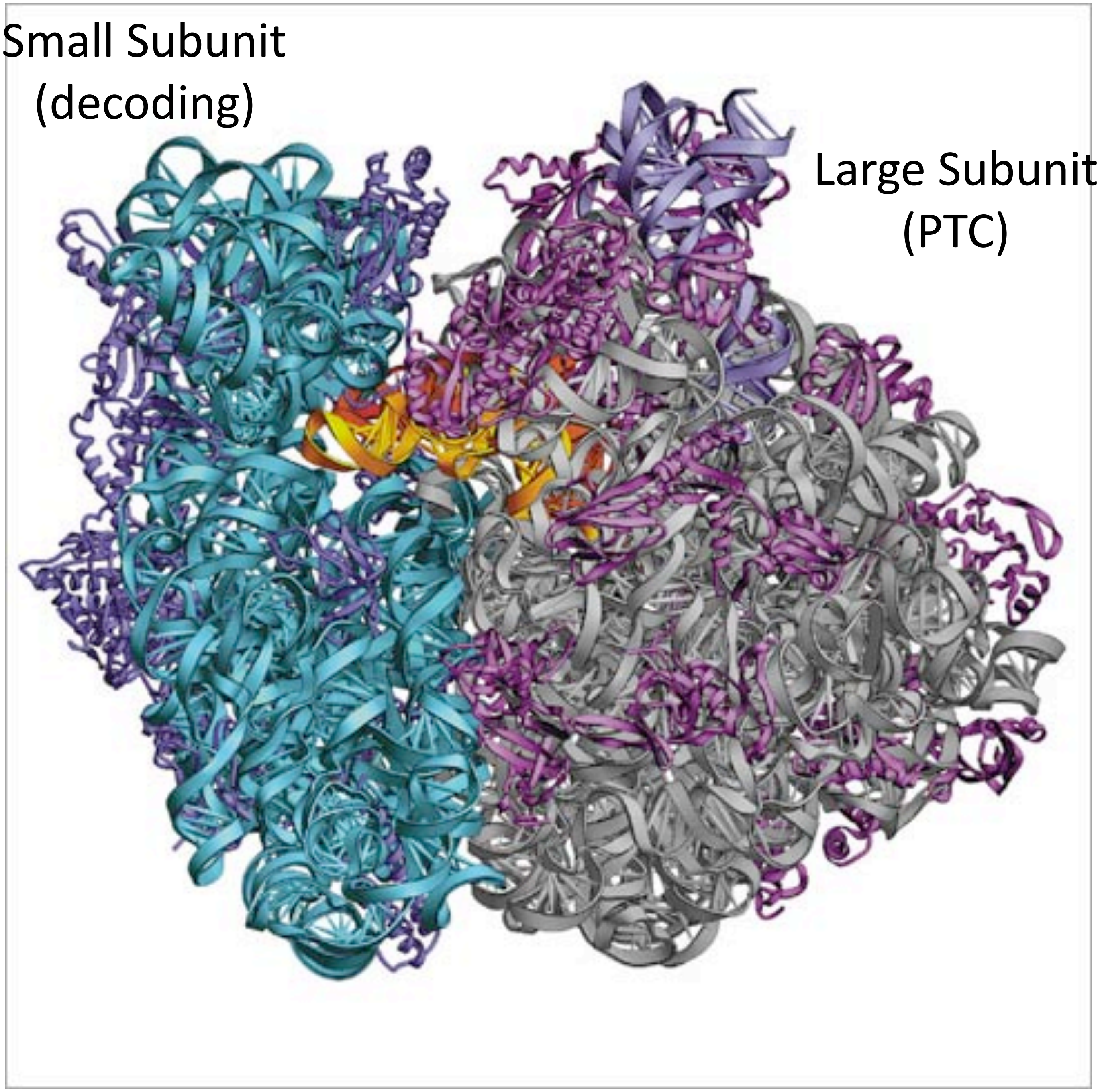


Lazcano (2014)

Biological catalysis: enzymes & ribozymes

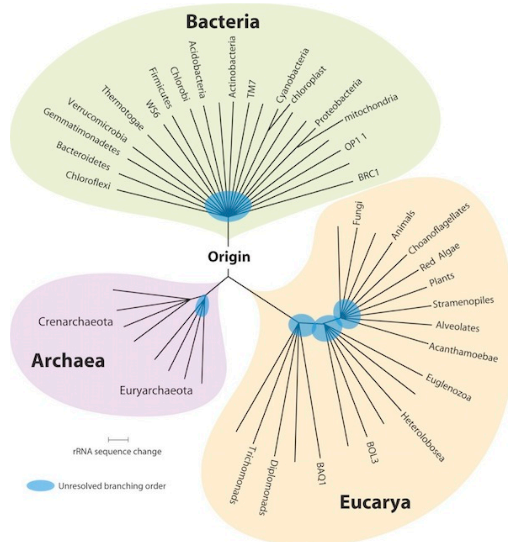
Class	Enzymes	Ribozymes
EC1 Oxidoreductases	Dehydrogenases Oxidases, peroxidases Reductases Monooxygenases Dioxygenases	Dehydrogenases Peroxidases
EC2 Transferases	C1-Transferases Glycosyltransferases Aminotransferases Phosphotransferases	Methyltransferases Aminoacyltransferases Pentosyltransferases Phosphotransferases Nucleotidyltransferases
EC3 Hydrolases	Esterases Glycosidases Peptidases Amidases	Esterases Endodeoxyribonucleases Endoribonucleases Glycosylases Amidases Phosphoamidases
EC4 Lyases (synthases)	C-C-Lyases C-O-Lyases C-N-Lyases C-S-Lyases	Carboxylyases Aldehydelyases Ferrochelatases
EC5 Isomerases	Epimerases *cis trans* Lyases Intramolecular transferases	Methylmanolyl CoA epimerases
EC6 Ligases (synthetases)	C-C-Ligases C-O-Ligases C-N-Ligases C-S-Ligases	C-C-Ligases C-O-Ligases C-N-Ligases C-S-Ligases Phosphoric ester ligases

Hernández-Morales, Becerra & Lazcano (submitted)


Small Subunit
(decoding)
Large Subunit
(PTC)

The RNA World

The catalytic, regulatory & structural properties of RNA molecules, combined with their ubiquity in cellular processes, are consistent with the proposal that they played a key role in early evolution and perhaps in the origin of life itself.



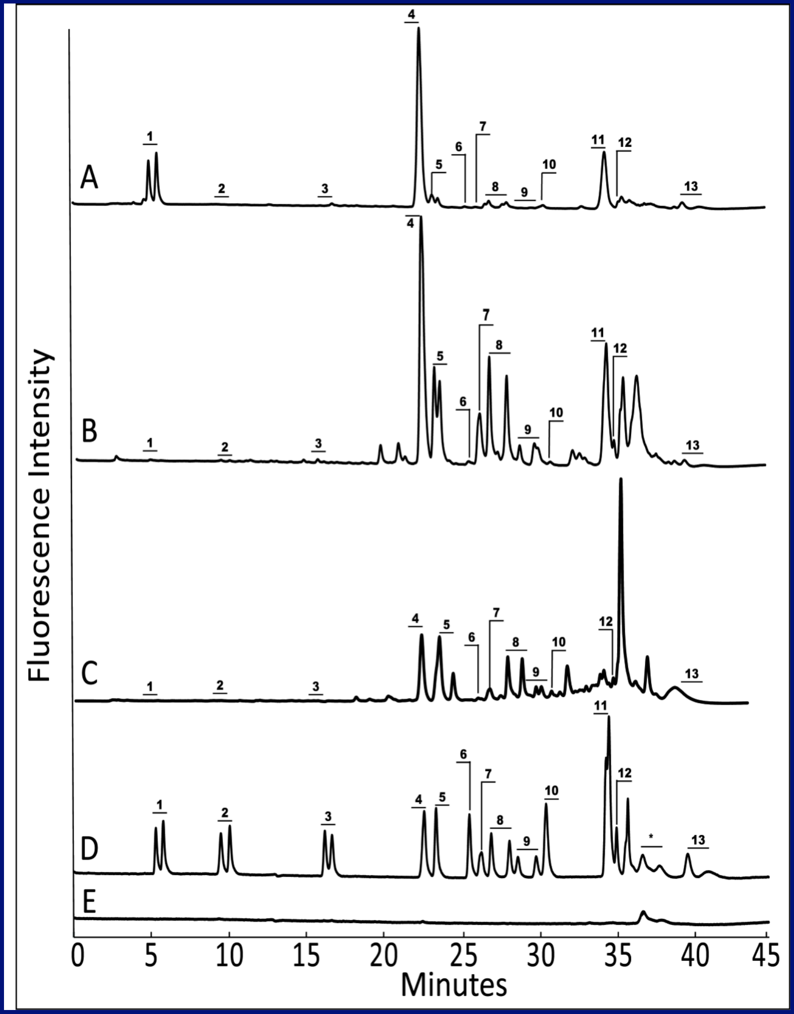
DNA, RNA & proteins

RNA & protein biosynthesis

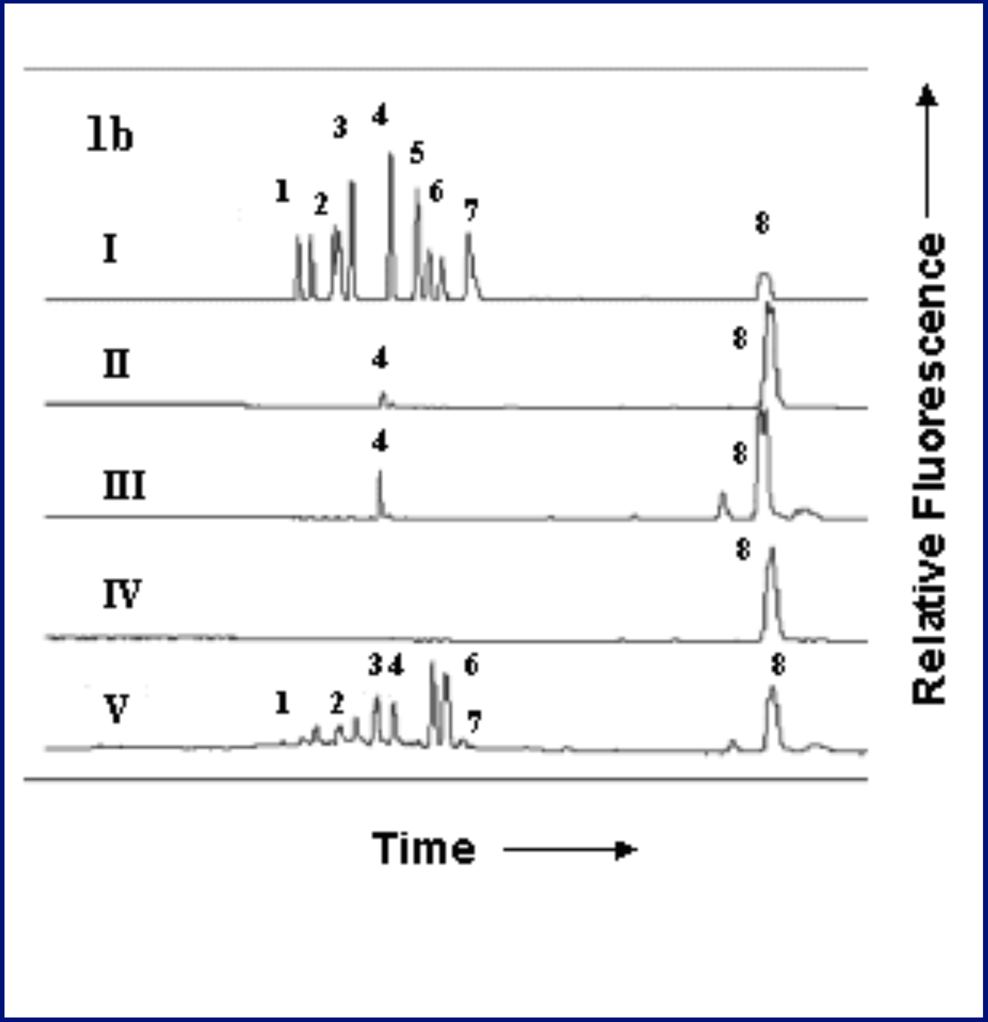
RNA World

?

Prebiotic syntheses are feasible under reducing and neutral conditions

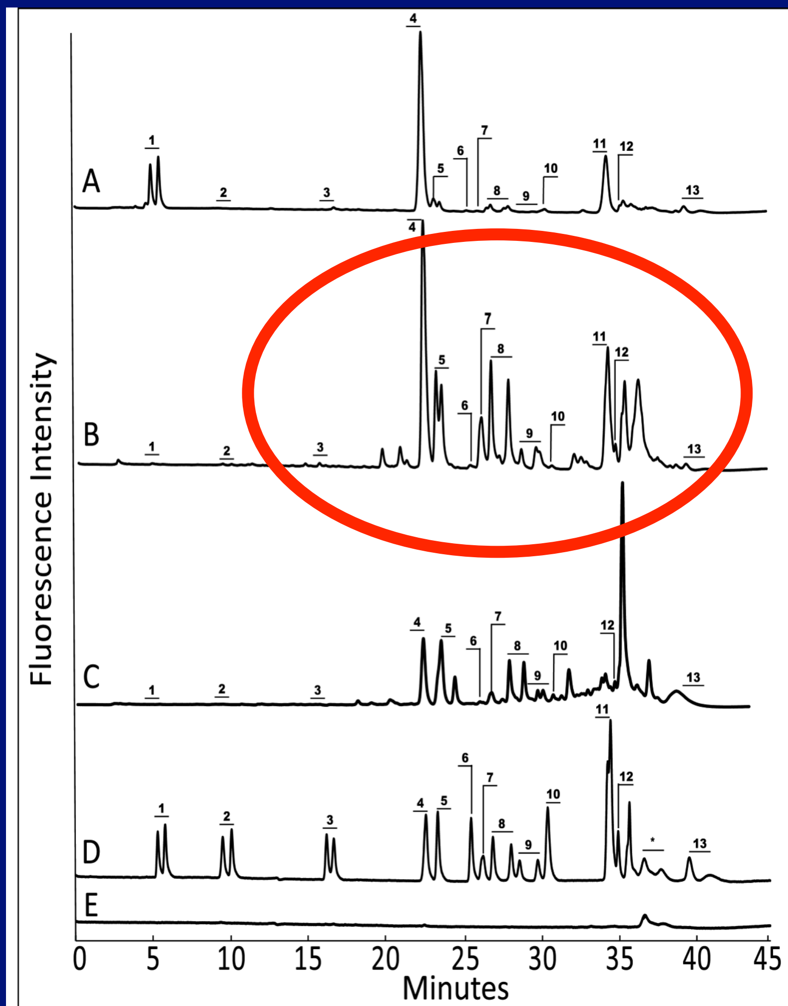


Johnson, Cleaves, Dworkin, Glavin, Lazcano, & Bada (2008) *Science* **322**: 404



Cleaves, Chalmers, Lazcano, Miller & Bada (2008) *Origins of Life and Evolution of Biospheres* **38**: 105

Prebiotic syntheses are feasible under reducing and neutral conditions



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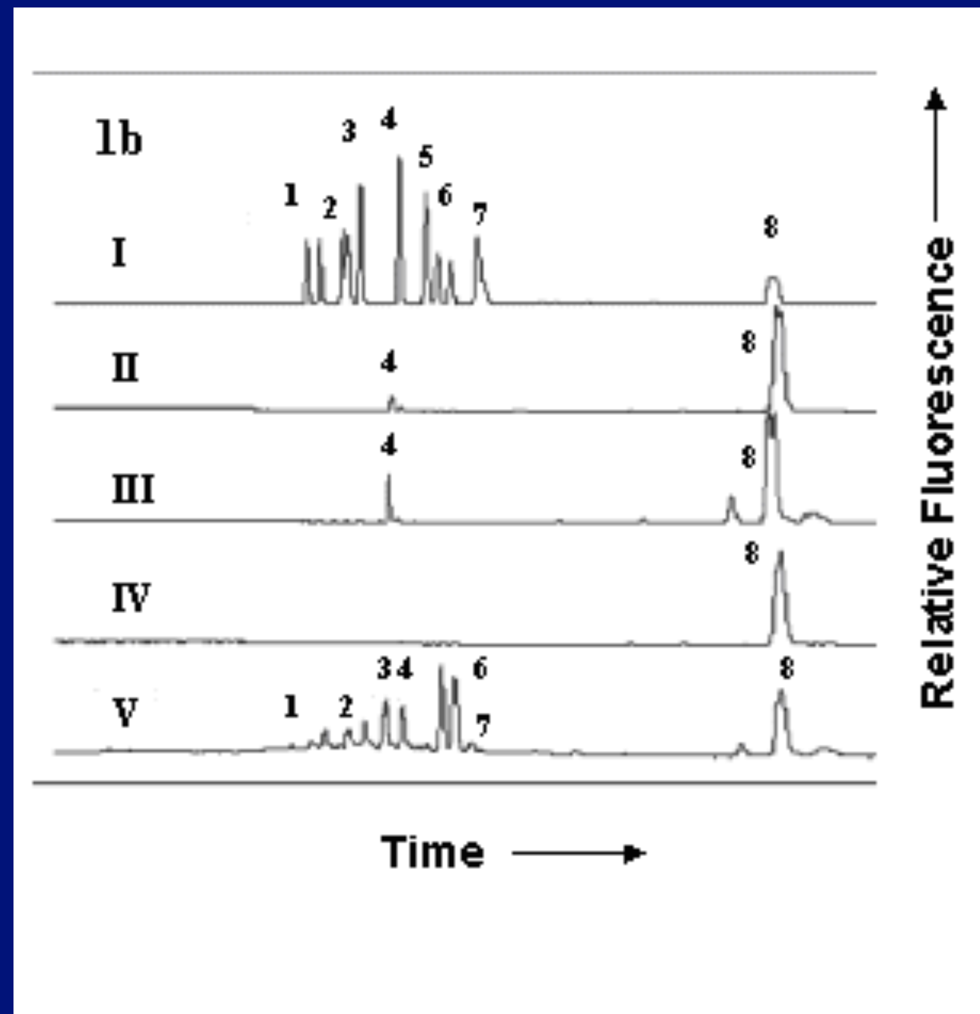
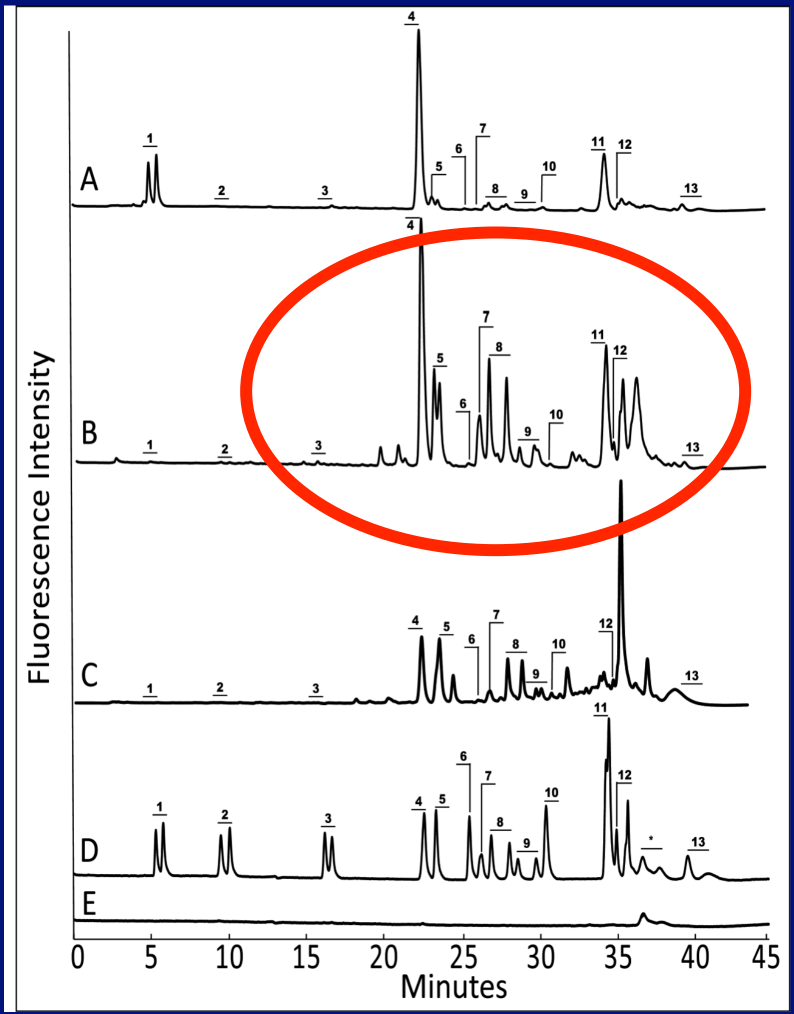
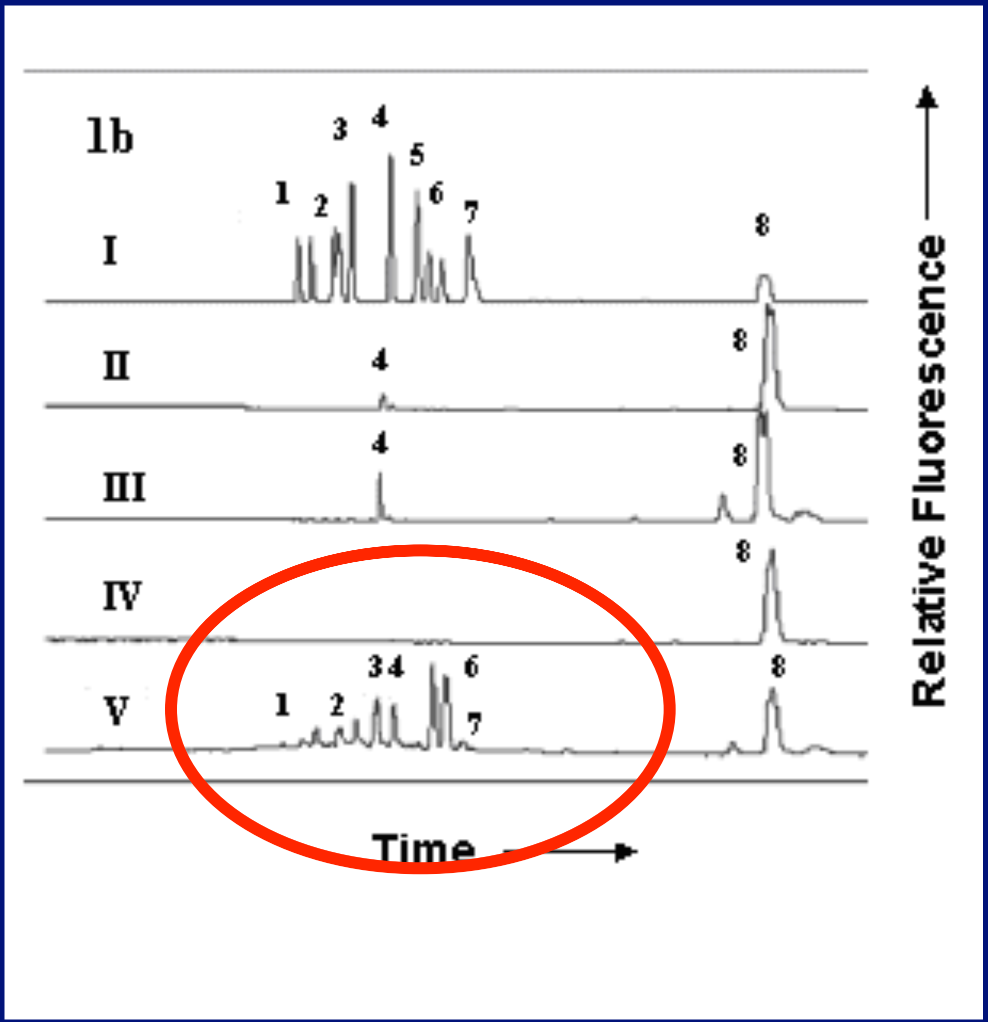


Cleaves, Chalmers, Lazcano, Miller & Bada (2008) *Origins of Life and Evolution of Biospheres* **38**: 105

Prebiotic syntheses are feasible under reducing and neutral conditions





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