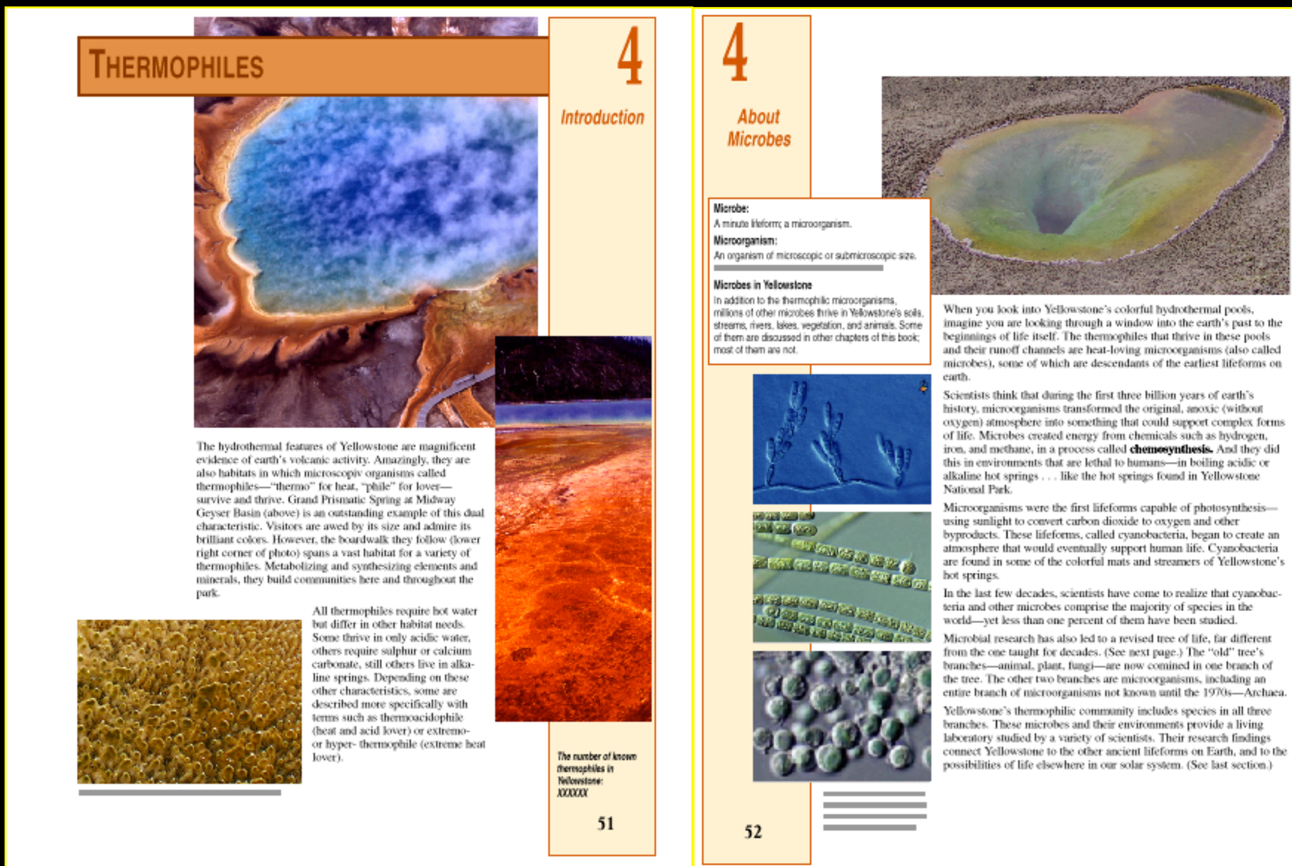
NASA Astrobiology Institute • Ames Research Center

The New 2004 Resource Manual

The Park's 3 million visitors often ask the question "What causes the colors in the hot springs?"



THERMOPHILES

4

Introduction

The hydrothermal features of Yellowstone are magnificent evidence of earth's volcanic activity. Amazingly, they are also habitats in which microscopiv organisms called thermophiles—"thermo" for heat, "phile" for lover—survive and thrive. Grand Prismatic Spring at Midway Geyser Basin (above) is an outstanding example of this dual characteristic. Visitors are awed by its size and admire its brilliant colors. However, the boardwalk they follow (lower right corner of photo) spans a vast habitat for a variety of thermophiles. Metabolizing and synthesizing elements and minerals, they build communities here and throughout the park.

All thermophiles require hot water but differ in other habitat needs. Some thrive in only acidic water, others require sulphur or calcium carbonate, still others live in alkaline springs. Depending on these other characteristics, some are described more specifically with terms such as thermoacidophile (heat and acid lover) or extremo- or hyper- thermophile (extreme heat lover).

The number of known thermophiles in Yellowstone: XXXXX

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About Microbes

Microbe:
A minute lifeform; a microorganism.

Microorganism:
An organism of microscopic or submicroscopic size.

Microbes in Yellowstone
In addition to the thermophilic microorganisms, millions of other microbes thrive in Yellowstone's soils, streams, rivers, lakes, vegetation, and animals. Some of them are discussed in other chapters of this book; most of them are not.

When you look into Yellowstone's colorful hydrothermal pools, imagine you are looking through a window into the earth's past to the beginnings of life itself. The thermophiles that thrive in these pools and their runoff channels are heat-loving microorganisms (also called microbes), some of which are descendants of the earliest lifeforms on earth.

Scientists think that during the first three billion years of earth's history, microorganisms transformed the original, anoxic (without oxygen) atmosphere into something that could support complex forms of life. Microbes created energy from chemicals such as hydrogen, iron, and methane, in a process called **chemosynthesis.** And they did this in environments that are lethal to humans—in boiling acidic or alkaline hot springs . . . like the hot springs found in Yellowstone National Park.

Microorganisms were the first lifeforms capable of photosynthesis—using sunlight to convert carbon dioxide to oxygen and other byproducts. These lifeforms, called cyanobacteria, began to create an atmosphere that would eventually support human life. Cyanobacteria are found in some of the colorful mats and streamers of Yellowstone's hot springs.

In the last few decades, scientists have come to realize that cyanobacteria and other microbes comprise the majority of species in the world—yet less than one percent of them have been studied.

Microbial research has also led to a revised tree of life, far different from the one taught for decades. (See next page.) The "old" tree's branches—animal, plant, fungi—are now comined in one branch of the tree. The other two branches are microorganisms, including an entire branch of microorganisms not known until the 1970s—Archaea.

Yellowstone's thermophilic community includes species in all three branches. These microbes and their environments provide a living laboratory studied by a variety of scientists. Their research findings connect Yellowstone to the other ancient lifeforms on Earth, and to the possibilities of life elsewhere in our solar system. (See last section.)

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View the handbook on-line at:
http://www.nps.gov/yell/publications/pdfs/handbook/index.html

The New Resource Manual Features:

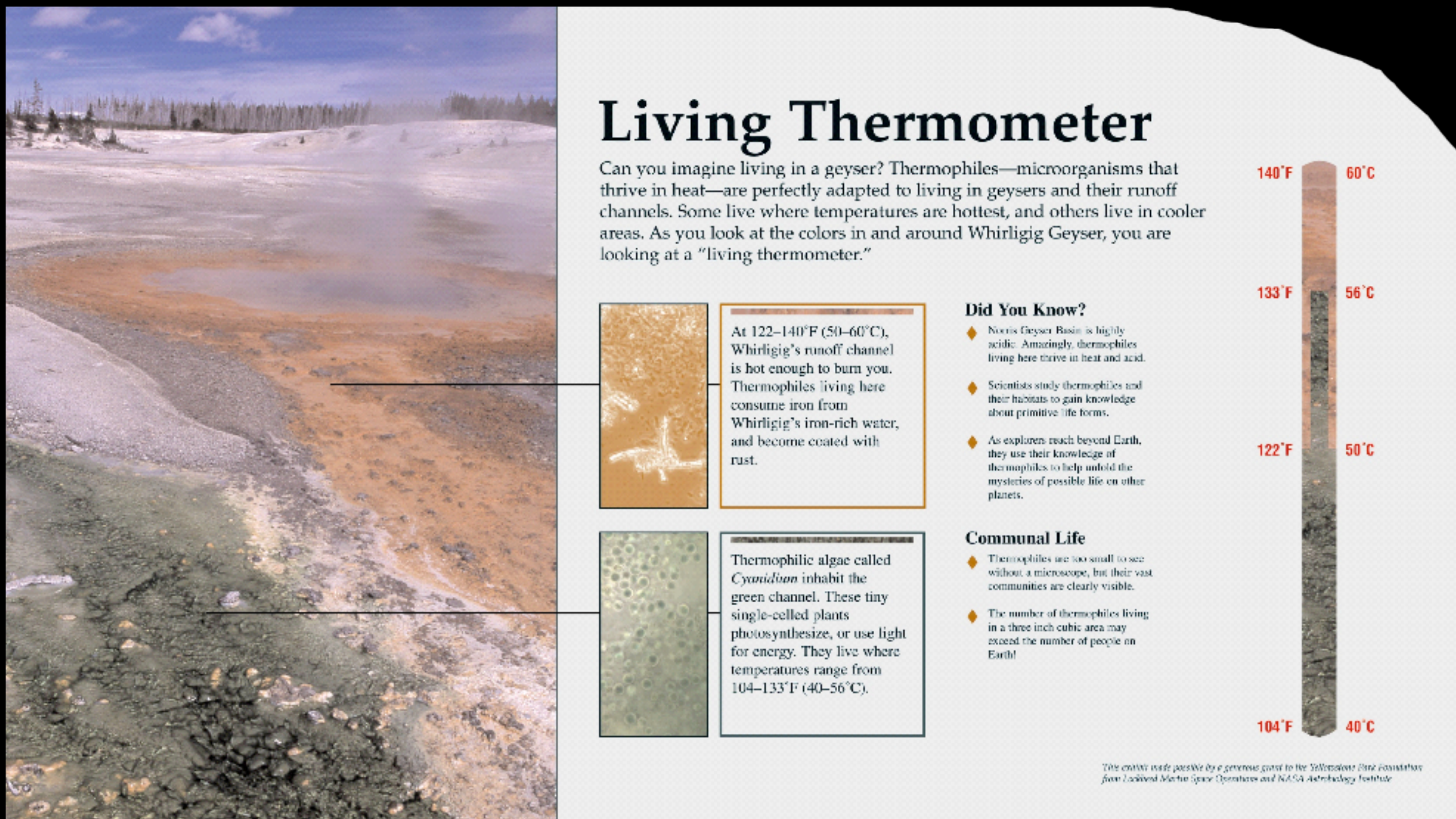
- **2 draft chapters on microbiology of YNP & astrobiology in YNP melded into 1 chapter**
- **Reviewed and condensed by YNP**
- **Reviewed by NAI team**
- **Raised funds for color printing.**

Color printing was a major success. For the first time, the New 2004 Edition has been "sold-out" in the YNP Bookstore.

Color publication enabled by:

- **Lockheed Martin Space Operations**
- **Agouron Institute**
- **Montana State University Thermal Biology Institute**
- **American Soc. Microbiology**

Wayside Exhibit (Draft)



•This exhibit made possible by the generous donation from the NASA Astrobiology Institute and Lockheed Martin Space Operations

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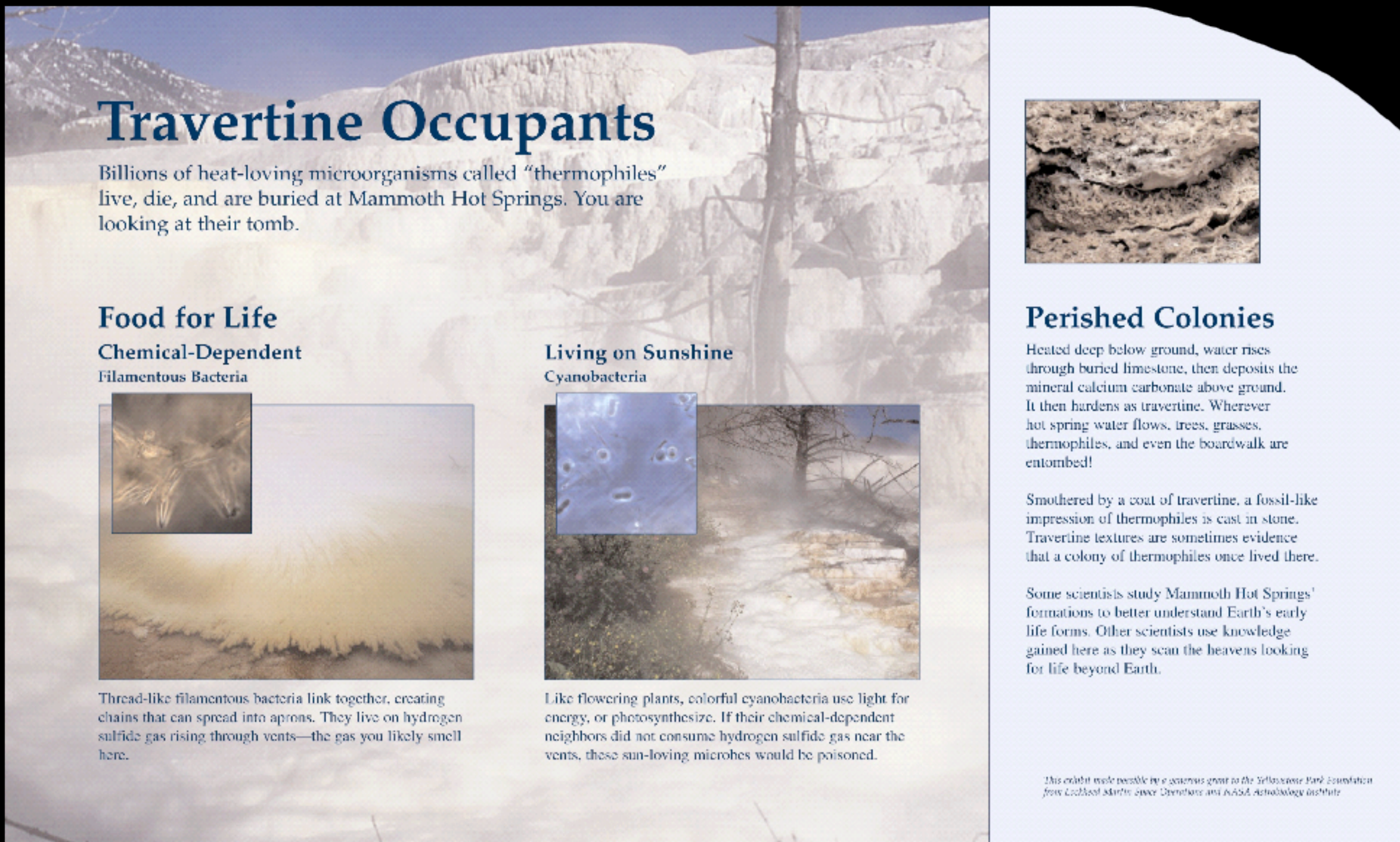
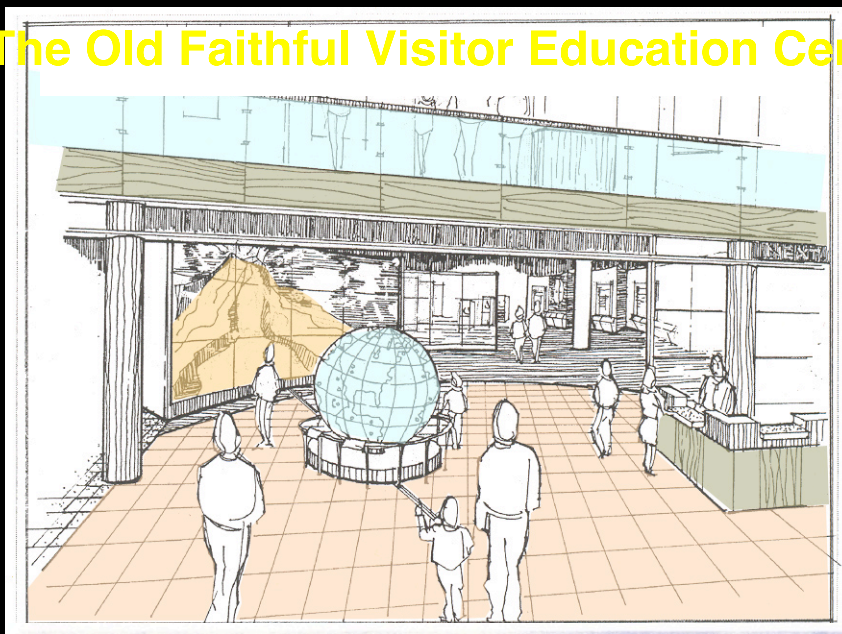
Wayside Exhibit (Draft)



•This exhibit made possible by the generous donation from the NASA Astrobiology Institute and Lockheed Martin Space Operations

NASA Astrobiology Institute • Ames Research Center

The Old Faithful Visitor Education Center



The Old Faithful Visitor Education Center focuses on helping visitors develop a deeper understanding of perhaps the most diverse and accessible hydrothermal field on Earth.

Education Center Facts:

- 43,000 square feet
- Ground breaking in 2006
- Completion in 2008

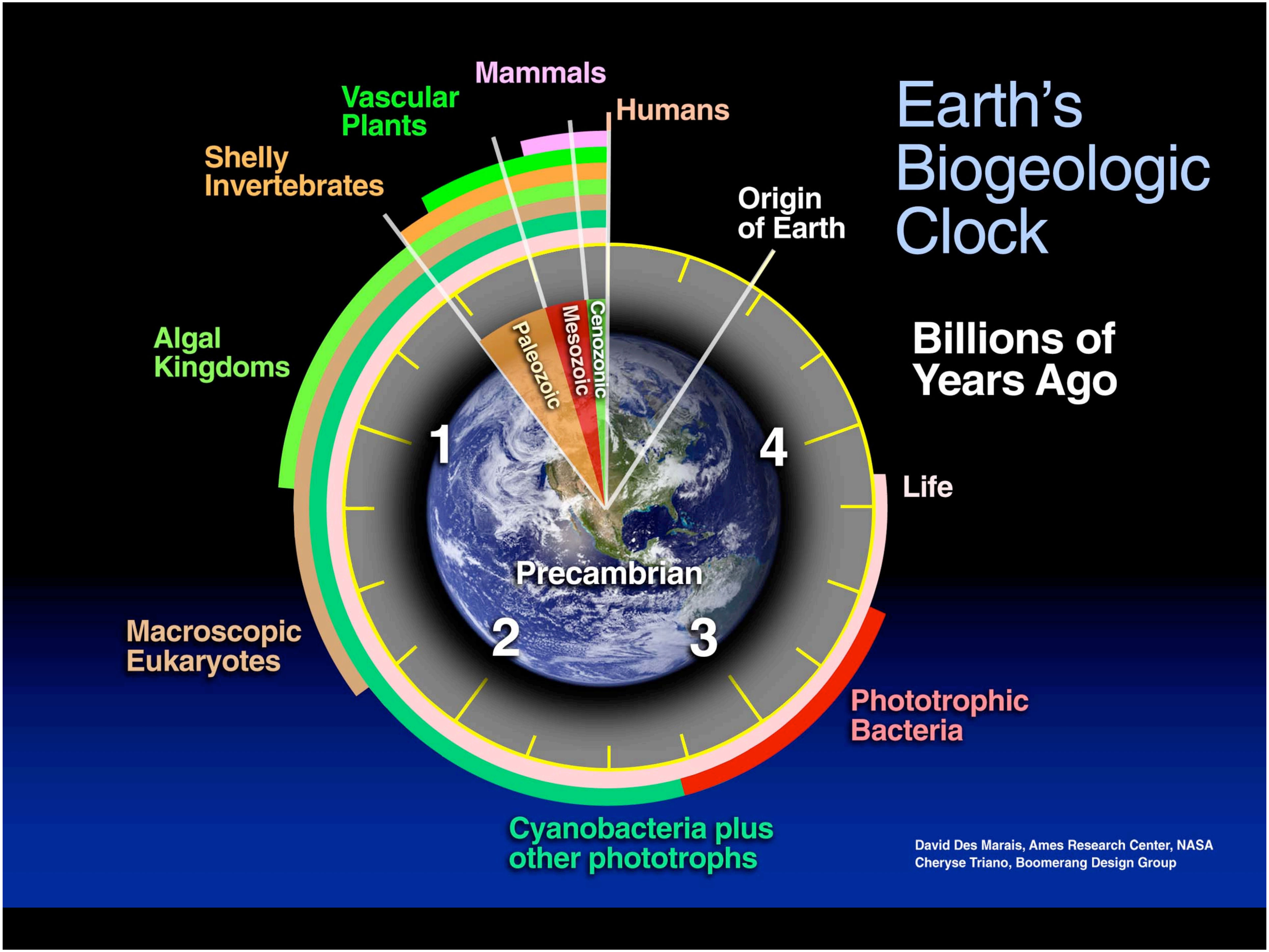
National Science Foundation funding for

- exhibits (8,000 sq. ft.)
- classroom
- web-based programs

Biosignatures

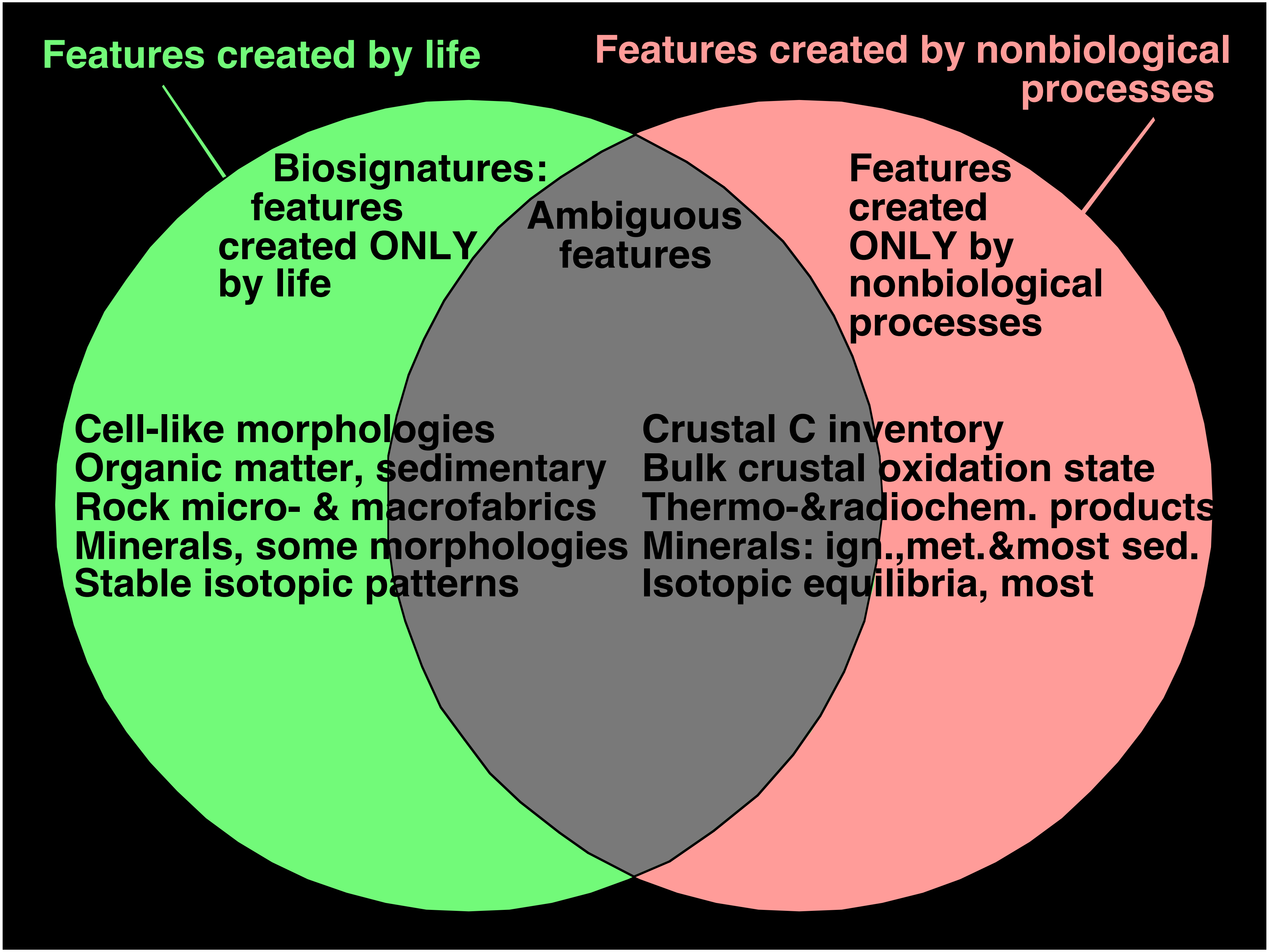
Yellowstone National Park, August 2005

David J. Des Marais
Ames Research Center
Moffett Field, CA 94035


Earth's Biogeologic Clock
Billions of Years Ago
Mammals
Vascular Plants
Humans
Shelly Invertebrates
Origin of Earth
Algal Kingdoms
Paleozoic
Mesozoic
Cenozoic
1
4
Life
Precambrian
Macroscopic Eukaryotes
2
3
Phototrophic Bacteria
Cyanobacteria plus other phototrophs
David Des Marais, Ames Research Center, NASA
Cheryse Triano, Boomerang Design Group

Biosignatures/Biomarkers

- A biosignature is an object, substance and/or pattern whose origin specifically requires a biological agent
- Astrobiological exploration is founded upon the premise that biosignatures encountered beyond Earth will be recognizable
- The principal value of a biosignature arises, not from the probability that it was made by life, but rather from the <u>improbability</u> that it was made by nonbiological processes


Features created by life
Features created by nonbiological processes
Biosignatures: features created ONLY by life
Ambiguous features
Features created ONLY by nonbiological processes
Cell-like morphologies
Organic matter, sedimentary
Rock micro- & macrofabrics
Minerals, some morphologies
Stable isotopic patterns
Crustal C inventory
Bulk crustal oxidation state
Thermo-&radiochem. products
Minerals: ign.,met.&most sed.
Isotopic equilibria, most

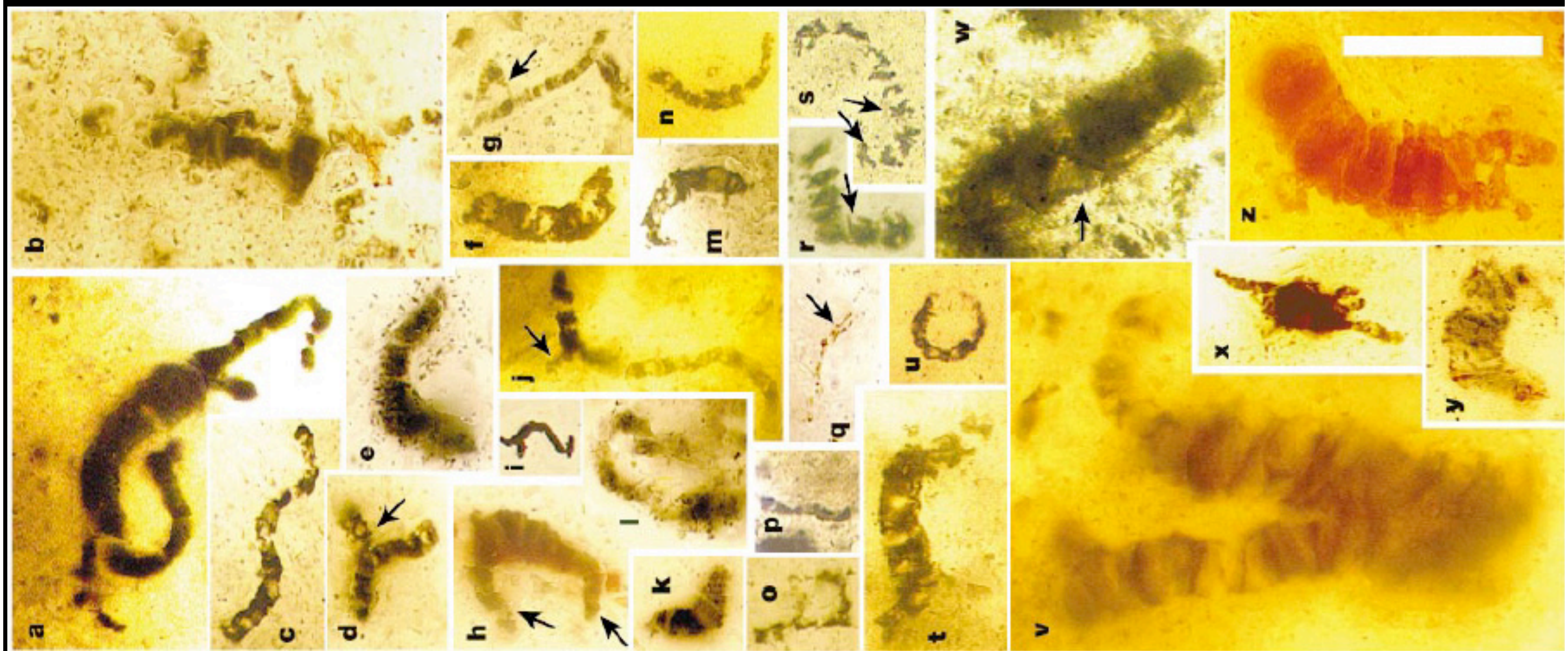
Biosignature Categories

- **Cellular and extracellular morphologies**
- “Biomarker” molecular structures
- Biofabrics: microscale biogenic rock textures
- Community-level structures, e.g., stromatolites
- “Biomarker” minerals
- Biogenic stable isotope patterns
- Light from inhabited extrasolar planets


0 µm 50
J. W. Schopf
Kildinosphaera -- ARIZONA -- 850 Ma

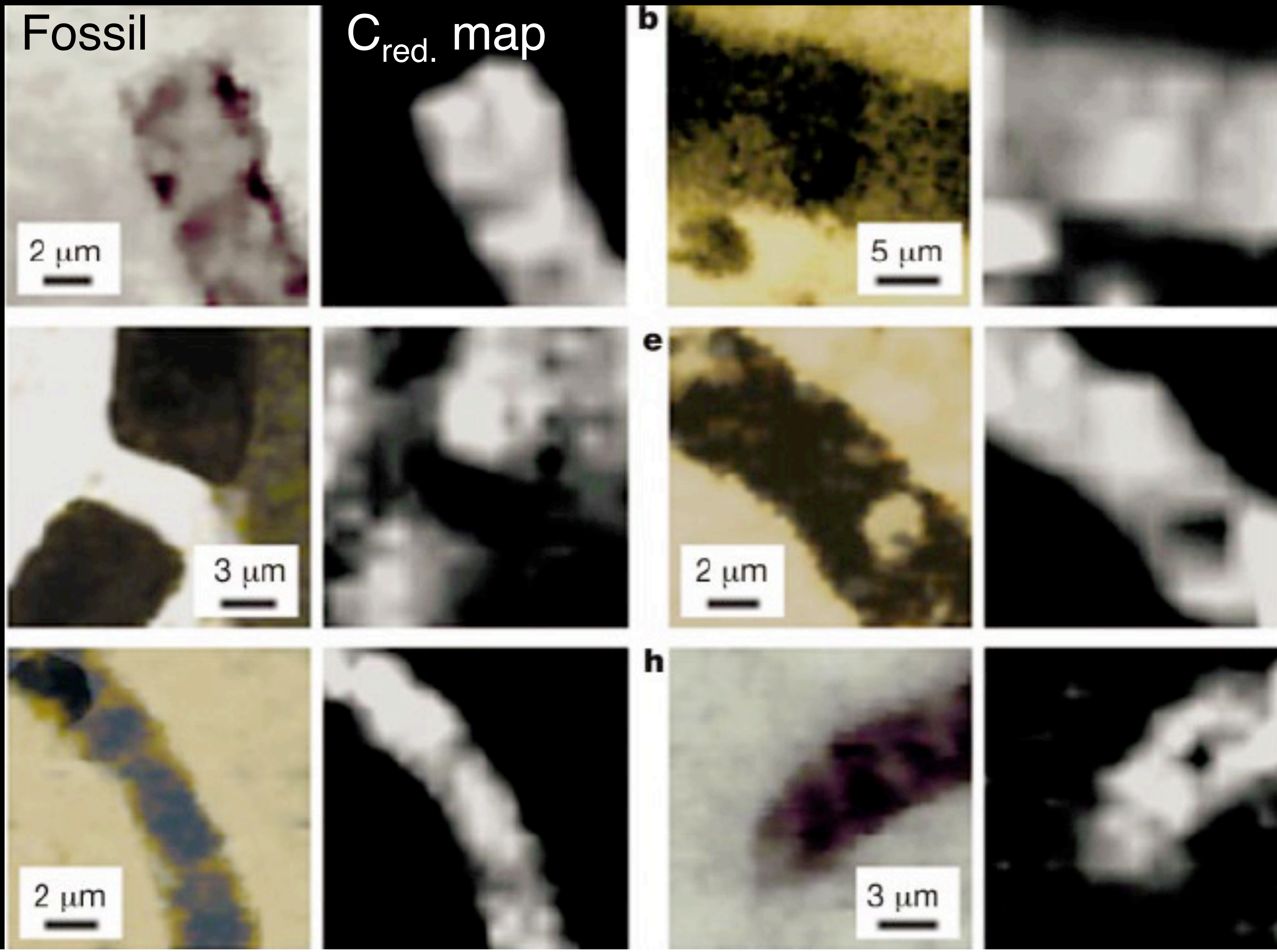

L. Prufert Bebout

Chert, Apex Basalt, Western Australia, 3.458 Ga
Large (> 1 um dia.) fossil-like filaments:
biotic or abiotic?



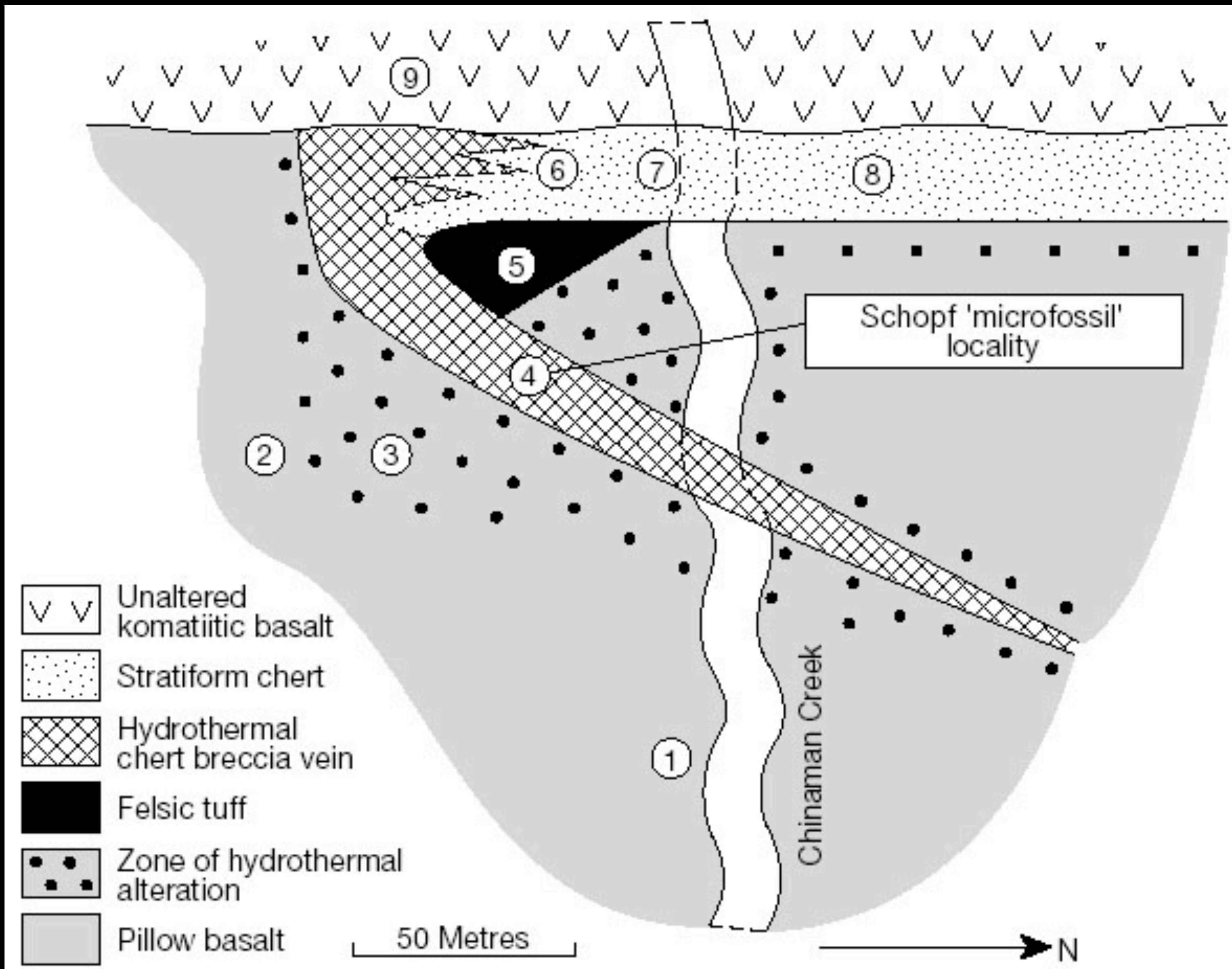
Brassier et al., 2002

Correspondence between fossil structures and reduced C distribution (J. W. Schopf, et al., 2002)



Apex Chert Locality:

Evidence for a subsurface hydrothermal paleoenvironment



Brassier et al., 2002

Cellular and extracellular morphologies

- Microbial cell populations can have characteristic size and shape distributions
- Physical forces dominate the shapes of objects smaller than ~1 micron
- Typically difficult to infer function from shapes, although associations among objects can be diagnostic
- Compositions of objects (e.g., organic?) offer critical information
- Environmental context (rock type, mineralogy, environmental history, etc.) is crucial for proper interpretation

Biosignature Categories

- Cellular and extracellular morphologies
- **“Biomarker” molecular structures**
- Biofabrics: microscale biogenic rock textures
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- “Biomarker” minerals
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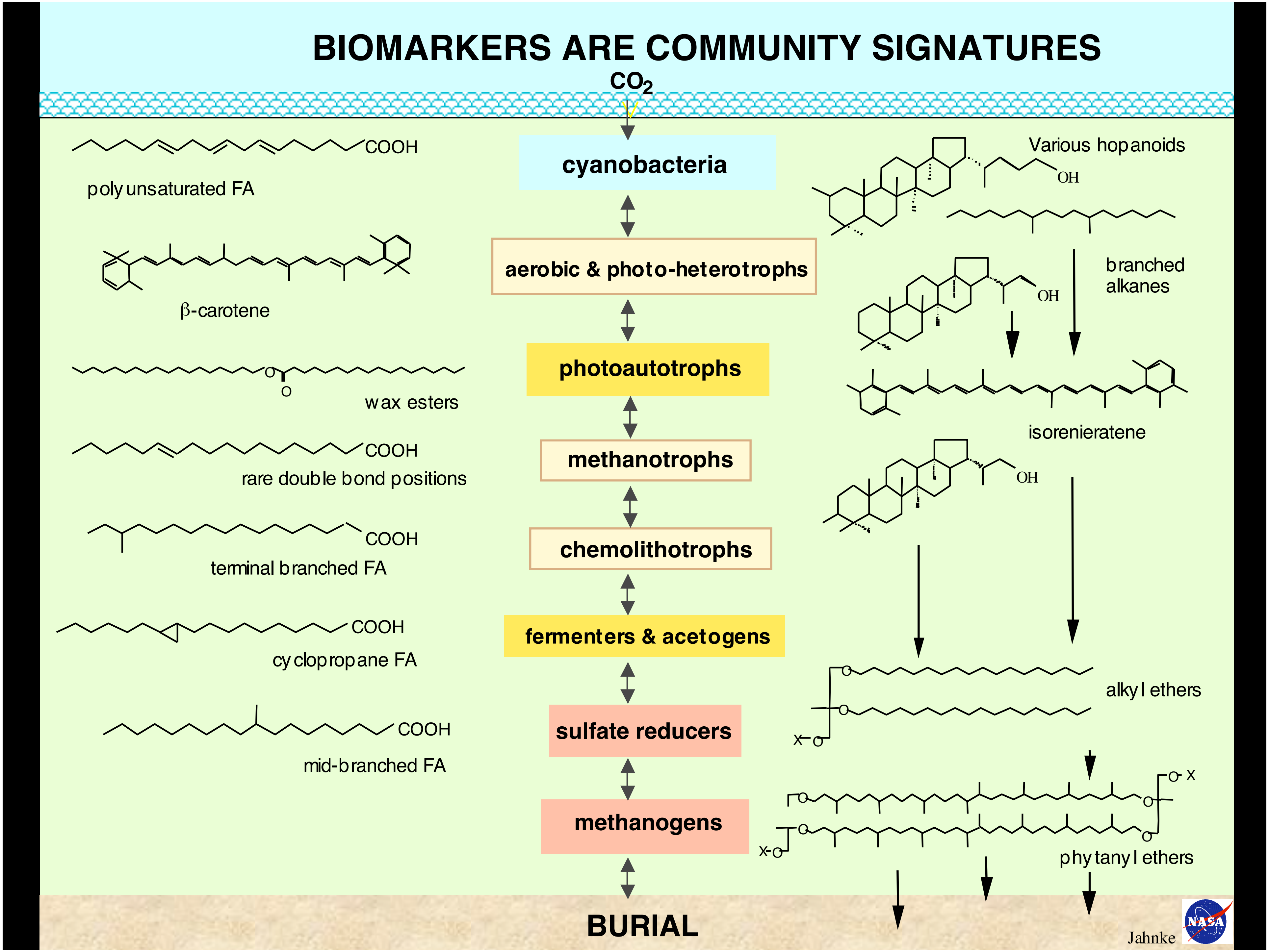
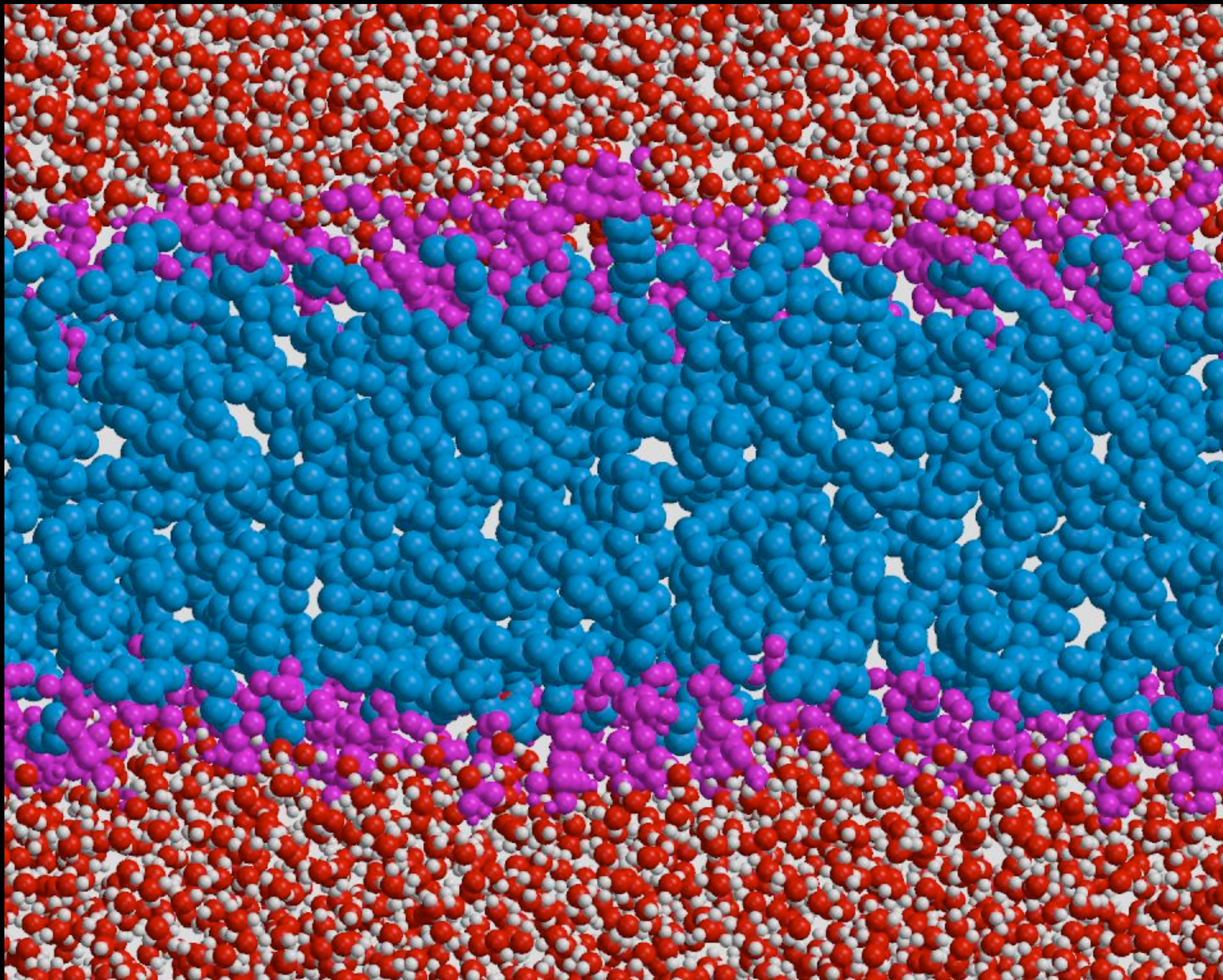
- Light from inhabited extrasolar planets



BIOMARKERS ARE COMMUNITY SIGNATURES
CO_2
cyanobacteria
aerobic & photo-heterotrophs
photoautotrophs
methanotrophs
chemolithotrophs
fermenters & acetogens
sulfate reducers
methanogens
BURIAL
COOH
polyunsaturated FA
β-carotene
O
O
wax esters
COOH
rare double bond positions
COOH
terminal branched FA
COOH
cyclopropane FA
COOH
mid-branched FA
Various hopanoids
OH
branched alkanes
OH
isorenieratene
OH
alkyl ethers
X-O
O
O
O-X
phytanyl ethers
X-O
O
O
Jahnke
NASA

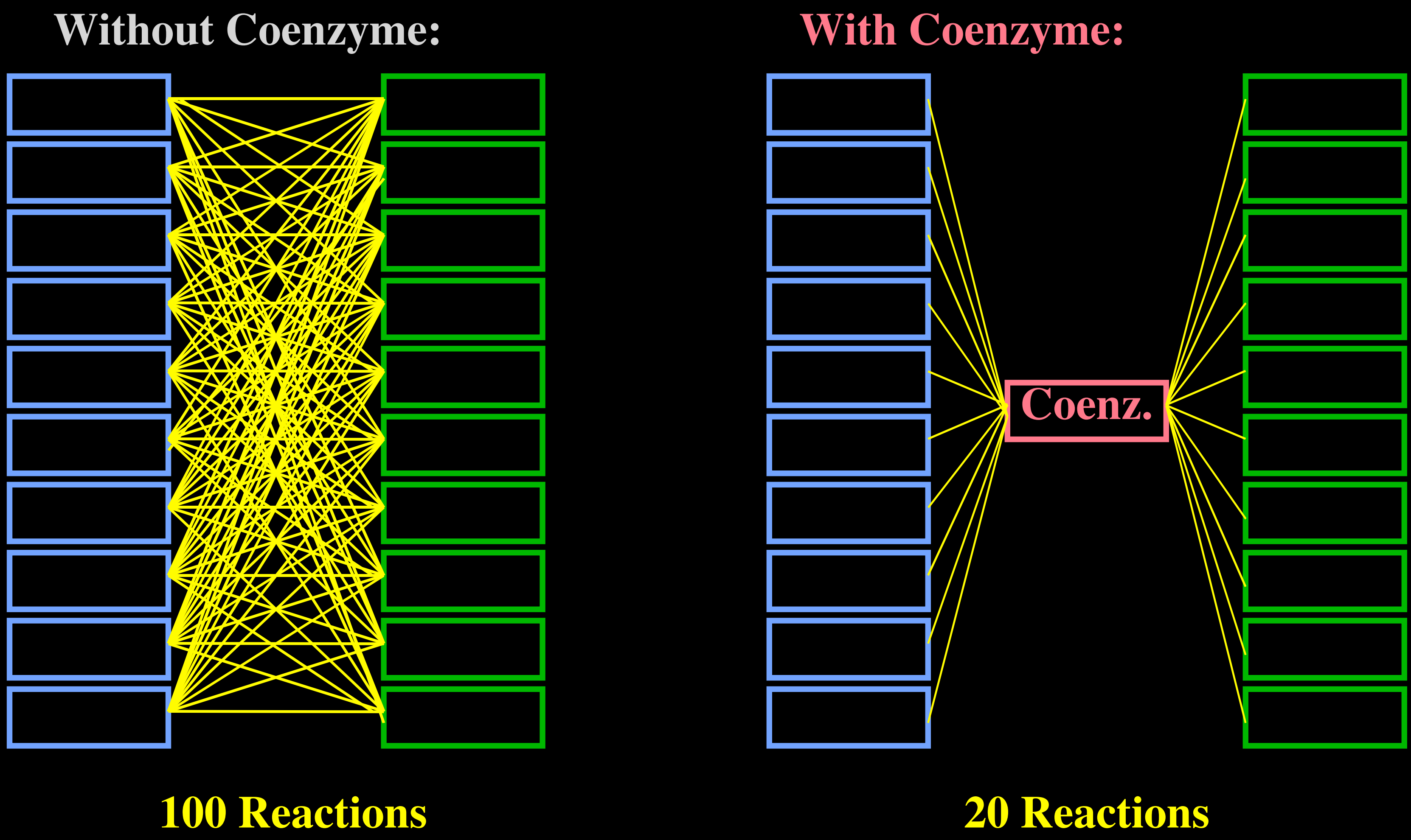
Molecular (Biomarker) Structures

- Large, complex molecules (e.g., RNA, lipids, proteins) can be highly diagnostic for specific biota
- Labile (e.g., RNA) & stable (e.g., certain lipids) are suitable for modern or ancient samples, respectively
- Biomarkers in sediments are usually altered by microbial & geological processes
- Uses of biomarkers: presence of life, microbial physiology & activity, paleoenvironmental conditions
- Best biomarkers are those whose specific biological function are known & are diagnostic for specific biota
- Environmental context (rock type, mineralogy, environmental history, etc.) is crucial



A. Pohorille, Ames Research Center

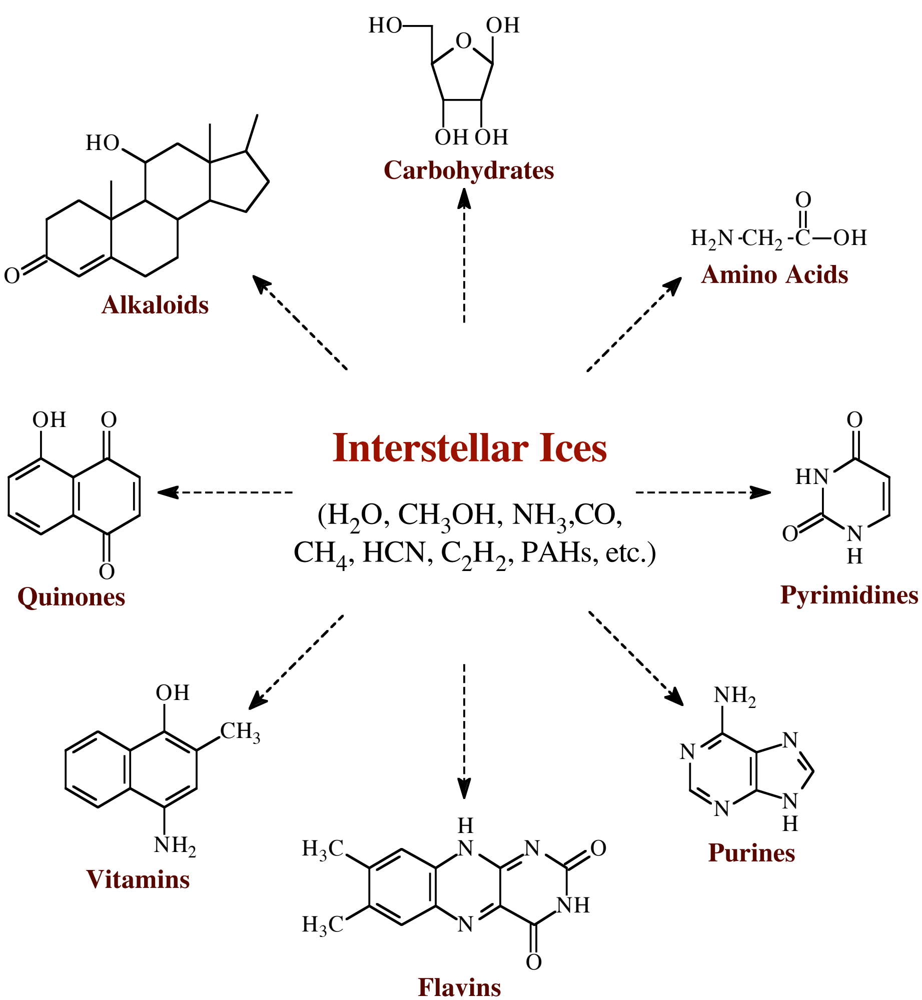
Coenzymes Streamline Group and Electron Transfers

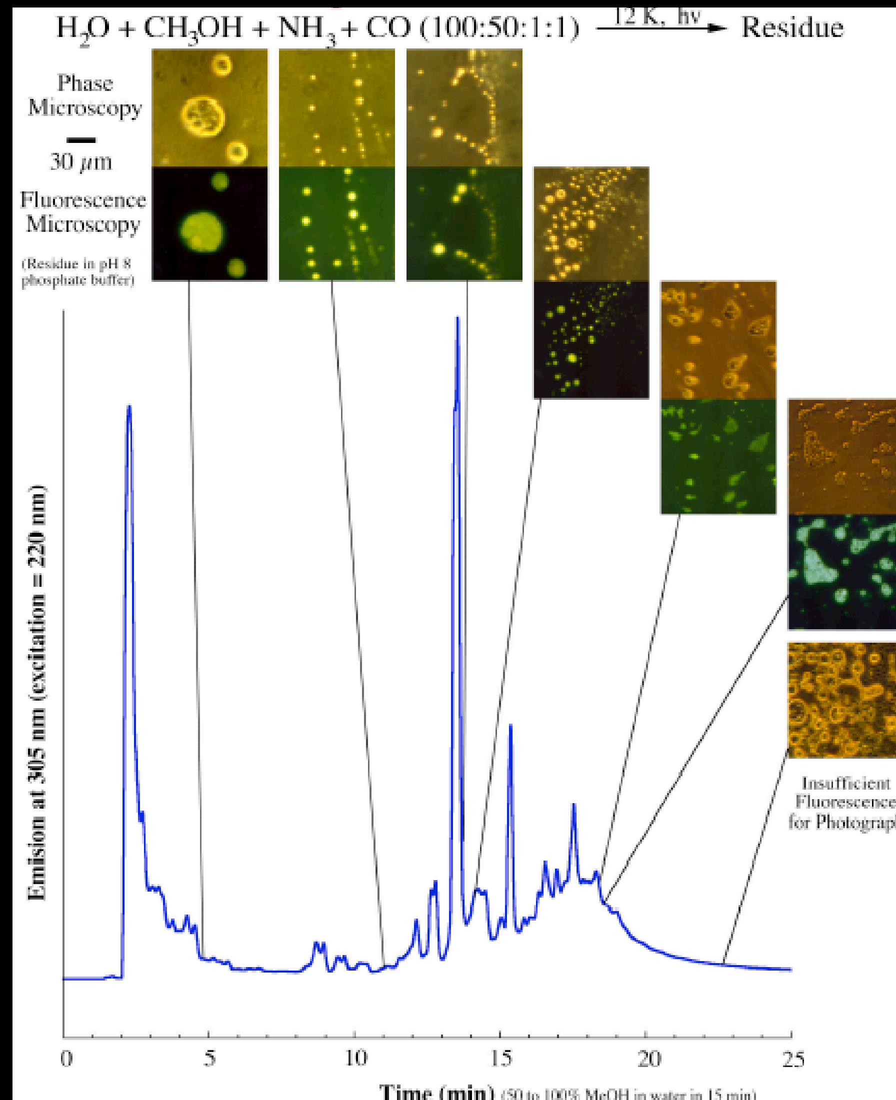


(Des Marais, 2000)

Ames Astrochemistry Laboratory - L. Allamandola, et al.

Abiotic Synthesis of Biogenically Useful Molecules in Cometary and Interstellar Ices





HPLC of Residue with Micrographs of Selected Fractions

Dworkin, J. P., Deamer, D. W., Sandford, S. A., & Allamandola, L. J. (2001). Self-Assembling Amphiphilic Molecules: Synthesis in Simulated Interstellar/Precometary Ices. Proc. Nat. Acad. Sci. 98, 815-819.

Biosignature Categories

- Cellular & extracellular morphologies
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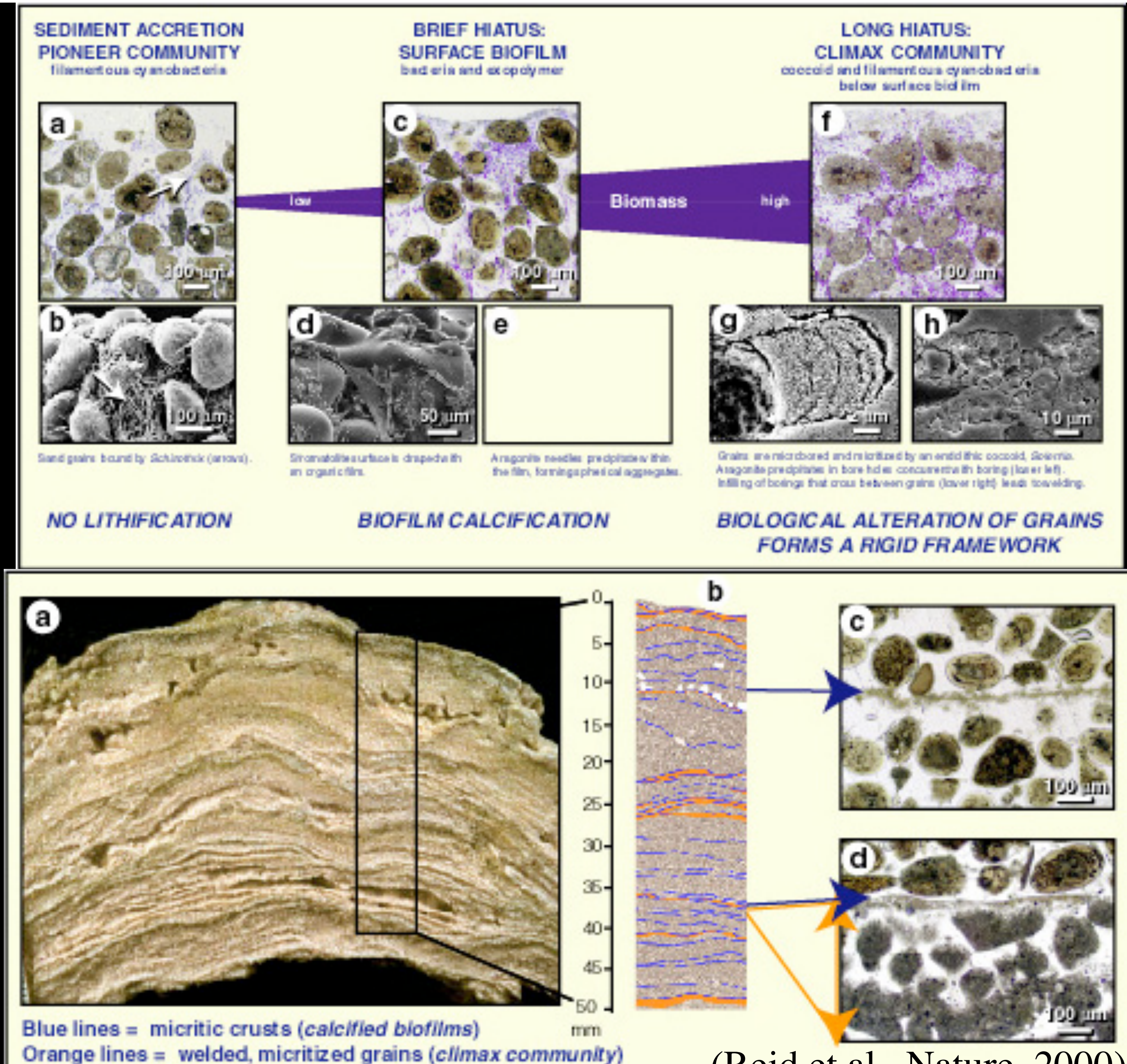
- Light from inhabited extrasolar planets

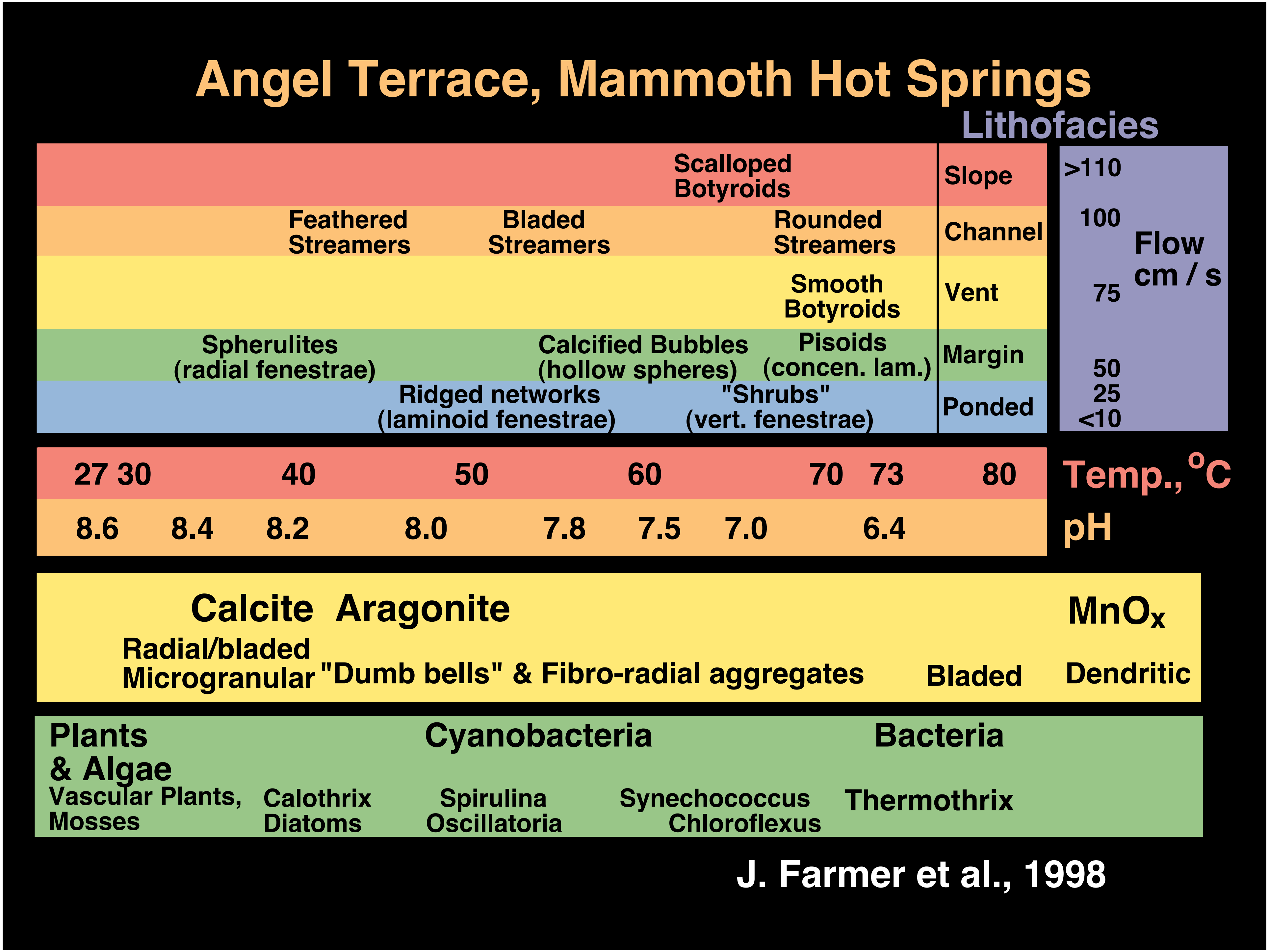

D. Des Marais

Biofabrics and Community Structures

- Can reflect shapes of microbes, motility, community structure, exudates & biominerals
- Architectures reflect interactions between biota & their environment
- Environmental changes can alter the biofabrics that are integrated into larger, community level structures (e.g., biolaminae & stromatolites)
- Abiotic processes can mimic community structures; must document morphology & paleoenvironment to demonstrate biogenicity
- Environmental context (rock type, mineralogy, environmental history, etc.) is crucial



(Reid et al., Nature, 2000)


Angel Terrace, Mammoth Hot Springs
Lithofacies
Scalloped Botyroids
Slope
Feathered Streamers
Bladed Streamers
Rounded Streamers
Channel
Smooth Botyroids
Vent
Spherulites (radial fenestrae)
Calcified Bubbles (hollow spheres)
Pisoids (concen. lam.)
Margin
Ridged networks (laminoid fenestrae)
"Shrubs" (vert. fenestrae)
Ponded
>110
100
75
50
25
<10
Flow cm / s
27 30 40 50 60 70 73 80
Temp., °C
8.6 8.4 8.2 8.0 7.8 7.5 7.0 6.4
pH
Calcite
Aragonite
MnOx
Radial/bladed
Micrgranular
"Dumb bells" & Fibro-radial aggregates
Bladed
Dendritic
Plants & Algae
Cyanobacteria
Bacteria
Vascular Plants, Mosses
Calothrix Diatoms
Spirulina Oscillatoria
Synechococcus Chloroflexus
Thermothrix
J. Farmer et al., 1998

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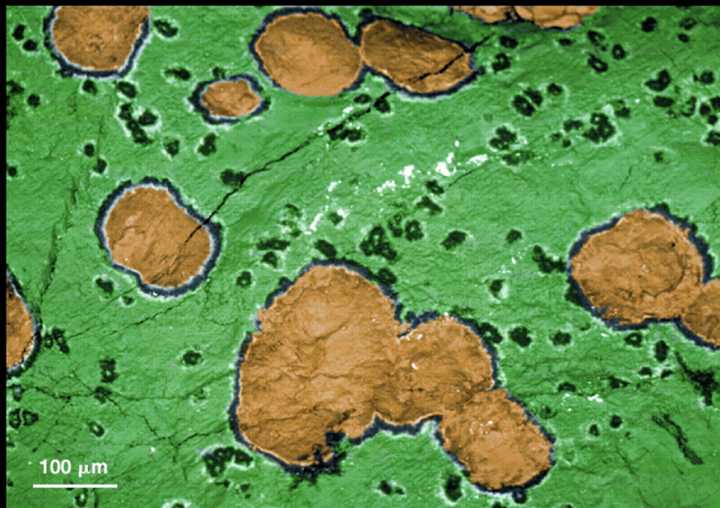
Biogenic minerals

- Formation often reflects processes related to harvesting of energy and/or organic synthesis
- Biomineral composition is influenced by environmental conditions, fluids and minerals
- Diagnostic features arise from effects of biota upon microenvironments and reaction rates
- Key features: definitive contrasts with nonbiological minerals with respect to chemical composition and morphology
- Interpretation depends critically upon understanding environmental context (rock type, mineralogy, environmental history, etc.)

Carbonate "globules," or "rosettes," that were proposed to contain evidence of ancient bacterial life

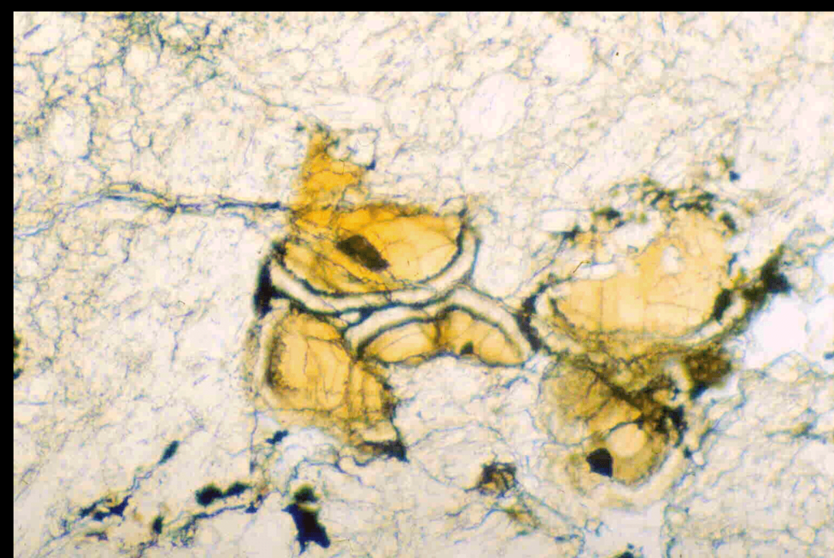
(McKay et al)



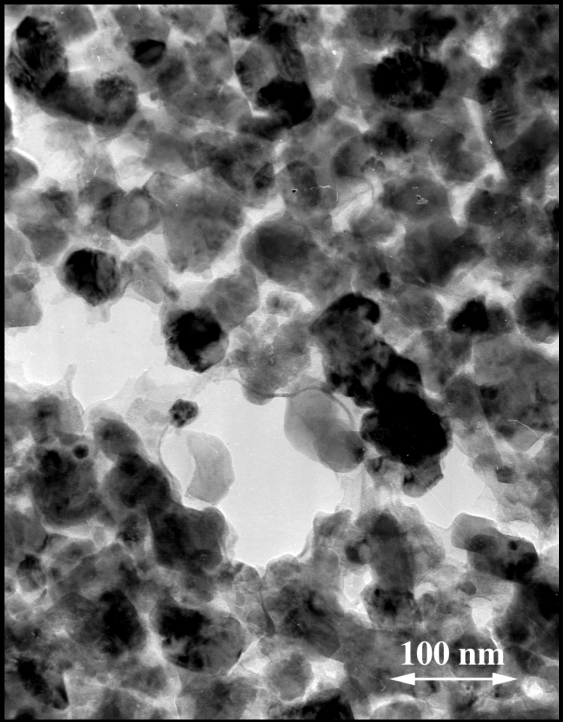
Rosettes on a fracture surface (false color)

Carbonates have a formation age of 3.9 billion years, are secondary phases that formed in fractures. All of the evidence cited to support ancient bacterial life is contained within the carbonates.

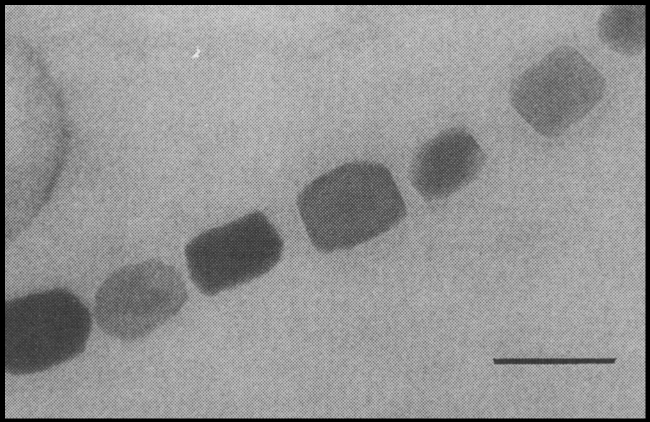
Rosettes on a fracture surface (true color)



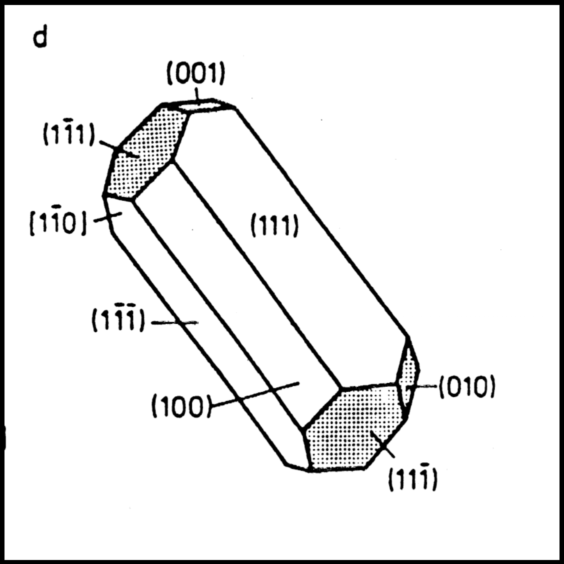
Rosettes in a geologic thin section (transmitted light)



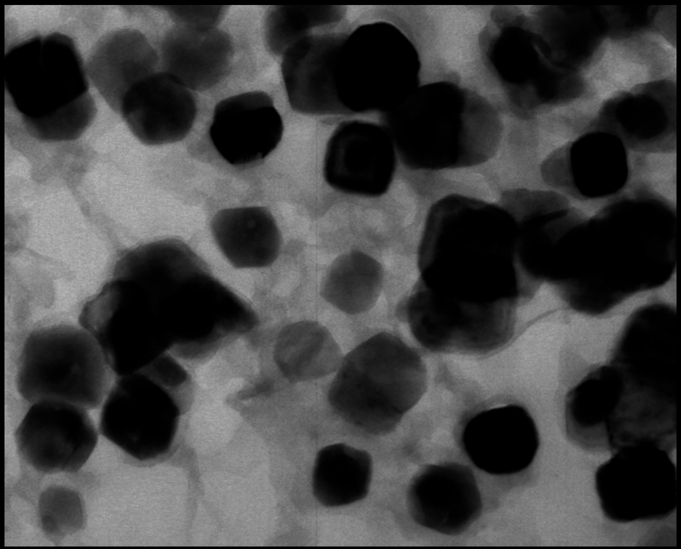
ALH84001 magnetite



bacterial magnetite



disequilibrium MT crystal form



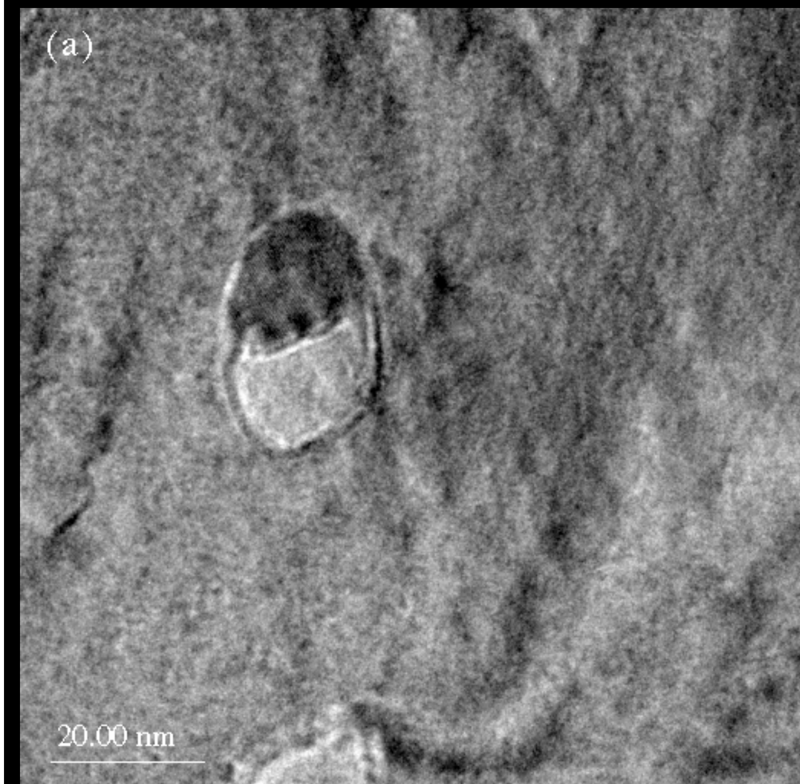
inorganic nanophase magnetite

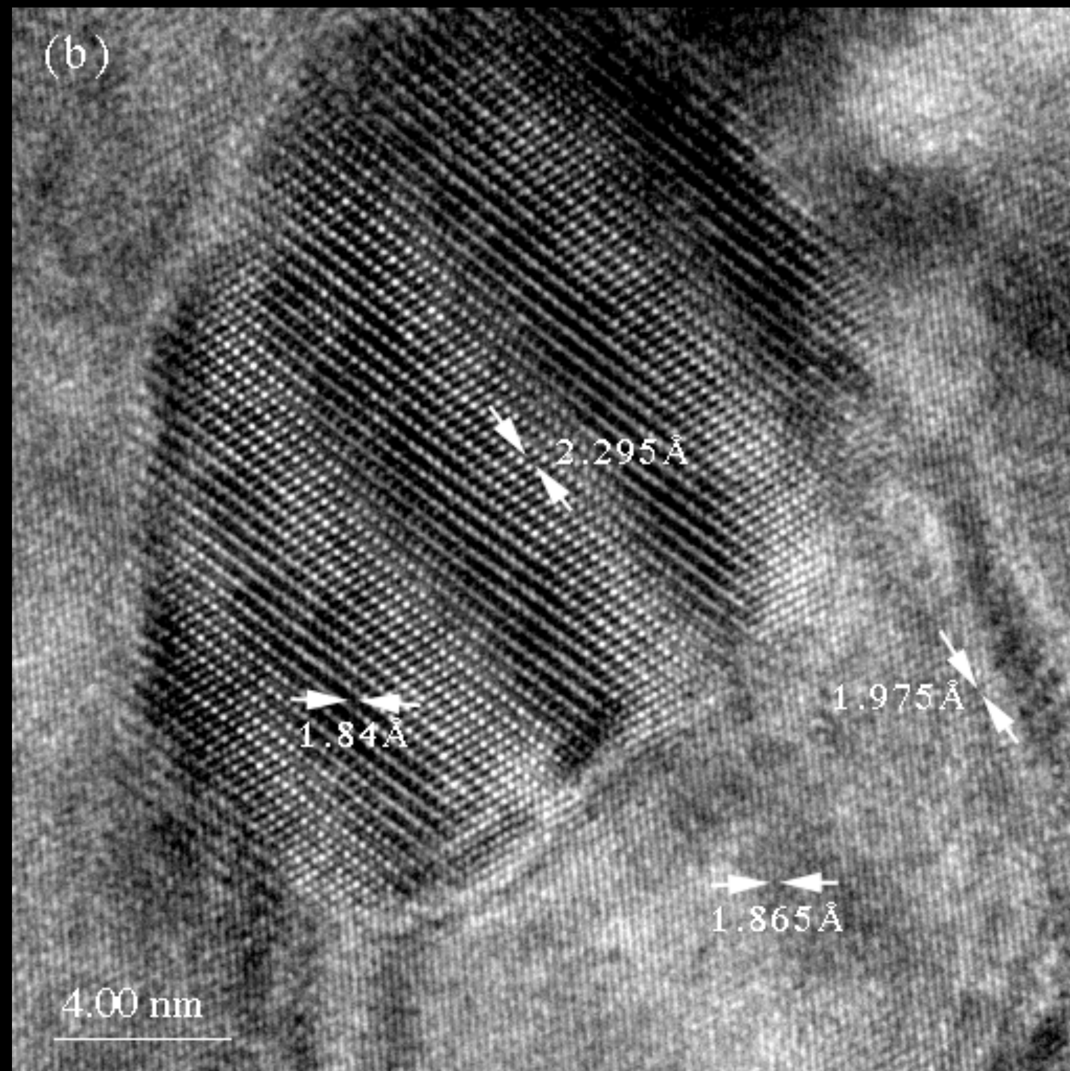
- single magnetic domain size range (30-120 nm)
- relatively perfect - no defects
- faceted crystals
- non-equilibrium forms
- association with other “biogenic” minerals

David Blake, ARC

A large number of ALH 84001 magnetites appear to be epitaxially oriented to the surrounding carbonate

But… bacterial magnetosomes are completely enclosed in membranes, isolated from the surrounding environment





D. Blake, Ames Res. Ctr.

Biosignature Categories

- Cellular and extracellular morphologies
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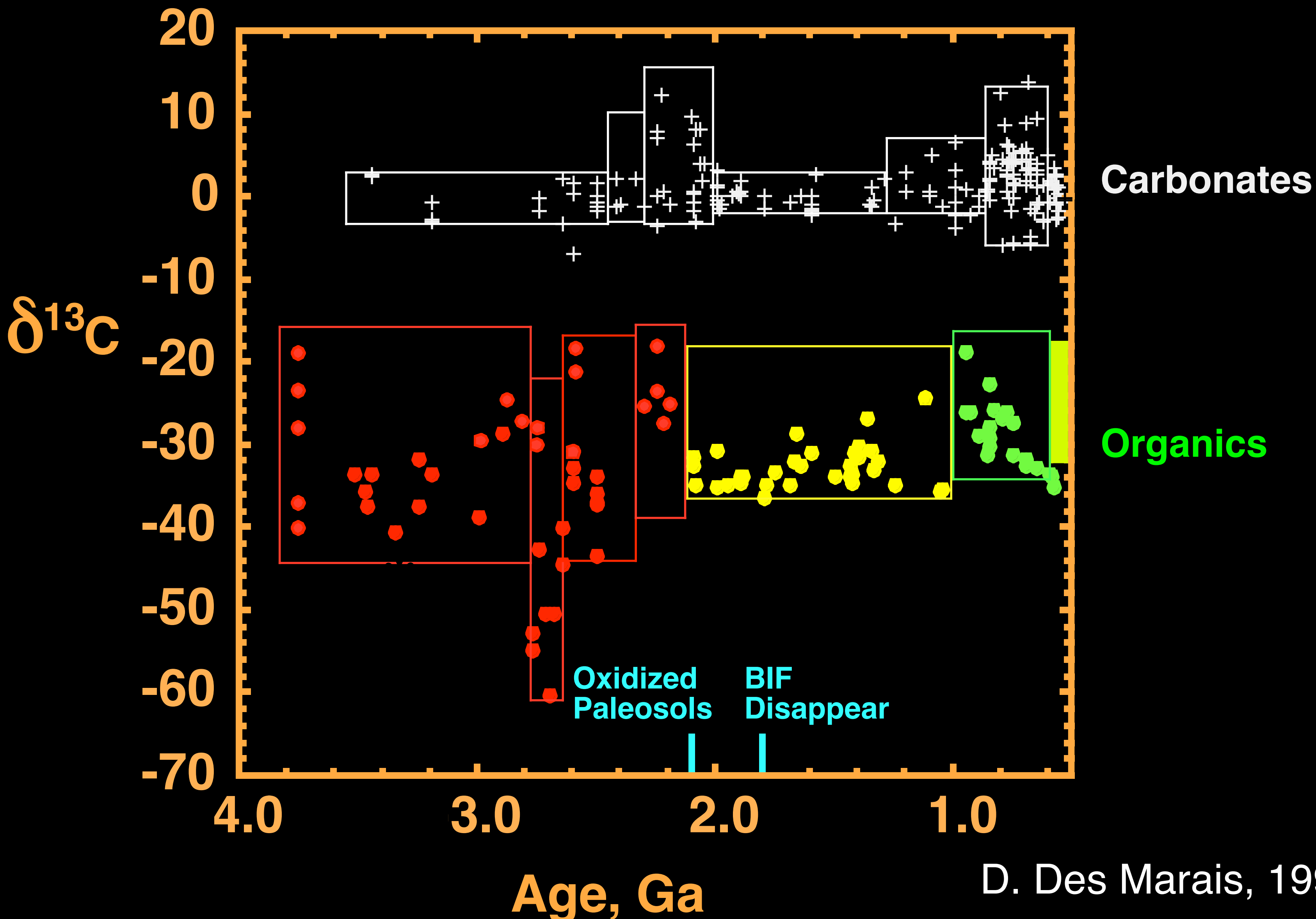
- “Biomarker” minerals
- **Biogenic stable isotope patterns**
- Light from inhabited extrasolar planets

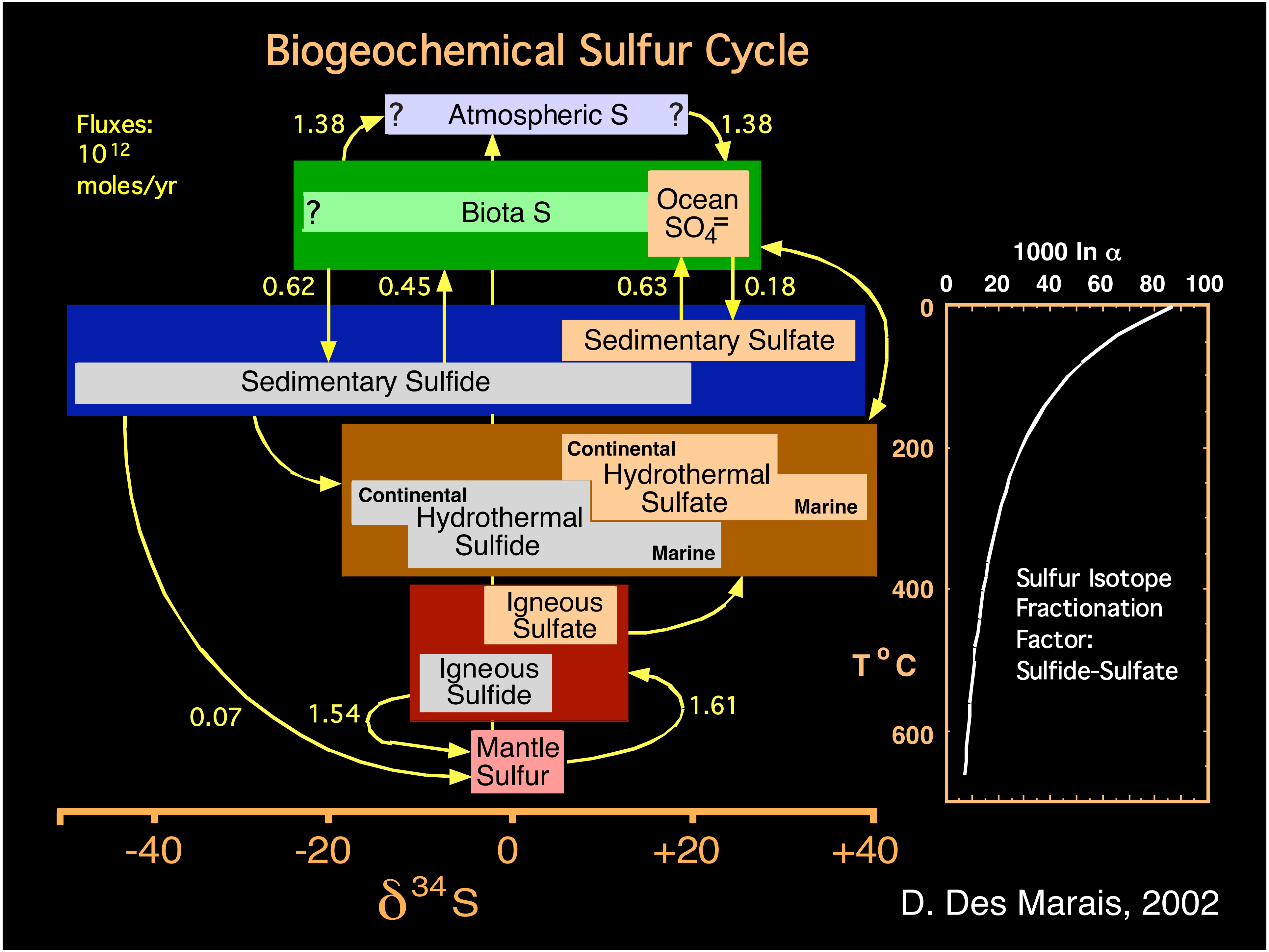
Biogenic stable isotope patterns

- Major isotope patterns reflect processes related to harvesting of energy and/or organic synthesis
- Isotopic discrimination determined by enzymatic reaction mechanisms
- Biota differ with respect to key enzymes and discrimination
- Expressed environmental discrimination also reflects availability/competition for substrate
- Biogenicity: Magnitude and distribution of isotopic discrimination in context of environmental conditions, molecular isotopic patterns

Carbon Isotopic Record in Sedimentary Carbonates and Organic Matter



D. Des Marais, 1997



Biogeochemical Sulfur Cycle
Fluxes:
10^12
moles/yr
1.38
? Atmospheric S ?
1.38
? Biota S
Ocean
SO4=
0.62
0.45
0.63
0.18
Sedimentary Sulfate
Sedimentary Sulfide
Continental
Hydrothermal
Sulfate
Marine
Continental
Hydrothermal
Sulfide
Marine
Igneous
Sulfate
Igneous
Sulfide
0.07
1.54
1.61
Mantle
Sulfur
-40
-20
0
+20
+40
δ34S
1000 ln α
0
20
40
60
80
100
0
200
400
600
T °C
Sulfur Isotope
Fractionation
Factor:
Sulfide-Sulfate
D. Des Marais, 2002

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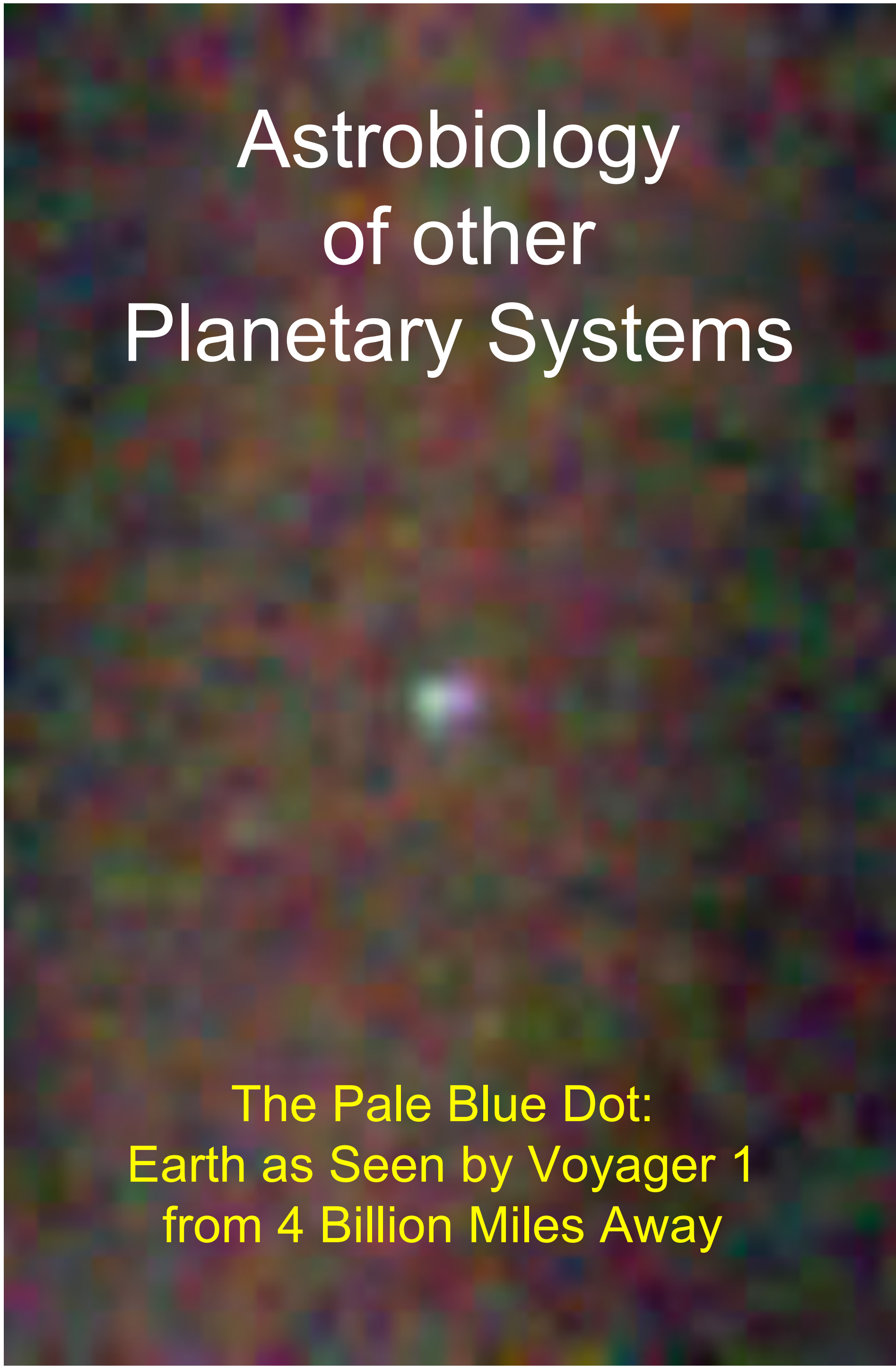
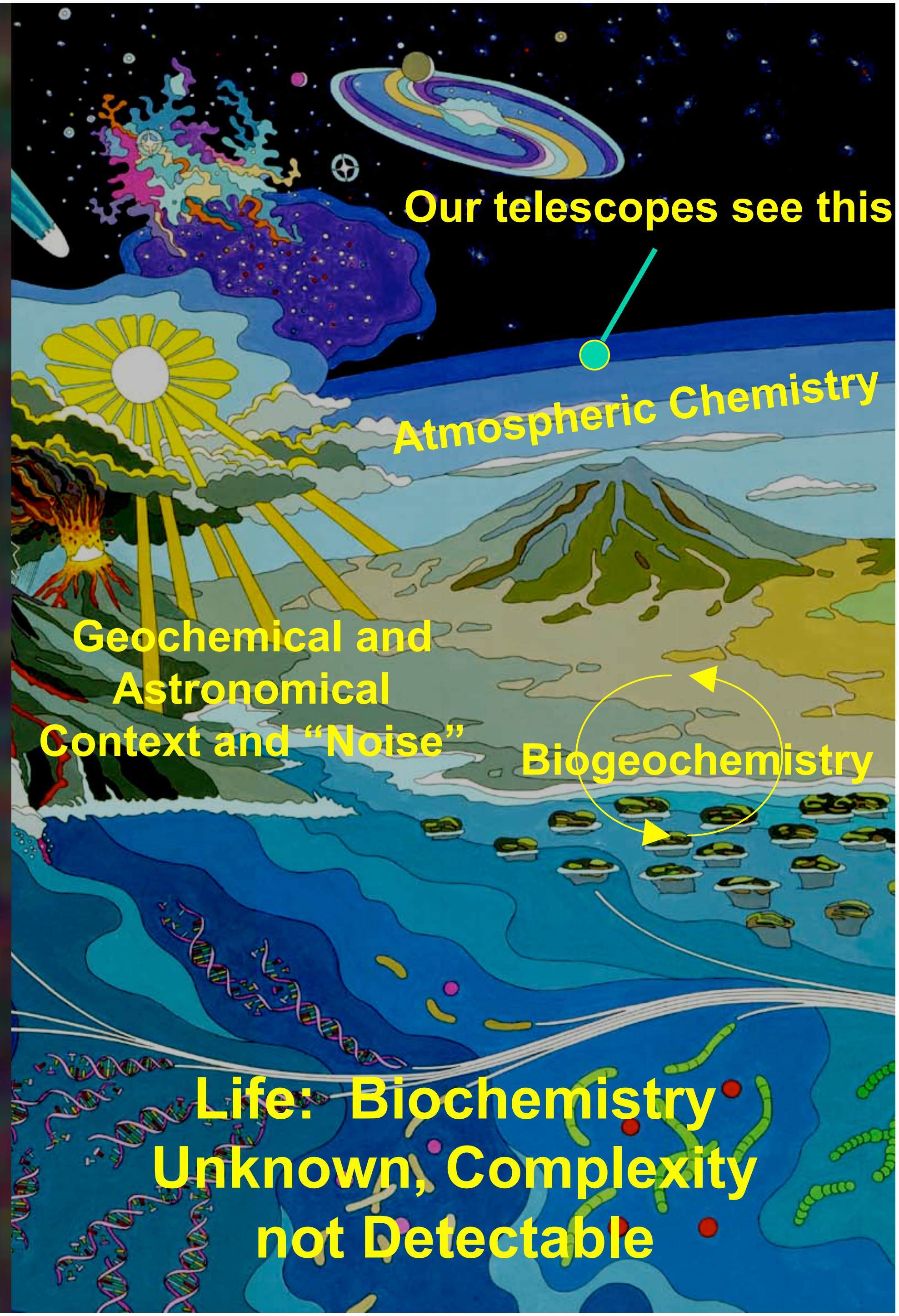
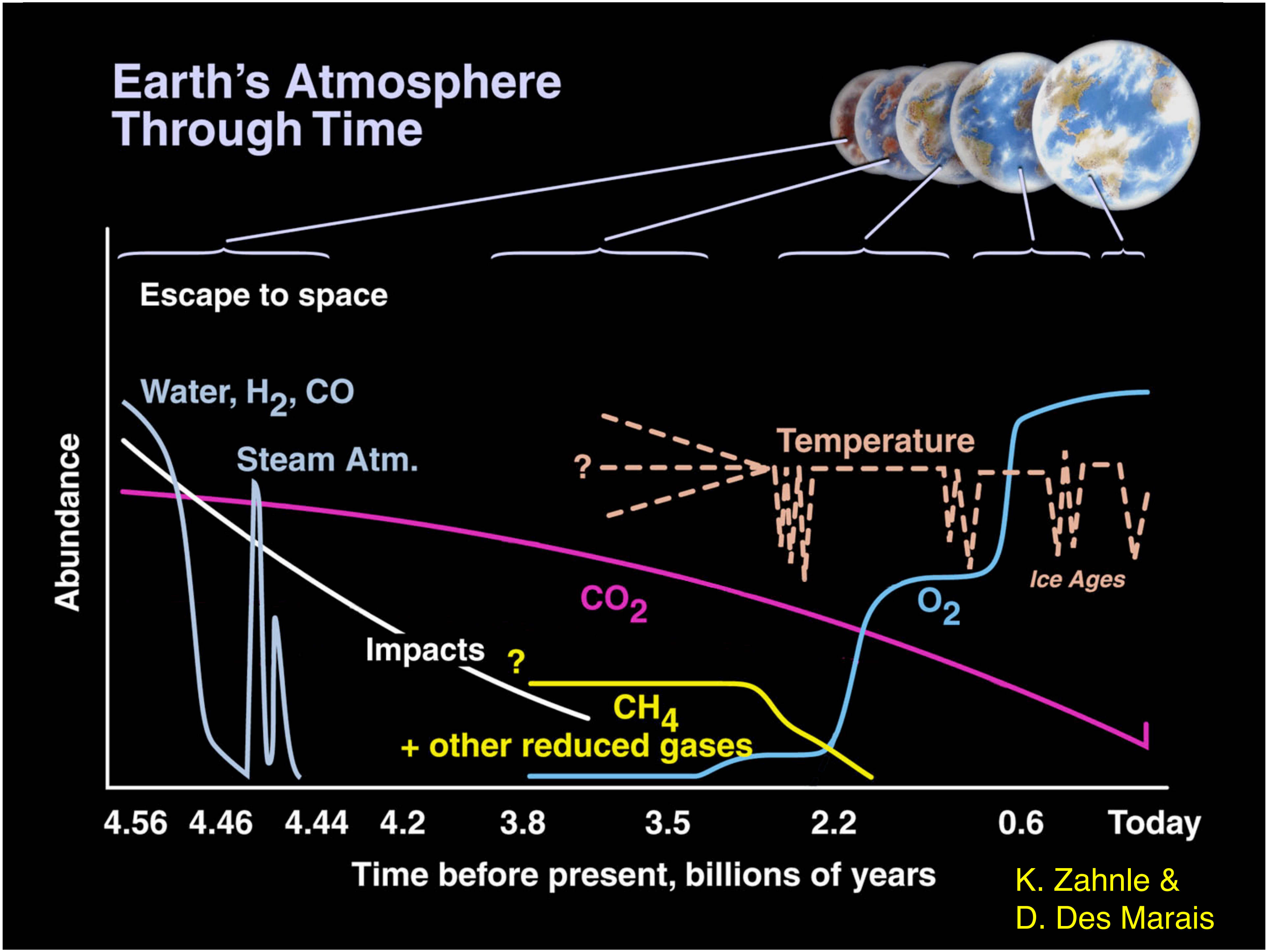
Astrobiology of other Planetary Systems



The Pale Blue Dot:
Earth as Seen by Voyager 1
from 4 Billion Miles Away

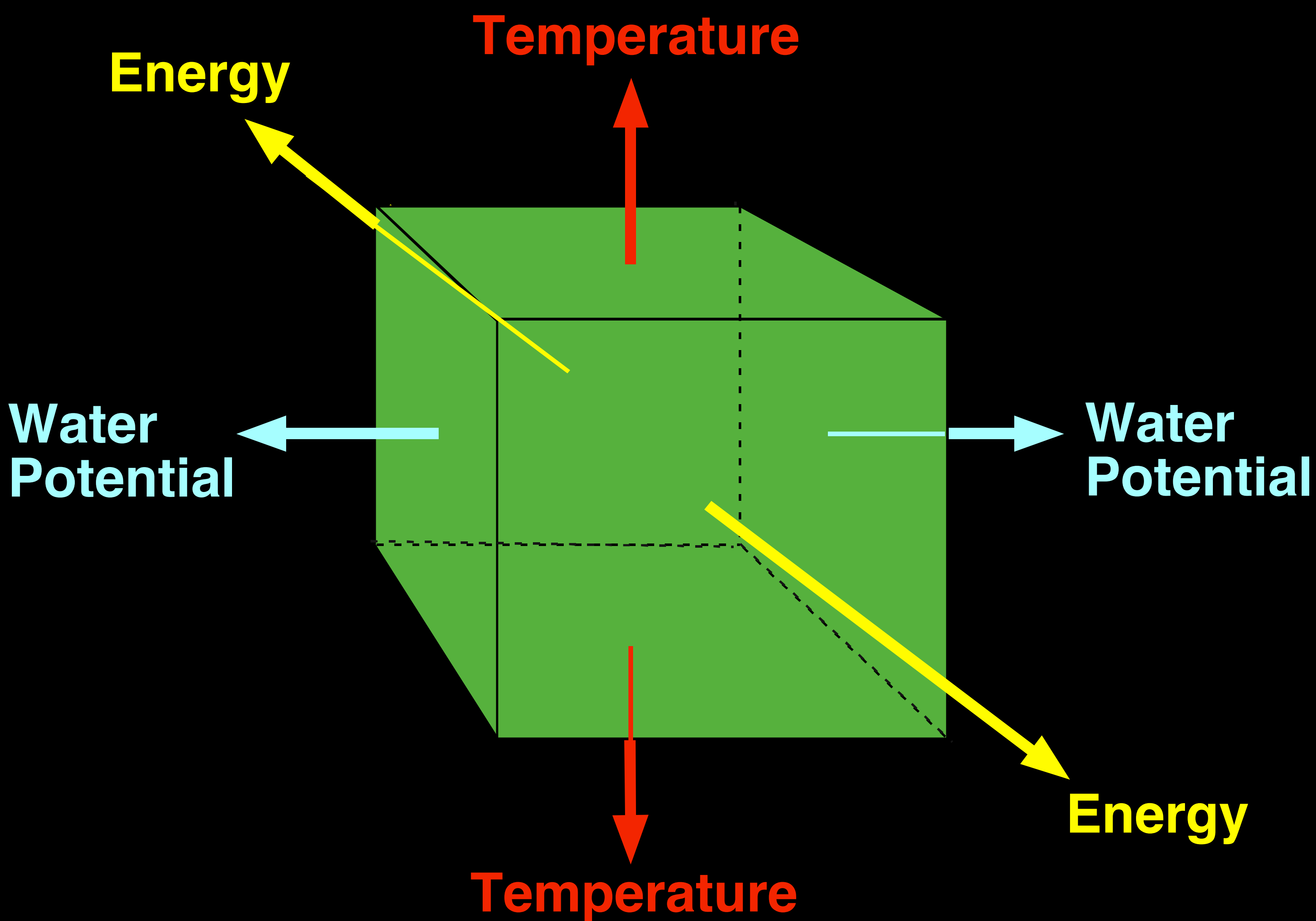



Earth's Atmosphere
Through Time
Escape to space
Water, H_2, CO
Steam Atm.
Abundance
Temperature
?
Ice Ages
CO_2
O_2
Impacts
?
CH_4
+ other reduced gases
4.56
4.46
4.44
4.2
3.8
3.5
2.2
0.6
Today
Time before present, billions of years
K. Zahnle &
D. Des Marais

Light from inhabited extrasolar planets

- What are the constraints on astronomical observations?
- Is the planet within a circumstellar habitable zone?
- Are the size & composition of the planet consistent with habitability?
- What nonbiological contributions to the atmosphere & surface create background “noise?”
- What are the biological consequences of the composition & evolution of the habitable planet?
- What might be the consequences of the composition & evolution of the biota?

Range of Conditions that Sustains Life

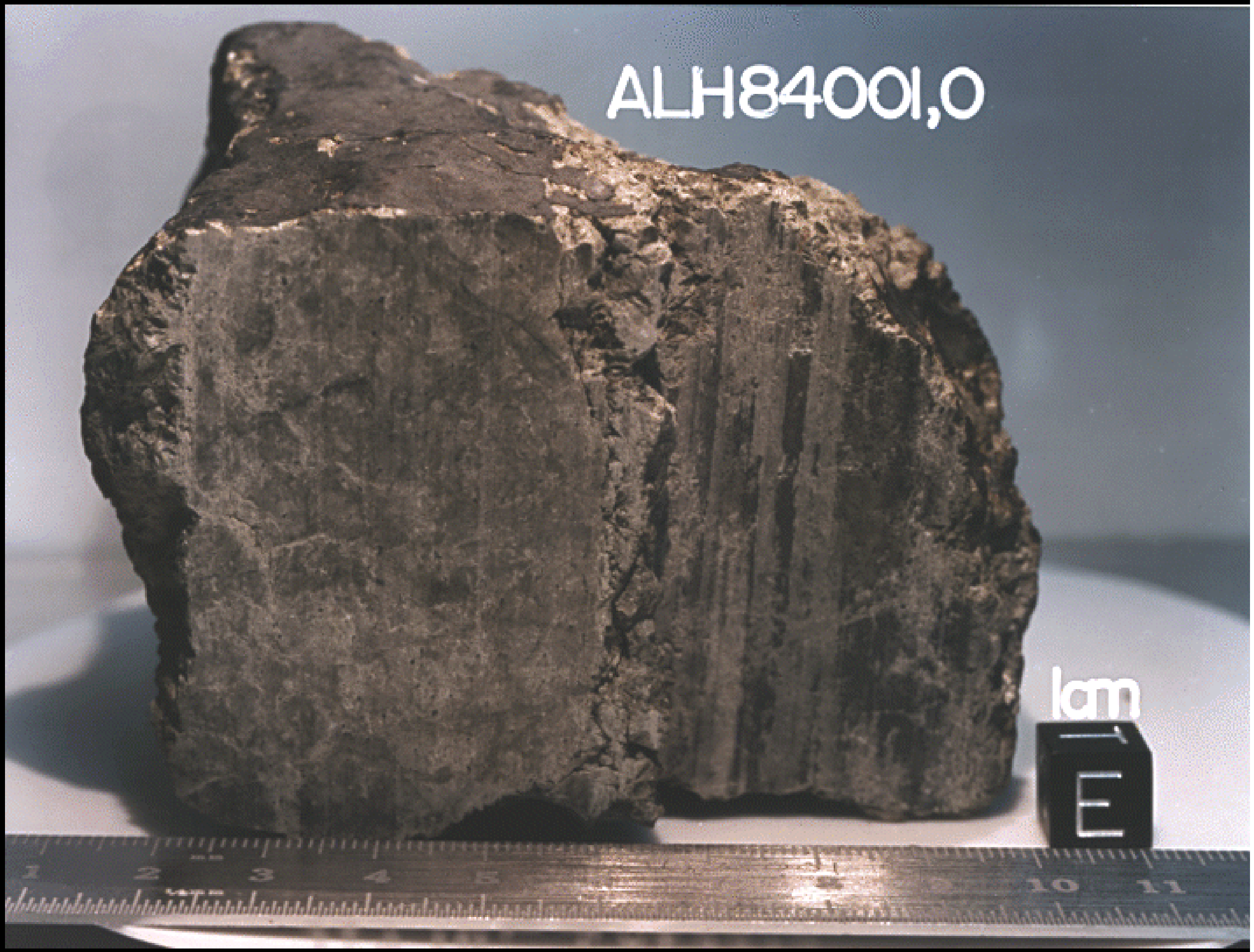


D. Des Marais, 2002

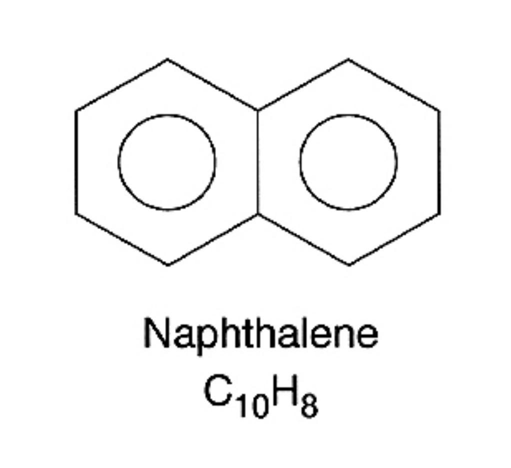
End

ALH 84001
Martian meteorite with fossil-like features proposed to be evidence of ancient life on Mars

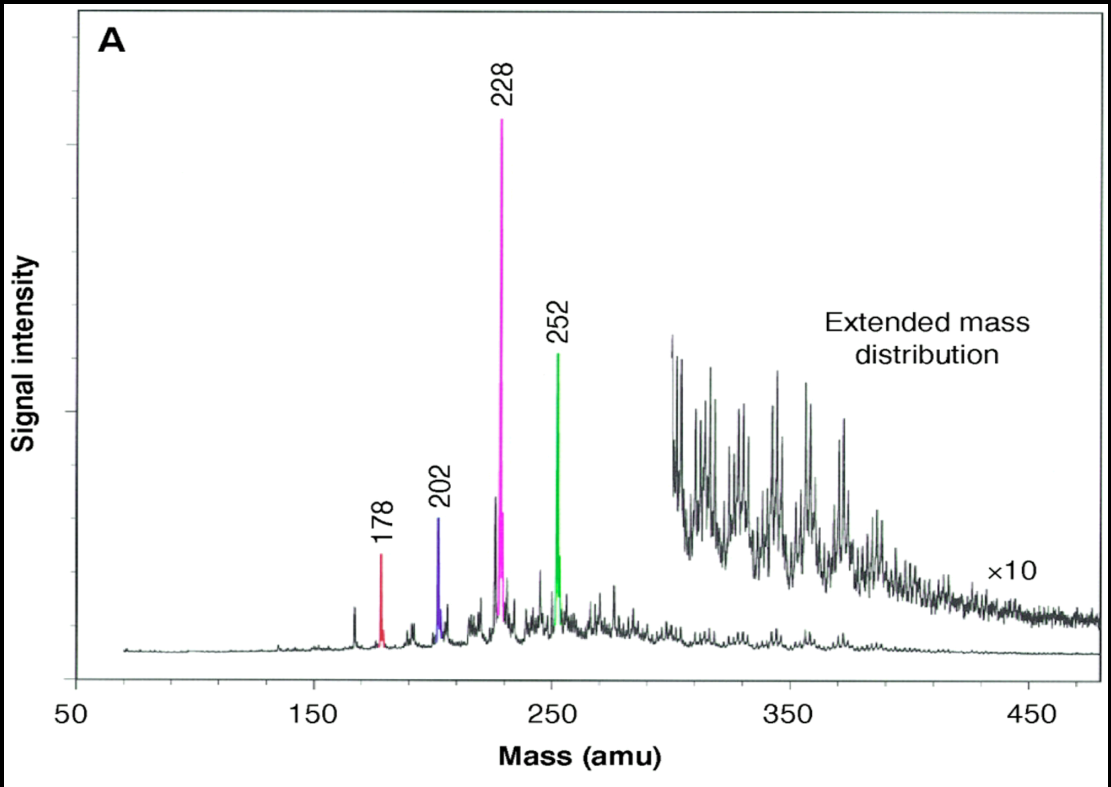
- Achondrite, martian origin, ~2 kg total weight
- Formed from molten magma ~4.5 billion years ago.
- Carbonate globules formed ~3.9 billion years ago, and contain proposed evidence of ancient life
- Sustained multiple shock events during multi-billion year history
- Found in Antarctic ice



ALH84001 Polycyclic Aromatic Hydrocarbons (PAH)



Following naphthalene, more and more six-carbon rings can be attached in more and more complicated patterns to form different PAH molecules. The few PAHs recognized in ALH 84001 include phenanthrene, pyrene, chrysene, perylene or benzopyrene, and anthanthrene.



McKay and co-workers have not demonstrated that the variety and abundances of different PAH molecules in ALH 84001 are actually what would form during the breakdown of simple living organisms.

PAHs in ALH 84001 are indeed indigenous to Mars, and not like those from other extraterrestrial sources. However, the aromatic rings of the ALH 84001 PAH lack the side groups that are needed to distinguish between biotic from abiotic sources.

CONCENTRATIONS AND MOLECULAR CHARACTERISTICS OF SOLUBLE ORGANIC COMPOUNDS IN METEORITES

Class	Concentration (PPM)	# Compounds identified	Chain Length
Amino Acids	**60**	**74**	**C_2-C_7**
Aliphatic hydrocarbons	**>35**	**140**	**C_1-C_{23}**
Aromatic hydrocarbons	**15-28**	**87**	**C_6-C_{20}**
Carboxylic acids	**>300**	**20**	**C_2-C_{12}**
Dicarboxylic acids	**>30**	**17**	**C_2-C_9**
Hydrocarboxylic acids	**15**	**7**	**C_2-C_6**
Purines and Pyrimidines	**1.3**	**5**	**NA**
Basic N-heterocycles	**7**	**32**	**NA**
Amines	**8**	**10**	**C_1-C_4**
Amides	**55-70**	**>2**	**NA**
Alcohols	**11**	**8**	**C_1-C_4**
Aldehydes & Ketones	**27**	**9**	**C_1-C_5**
Total	**>560**	**411**	

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