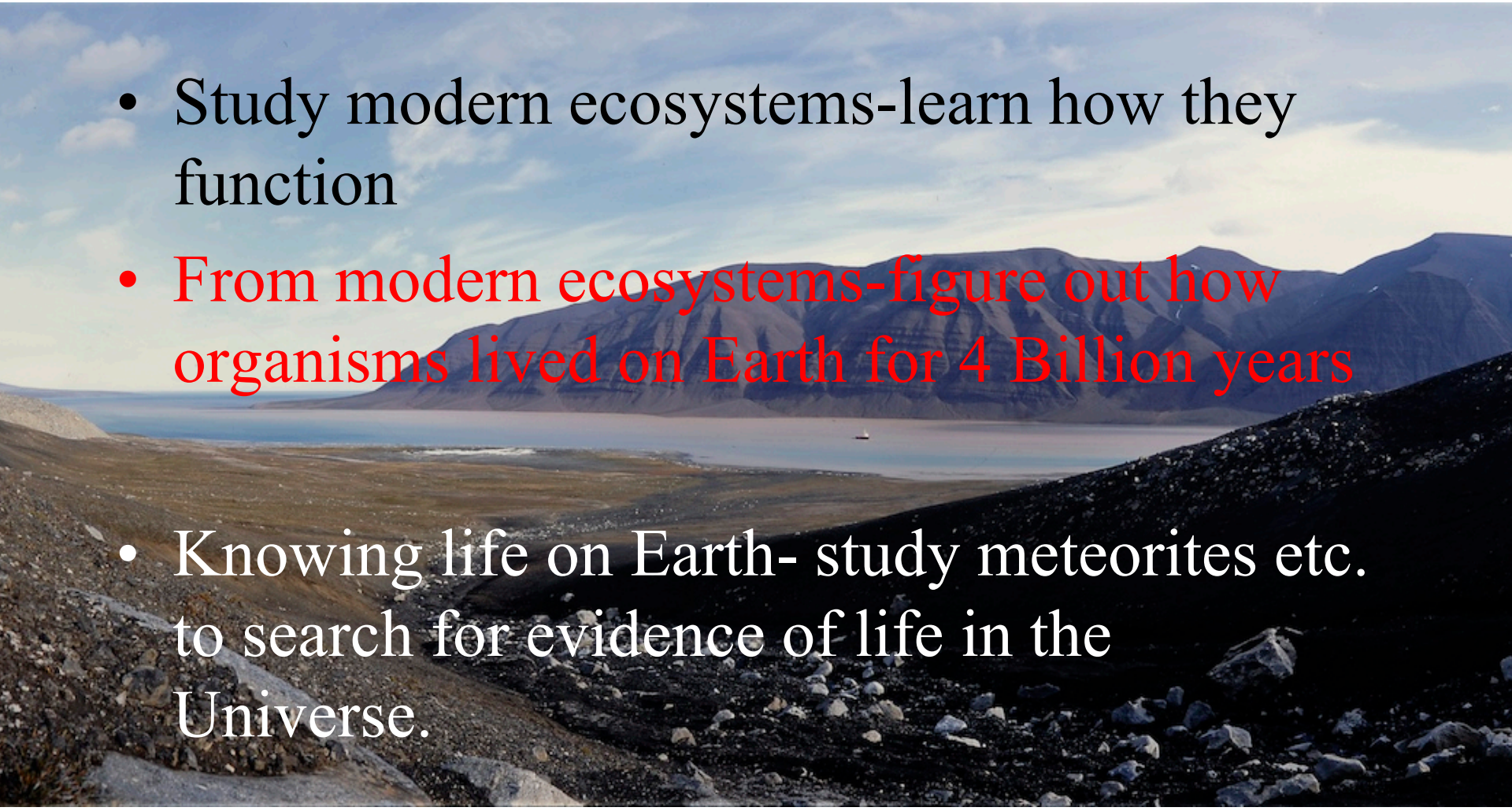
Biology or Geochemistry? Stable Isotope Tales in Astrobiology: Distinguishing the biotic from the abiotic

Marilyn L. Fogel
School of Natural Science,
University of California Merced

Biogeochemist or Geobiologist: Stable Isotope Geochemistry & Ecology

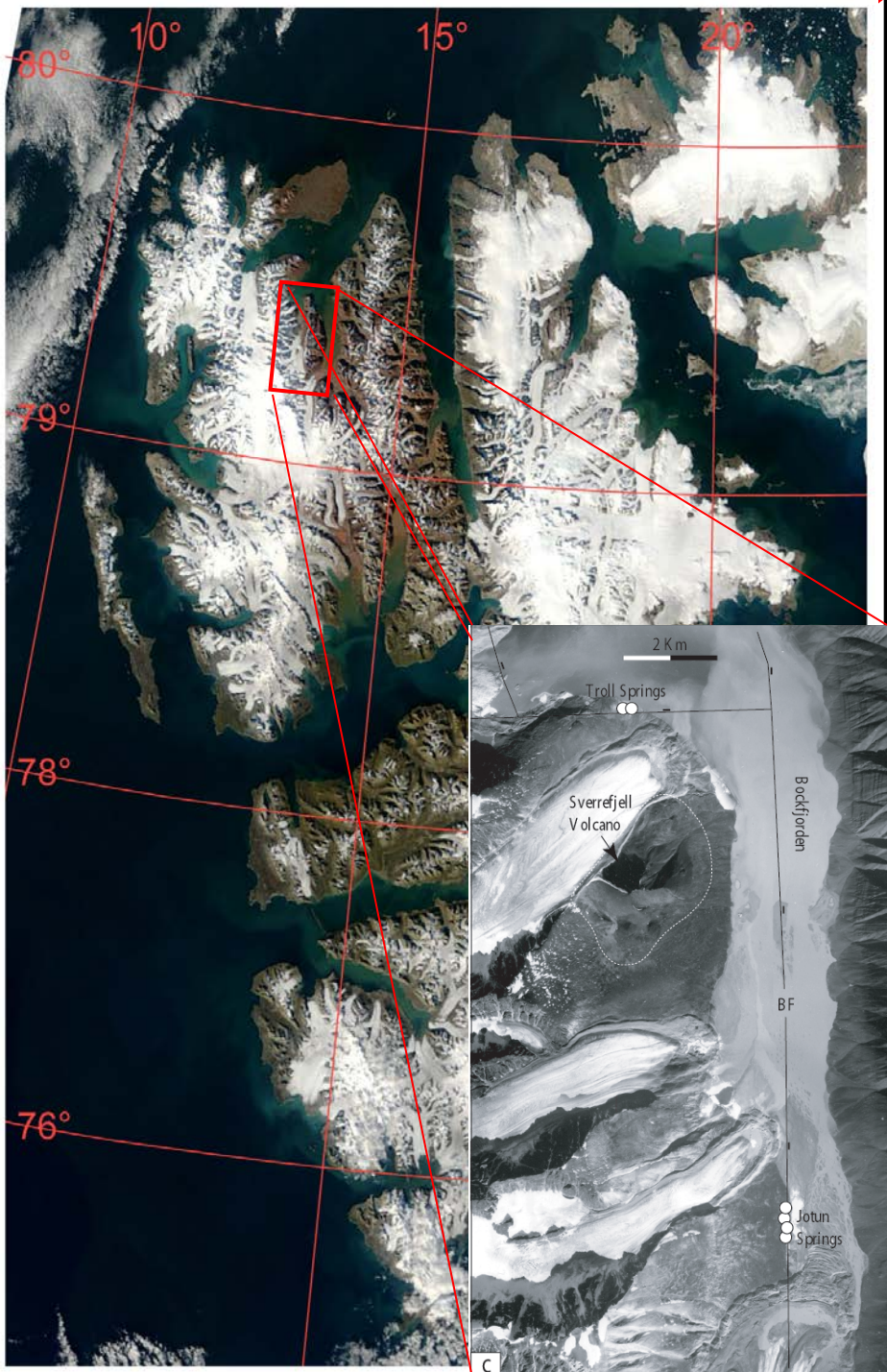


- Study modern ecosystems-learn how they function
- From modern ecosystems-figure out how organisms lived on Earth for 4 Billion years

- Knowing life on Earth- study meteorites etc. to search for evidence of life in the Universe.

AMASE

Arctic Mars Analog Svalbard Expedition




LANCE

Bringing the Search for Life Down to Earth

AMASE: Arctic Mars Analogue Svalbard Expedition

Life in Rocks

How can we recognize it?

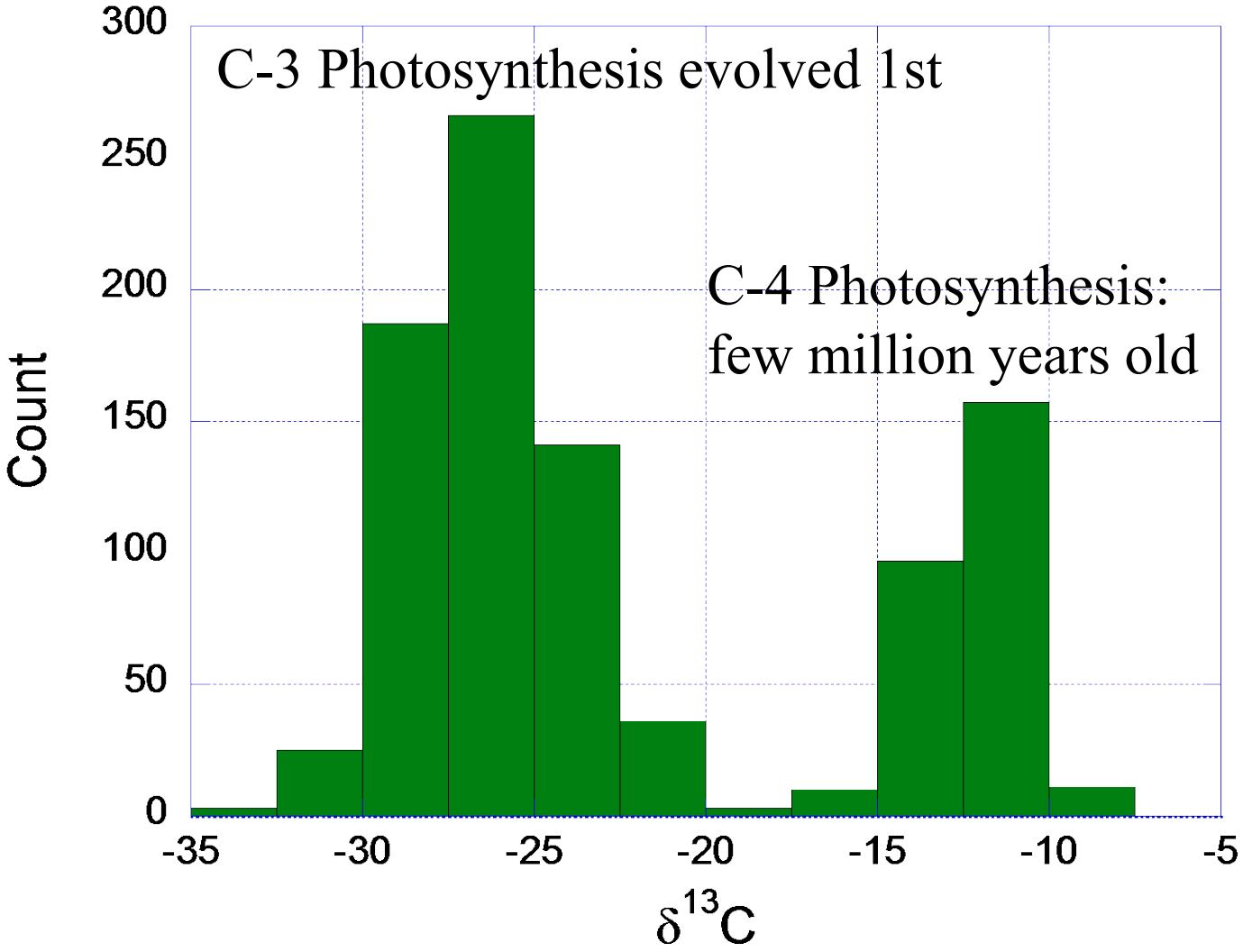
Stable Isotope Measurements: 1 millimeter in a Kilometer

- ^{12}C 98.89% ^{14}N 99.7%
  ^{13}C 1.11% ^{15}N 0.3%

- Isotopic Composition (δ)

$\delta^{13}C$ (‰) = [$^{13}C/^{12}C$ sample/ $^{13}C/^{12}C$ standard -1] *1000

Carbon isotopes ($\delta^{13}C$) of Plants = Photosynthesis (Biology)



Rubisco is the Key Enzyme causing the carbon isotope fractionation during photosynthesis:

Molecular Weight of 550,000 Daltons

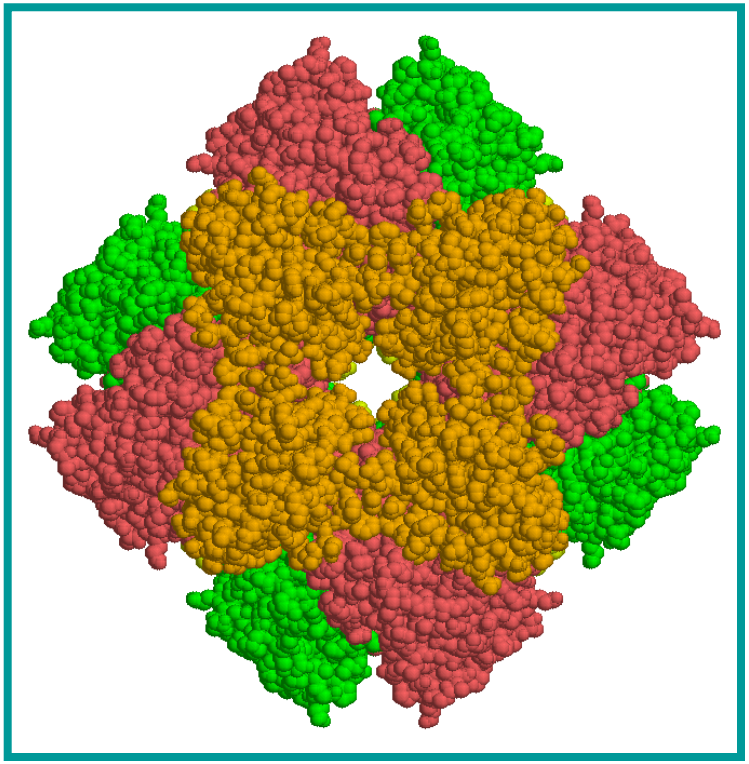


Table II. *Summary of isotope discrimination factors (Δ) for reactions catalyzed by Rubisco as determined in this study*

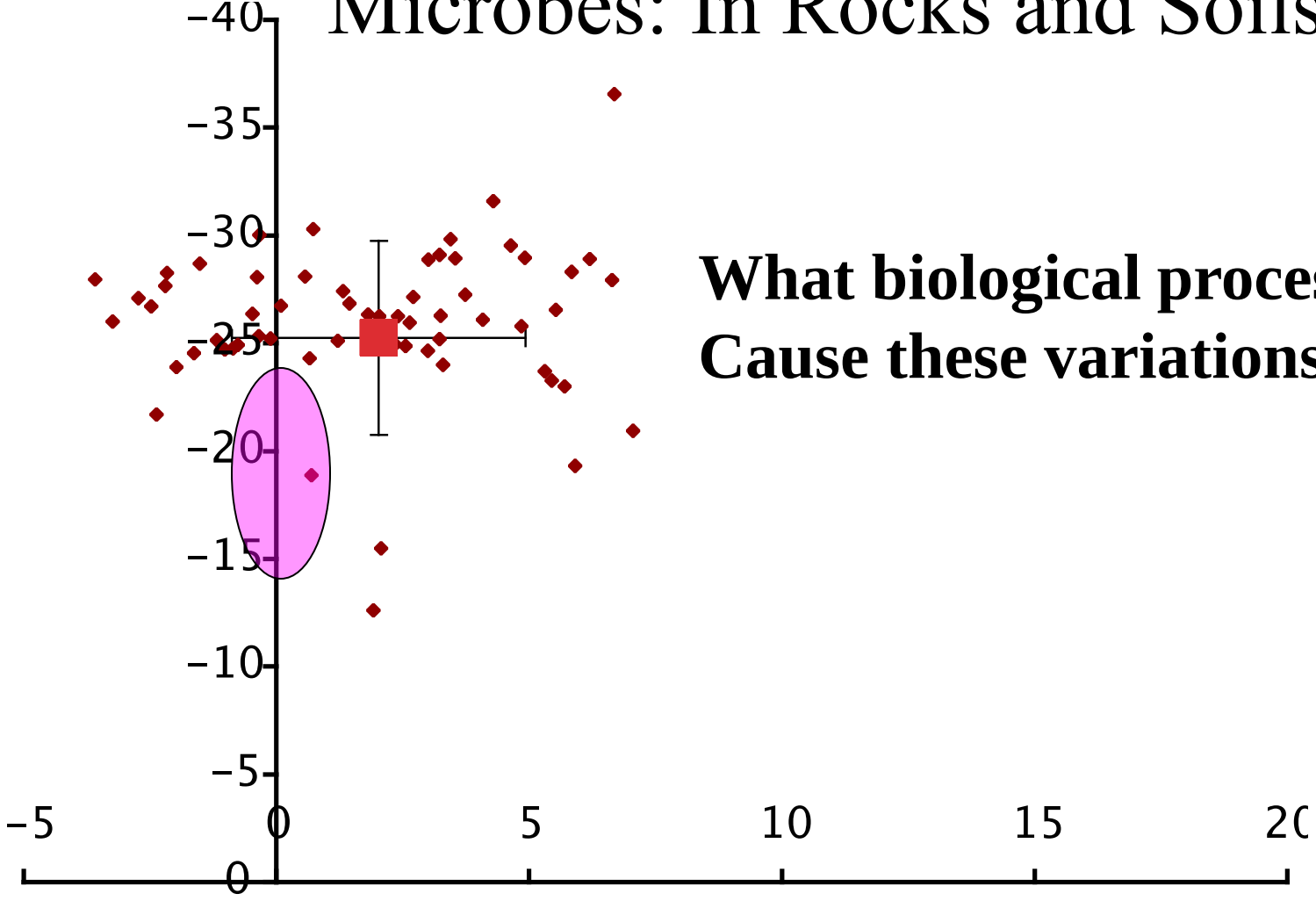
SE and number of sample:reference comparisons used for each estimate are provided.

Reaction and Enzyme Source	Conditions	Δ	±SE (n)
Oxygenase			
A. nidulans[a]	pH 8.1, 25 mM Mg^{2+}	21.6	±1.2 (9)
R. rubrum[a]	pH 7.9, 20 mM Mg^{2+}	21.4	±0.4 (7)
Spinach	pH 8.5, 20 mM Mg^{2+}	21.1	±0.3 (10)
Overall		21.3	±0.2 (26)
Carboxylase			
A. nidulans[a]	pH 8.1, 25 mM Mg^{2+}	22.0	±0.2 (18)
R. rubrum[a]	pH 7.9, 25 mM Mg^{2+}	23.0	±0.6 (10)
	pH 7.9, 2 mM Mg^{2+}	19.6	±0.4 (24)
Spinach	pH 8.5, 20 mM Mg^{2+}	30.3	±0.8 (22)
	pH 7.6, 5 mM Mg^{2+}	29.0	±0.3 (5)

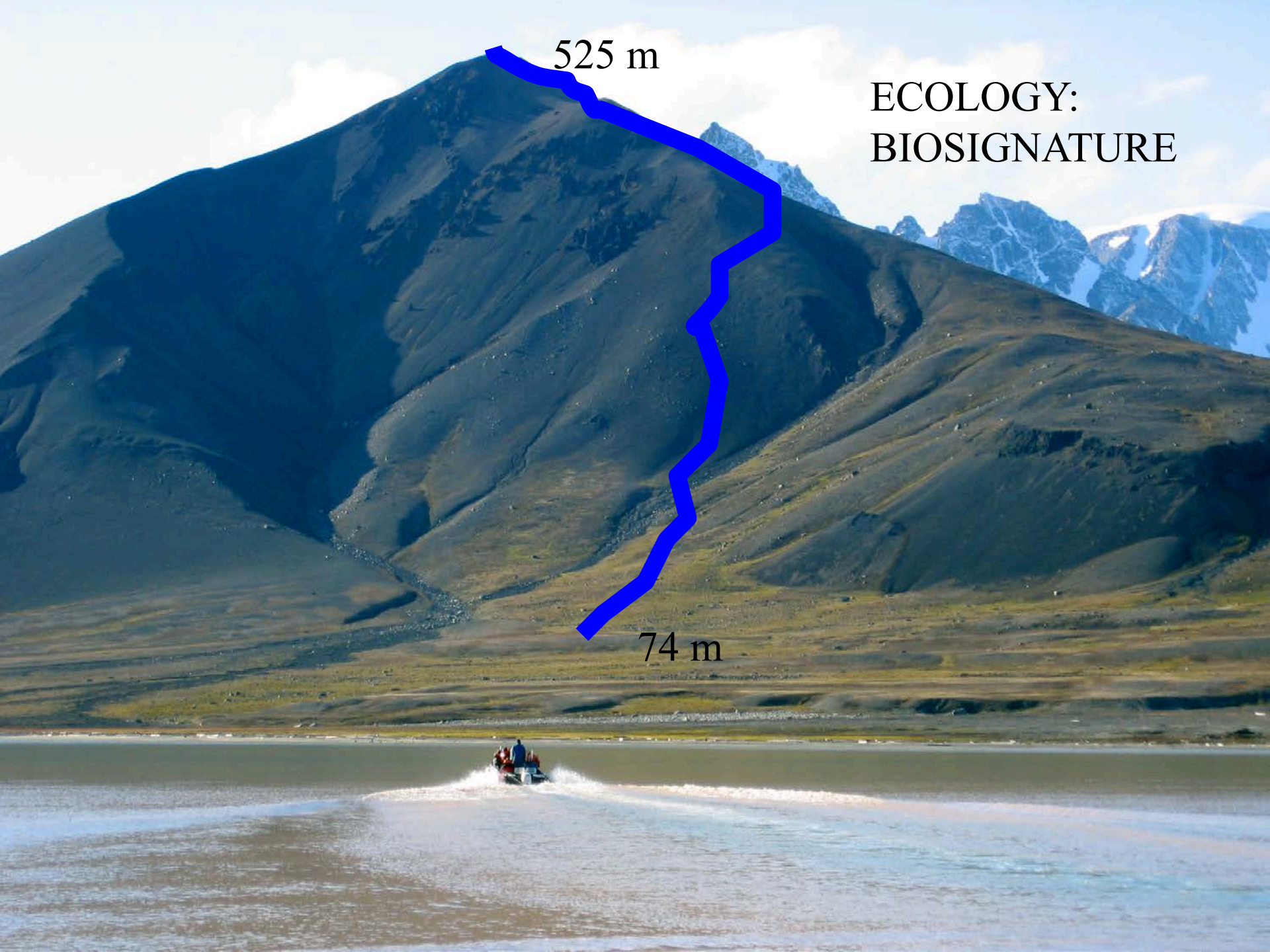
[a] Expressed in *E. coli*.

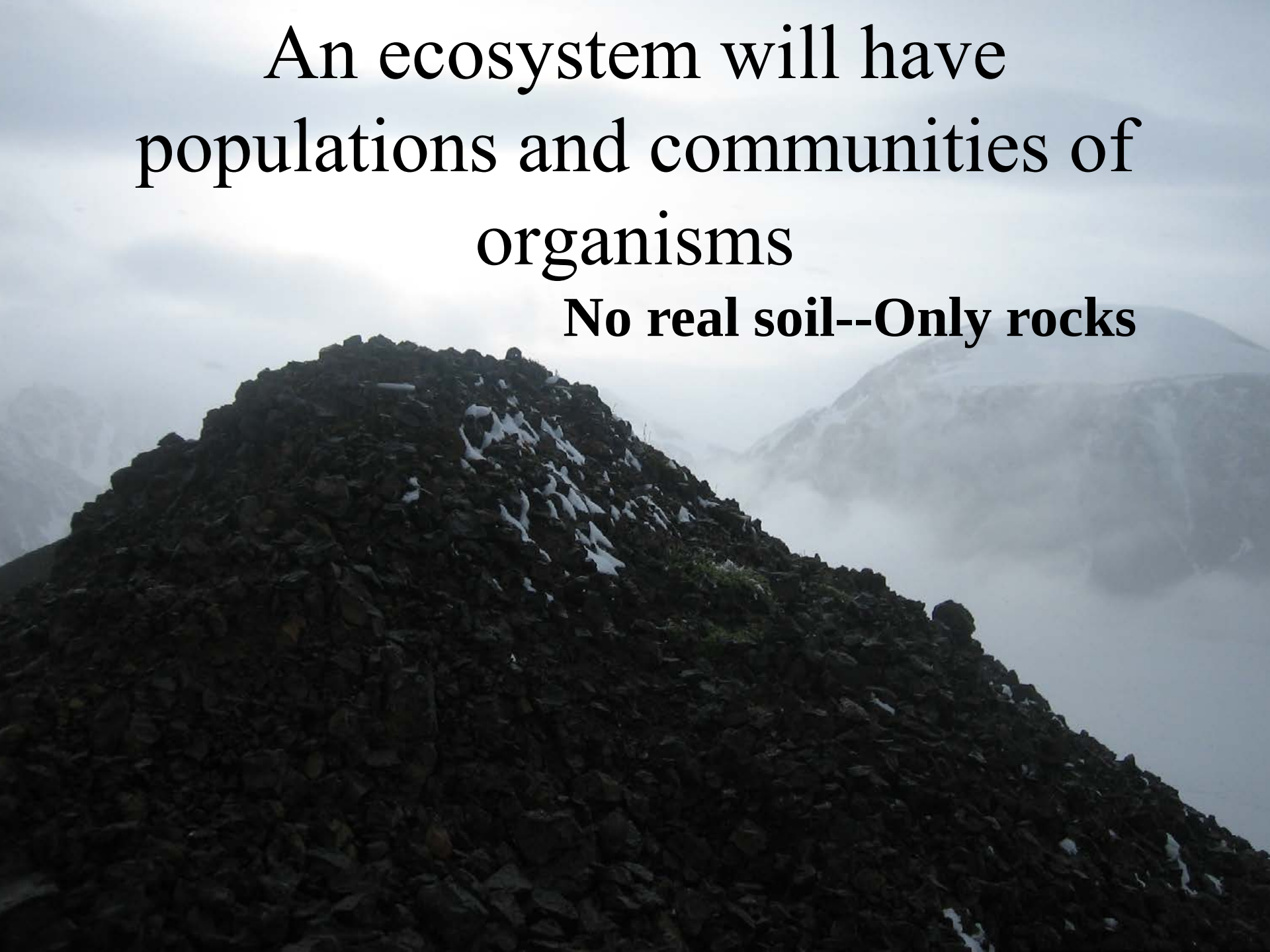
Guy, Fogel, and Berry, 1993

Svalbard is a Polar Desert.
Microbes: In Rocks and Soils



What biological processes Cause these variations?

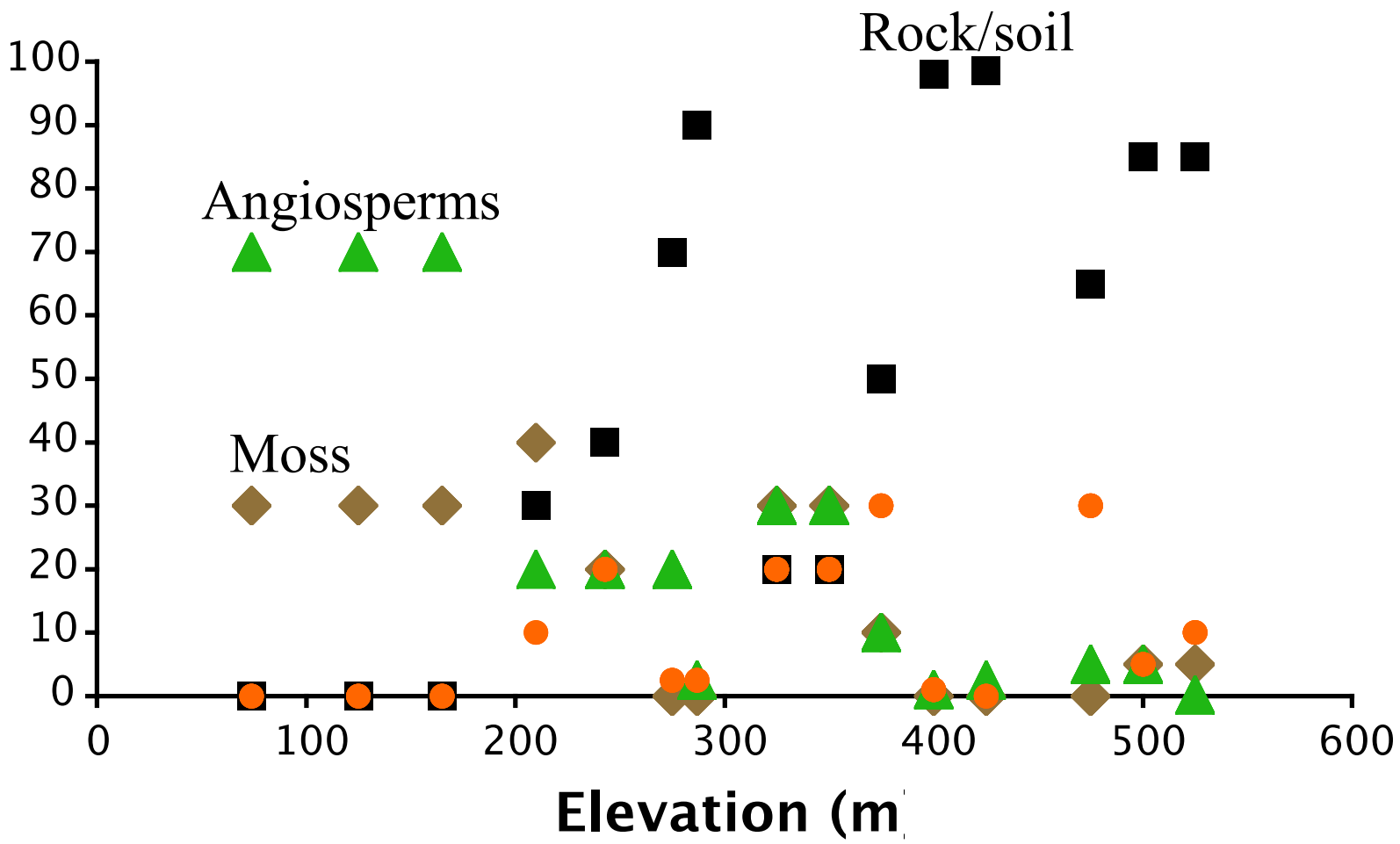

525 m
74 m
ECOLOGY:
BIOSIGNATURE



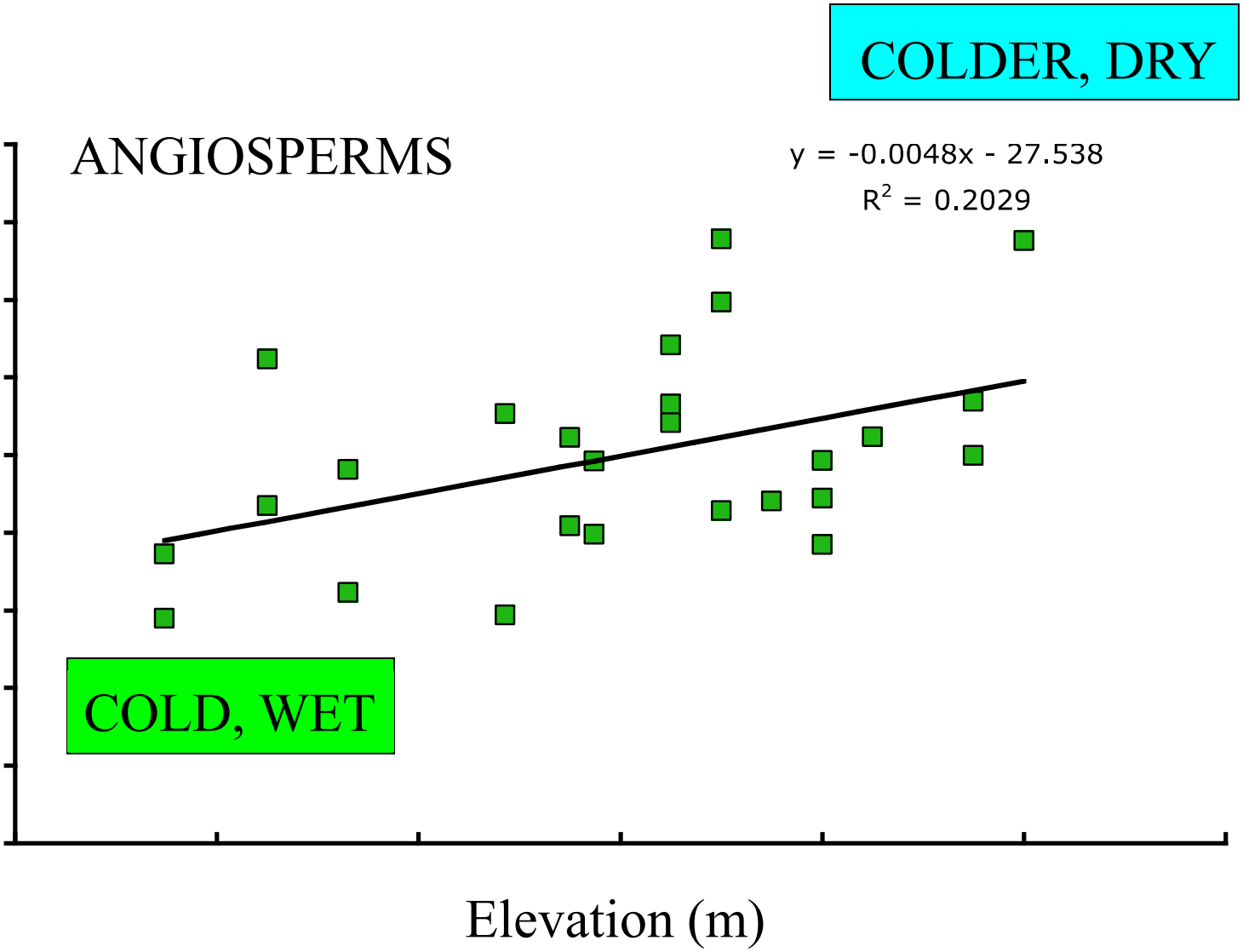
An ecosystem will have populations and communities of organisms

No real soil--Only rocks

Presence or Absence/Change in Abundance



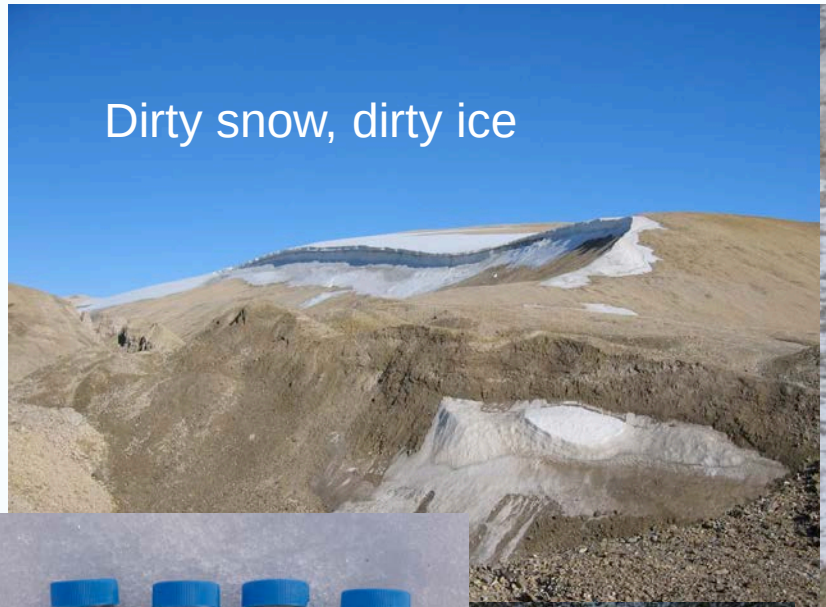
Stable isotopes in organisms will be affected by the environment

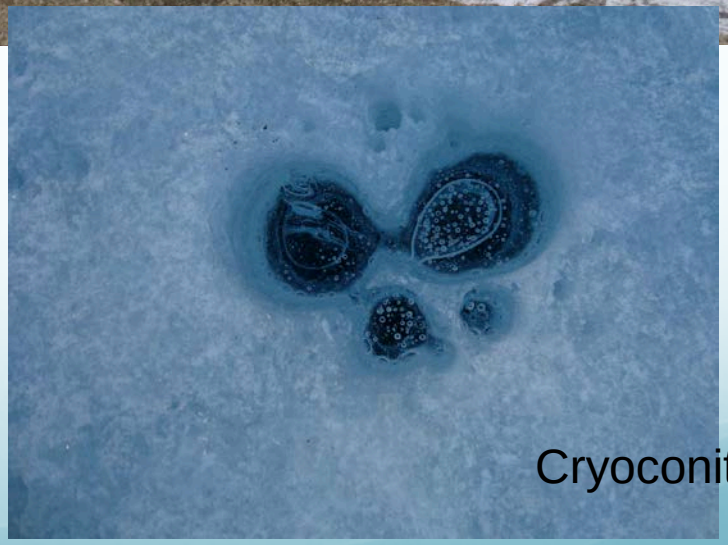


Life in Ice and Snow?

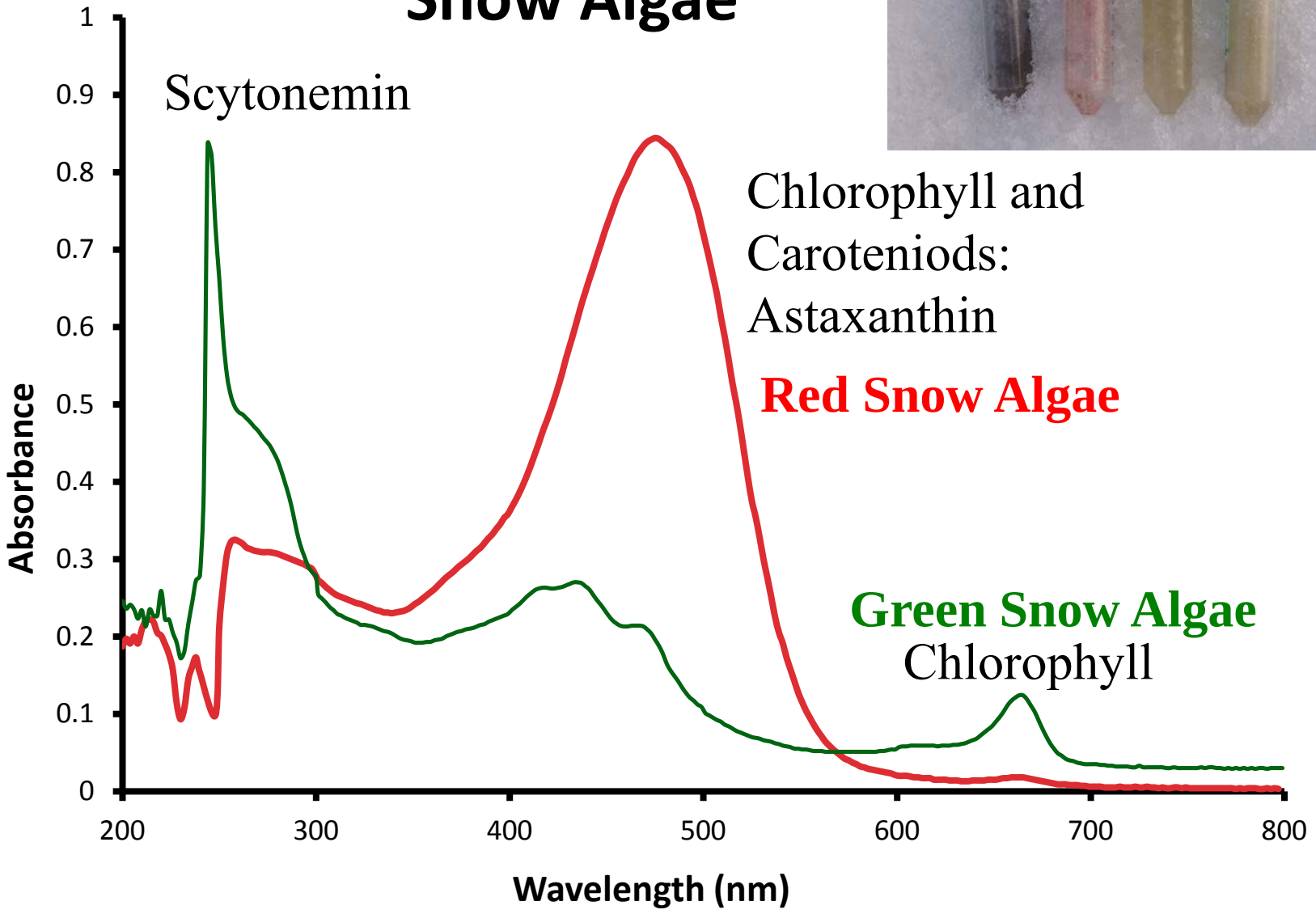

VWR

Possible Sources of OM

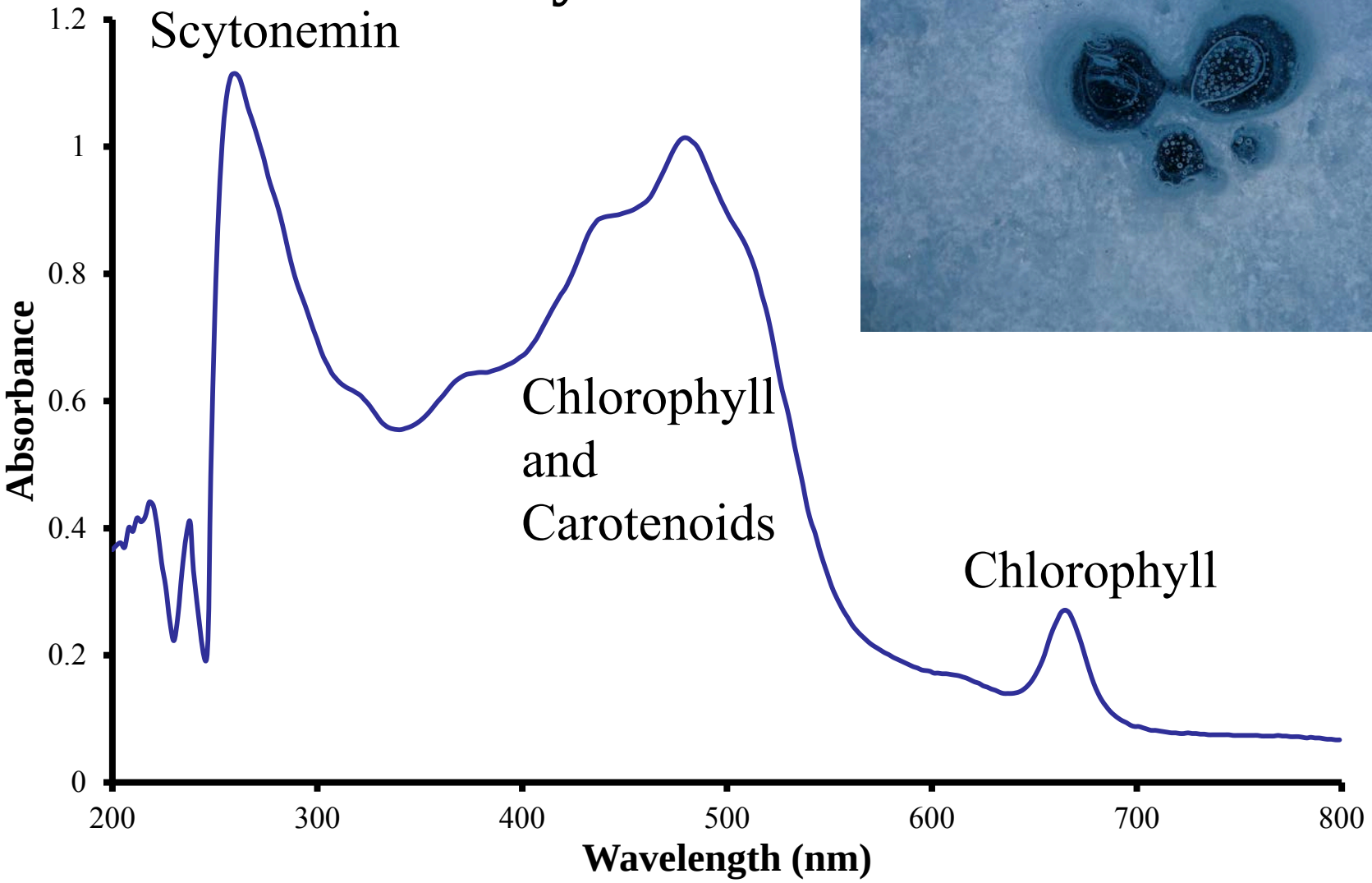




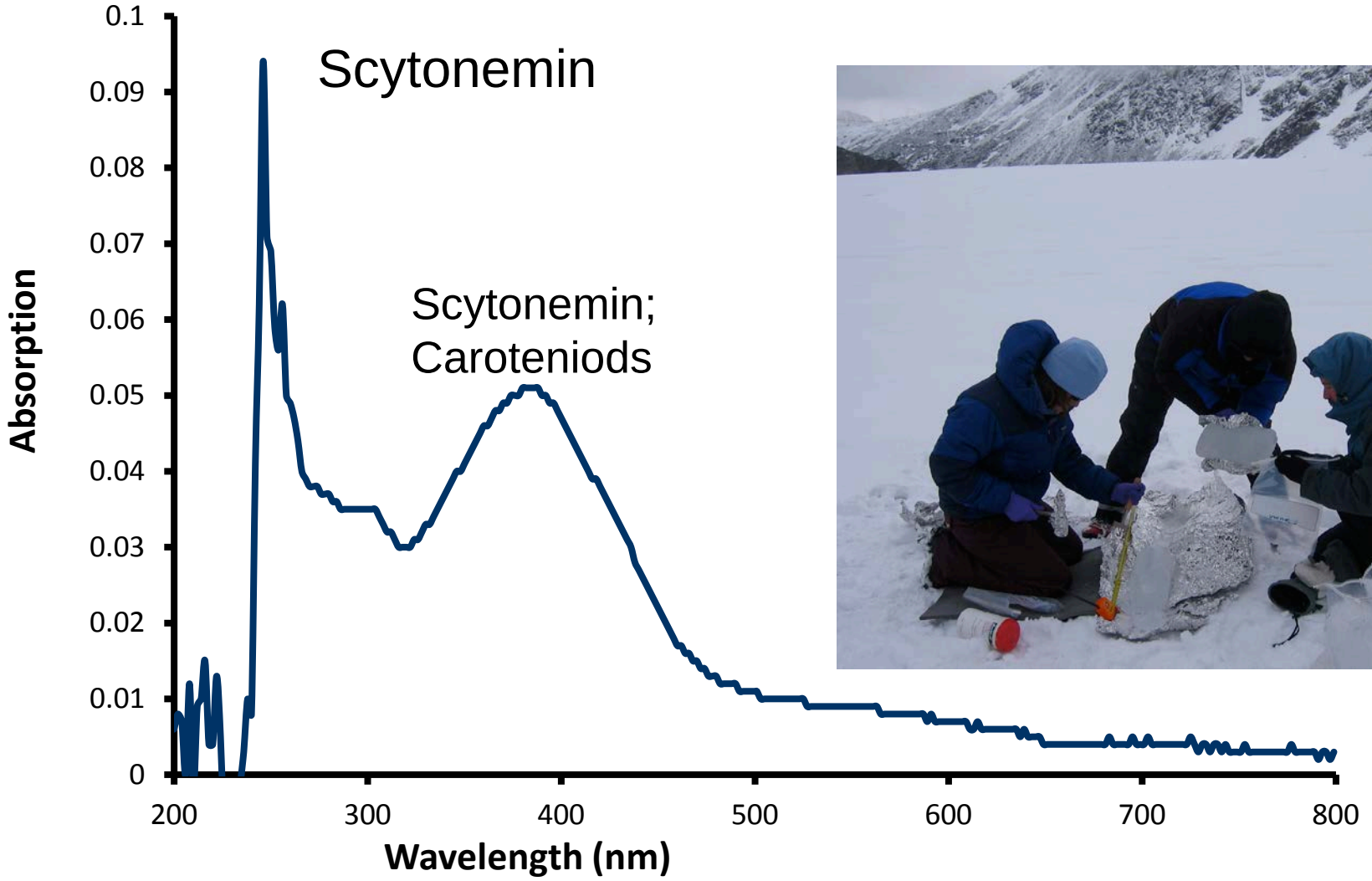
Snow Algae


Scytonemin
Chlorophyll and
Caroteniods:
Astaxanthin
Red Snow Algae
Green Snow Algae
Chlorophyll
Absorbance
Wavelength (nm)
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
200
300
400
500
600
700
800

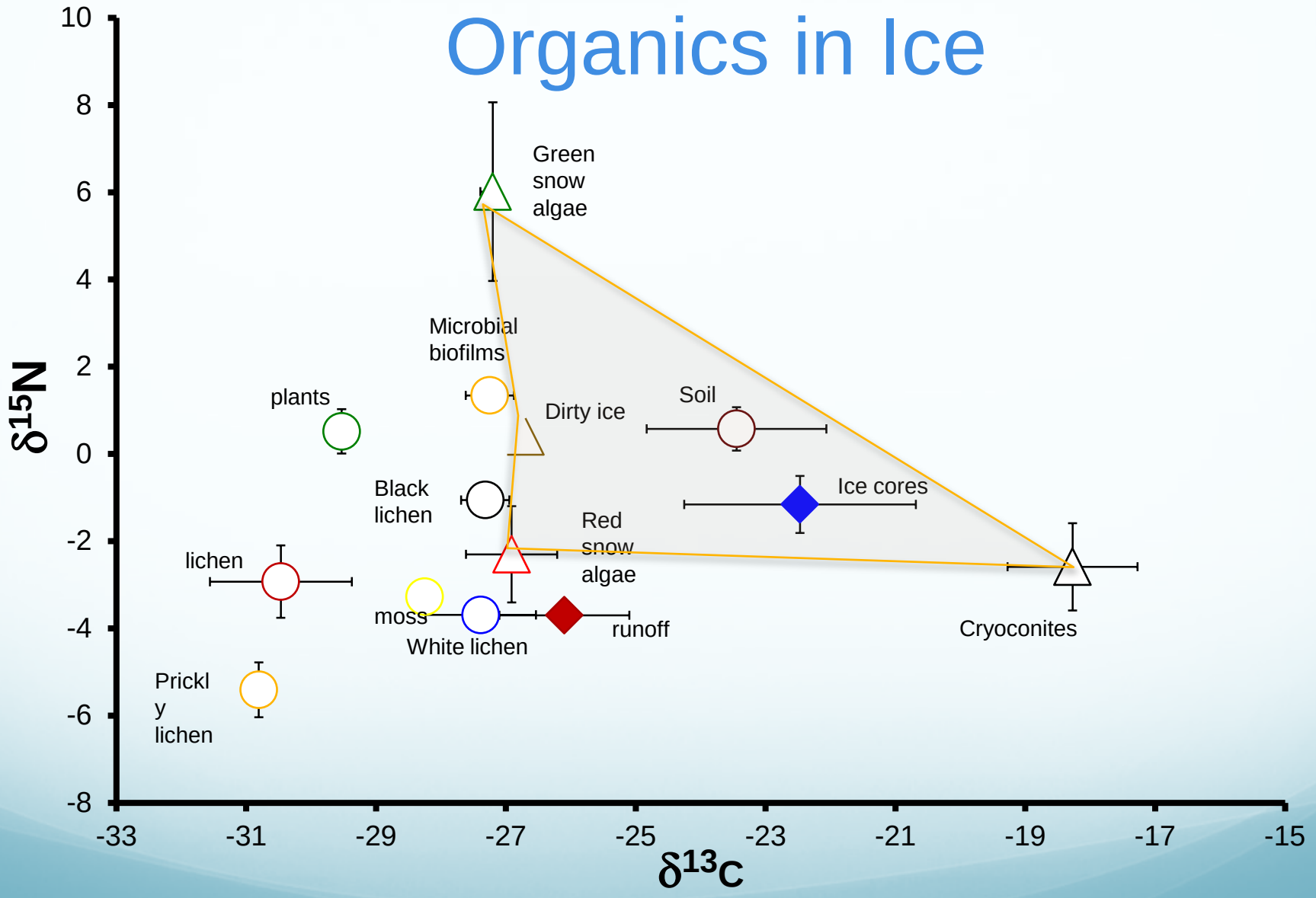
Cryoconite


Scytonemin
Chlorophyll
and
Carotenoids
Chlorophyll
Absorbance
1.2
1
0.8
0.6
0.4
0.2
0
200
300
400
500
600
700
800
Wavelength (nm)

Friedrichsbreen core = Cryoconites



In situ and Wind-blown sources = Organics in Ice



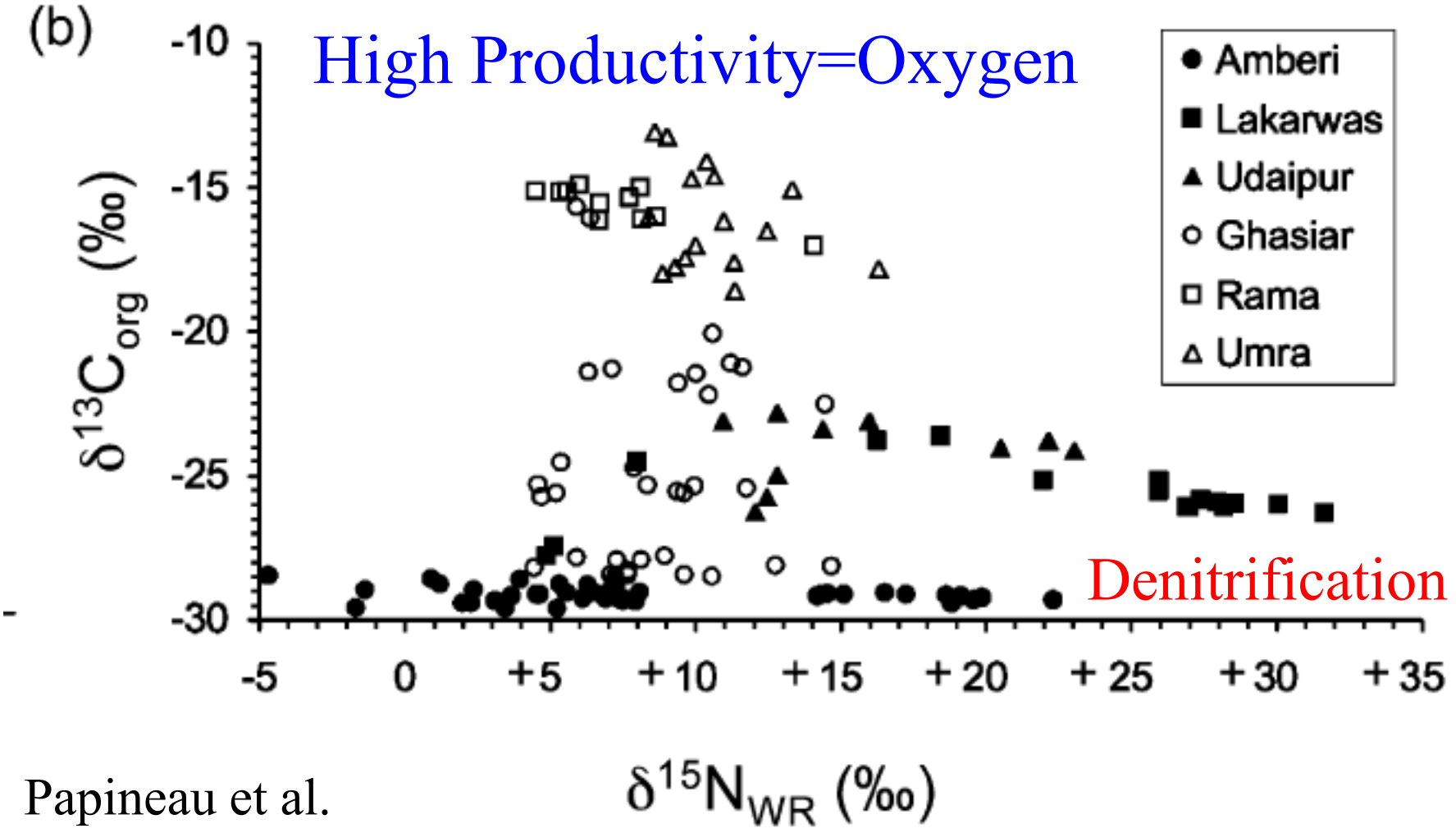
What is the earliest evidence of life on Earth?

1.8 Billion Years old stromatolites

Richmond Gulf, Quebec, Canada

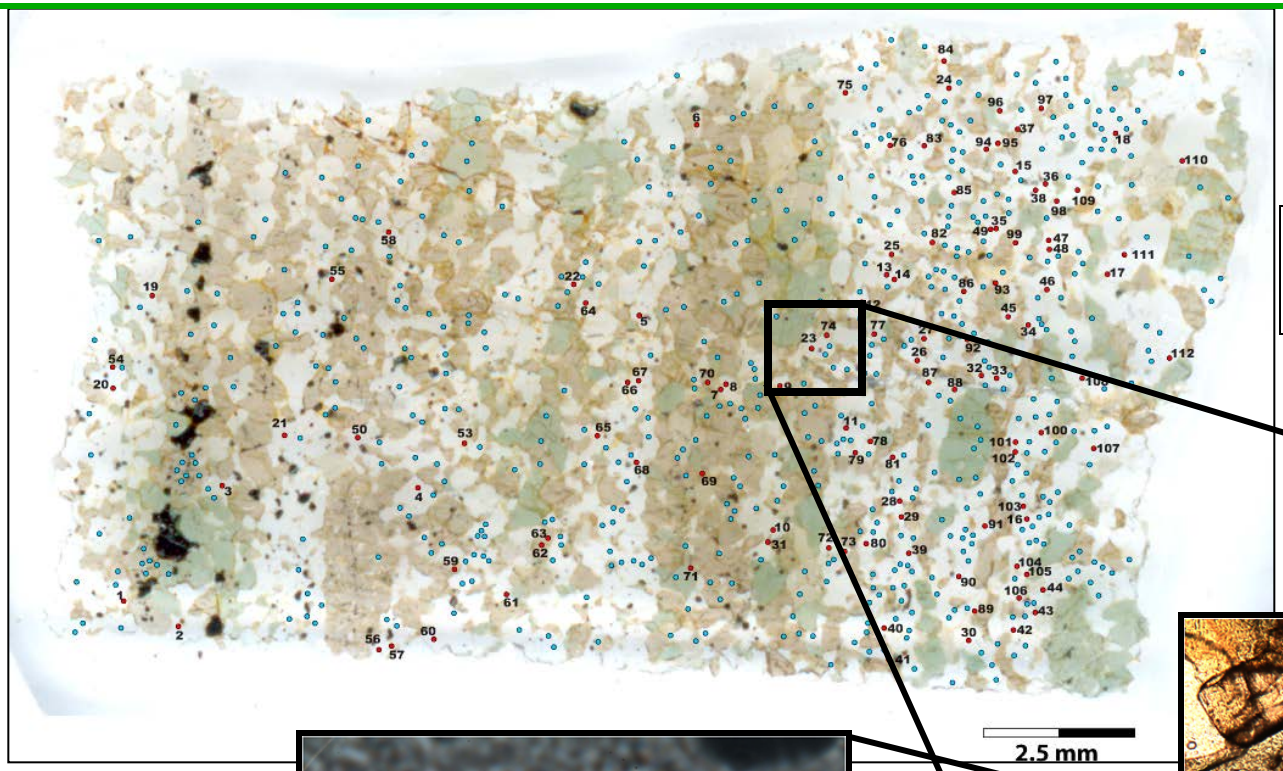
Aravalli Supergroup, India (1.8 By)
Dominic Papineau

Rise of Oxygen in Atmosphere-response of ecosystems



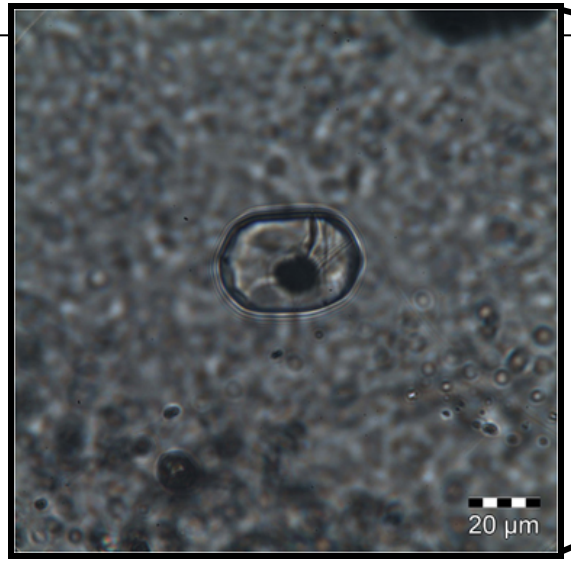
Papineau et al.

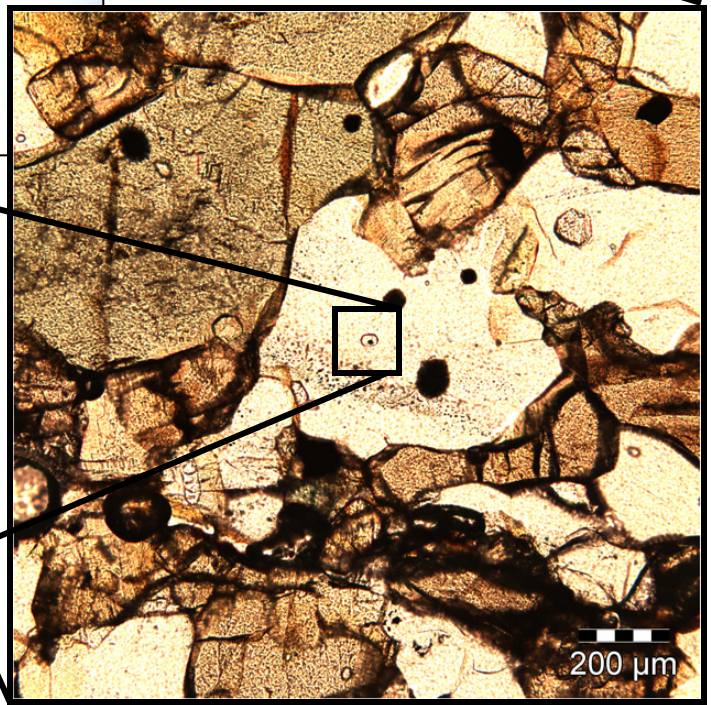
Akilia Greenland 3.7 Billion Years old



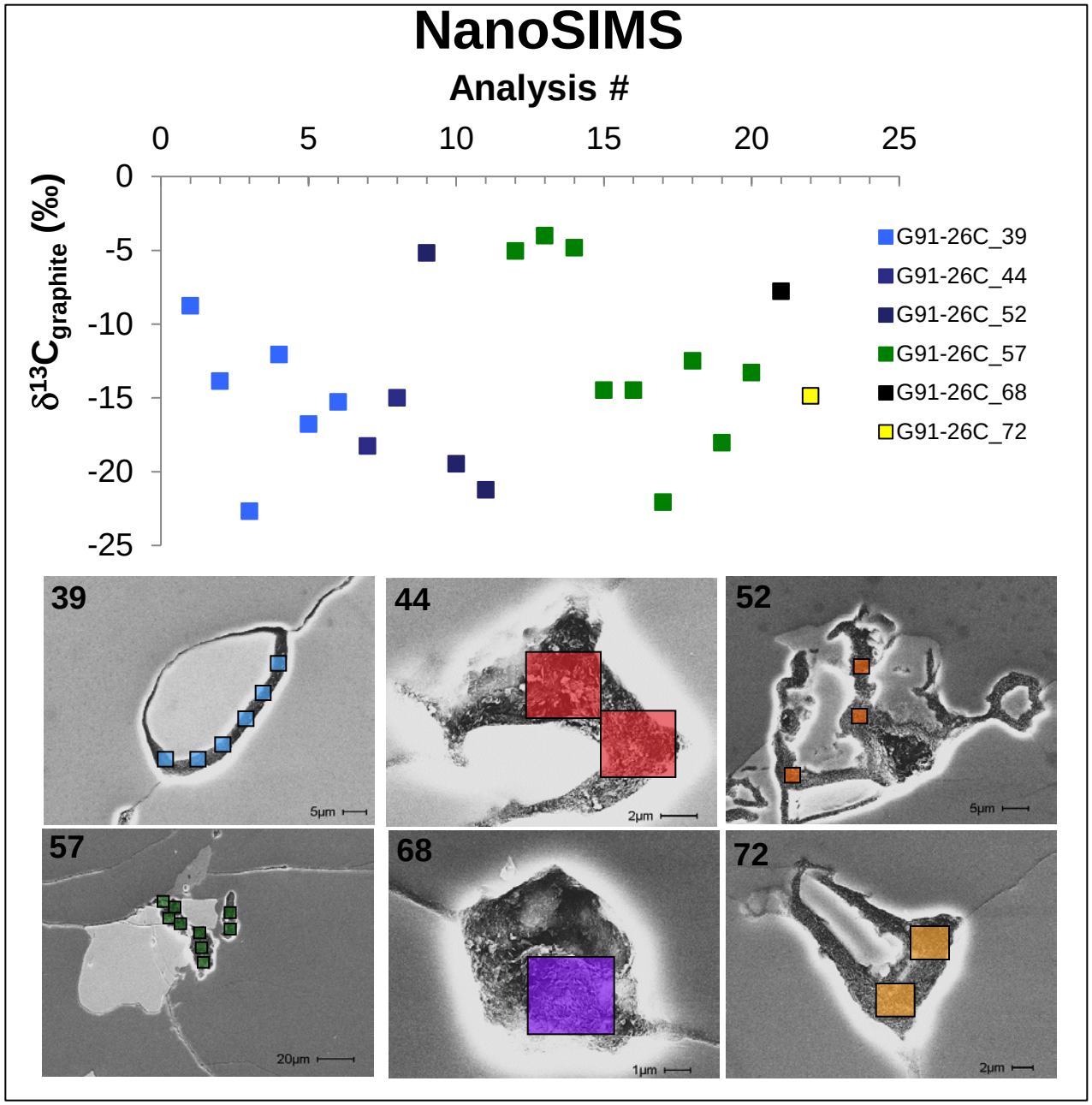
Papineau et al, GCA

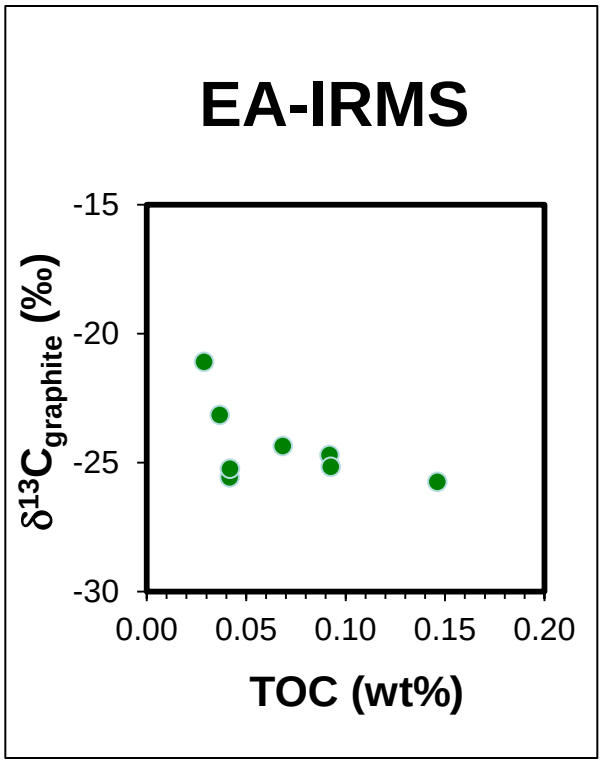
- = apatite with graphite (n=112)
- = apatite without graphite (n=511)





C-isotopes of graphite by nanoSIMS and IRMS



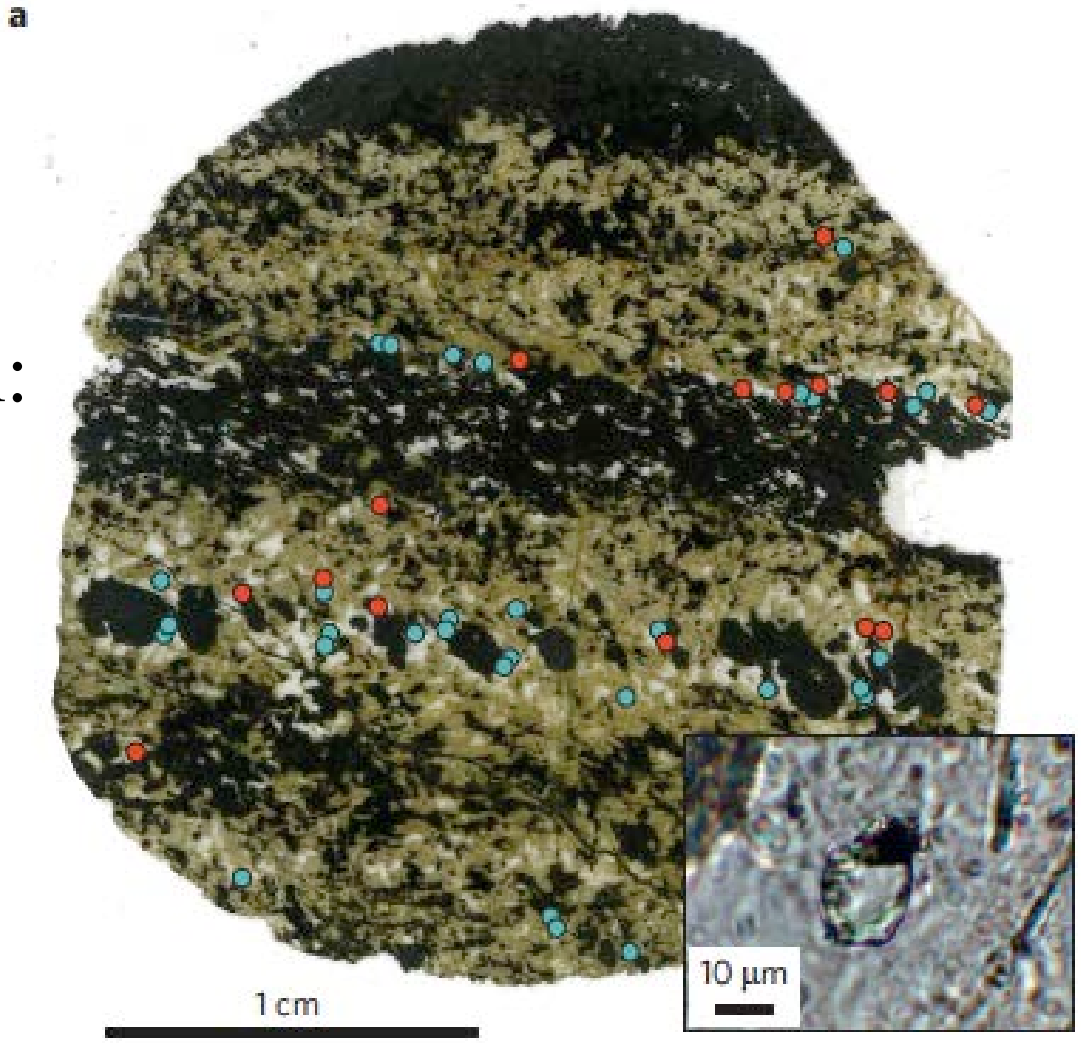


>3:8-Gyr-old Nuvvuagittuq banded iron formation: Earth's Oldest Sedimentary Rocks?

● = apatite with graphite

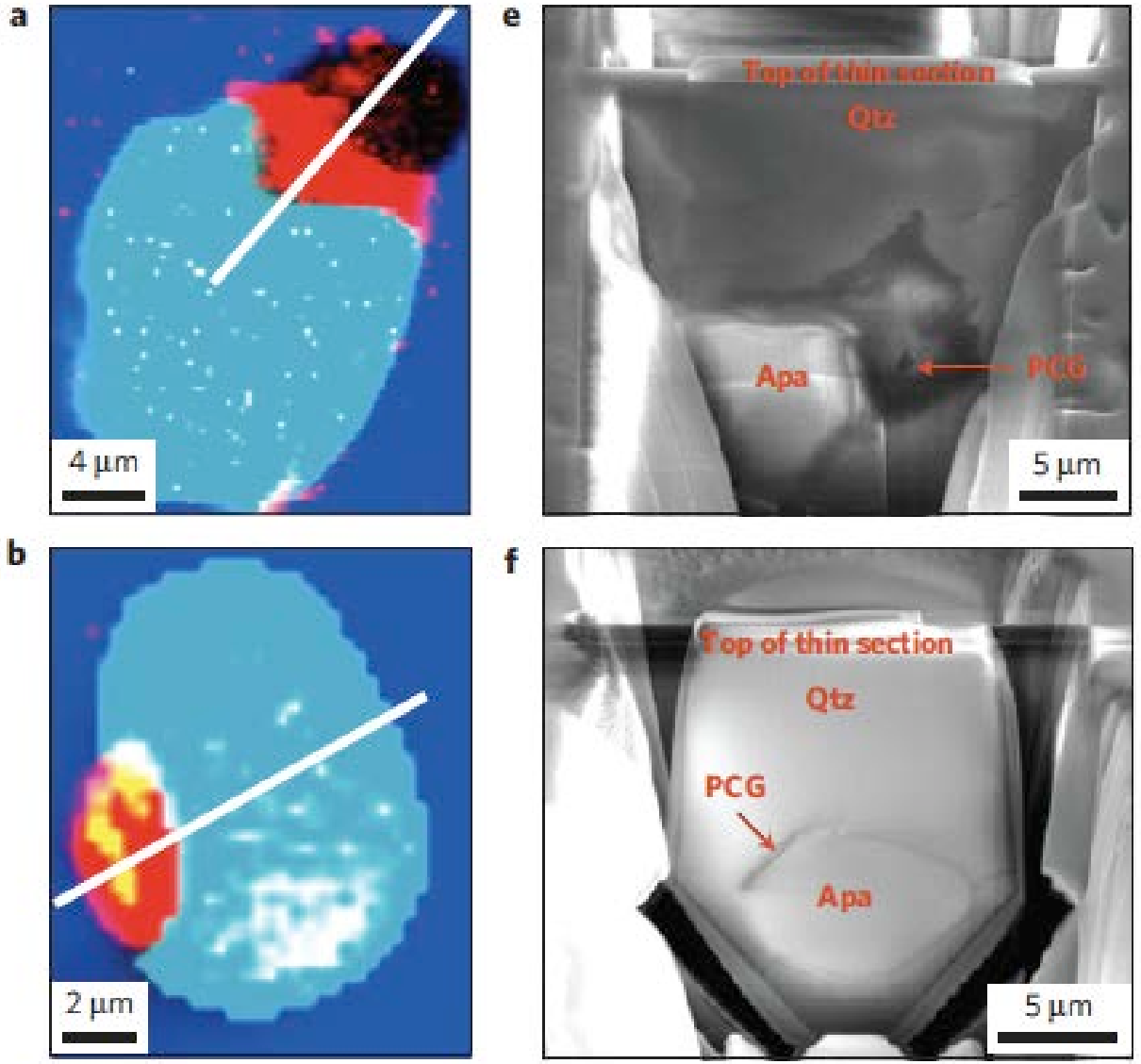
● = apatite without graphite

Low Organic Carbon:
0.011%C
$\delta^{13}C$ = -18 to -26‰;
Ave. -22.1‰



Metamorphic Fluid derived Carbon—at this time

Carbon is red
Phosphate is light blue



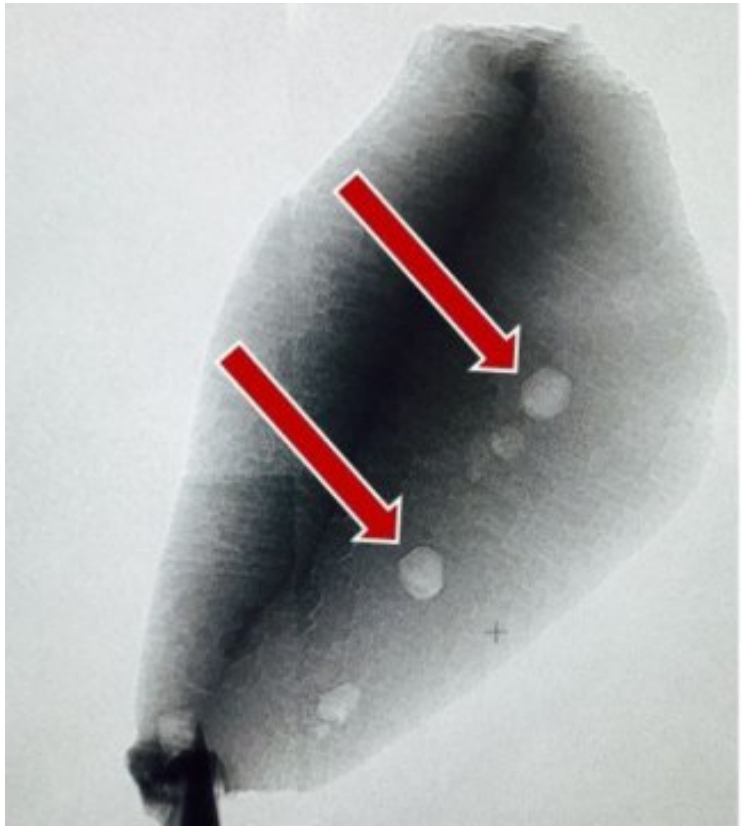
FIB section

Macromolecular Carbon Synthesis On Mars is Abiotic

Martians	$\delta^{13}C$	μg C	%C	Signal/Noise
DAG 476 Matrix	-20.7	0.6	0.0035	5
DAG 476 Olivine	-21.1	0.3	0.0034	5
DAG 476 Bulk Olivine	-15.6	0.5	0.0024	5
NWA 998	-24.7	0.5	0.0017	4

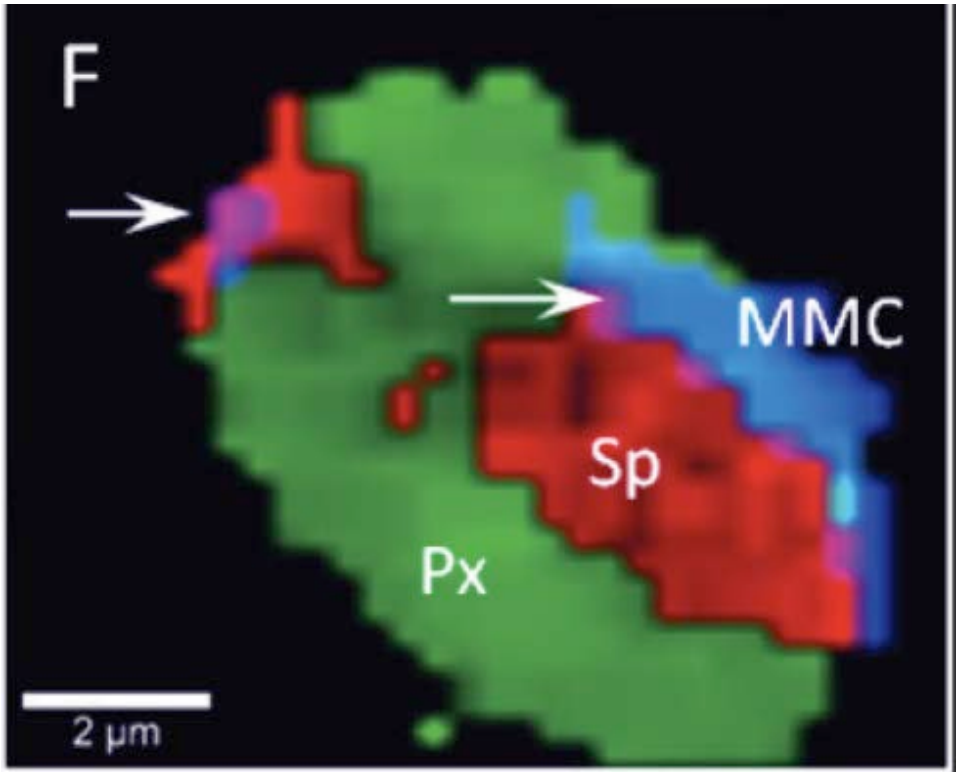
Are carbon isotope ratios biomarkers?—Not really

$\delta^{13}C_{PDB}$ of −24 ± 5‰



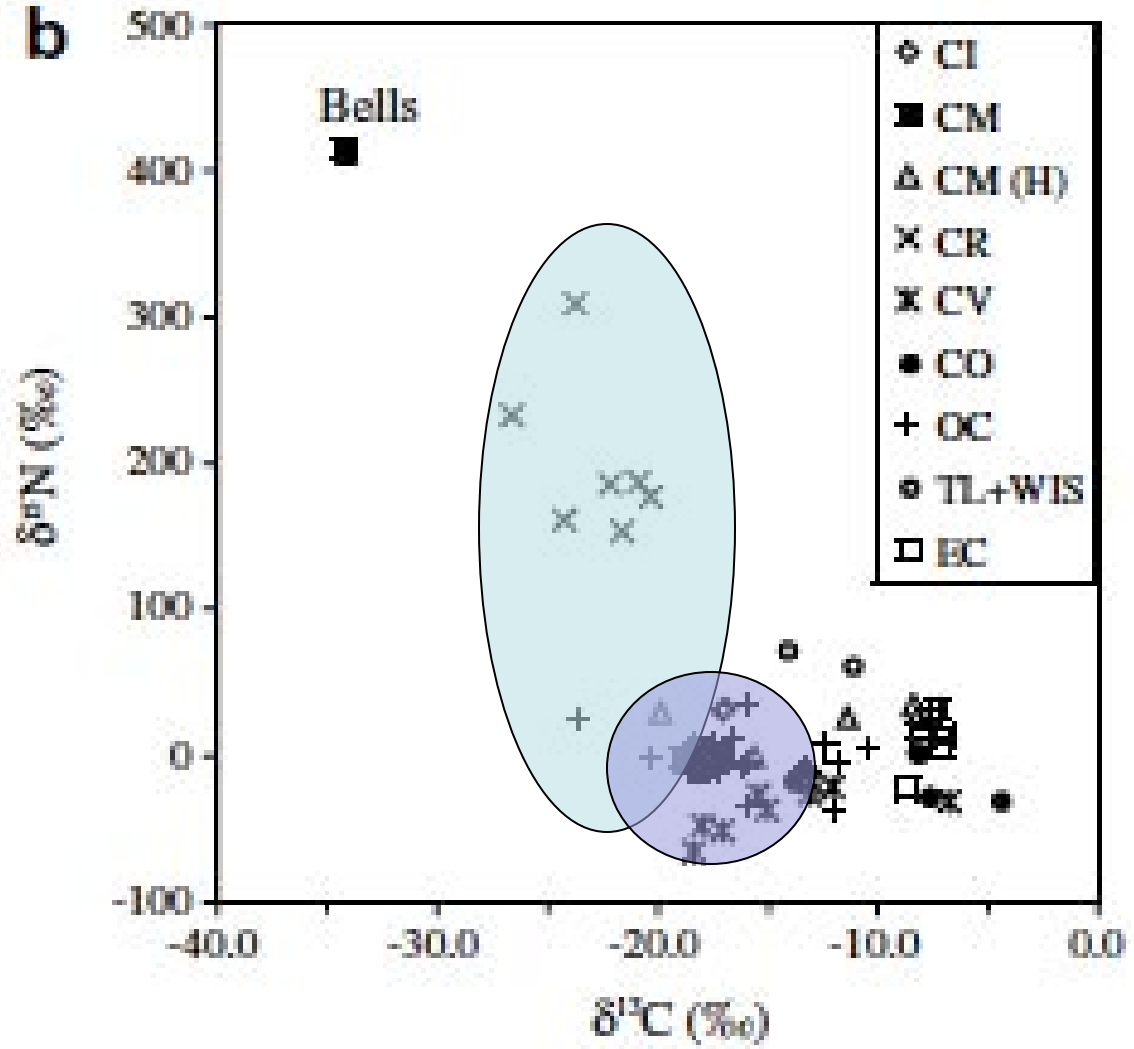
Bell et al., PNAS 2015, Graphite in Zircon (>4.1 By)

$\delta^{13}C_{PDB}$ of −21 ± 0.5‰

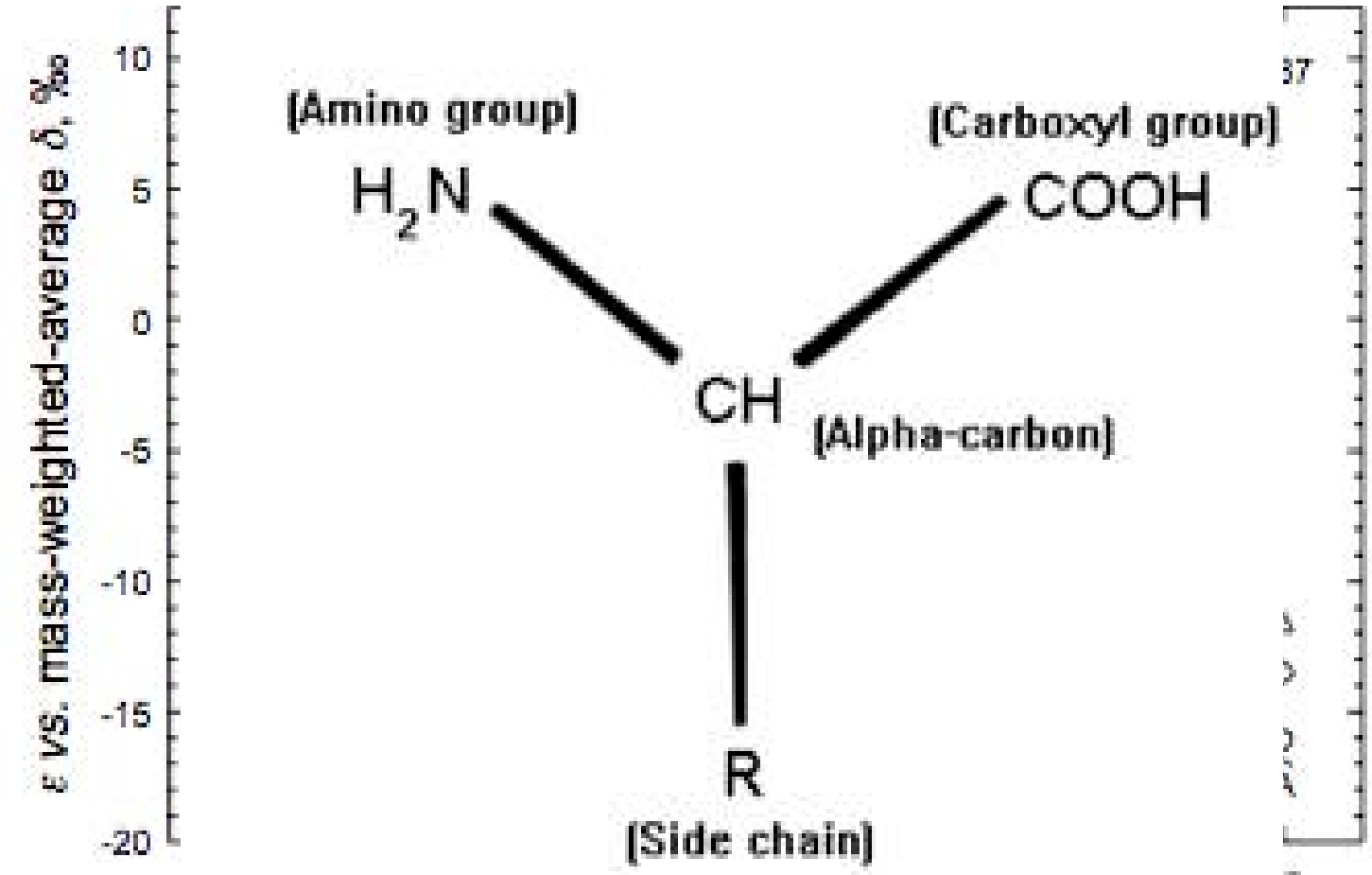


Martian Meteorite DAG 476

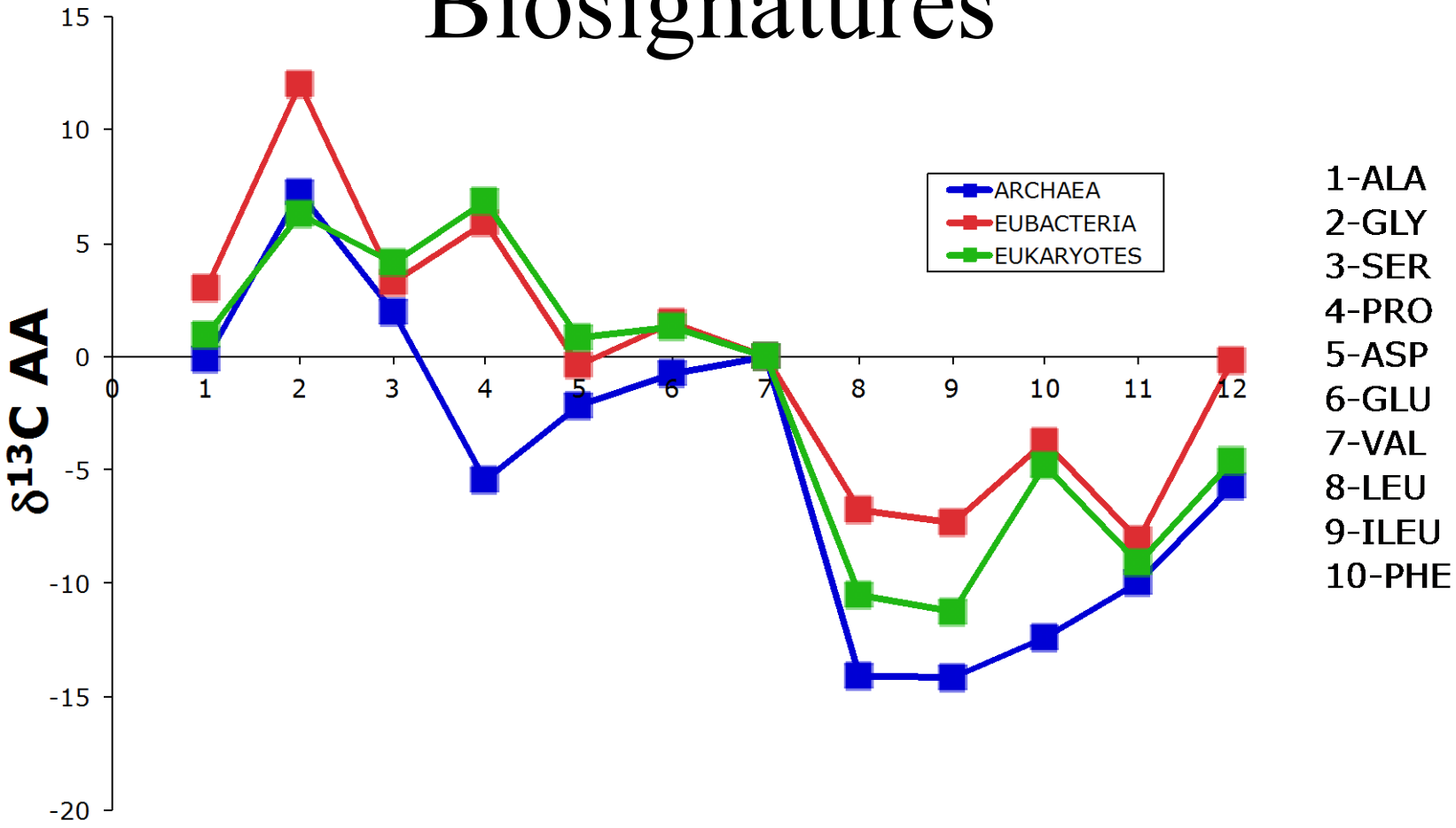
Carbonaceous chondrites are not biologically formed



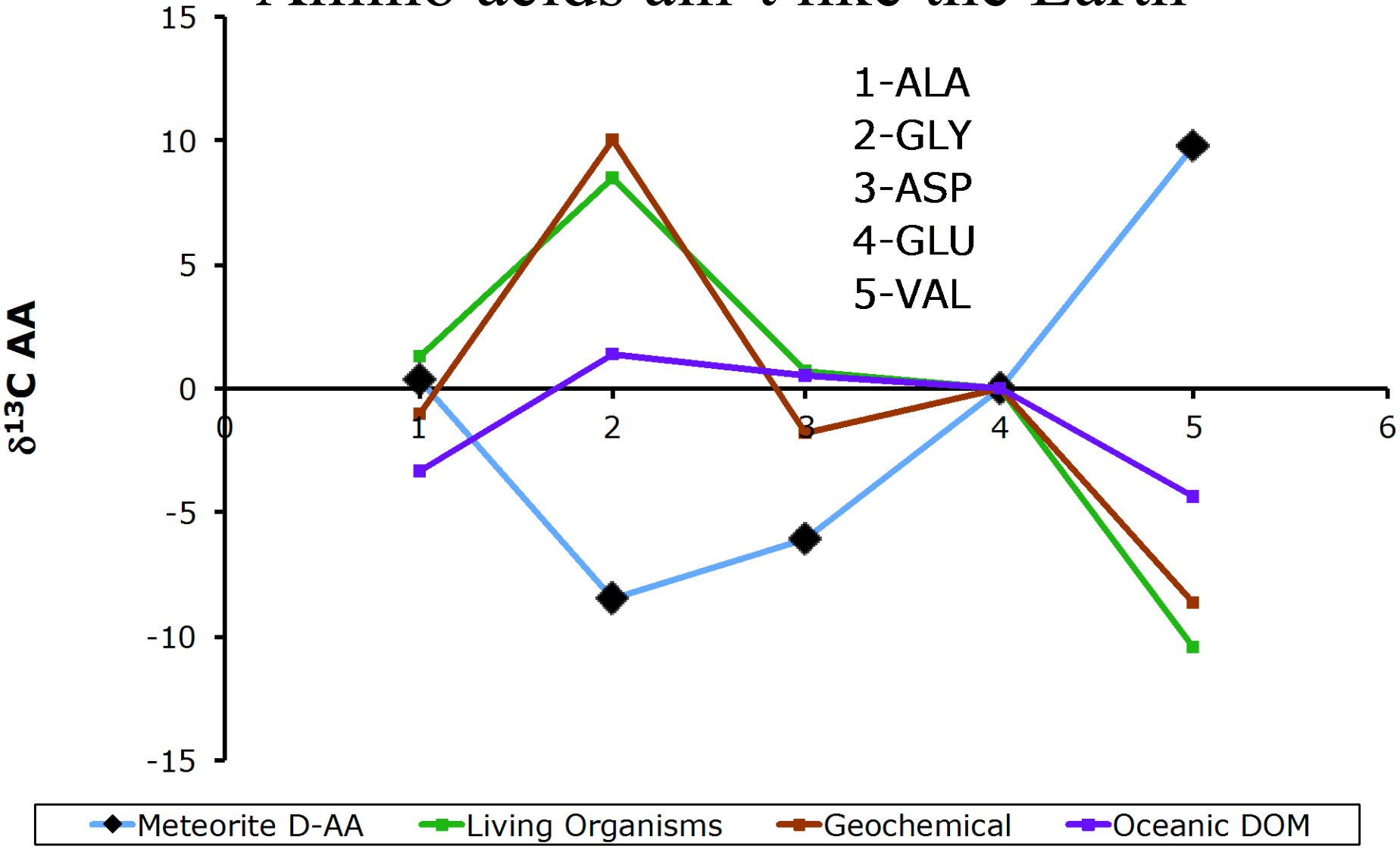
Amino Acids are common biological molecules, also found in planetary materials

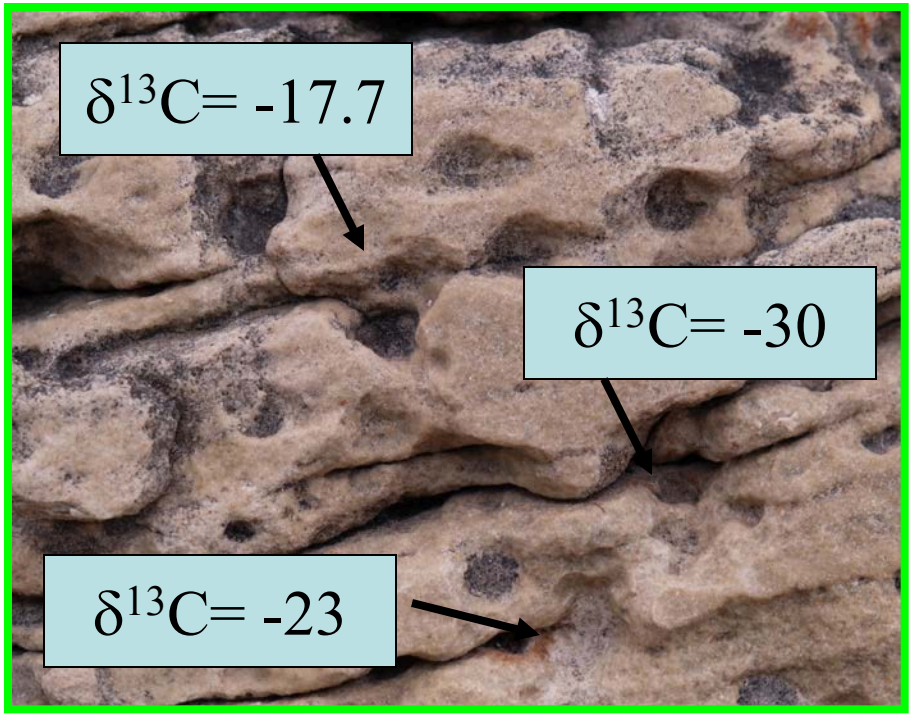


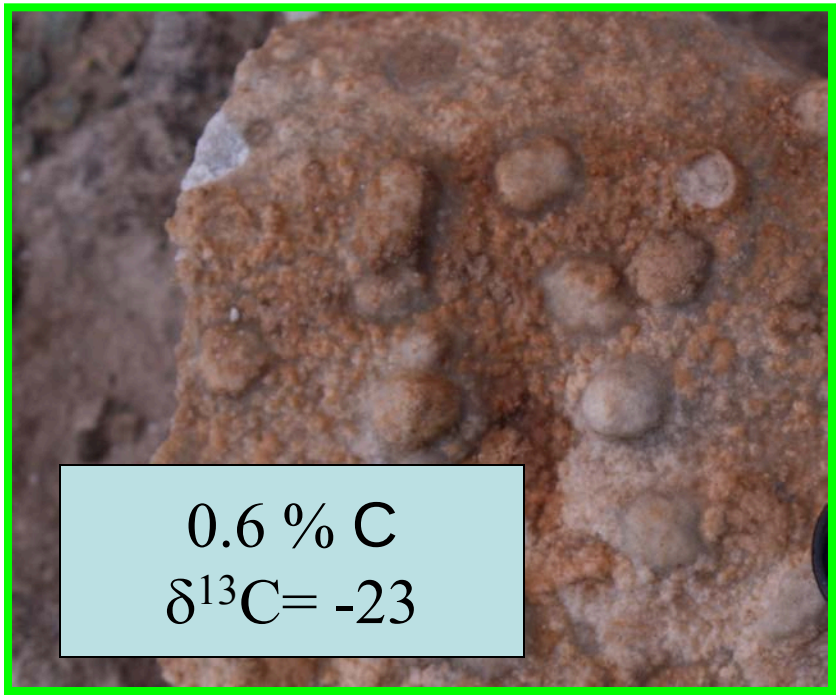
Enzymatic Processes Create Biosignatures

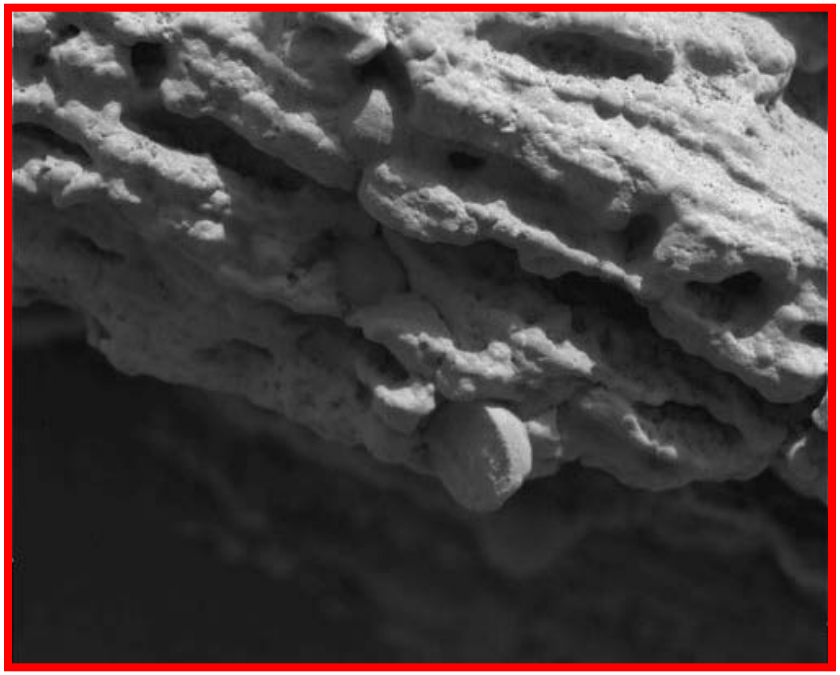


Isotope Pattern for Extraterrestrial Amino acids ain't like the Earth




$\delta^{13}C$= -17.7
$\delta^{13}C$= -30
$\delta^{13}C$= -23


0.6 % C
$\delta^{13}C$= -23




Andrew Steele &
Liane Benning