Ancient Green and Purple Sulfur Bacteria

Results of Research funded by the NASA Exobiology Program

Discovery of an ancient (1.6 *billion* year old) ecosystem and evidence that modern ocean conditions arose recently in geologic time

Appearing in *Nature*
6 October 2005

Why is the state of the seas important?

- Today's oceans are oxygenated all the way to the seafloor.
- Marine animal life depends on this oxygen. Plant life and much microbial life depends on current conditions too.
- The oceans could not become oxygenated until after the atmosphere, which appears to have seen its first traces of oxygen 2.2-2.3 billion years ago.
- If the oceans had became oxygenated at about the same time, then animal and plant life could have evolved in the oceans for at least the last 2 billion years.
- If there was a major delay in the oceans becoming oxygenated, then there was much less time available for marine life to evolve.

Why is the state of the seas important? (cont.)

- The oxygenation of the oceans was delayed by buffering from massive amounts of reduced iron and sulfur.
- Basalt, erupting at mid-ocean ridges reacts with seawater to produce a steady supply of ferrous iron and other reduced species. This would ‘mop up’ most oxygen being produced by photosynthesis at the surface.
- Also, there was little sulfate in the oceans before the atmosphere became oxygenated.
- Once the atmosphere contained some oxygen, sulfate could be produced by the weathering of rocks and carried to the oceans by rivers.
- Sulfate-reducing bacteria in the oceans would then have converted this sulfate to sulfide (ie rotten egg gas), making the oceans toxic and preventing most animal and plant life from establishing a marine habitat.

Life in an alien sea: Earth, 1.6 billion years ago

- The research reported here indicates that the center diagram describes Earth's oceans 1-2 billion years ago

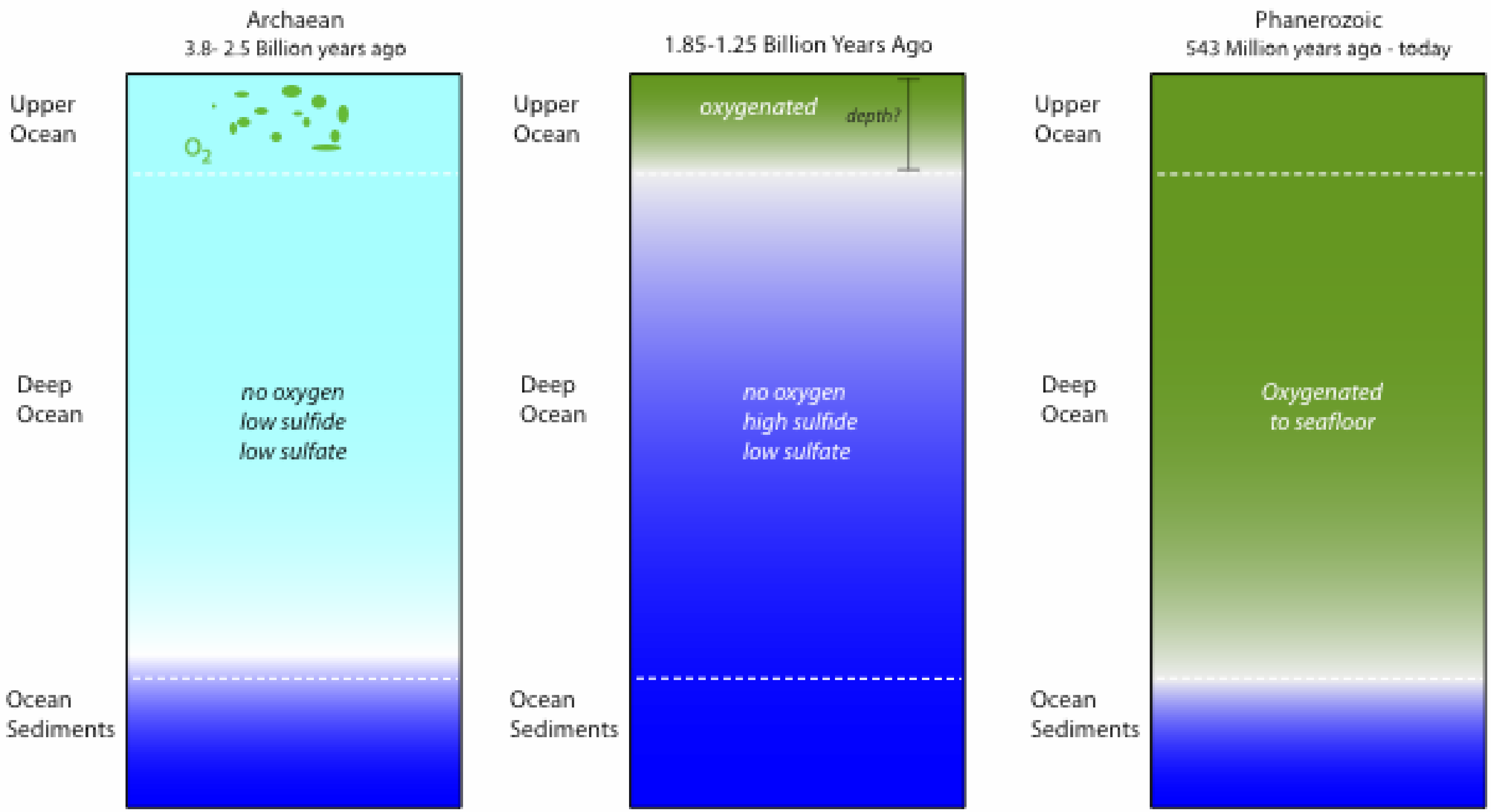


Figure adapted from Anbar & Knoll, *Science,* **297,** 1137-1139.

What’s a biomarker?

- A biomarker is an organic molecule produced by the geological processing of dead organisms.
- Biomarkers can be specific for particular types of organisms.

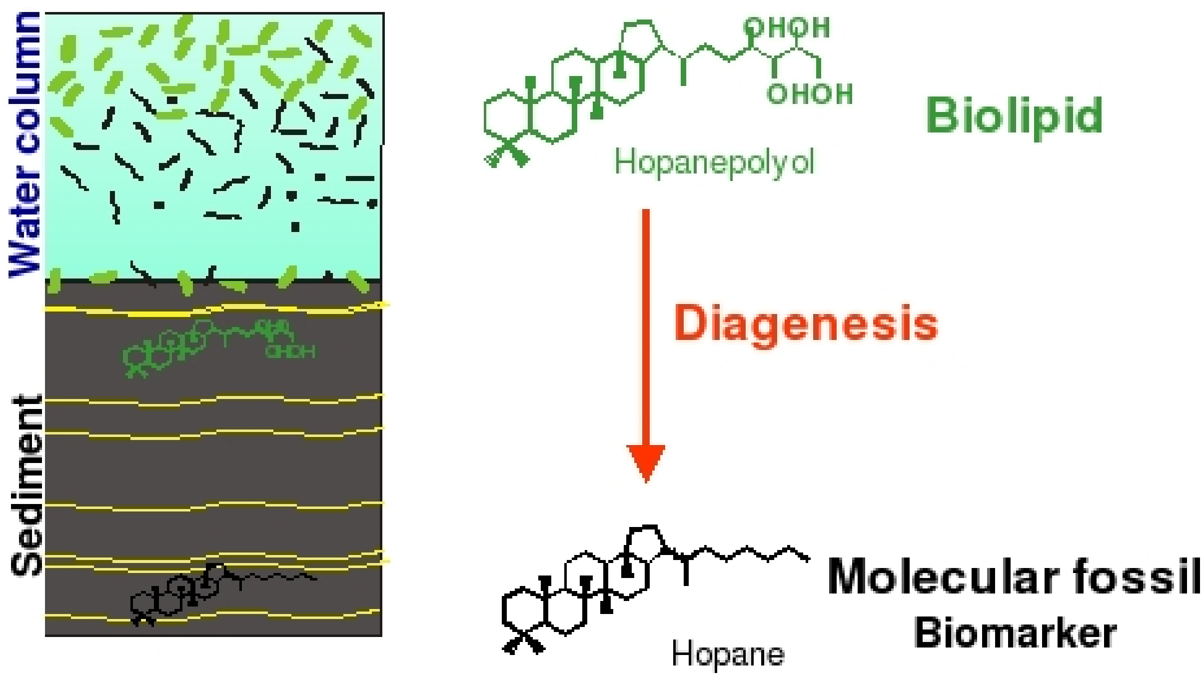
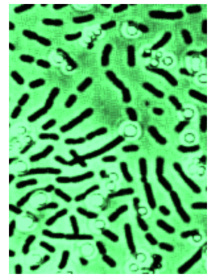


Figure “borrowed” from J.J. Brochs

Dramatis Bacteriae

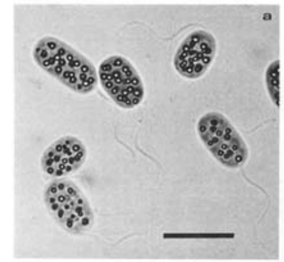
Cyanobacteria

- Ancestor of plants
- Photosynthetic
- Splits water to make O_2
- Common in modern, sunlit ocean
- Source of atmospheric O_2
- Biomarker: 2α-methylhopanes



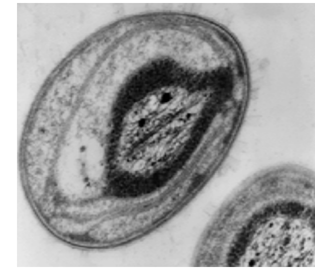
Chlorobiaceae

- AKA "Green Sulfur Bacteria"
- Strictly anaerobic
- Phototrophic
- Require sulfide + light
- Restricted to sunlit, sulfidic waters *e.g.*, Black Sea, sulfur springs
- Narrowly distributed on modern Earth
- Biomarker: trimethyl arylisoprenoids



Chromatiaceae

- AKA "Purple Sulfur Bacteria"
- Strictly anaerobic
- Phototrophic
- Use sulfide + light
- Widely distributed among stagnant water bodies.
- Found higher in the water column than GSBs.
- Biomarker: okenone



Methanotroph

- Inhabit low-O_2 environments
- Require methane which is only made in absence of O_2
- Oxidize methane (CH_4) for energy
- Ubiquitous on modern Earth; keep CH_4 concentrations low
- Biomarker: C4-methylated steroids

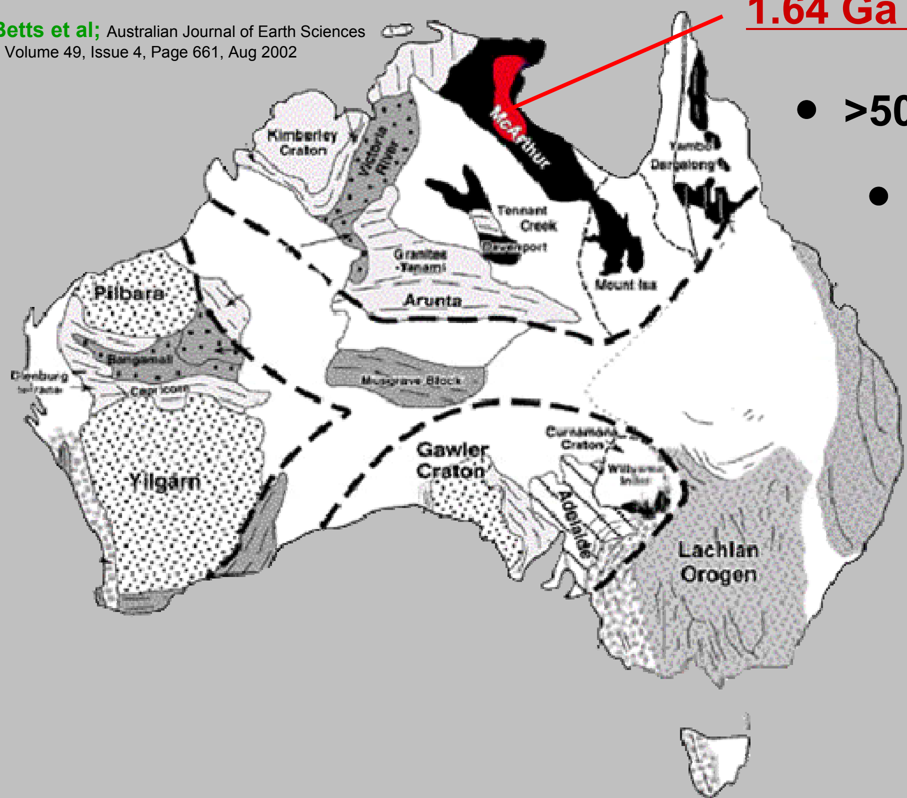
The rocks……..

Very well preserved, flat lying sediments from Northern Australia.

It’s very unusual to find very old sediments that are so pristine

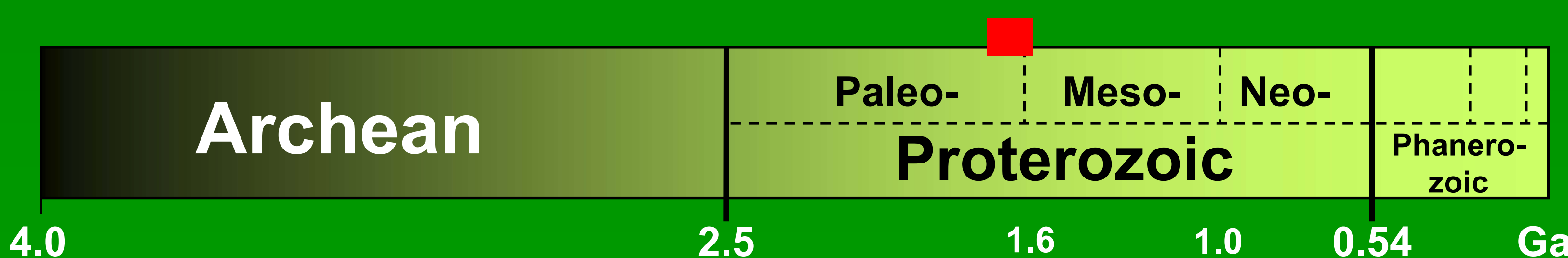
1.64 Ga Barney Creek Formation, McArthur Basin, Australia

P. G. Betts et al; Australian Journal of Earth Sciences Volume 49, Issue 4, Page 661, Aug 2002



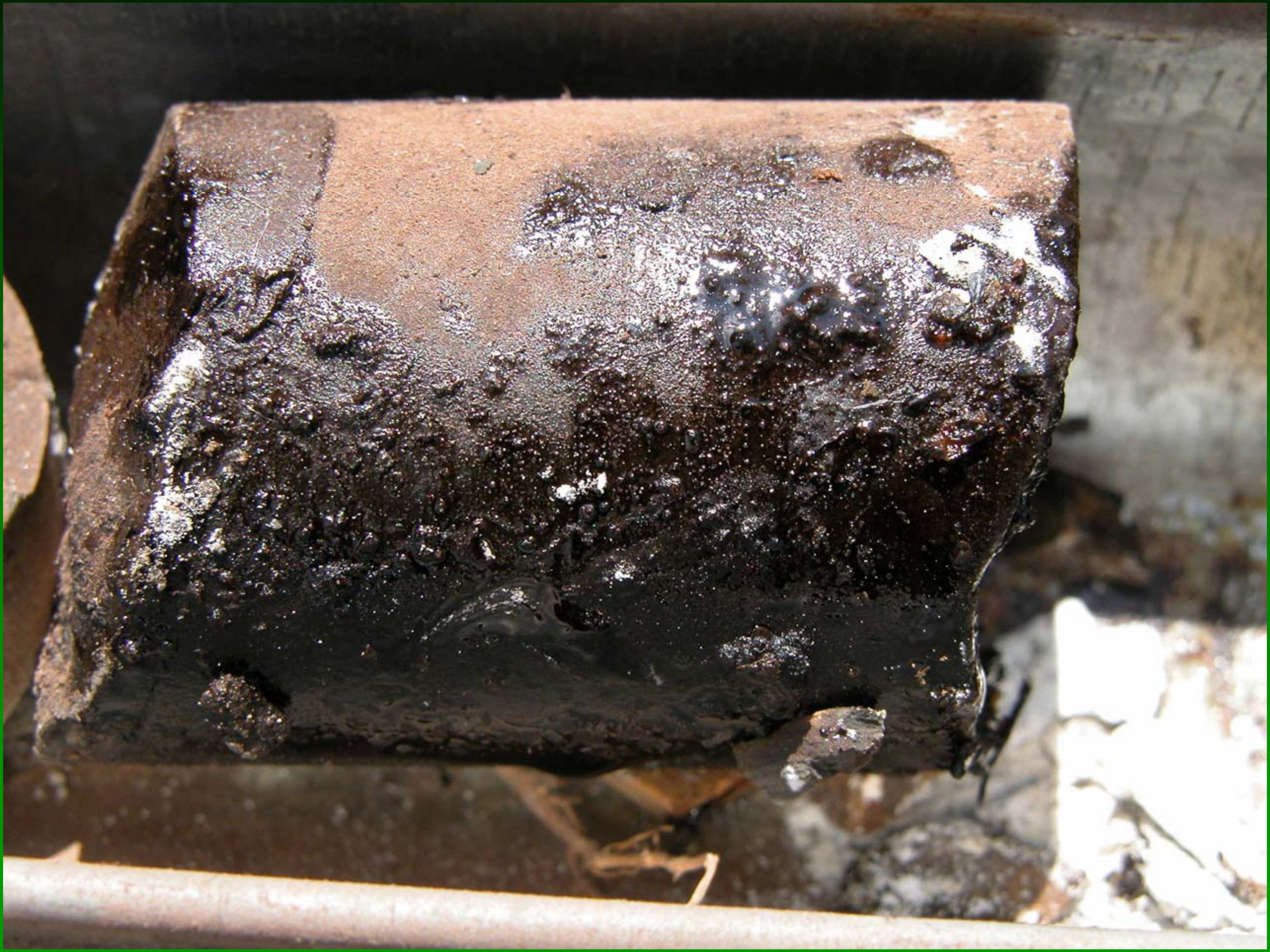
1.64 Ga Barney Creek Fm

- >50,000 km^2
- basinal, sub-wave base
- marine
- open to the ocean or restricted?
- Samples from 10 drill holes



1.65 Ga Kombolgie Formation deposited by a braided river system that was probably syndepositional with the Barney Creek Formation and possibly feeding into the sea of the McArthur Basin (Photo: Jochen J. Brocks, 12 August 2003, Bardedjilidji in Kakadu National Park, northern Australia).

The oldest known live oil seeping out of a dolomitic mudstone of the 1.64 Ga Barney Creek Formation (drill core McA20; ~375 meters depth). (Photo: Jochen J. Brocks, 4 August 2003)

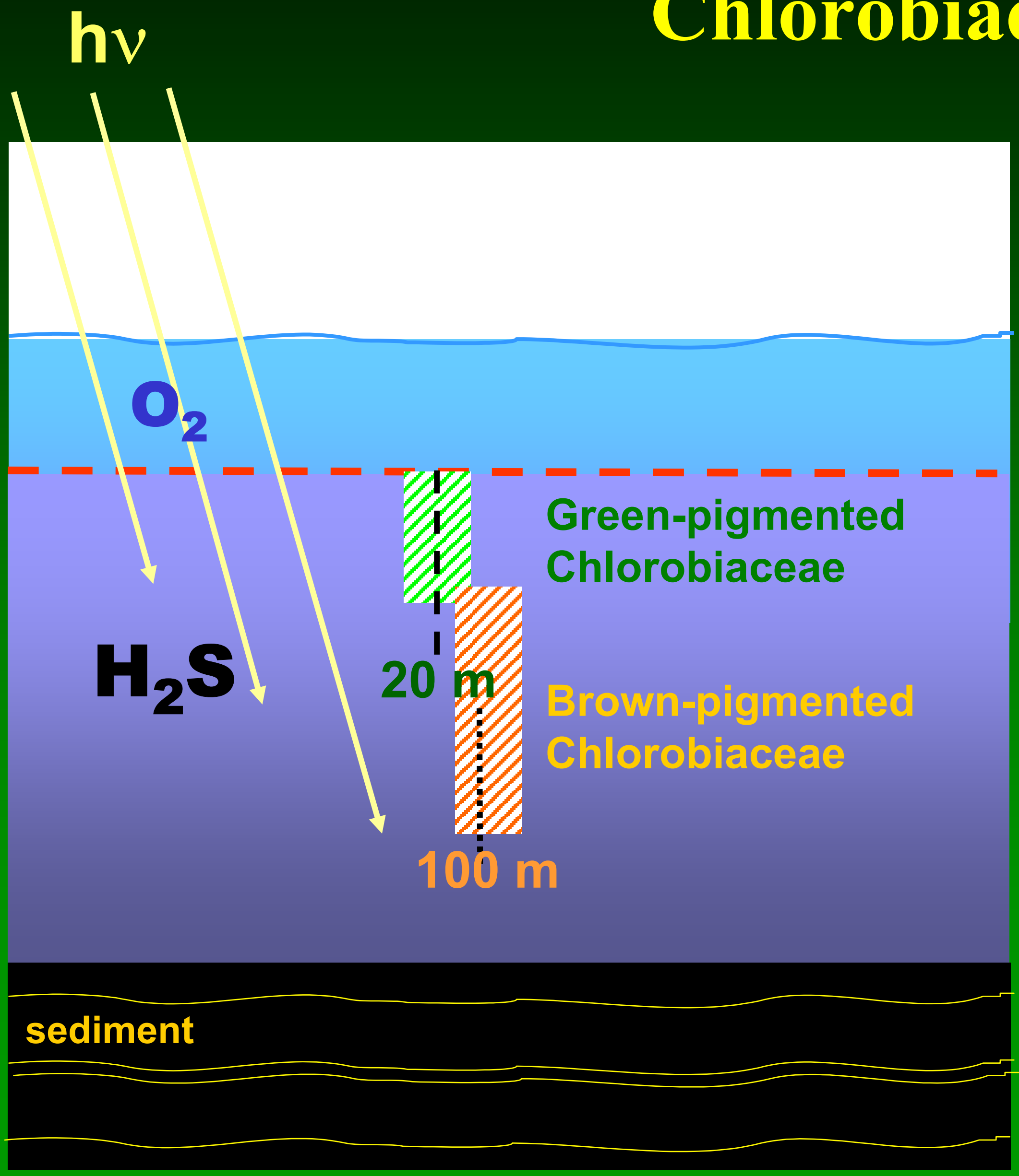


What was found…

- Performed gas chromatography/mass spectrometry on bitumens from rocks of the Barney Creek Formation, Australia.
- The rocks are 1.64 billion years old. They are thought to have been laid down in a quiet, sub-wave base environment — so relatively deep water.
- Large number of biomarkers detected, including:
  - High concentrations of triterpanes associated with Type I methanotrophs,
  - Very low concentrations of 2α-methylhopanes indicating a surprisingly low population of cyanobacteria,
  - An insignificant amount of eukaryotic biomarkers,
  - Very high concentrations of aromatic hydrocarbons indicative of *Chlorobiaceae* (Green Sulfur Bacteria which *eat* sulfide).
  - First detection of okenone, indicative of *Chromatiaceae* (Purple Sulfur Bacteria which also *eat* sulfide).

Green sulfur bacteria

Chlorobiaceae

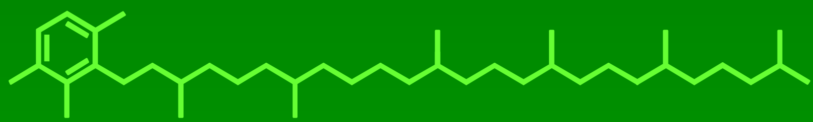


Anoxygenic photosynthesis

$$H_2S + CO_2 \xrightarrow{h\nu} SO_4^{2-} + C_{org}$$

- requires reduced sulfur
- requires light
- strictly anaerobic

Biomarkers of Chlorobiaceae



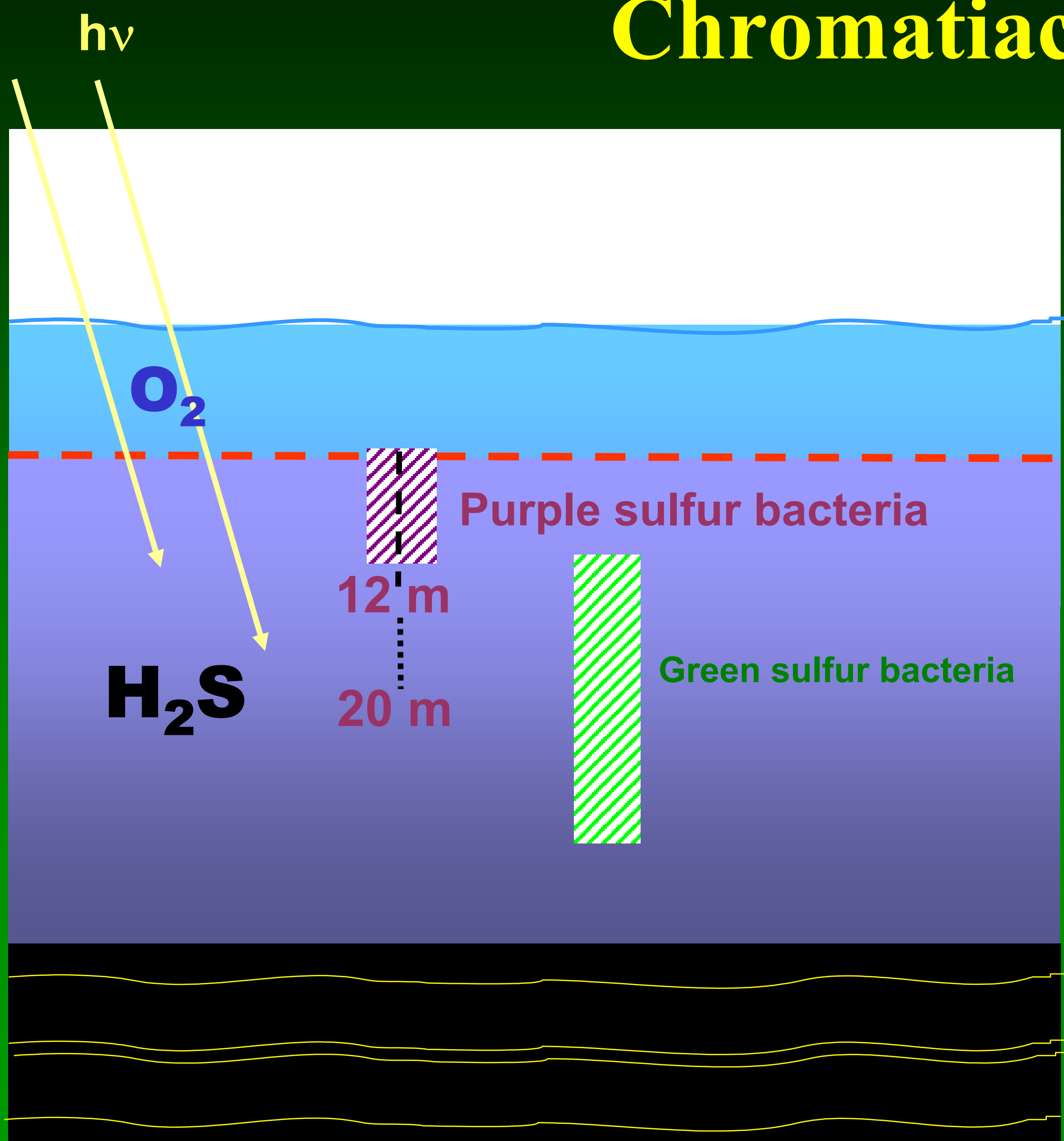
chlorobactane

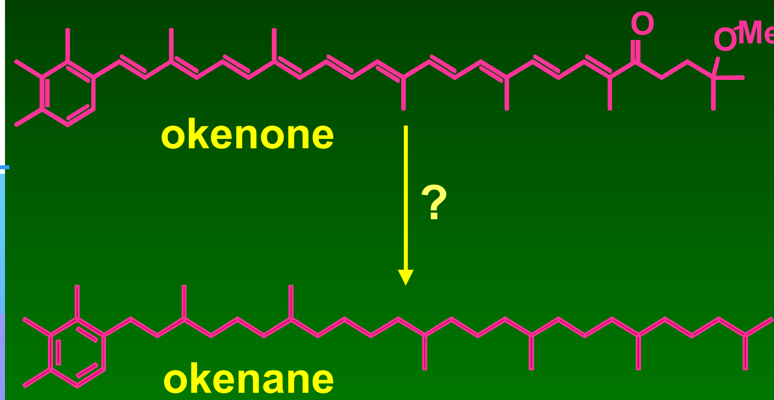
isorenieratane

Summons et al., 1987; JJ Brocks et al 2005

Purple sulfur bacteria

Chromatiaceae





A potential biomarker for Chromatiaceae which need:

- reduced sulfur
- light
- anoxic conditions

ASTROBIOLOGY

The logic of microbes…

- Few/no eukaryotes → Oceans low in oxygen
- Few cyanos → Oxygen only at shallow depths
- Presence of methanotrophs → Oceans low in sulfate
- Presence of purple and green sulfur bacteria → Oceans high in sulfide from the depths to near the surface

So 1.6 billion years ago, although oxygen in the atmosphere, it had not yet largely penetrated the oceans.

What all this means…

- Independent evidence that late Paleoproterozoic ocean had low oxygen and sulfate concentrations,

  (because few algae and high activity of methanotrophs)

- and high sulfide concentrations…

  (because purple and green sulfur bacteria were present)

- …that extended high into the water column, up to where sunlight could penetrate.

  (because the purple and green sulfur bacteria need sunlight to live)

- First molecular evidence for a complex Paleoproterozoic microbial ecosystem.
- Implication: modern complex life (animals and plants) could not have begun evolving in the oceans until ~0.6 billion years ago.

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