

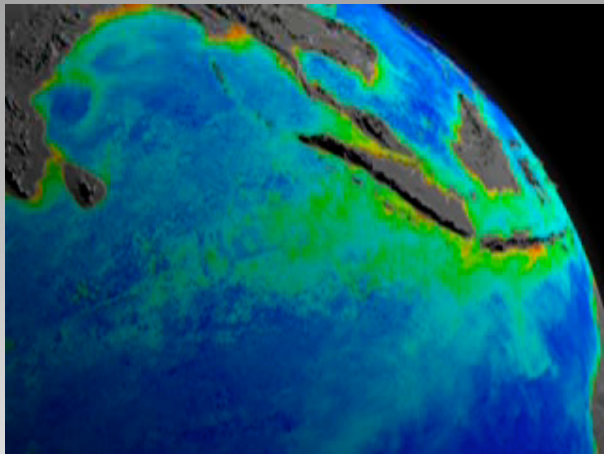
Microbial Diversity and Evolution

Part III: Interpreting molecular fossils of oxygenic photosynthesis

Professor Dianne Newman
Divisions of Biology and
Geological and Planetary Sciences
California Institute of Technology, and
Howard Hughes Medical Institute



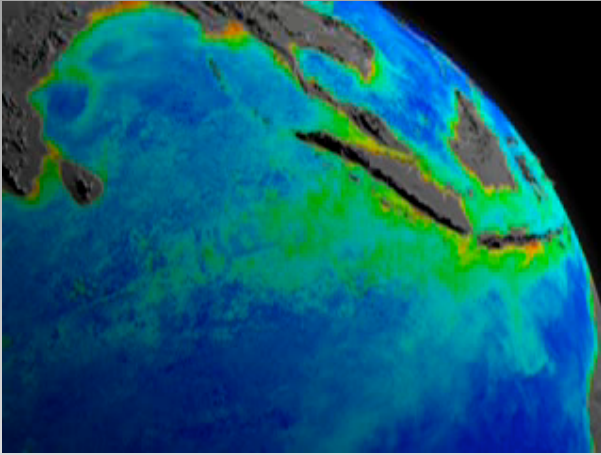
Global microbial photosynthesis



3-year compression of NASA SeaWiifs satellite images

From NASA SeaWiifs satellites. is a composite compressed over three years
time (with cloudy days taken out, of course). Chl is only from surface waters, one optical depth (~ upper 10 m I think), inferred from ocean color...

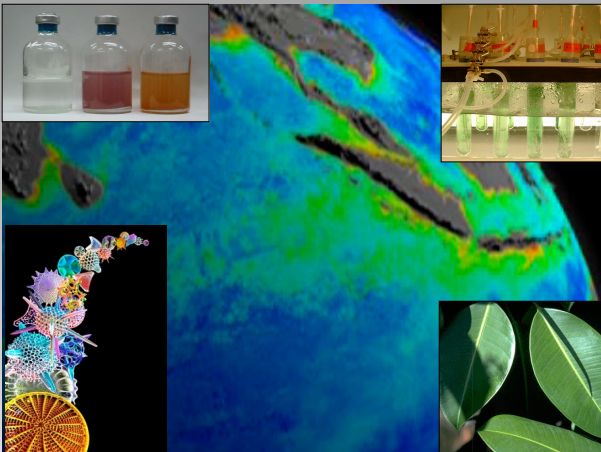
Global microbial photosynthesis



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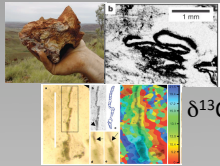
Global microbial photosynthesis



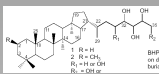
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Morphological

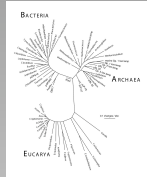


Molecular

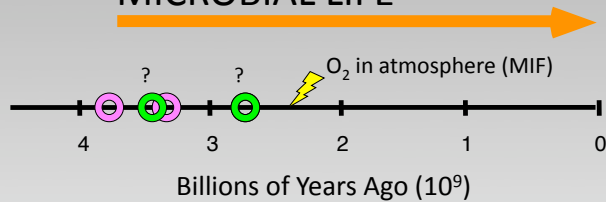


$\delta^{13}\text{C} \text{ ‰}$, $\delta^{34}\text{S} \text{ ‰}$, $\delta^{56}\text{Fe} \text{ ‰}$

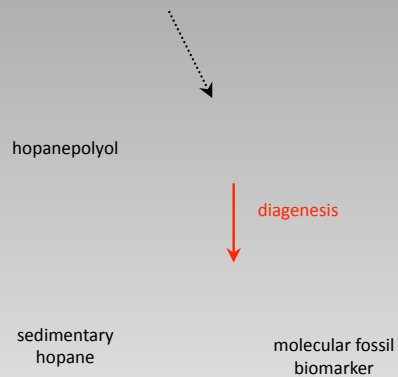
Genomic



MICROBIAL LIFE



Converting a lipid into a molecular fossil ("biomarker")



Hopanoids also function as molecular fossils or biomarkers

Straightforward principle

Organic geochemists can extract from sediments

Based on distribution in modern organisms, can be used to correlate certain bacterial group or metabolism to ancient Earth based on age of sediment

Converting a lipid into A molecular fossil (“biomarker”)

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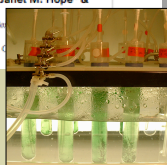
2-Methylhopanoids as biomarkers for cyanobacterial oxygenic photosynthesis

Roger E. Summons*, Linda L. Jahnke, Janet M. Hope* &
Graham A. Logan*

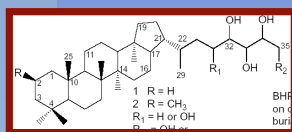
* Australian Geological Survey Organisation, GPO Box
Australia

† Exobiology Branch, NASA Ames Research Center,
California 94035, USA

1999 *Nature*



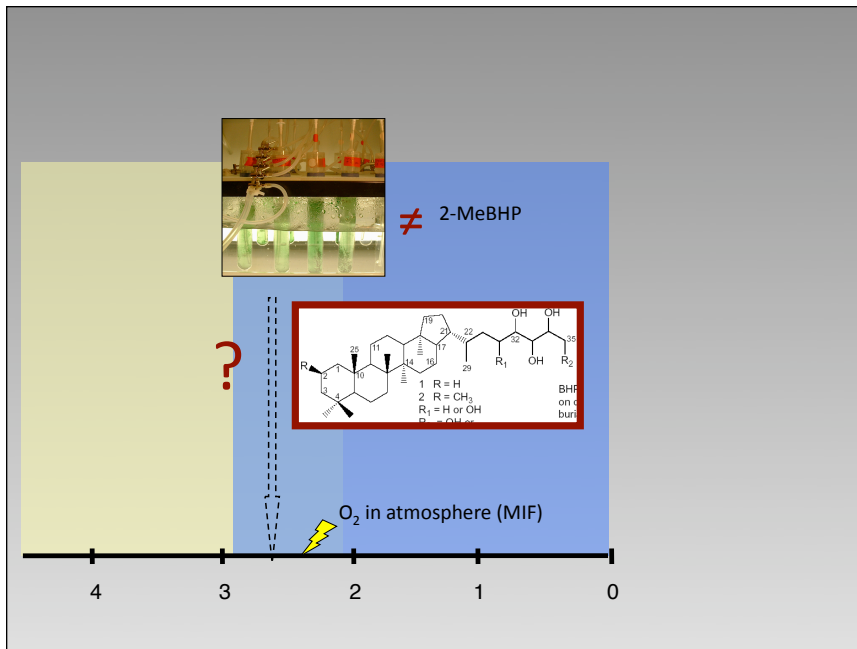
= 2-MeBHP



O₂ in atmosphere (MIF)

Billions of Years Ago (10⁹)

- Hammersley, Western Australia
- Characterized by laminations of Fe(III) minerals and chert (Si)
- ~>15 wt % Fe
- Account for 90% of the world's Fe



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Criteria for a robust biomarker

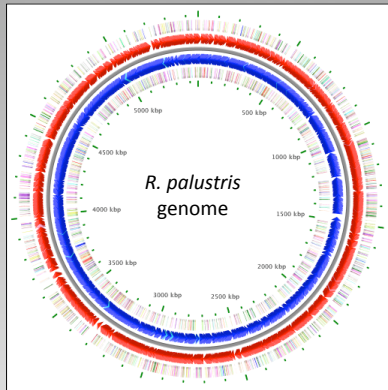
1. It must be indigenous to the rocks it is meant to represent
2. It must have a unique distribution amongst modern organisms, or clear evolutionary history
and/or
3. It must have a specific and conserved biological function related to the process of interest

This image shows a blank sheet of white paper with horizontal ruling lines. The lines are evenly spaced and extend across the width of the page. There is no text or other markings on the paper.

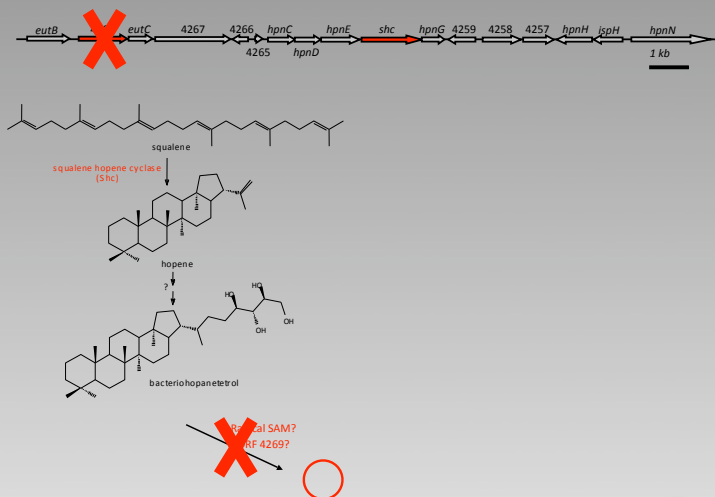
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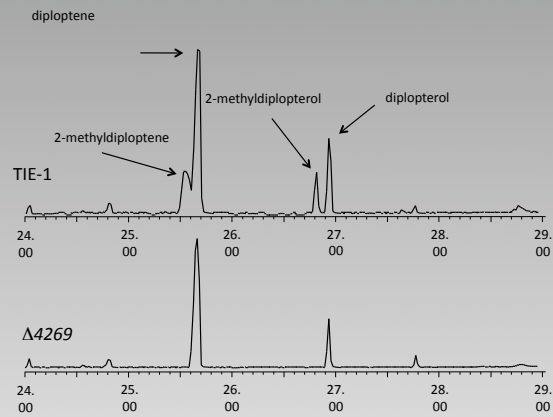
Using *R. palustris* to understand the evolutionary history of 2-MeBHPs



Is there a specific C-2 methylase?

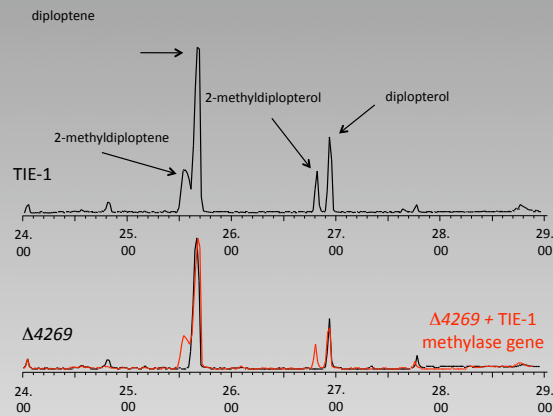


ORF4269 (*hpnP*) encodes the C-2 methylase



Welander *et al.* (2010) PNAS

ORF4269 (*hpnP*) encodes the C-2 methylase



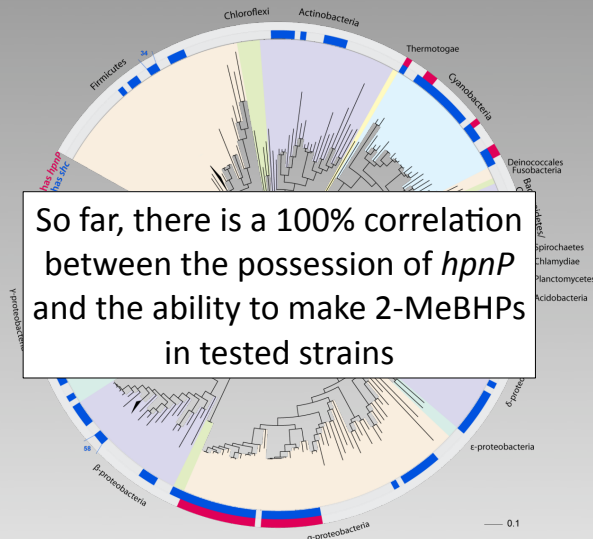
$\Delta 4269$ + TIE-1
methylase gene

Phylogenetic distribution of *hpnP*

Blue bar = *shc* gene

Red bar = *hpnP* (methylase) gene

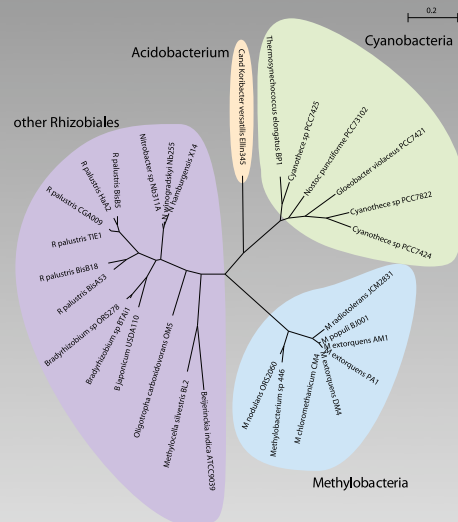
So far, there is a 100% correlation between the possession of *hpnP* and the ability to make 2-MeBHPs in tested strains



What is the root of the HpnP tree?

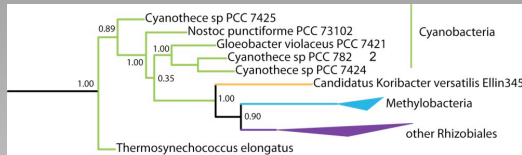
Maximum likelihood tree inferred using PhyML; Muscle alignment

Use primers to get more sequences, environmental samples and bacteria not yet tested: future work

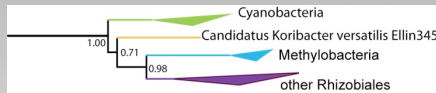


The root is (presently) ambiguous!

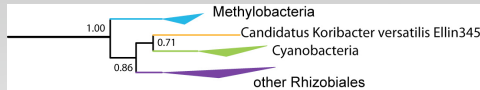
Topology A: ancestral cyanobacterial



Topology B: unresolved



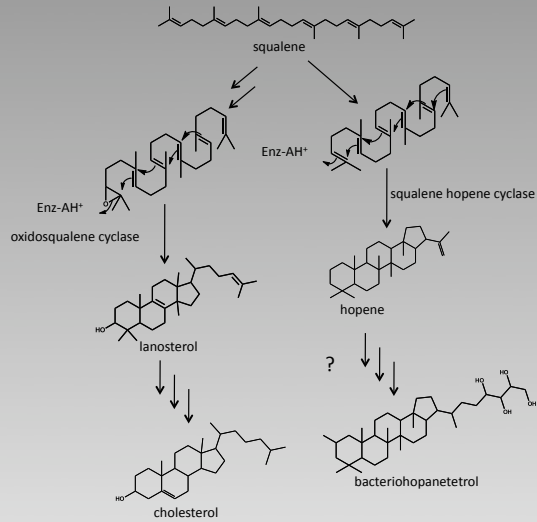
Topology C: ancestral a-proteobacterial



Criteria for a robust biomarker

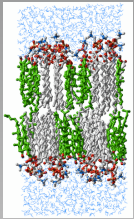
1. It must be indigenous to the rocks it is meant to represent
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Hopanoids: sterols in bacteria?



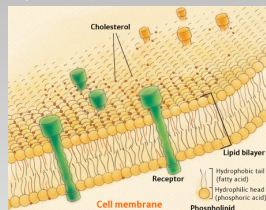
Sterols in eukaryotic membranes

membrane fluidity and integrity



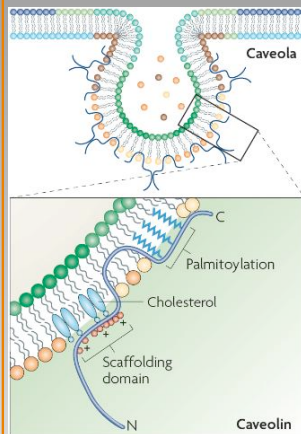
Smondyrev A & Berkowitz ML. (2009) *Biophys J* 77: 2075-2089

protein localization



Kobayashi T. (2009) *Riken Research Frontlines* 4(4)

membrane curvature

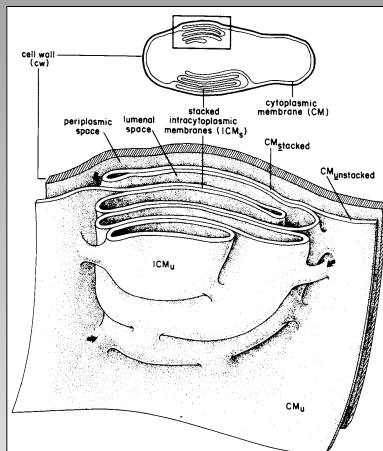


Parton RG & Smons K. (2007) *Nat Rev Mol Cell Biol* 8(3): 185-194

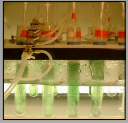
Do hopanoids localize to particular membranes?



Do hopanoids localize to particular membranes?



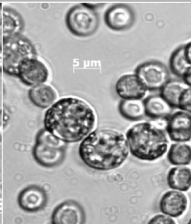
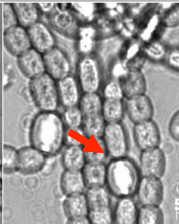
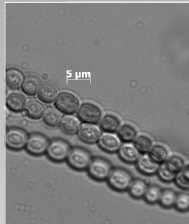
Nostoc punctiforme: A model system for cellular differentiation



Vegetative

Heterocyst

Akinete



N₂-fixation

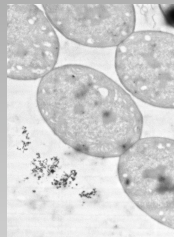
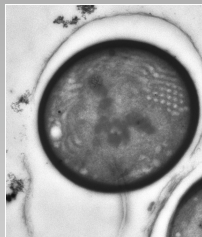
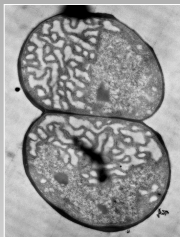
Stress resistant

Membrane architecture changes during cellular differentiation

Vegetative

Heterocyst

Akinete



↑ cell envelope

↓ in thylakoid

Does hopanoid content/localization change accordingly?

Hopanoids predominantly localize to the outermembrane of akinetes

Cytoplasmic Membrane

0

Akinetes can develop when cells are grown in the absence of light. 2-MeBHP record could be entirely decoupled from oxygenic photosynthesis!

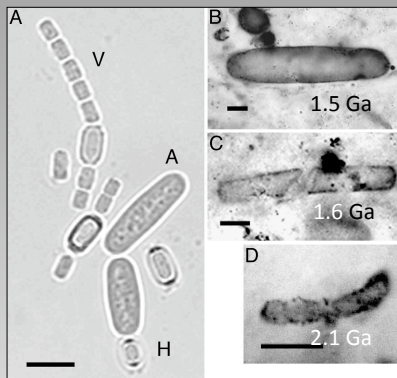
1
Vegetative

2
Heterocyst

3
Akinete

Doughty *et al.* (2010) *Geobiology*

Akinete fossils are ancient



Tomitani *et al.* (2004) *PNAS*

SUMMARY

- 2-MeBHPs are produced by diverse bacteria
- We cannot yet say which type of organism “invented” the ability to make 2-MeBHPs
- Cellular localization and other functional studies suggest they play no role in (oxygenic) photosynthesis
- 2-MeBHPs are not good biomarkers of oxygenic photosynthesis

Acknowledgements



Sky



Alex



Roger



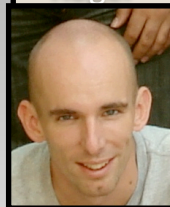
Maureen
Coleman



Dave
Doughty



Paula
Welande
r



Ryan

HIMI, NASA, NSF