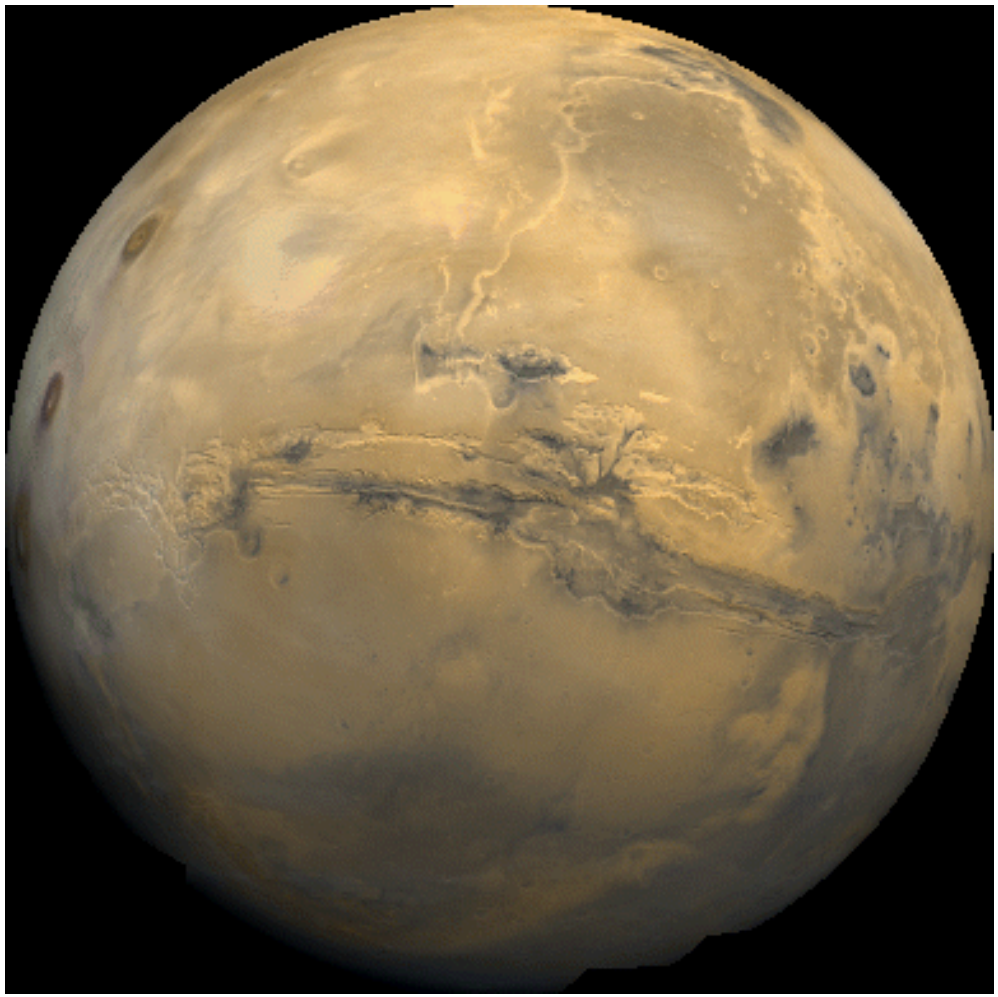
12.007 Geobiology
Spring 2009



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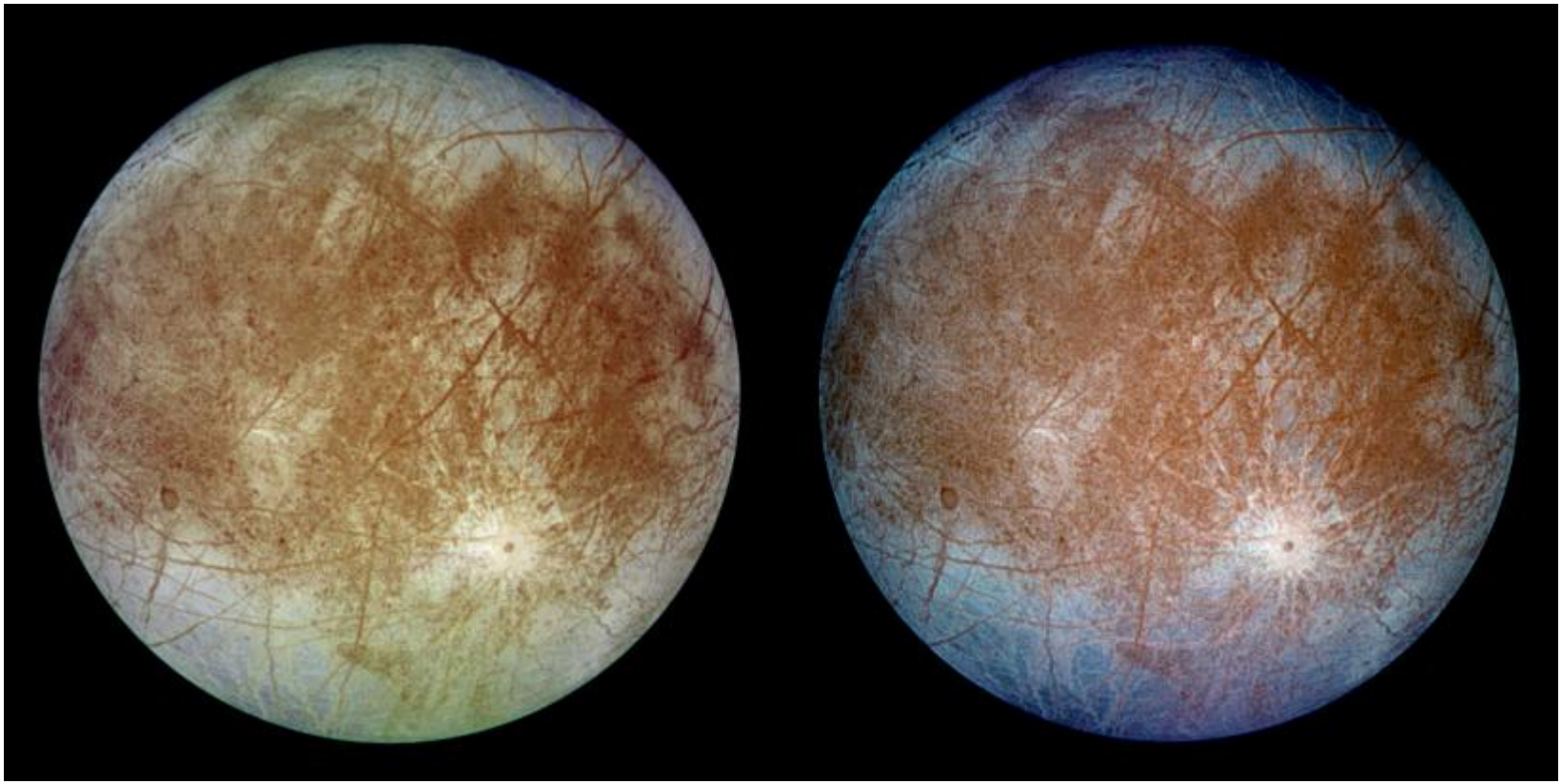

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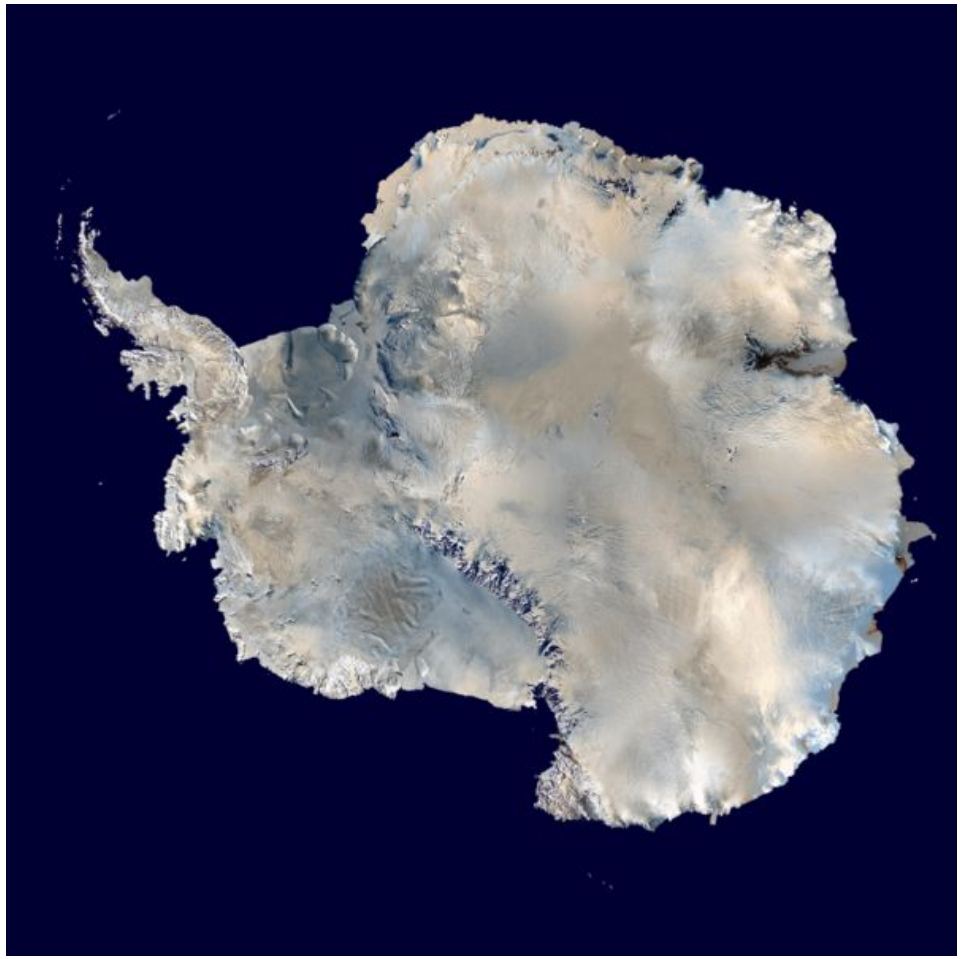

http://visibleearth.nasa.gov/view_rec.php?id=2433

Endolithic Microorganisms in the Antarctic Cold Desert

E. Imre Friedmann

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Please see: E. Imre Friedmann, "Endolithic Microorganisms in the Antarctic Cold Desert" *Science* 26 February 1982: Vol. 215. no. 4536, pp. 1045 - 1053.

The Effects of Freezing and Desiccation on Photosynthesis and Survival of Terrestrial Antarctic Algae and Cyanobacteria

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Please see: Figure 1 and 10 in Martin C. Davey "The effects of freezing and desiccation on photosynthesis and survival of terrestrial Antarctic algae and cyanobacteria" *Polar Biology* Vol. 10 no. 1, pp. 29 - 36.

The Effects of Freezing and Desiccation on Photosynthesis and Survival of Terrestrial Antarctic Algae and Cyanobacteria

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Please see: Figure 4 and 6 in Martin C. Davey "The effects of freezing and desiccation on photosynthesis and survival of terrestrial Antarctic algae and cyanobacteria" *Polar Biology* Vol. 10 no. 1, pp. 29 - 36.

Colwellia psychrerythraea

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Ice-active substances associated with Antarctic freshwater and terrestrial photosynthetic organisms

JAMES A. RAYMOND1* and CHRISTIAN H. FRITSEN*

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Please see: Figure 1 in James A. Raymond and Christian H. Fritsen "Ice-active substances associated with Antarctic freshwater and terrestrial photosynthetic organisms" *Antarctic Science* (2000), 12:4:418-424.

ICE-NUCLEATION PROTEINS AND ANTIFREEZE SUBSTANCES

Deinococcus radiodurans

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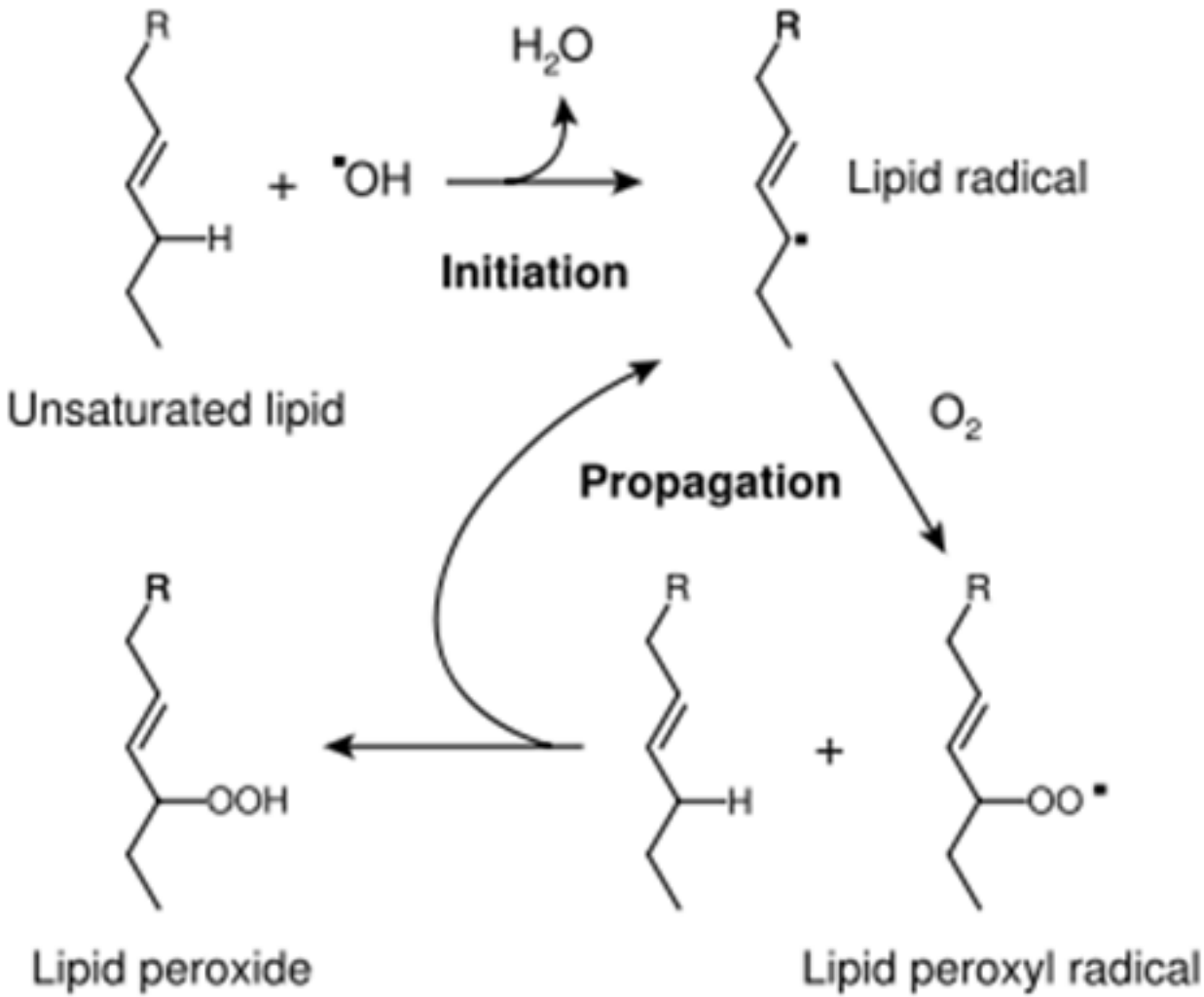
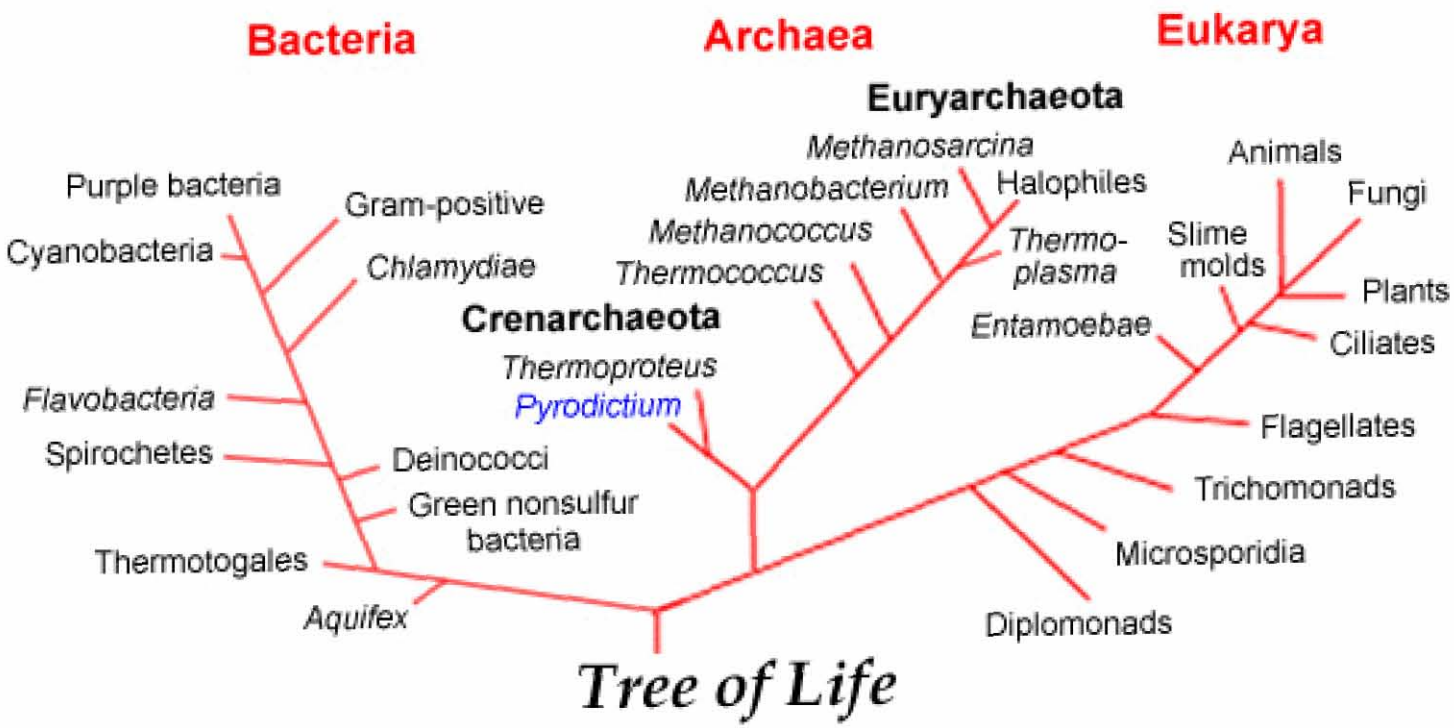
Please see:
http://www.scifun.ed.ac.uk/card/images/facts/d_radiodurans.jpg

Lipid radical formation



Accumulation of Mn(II) in Deinococcus radiodurans Facilitates Gamma-Radiation Resistance

Please see:
Table 1 in M. J. Daly, *et al* "Accumulation of Mn(II) in Deinococcus radiodurans Facilitates Gamma-Radiation Resistance" *Science* 5 November 2004: Vol. 306. no. 5698, pp. 1025 - 1028.


Bacteria
Archaea
Eukarya
Euryarchaeota
Methanosarcina
Methanobacterium
Halophiles
Methanococcus
Thermo-
plasma
Thermococcus
Crenarchaeota
Thermoproteus
Pyrodictium
Animals
Fungi
Slime
molds
Plants
Entamoebae
Ciliates
Purple bacteria
Gram-positive
Cyanobacteria
Chlamydiae
Flavobacteria
Spirochetes
Deinococci
Green nonsulfur
bacteria
Thermotogales
Aquifex
Flagellates
Trichomonads
Microsporidia
Diplomonads
Tree of Life

Life in hot springs

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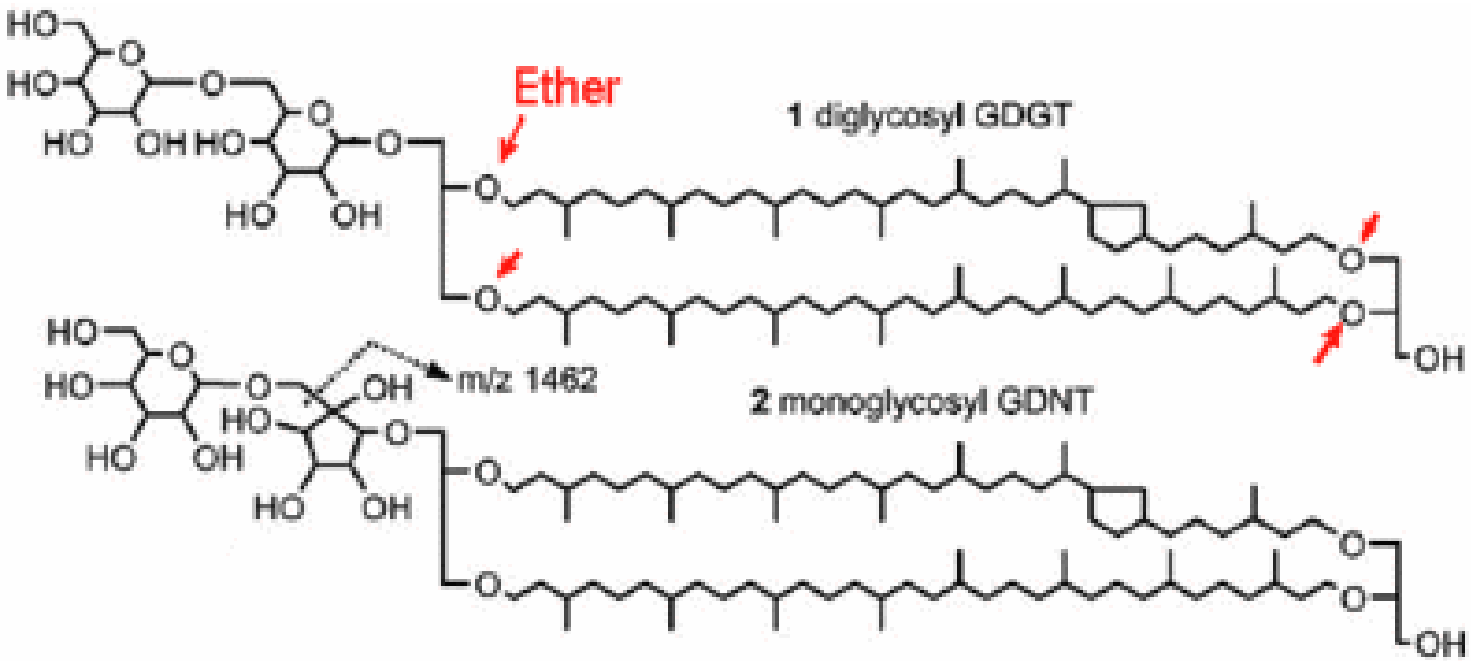
Please see: Lynn J. Rothschild and Rocco L. Mancinelli “Life in extreme environments" *Nature* 409, 1092-1101 (22 February 2001).

Sulfolobus solfataricus

pH 3, 80°C

Rotschild and Mancinelli, 2001



TETRAETHER LIPIDS

Life in hot springs

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Please see: Lynn J. Rothschild and Rocco L. Mancinelli “Life in extreme environments" *Nature* 409, 1092-1101 (22 February 2001).

Rotschild and Mancinelli, 2001

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Aquifex

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Please see: http://microbewiki.kenyon.edu/index.php/Image:Aquifex_environment.jpg

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Thermotoga

K. Stetter

Photosynthetic extremophiles

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Please see: Lynn J. Rothschild and Rocco L. “Mancinelli Life in extreme environments" *Nature* 409, 1092-1101 (22 February 2001).

Cyanidium – red alga that lives at pH <4 and T ~ 42°C

Rotschild and Mancinelli, 2001

Image removed due to copyright restrictions.

Cyanobacteria (*Synechococcus*) are found at pH > 4

Please see:
http://www.sciencedaily.com/images/2008/03/080311131851-large.jpg

Castenholz

Acid-mine drainage

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Please see:
http://upload.wikimedia.org/wikipedia/commons/8/8b/Acid_mine_drainage_2.jpg

$$H_2S + 2\ O_2 \rightarrow H_2SO_4$$
$$2\ H_2S + O_2 \rightarrow 2\ S^\circ + 2\ H_2O$$
$$2\ S^\circ + 3\ O_2 + 2\ H_2O \rightarrow 2\ H_2SO_4$$
$$Na_2S_2O_3 + 2\ O_2 + H_2O \rightarrow Na_2SO_4 + H_2SO_4$$
$$4\ Na_2S_2O_3 + O_2 + 2\ H_2O \rightarrow 2\ Na_2S_4O_6 + 4\ NaOH$$
$$2\ Na_2S_4O_6 + 7\ O_2 + 6\ H_2O \rightarrow 2\ Na_2SO_4 + 6\ H_2SO_4$$
$$2\ KSCN + 4\ O_2 + 4\ H_2O \rightarrow (NH_4)_2SO_4 + K_2SO_4 + 2\ CO_2$$
$$5\ H_2S + 8\ KNO_3 \rightarrow 4\ K_2SO_4 + H_2SO_4 + 4\ N_2 + 4\ H_2O$$
$$5\ S^\circ + 6\ KNO_3 + 2\ H_2O \rightarrow 3\ K_2SO_4 + 2\ H_2SO_4 + 3\ N_2$$
$$2\ FeS_2 + 2\ H_2O + 7\ O_2 \rightarrow 2\ FeSO_4 + 2\ H_2SO_4$$
$$4\ FeSO_4 + O_2 + 2\ H_2SO_4 \rightarrow 2Fe_2(SO_4)_3 + 2\ H_2O$$

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Thiobacillus ferooxidans

Please see:
http://www.torinoscienza.it/img/200x200/it/s00/00/0004/0000048c.png

Life around black smokers

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Please see: http://www.ceoe.udel.edu/kiosk/blacksmoker.html

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Please see: http://www.biologie.uni-regensburg.de/Mikrobio/Thomm/Bilder/bilder/pyrolobus-sec1.jpg

Pyrolobus fumarii

More hyperthermophiles

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http://www.sciencedaily.com/images/2005/10/051026083542.jpg

Pyrococcus furiosus

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Please see:
http://home.planet.nl/~evanhove/Microbiologie/JQuiz/thermus.jpg

Thermus aquaticus

Archean parasite at near-boiling temperatures

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Please see: http://www.mikrob.org.ua/gallery/mikrob_org_ua/Urzwerg.jpg

Nanoarcheon equitans on Ignicoccus

Life around black smokers

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http://www.sciencedaily.com/images/2005/02/050223124700.jpg

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Please see:
http://www.accessexcellence.org/BF/bf01/arp/bf01p3.php

A Hot-Vent Gastropod with Iron Sulfide Dermal Sclerites

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Please see: Anders Warén *et al* “A Hot-Vent Gastropod with Iron Sulfide Dermal Sclerites” *Science* 7 November 2003: Vol. 302. no. 5647, p. 1007.

Ware et al. 2003

Life at high pressures

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Please see:
http://microbewiki.kenyon.edu/images/e/e3/Photobacterium_profundum_flagella.JPG

Photobacterium profundum

Salt-loving organisms

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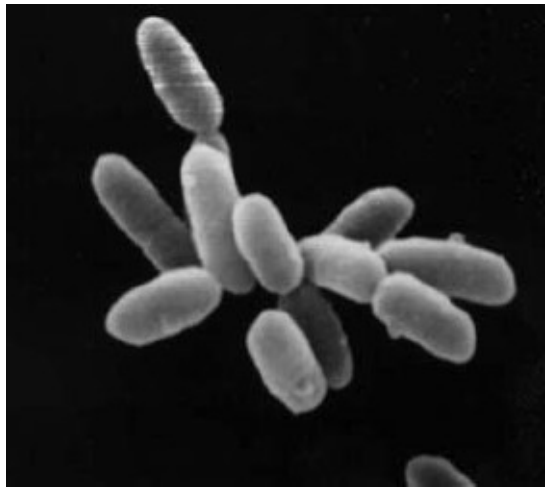
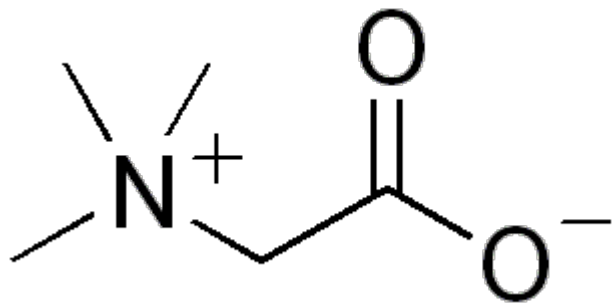


Image courtesy of NASA.

Halobacterium

Please see:
http://www.sas.upenn.edu/~pohlschr/



Glycine betaine

Bacteriorhodopsin

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Please see:
http://wpcontent.answers.com/wikipedia/commons/6/6b/Bacteriorhodopsin_conformation_change.gif

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Please see: Table 1 and Table 3 in Lynn J. Rothschild and Rocco L. Mancinelli “Life in extreme environments" *Nature* 409, 1092-1101 (22 February 2001).

Rotschild and Mancinelli, 2001