A Subzero high Arctic Methane Seep; Implications for Mars Methane?

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Are Cryoenvironments Active Microbial Ecosystems?


Eureka
Expedition Fjord
Montréal

Perennial Springs on Axel Heiberg Island

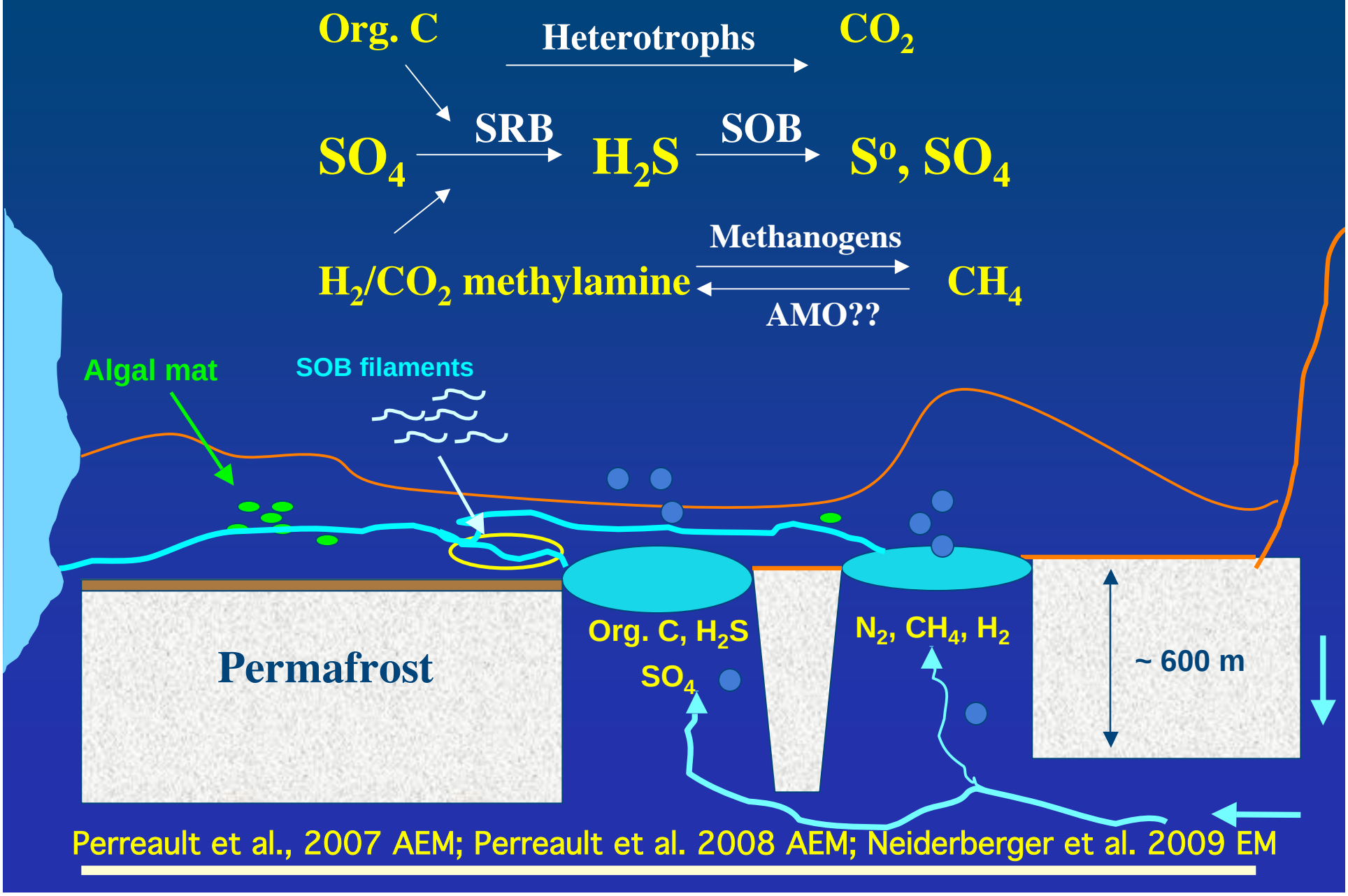
- 2 sets of springs: Gypsum Hill (GH) ~ 40 springs
  Colour Peak (CP) ~ 20 springs
- Only known example of cold springs in thick (~600m permafrost)
- Spring water discharge characteristics:
  - ~ 0 to 6°C; Neutral pH; anoxic (0.05-0.2 ppm O_2)
  - -283 to -375 mV ORP
  - ~7.5 (GH) and ~ 15.5 % (CP) NaCl
  - rich in S-compounds
    - 25-100 ppm sulfide ~ 2000–4000 mg/L sulfate

* Oligotrophic: undetectable DOC

Andersen *et al*. (2002) *J. Geophysical Research;* Perreault *et al*. (2007) *Appl. Environ. Microbiol*


GH-4

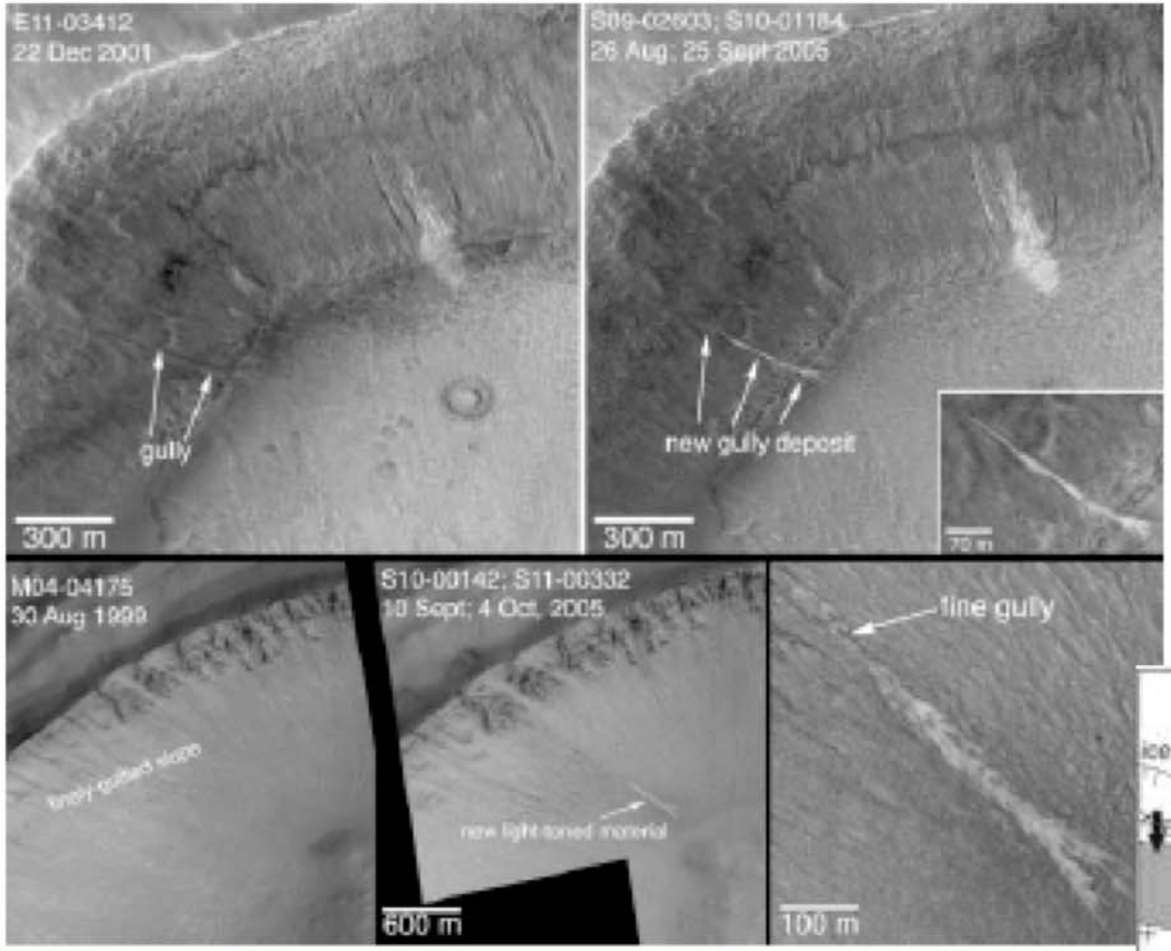
Cold Saline Springs Microbial Communities



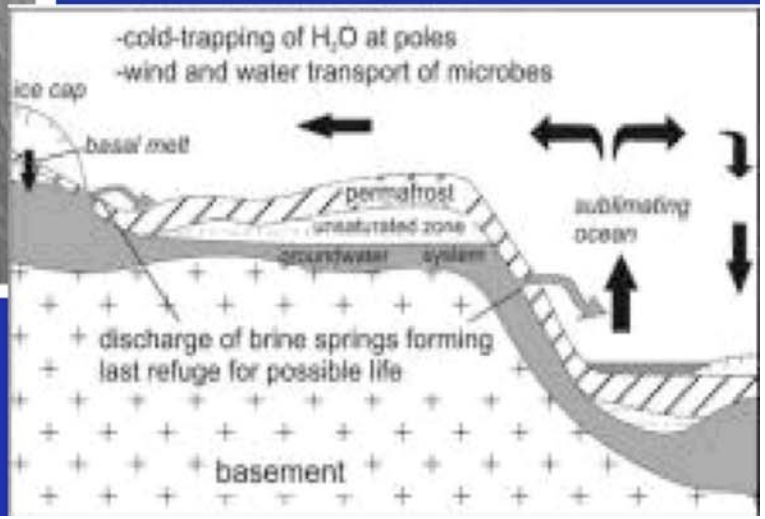
Perreault et al., 2007 AEM; Perreault et al. 2008 AEM; Neiderberger et al. 2009 EM

Present-Day Impact Cratering Rate and Contemporary Gully Activity on Mars

Science 314, 1573 (2006); Michael C. Malin, *et al.*



Grasby and Londrey 2007. *Astrobiology*



Large-scale spring deposits on Mars?

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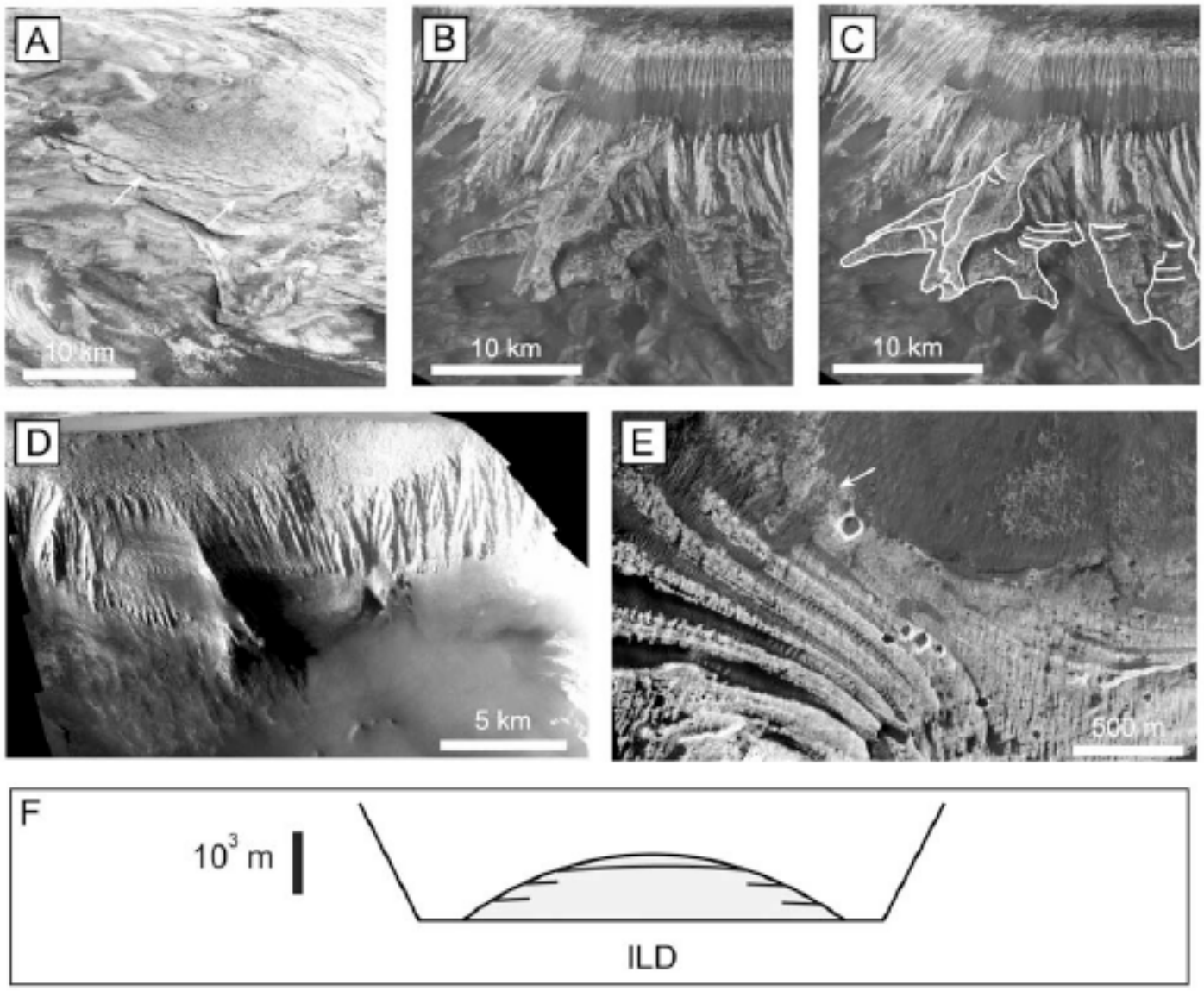


Figure 4. Valles Marineris LTDs: examples of candidate spring deposits, all in perspective view, draped on HRSC-derived DTM, except for Figures 4e and 4f. (a) Candor Mensa: the eroded mound-like relief


May 2007
Lost Hammer Spring
Annual Air Temperature -15ºC
Winter Temperatures -40 to -50ºC
Permafrost Temperature ~ -16ºC


July 2009


-4.8°C, ~23% NaCl, pH 6.3, DO 0.2 ppm, ORP -154 mV, H_2S, CH_4, H_2

Physical / Chemical Analyses of LH Spring

	2005 July	2006 July	2007 May	2008 April
Temp. (℃)	-4.8	-4.9	-4.7	-5.9
pH	6.3	5.96	6.37	7.38
DO (ppm)	0.2	0.1	n.d.	1.0
H_2S (ppm)	25-50	0-20	20-50	20-30
ORP (mV)	-154.0	-187.4	-159.0	-171.8
Conductivity (μS/cm)	n.d.	60761	116360	110992
TDS (g/L)	n.d.	241.72	175.0	176.0
Salinity (%)	23	26	22.4	22.1
Bacterial cells (FISH)	84.0%	79.2%	n.d.	n.d.
Archaeal cells (FISH)	3.8%	2.5%	n.d.	n.d.
ANME-1 cells (FISH)	3.4%	2.2%	n.d.	n.d.

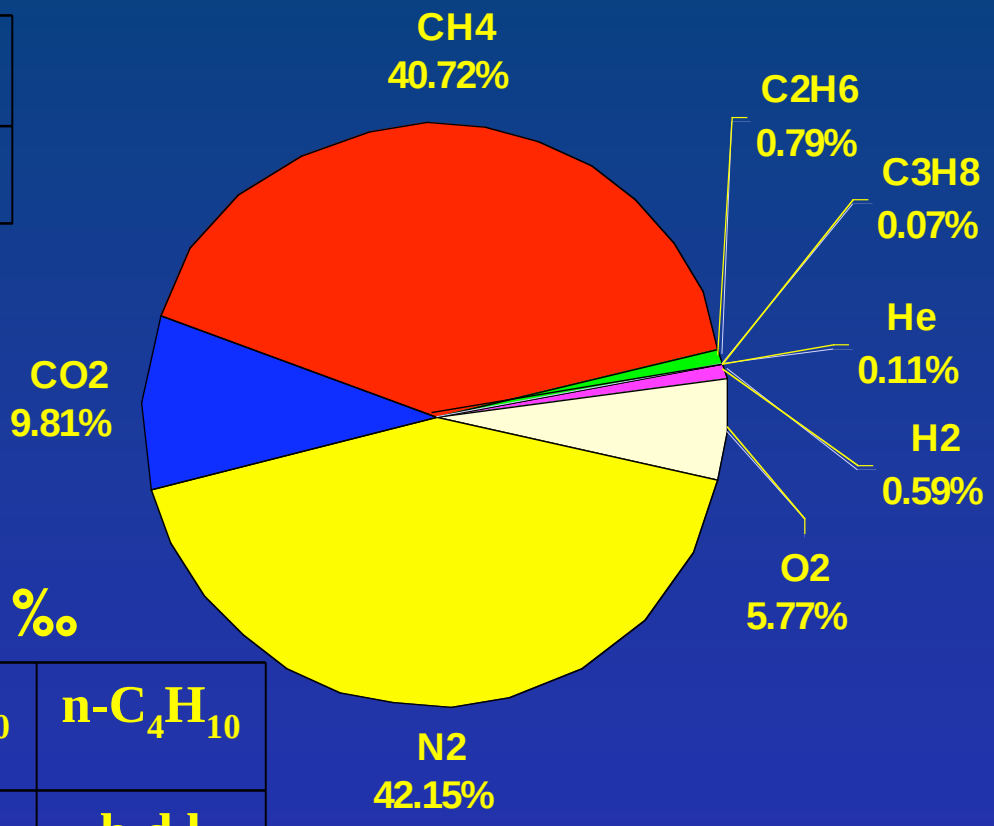

Methane Flux
~ 4060 g methane / year
~ 5970 L methane / year
~ 253 mol methane / year
C. Martineau

Gas Analyses of Lost Hammer (2005)

Hydrogen Isotopes ($\delta\ ^{2}H$) ‰

H_2	CH_4	C_2H_6	C_3H_8
b.d.l	-198	-171	b.d.l

Gas Composition



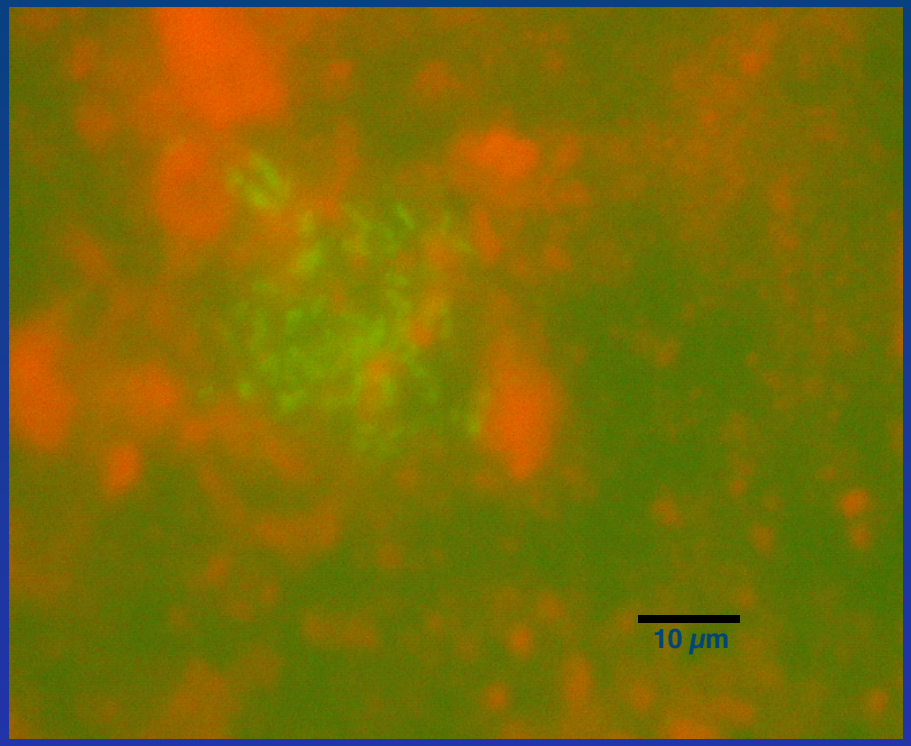
Carbon Isotopes ($\delta\ ^{13}C$) ‰

CO_2	CH_4	C_2H_6	C_3H_8	i-C_4H_{10}	n-C_4H_{10}
-26.2	-38.3	-28.0	-24.8	b.d.l	b.d.l

b.d.l = below detection level

B. Sherwood-Lollar

Microscopic Analyses of LH Sediments



Live/Dead stain of LH sediment

(green cells are 'live' = intact membrane)

Total cell counts (DTAF)

6.2 X 10^5 cells/g wet sediment

1.2 X 10^3 cells/ml pore water

Live/Dead cell counts

4.4 X 10^5 'live' cells/g of wet sediment

CARD-FISH

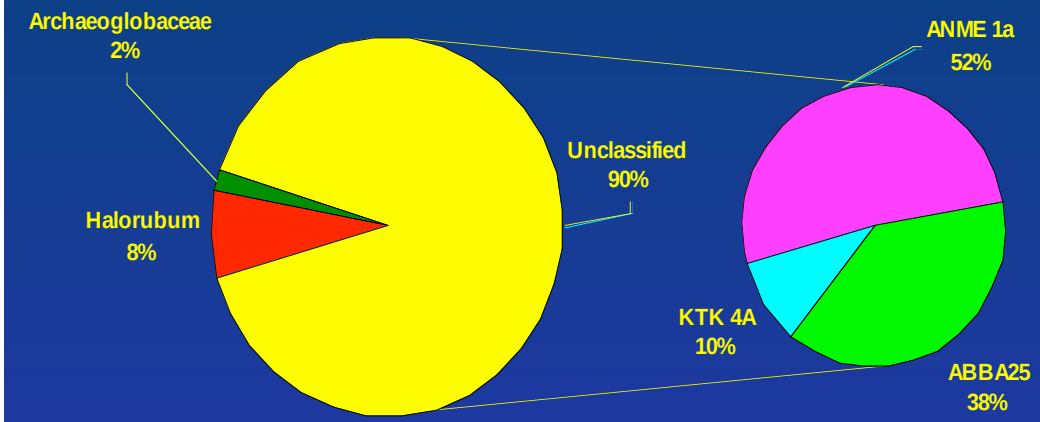
~ 80 % of total cell count = bacteria

~ 5 % of total cell count = archaea

~ 3 % of total cell count = ANME1

Molecular analyses of LH sediment

Archaea



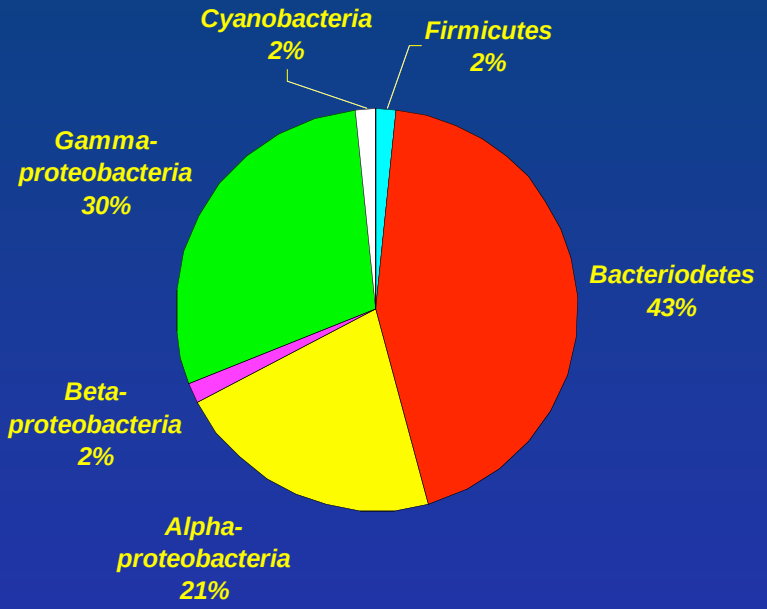
Unclassified clones: Closest relatives are clones from deep-sea sediment methane seeps (KTK 4A & ABBA25).

Dominated by clones closely related to

Anaerobic Methane (ANME) oxidizers clade 1a

Bacteria

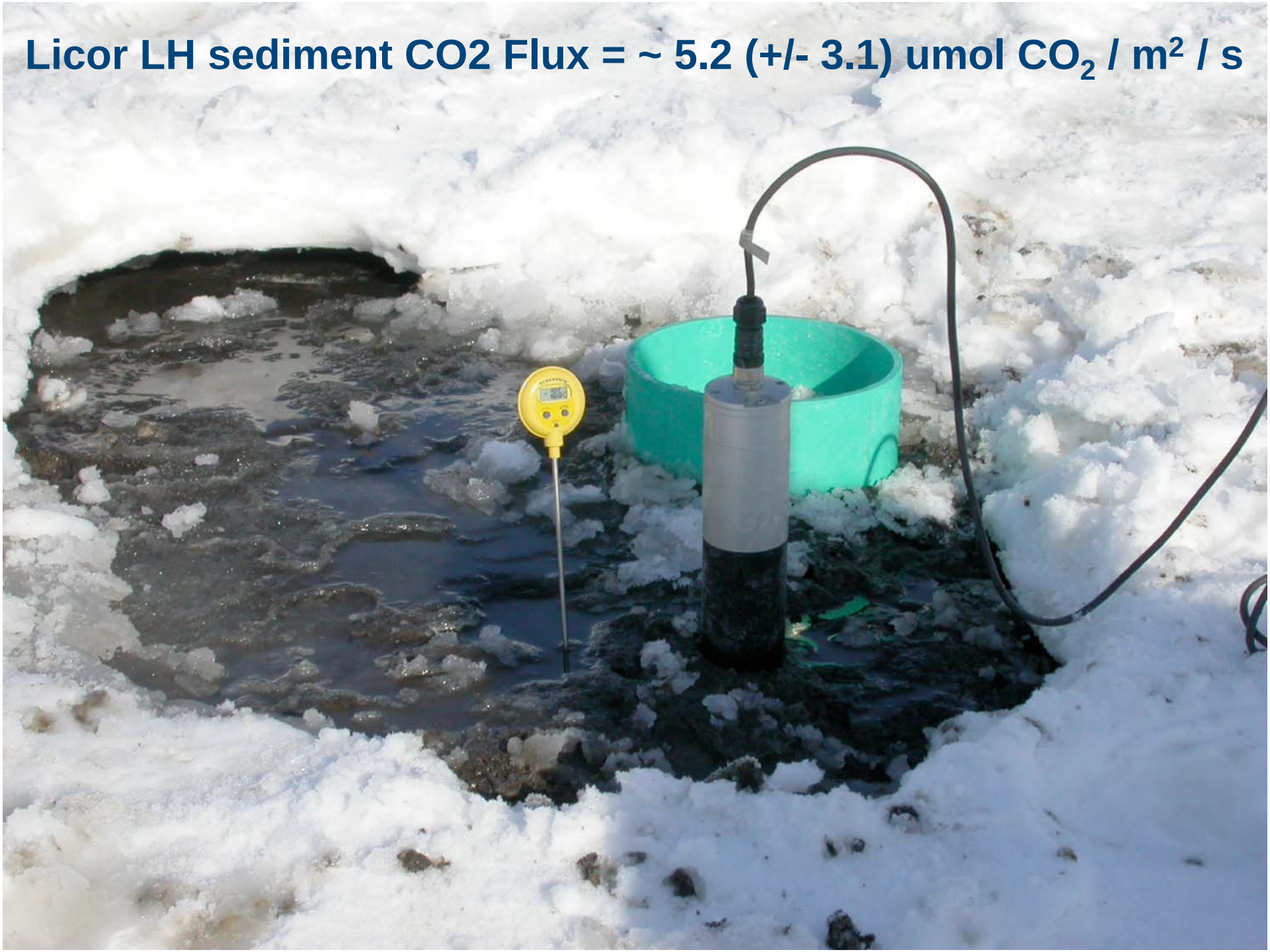
(detectable only by whole genome amplification)



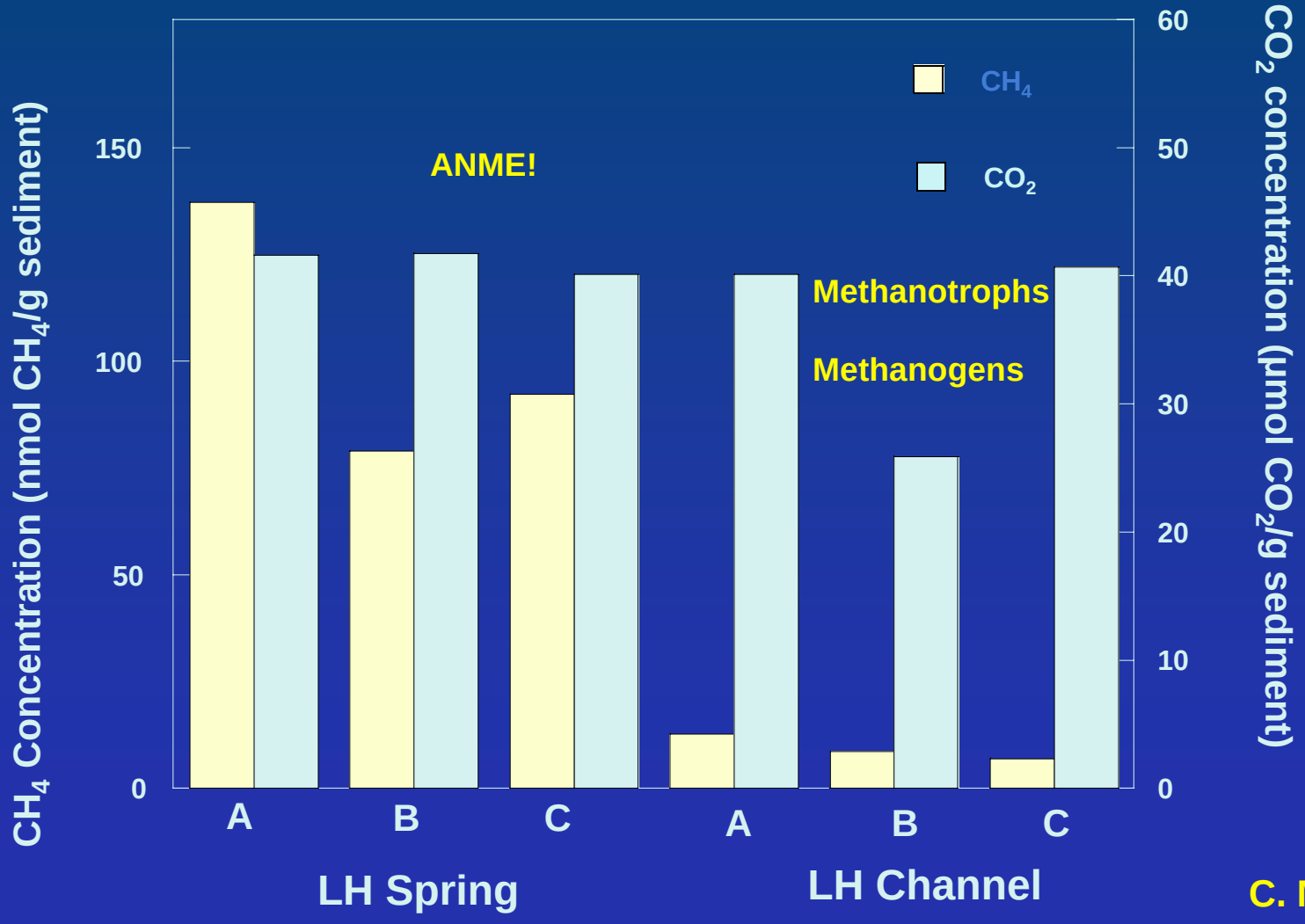
Phylotypes highly related to clones and/or isolates from polar terrestrial and marine environments --> *Nostoc*, *Gillisia*, *Marinobacter*, *Halomonas*, *Loktanella*

***Marinobacter* and *Halomonas* isolated in pure culture**

Licor LH sediment CO2 Flux = ~ 5.2 (+/- 3.1) umol CO_2 / m^2 / s



Methane and carbon dioxide concentration in LH spring and LH channel sediments

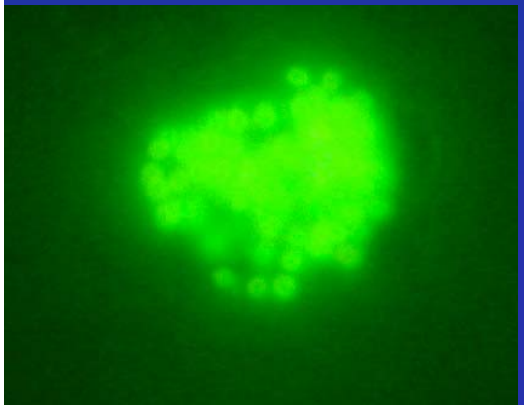


C. Martineau

CARD-FISH Enumeration

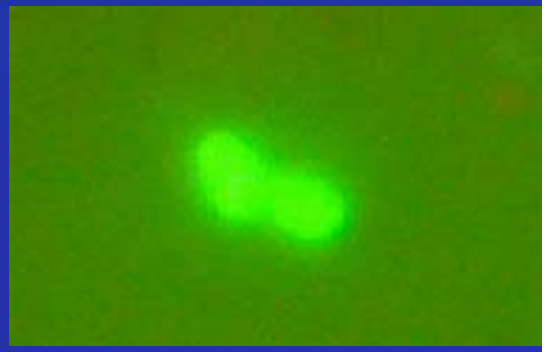
Samples	No. of Bacteria (cells/g)	No. of Archaea (cells/g)
C1 channel	5.25×10^{7}	3.48×10^{6}
C2 channel	4.22×10^{7}	4.30×10^{6}
CB channel	4.05×10^{7}	4.18×10^{6}
LH Spring	4.96×10^{5}	4.0×10^{4}

Numbers of *Bacteria* and *Archaea* by CARD-FISH in the three samples, C1, C2 and CB as well as the sample from Lost Hammer spring sediment (LH). CARD-FISH analyses were proceeded with *Bacteria* (EUB338) and *Archaea* (ARCH915) specific probes (Pernthaler and Pernthaler; 2007).



＜Bacteria from Sample C2

Archaea from Sample CB＞



Sub-zero, hypersaline Arctic methane seep: implications for Mars methane?

The LH site provides a model of how a methane seep can form in a thick permafrost cryoenvironment and provides a mechanism that could possibly be contributing to Martian methane plumes?

The methane, regardless of origin, could act as energy and carbon sources for sustaining microbial life by AMO metabolism similar to the ANME-1 archaea ---> $CH_4 + SO_4 \rightarrow CO_2 + HS^-$

Although methanogens are considered prime candidates for microbial life on Mars, AMO microorganisms could also exist in analogous Mars cryoenvironments.

An active microbial ecosystem (low biomass, very low diversity) inhabits this extreme hypersaline, cryoenvironment.