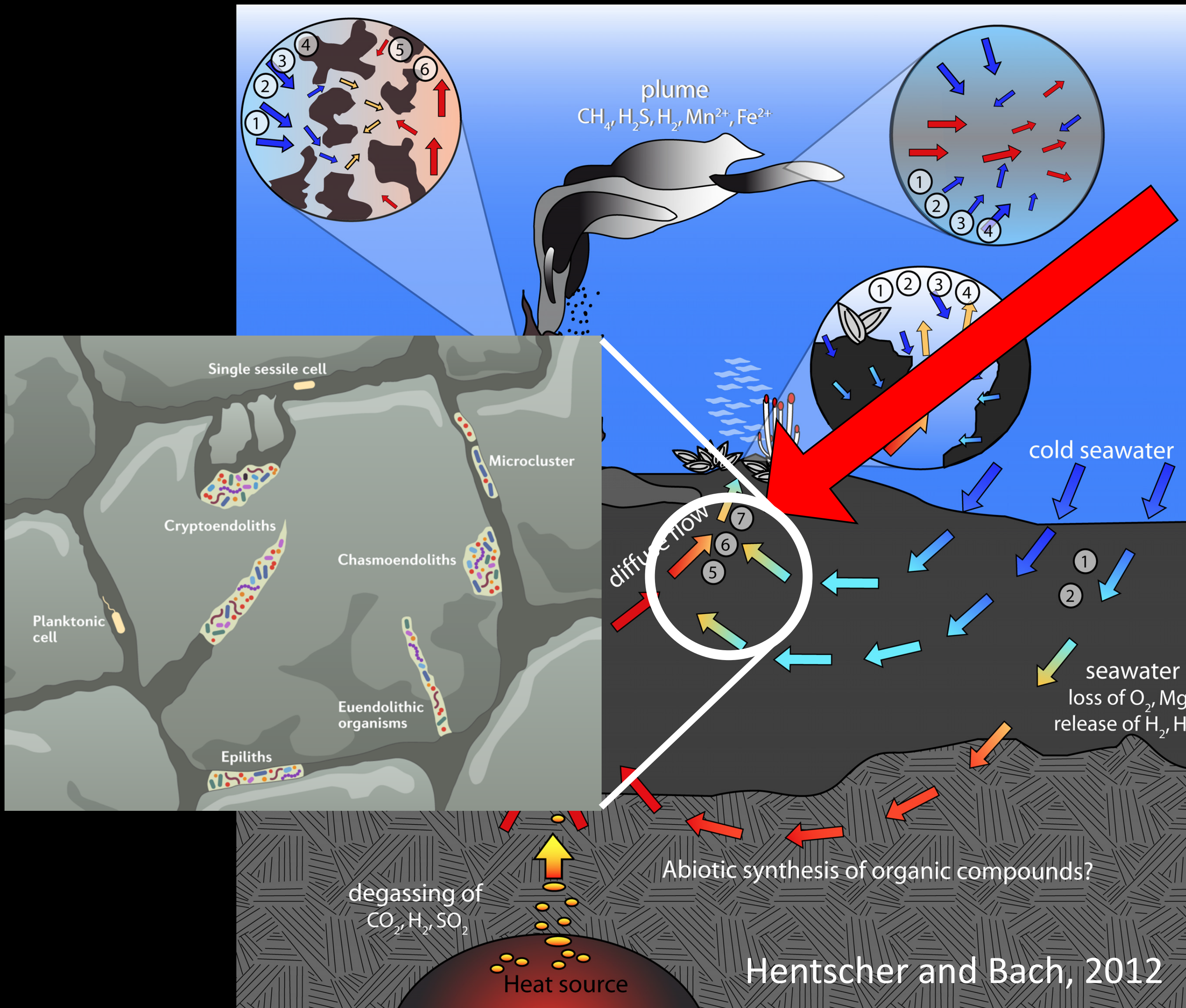
Sizing up the Deep-sea Vent Subseafloor Biosphere

Production, Standing Stock, and Turnover

Stefan Sievert
Biology

Deep-Sea Hydrothermal Vent System



Diffuse-Flow or Warm-Water Vent:

Mixing of hydro-thermal fluids with seawater below the seafloor

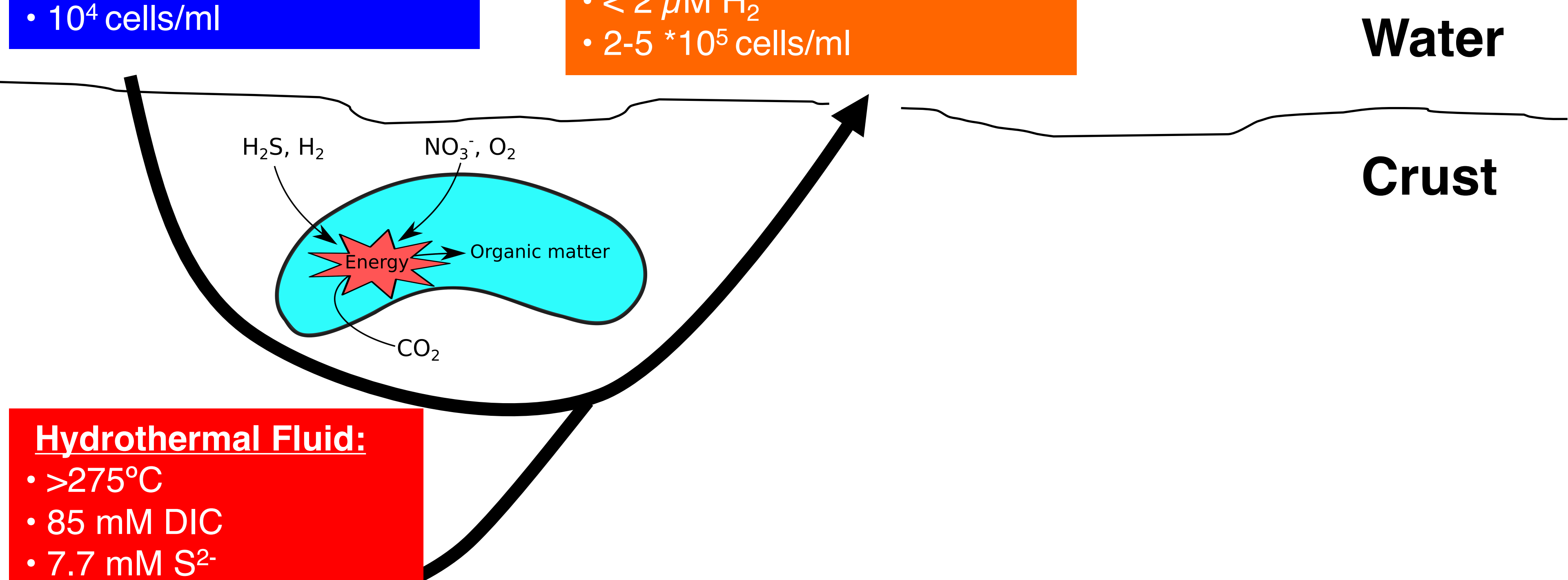
Providing conditions conducive for chemoautotrophs growing as biofilms in cracks and crevices of ocean crust

Ambient Deep-Sea Water:

- 2°C
- 2.3 mM DIC
- 115 μM O_2
- 40 μM NO_3^-
- 0 μM S^{2-}, H_2
- 10^4 cells/ml

Crab Spa Diffuse-Flow Fluid:

- 14:1 ADSW:HT
- 25°C
- 8.2 mM DIC
- < 3.6 μM O_2
- < 6 μM NO_3^-
- ~12 μM NH_4^+
- ~ 200 μM S^{2-}
- < 2 μM H_2
- 2-5 *10^5 cells/ml



Hydrothermal Fluid:

- >275°C
- 85 mM DIC
- 7.7 mM S^{2-}
- 410 μM H_2
- 0 μM O_2
- 0 μM NO_3^-
- 0 Cells

Based on McNichol et al., 2016, DSR-I; 2018, PNAS

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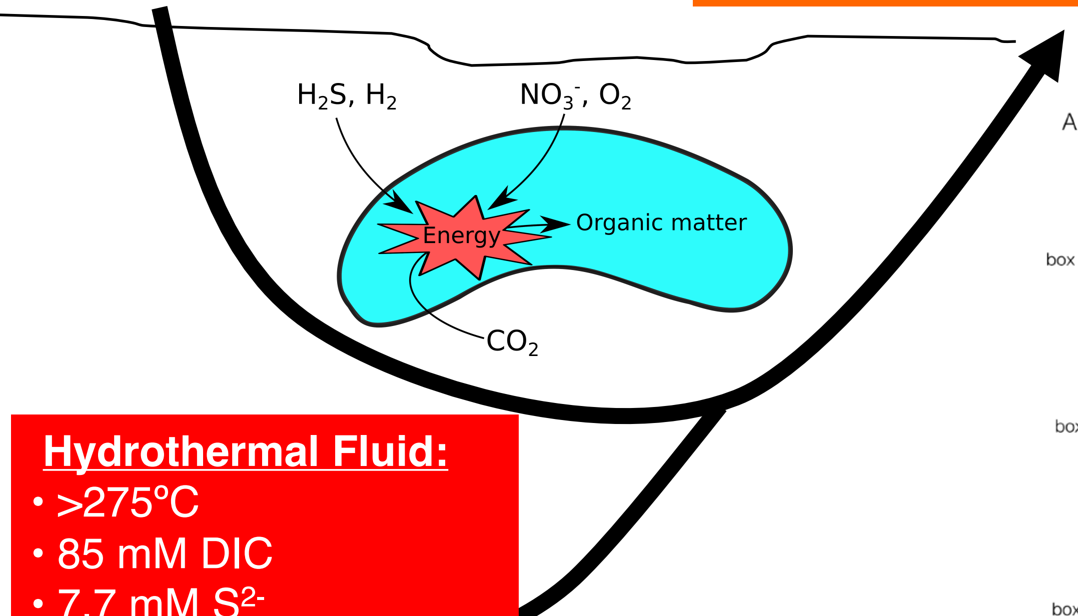
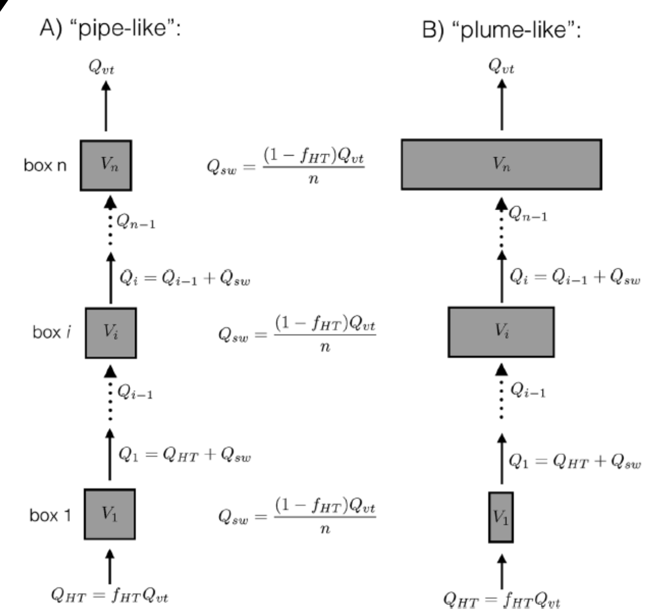
Water

Crust





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Stewart *et al.*, 2019, ISME J

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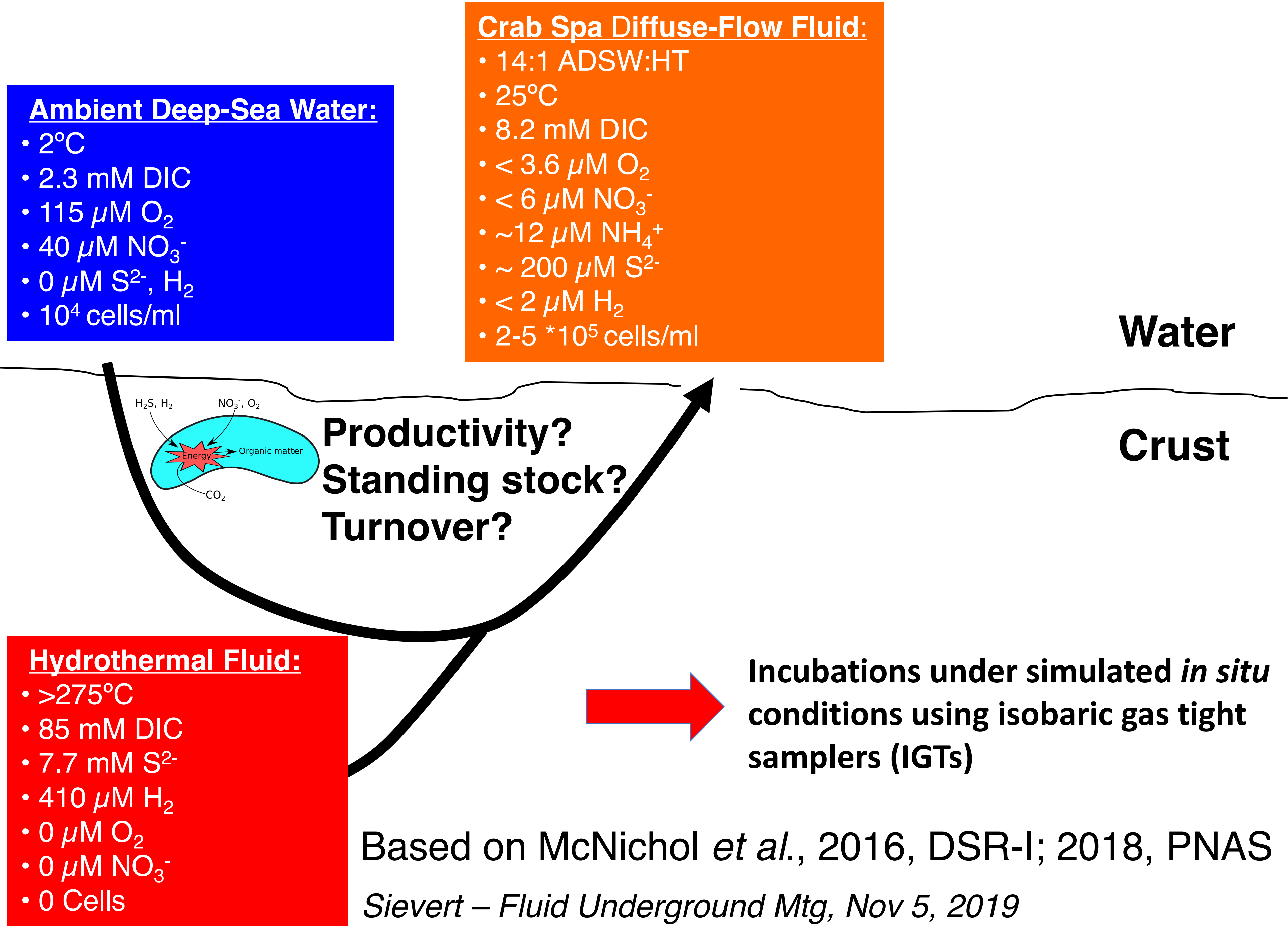
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Water
Crust
H_2S, H_2
NO_3^-, O_2
Energy
Organic matter
CO_2
Productivity?
Standing stock?
Turnover?
Hydrothermal Fluid:
• >275°C
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Incubations under simulated *in situ* conditions using isobaric gas tight samplers (IGTs)
Based on McNichol *et al.*, 2016, DSR-I; 2018, PNAS
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Primary productivity below the seafloor at deep-sea hot springs

Jesse McNichol[a,1,2], Hryhoriy Stryhanyuk[b], Sean P. Sylva[c], François Thomas[a,3], Niculina Musat[b], Jeffrey S. Seewald[c], and Stefan M. Sievert[a,1]

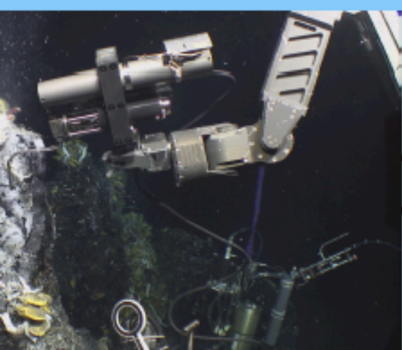
[a]Biology Department, Woods Hole Oceanographic Institution, Woods Hole, MA 02543; [b]Department of Isotope Biogeochemistry, Helmholtz Centre for Environmental Research – Umweltforschungszentrum (UFZ), 04318 Leipzig, Germany; and [c]Marine Chemistry and Geochemistry Department, Woods Hole Oceanographic Institution, Woods Hole, MA 02543

Edited by David M. Karl, University of Hawaii, Honolulu, HI, and approved May 16, 2018 (received for review March 13, 2018)

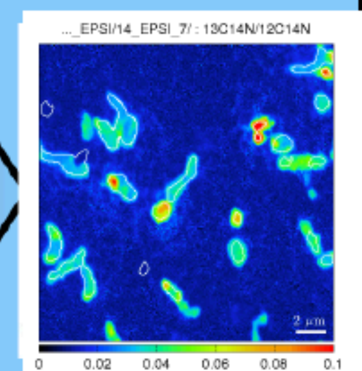
Jesse McNichol

Sample Fluids → Return under pressure → Add substrates ^{13}C-CO_2 → Monitor growth

IGT



nano-SIMS



SHIPBOARD INCUBATIONS WITH HYDROTHERMAL FLUIDS UNDER SIMULATED *IN SITU* CONDITIONS

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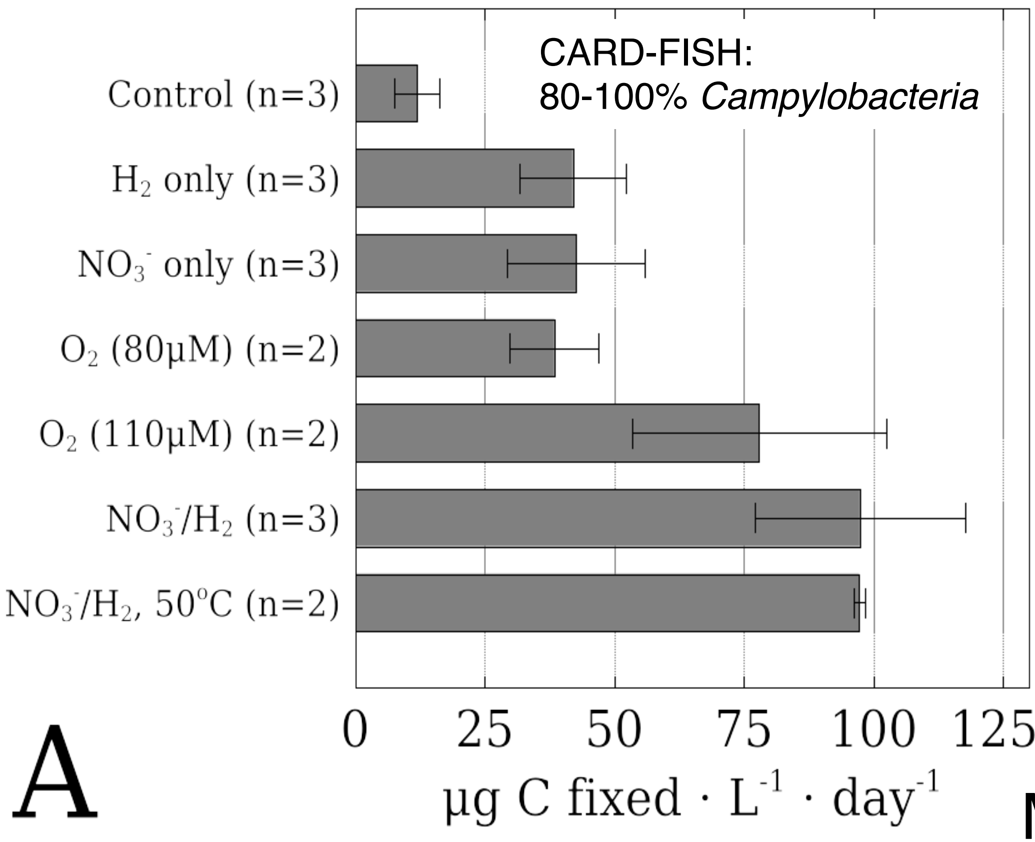
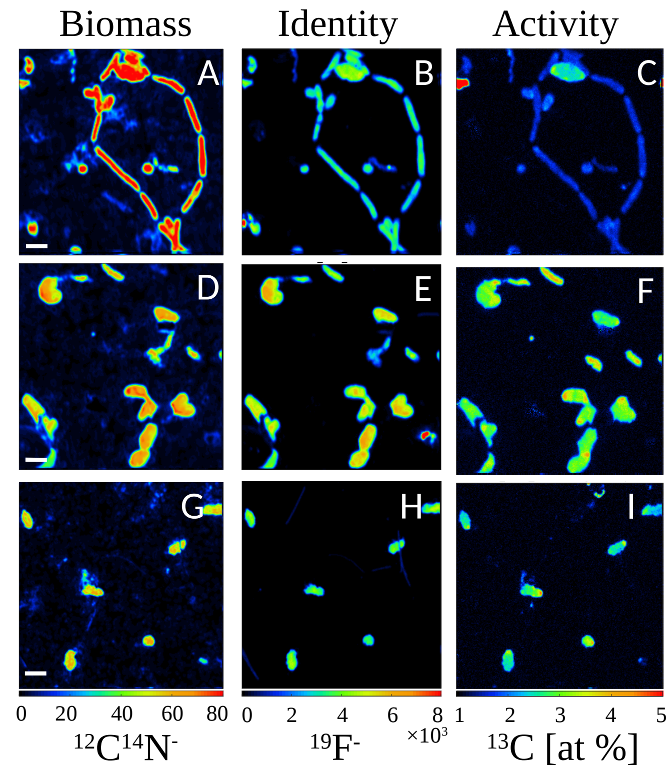
Primary Productivity Inferred from Incubations at *In Situ* Temperature and Pressure Using by HISH-SIMS

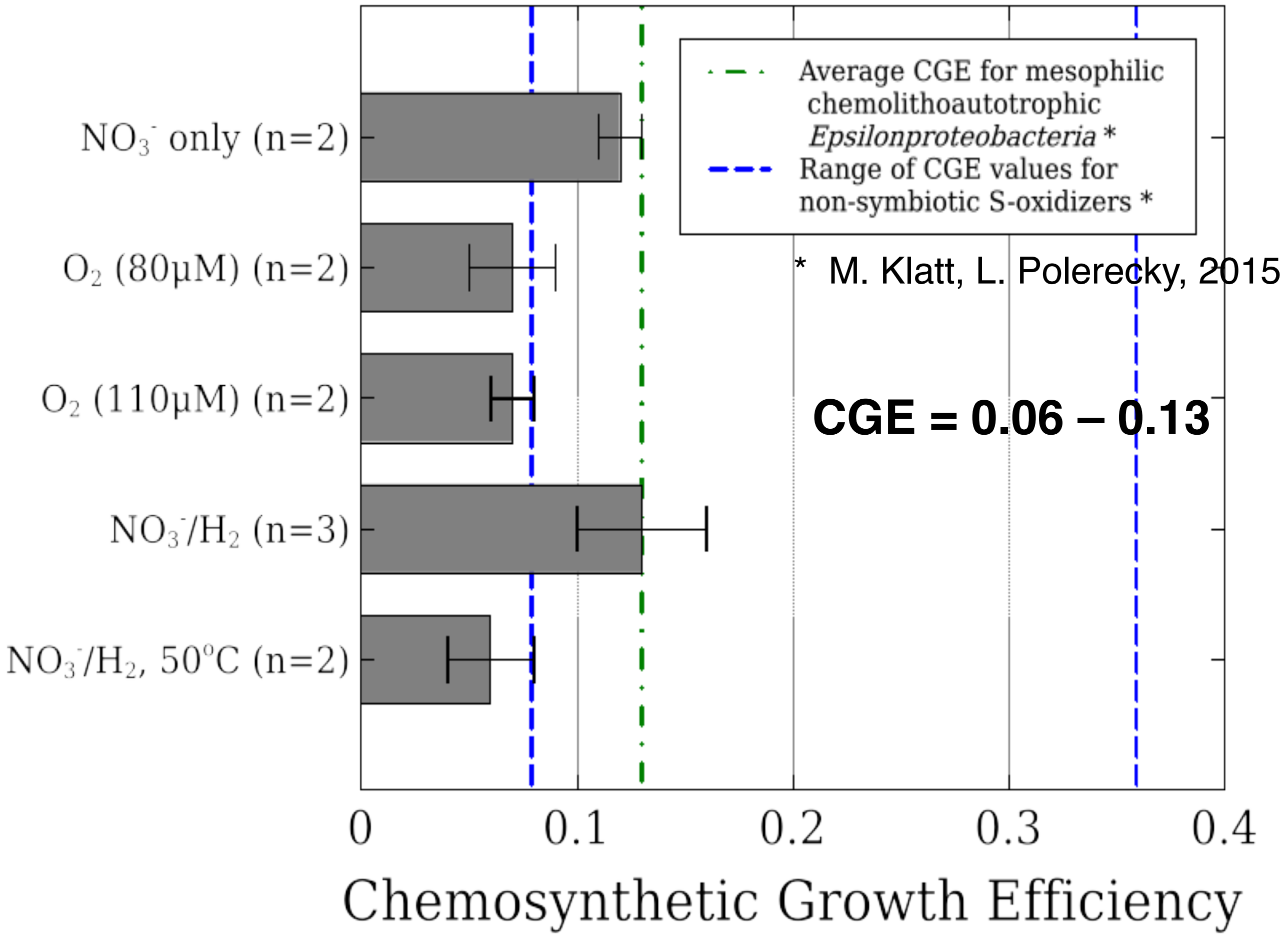




McNichol *et al.*, 2018, PNAS

- *Campylobacteria* dominate carbon fixation!
- Amendments increase carbon fixation

Fraction of Electrons from Dissimilatory Reactions Used for Carbon Fixation: Chemosynthetic Growth Efficiency (CGE)



McNichol *et al.*, 2018, PNAS

$$CGE = \frac{Eq_{CFIX}}{(Eq_{CFIX} + Eq_{DISS})}$$

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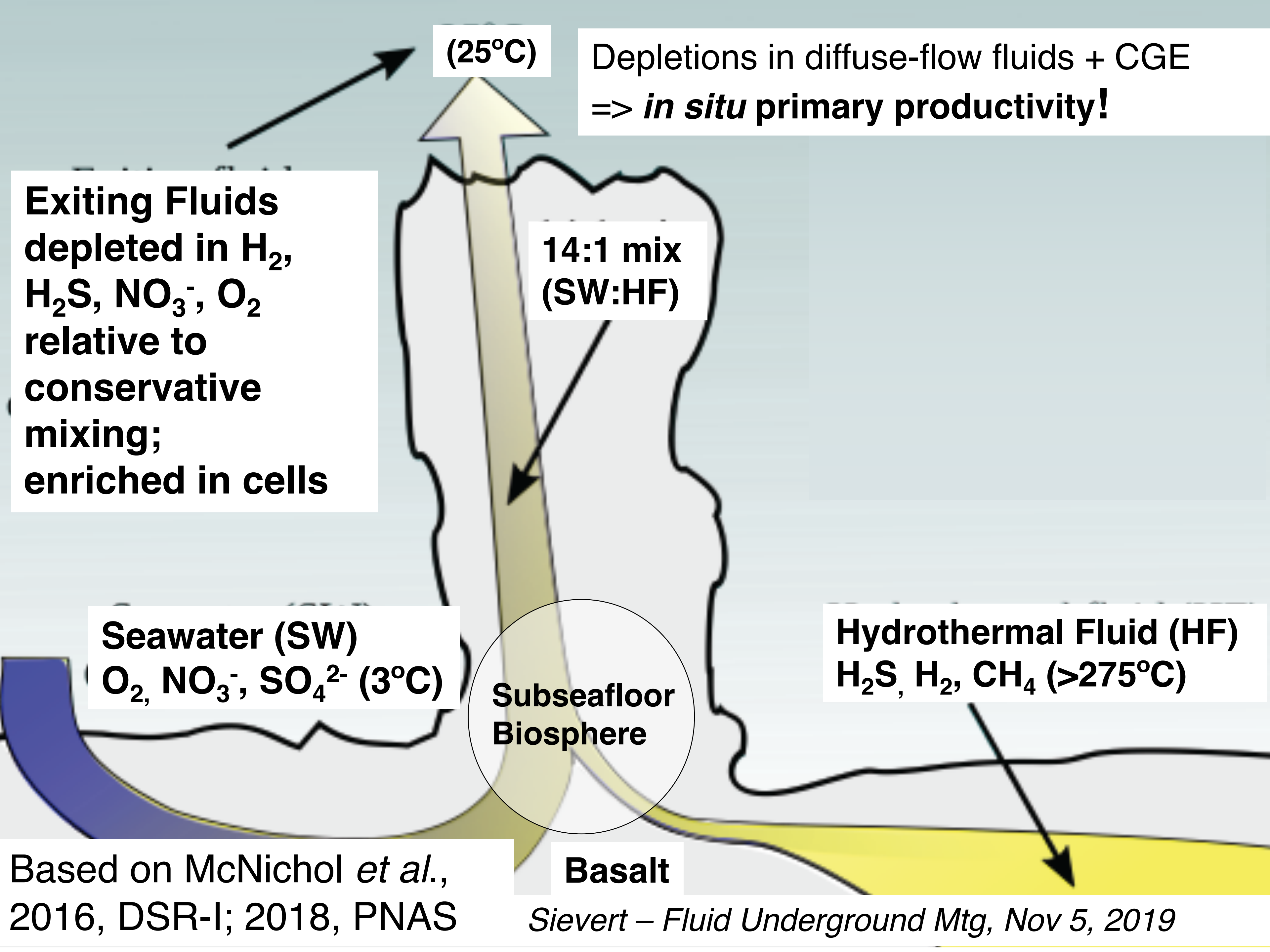
(25ºC)
Depletions in diffuse-flow fluids + CGE
=> *in situ* **primary productivity!**
Exiting Fluids depleted in H_2, H_2S, NO_3^-, O_2 relative to conservative mixing; enriched in cells
14:1 mix (SW:HF)
Seawater (SW)
O_2, NO_3^-, SO_4^{2-} (3ºC)
Subseafloor Biosphere
Hydrothermal Fluid (HF)
H_2S, H_2, CH_4 (>275ºC)
Basalt
Based on McNichol *et al.*, 2016, DSR-I; 2018, PNAS
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Determination of Rates of Various Chemosynthetic Reactions

Summary of rates of change in chemical concentrations and cell densities.

	Incubation condition						
	Control (24 °C)	H_2 addition (24 °C)	NO_3^- addition (24 °C)	O_2 (80 μM) (24 °C)	O_2 (110 μM) (24 °C)	NO_3^-/H_2 (24 °C)	NO_3^-/H_2 (50 °C)
H_2S consumption (fmol cell^{-1} d^{-1})	475.8	434.3	598.4			527.1	
	797.1	681.6	506.7	483.2	494.5	510.6	312.5
	642.7	238.6	481.7	776.5	523.3	458.1	753.9
H_2S production (fmol cell^{-1} d^{-1})		77.8					
	N.A.	51.7	N.A.	N.A.	N.A.	N.A.	N.A.
		30.6					
H_2 consumption (fmol cell^{-1} d^{-1})		87.9				418.1	
	N.A.	138.5	N.A.	N.A.	N.A.	351.8	1535.2
		49.6				508.4	989.7
O_2 consumption (fmol cell^{-1} d^{-1})	N.R.	N.R.	N.R.	604.4	290.4	N.R.	N.R.
				347.2	608.5		
NO_3^- consumption (fmol cell^{-1} d^{-1})			57.5			229.9	
	N.R.	N.R.	65.0	N.R.	N.R.	193.0	654.7
			87.9			187.7	522.2
NH_4^+ production (fmol cell^{-1} d^{-1})	−42.9	6.1	0			37.8	
	−31.8	−5.7	13.5	−12.2	−14.1	33.0	229.5
	4.9	6.4	37.3	−15.2	−21.3	41.9	245.7
% NO_3^- to DNRA at t_{end}	0	27.9	0			17.5	
	0	0	11.8	0	0	19.4	55.2
	48.5	63.2	21.1	0	0	18.2	53.1
Initial cell density ($\times 10^5$ cells mL^{-1})	2.3	4.1	2.4			2.7	
	9.8	3.1	5.1	1.9	1.3	2.0	1.0
	2.8	4.7	4.1	1.9	1.7	1.7	1.0
Maximum cell density ($\times 10^5$ cells mL^{-1})	6.8	5.0	7.1			8.2	
	5.0	6.3	6.3	4.7	10.0	9.2	11.2
	4.6	8.8	6.1	4.8	9.1	7.5	9.5

McNichol *et al*, *Deep-Sea Research I:* 115 (2016) 221–232

- Using *in situ* consumption and rates per cell allows calculation of **standing stock**
- **Biomass residence time** can be inferred from CGE-derived productivity and standing stock assuming steady state

Constraints on Subseafloor Productivity, Standing Stock, and Turnover from Measurements of CGE

Parameter	Lower bound	Upper bound	Units
Absolute carbon fixation rates[1]	17.3	321.4	$\mu g\ C \circ L^{-1} \circ day^{-1}$
Chemosynthetic growth efficiency[1]	0.06	0.13	Fraction electron equivalents to Carbon fixation
Estimated in situ carbon fixation[2]			
(per L Crab Spa mixed fluid):	104	253	$\mu g\ C \circ L^{-1}$
(per L Crab Spa end-member fluid):	1.4×10^{3}	3.5×10^{3}	
Estimated annual productivity[3] of:			
Crab Spa vent[4]	6.1×10^{3}	1.5×10^{4}	$g\ C \circ y^{-1}$
Surrounding vent field[5]	3.8×10^{6}	9.3×10^{6}	
Global diffuse-flow vents[6]	4.5×10^{10}	1.4×10^{12}	
Standing stock[7], Crab Spa	28.6	NA	g C
Biomass residence time[8], Crab Spa	17	41	hours
Global standing stock[6]	1.4×10^{9}	2.7×10^{9}	g C

McNichol *et al.*, 2019, PNAS

Synthesis

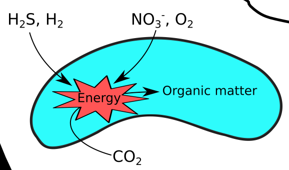
Ambient Deep-Sea Water:
- 2°C
- 2.3 mM DIC
- 115 μM O_2
- 40 μM NO_3^-
- 0 μM S^{2-}, H_2
- ~10^4 cells/ml
- ***~0% Campylobacteria***

Diffuse-Flow Fluid:
- 25°C
- 8.2 mM DIC
- < 3.6 μM O_2
- < 6 μM NO_3^-
- ~12 μM NH_4^+
- ~ 200 μM S^{2-}
- < 2 μM H_2
- ~$5*10^5$ cells/ml
- ***~80% Campylobacteria***

Subseafloor productivity rivals above seafloor production by symbiotic associations!

Water

Crust



Productivity?
Standing stock?
Turnover?

Productivity: 40 gC d^{-1}
Standing stock: 29 g C
Biomass residence time: 17-41 h

Hydrothermal Fluid:
- >275°C
- 85 mM DIC
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- 410 μM H_2
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Based on McNichol *et al.*, 2016, DSR-I; 2018, PNAS

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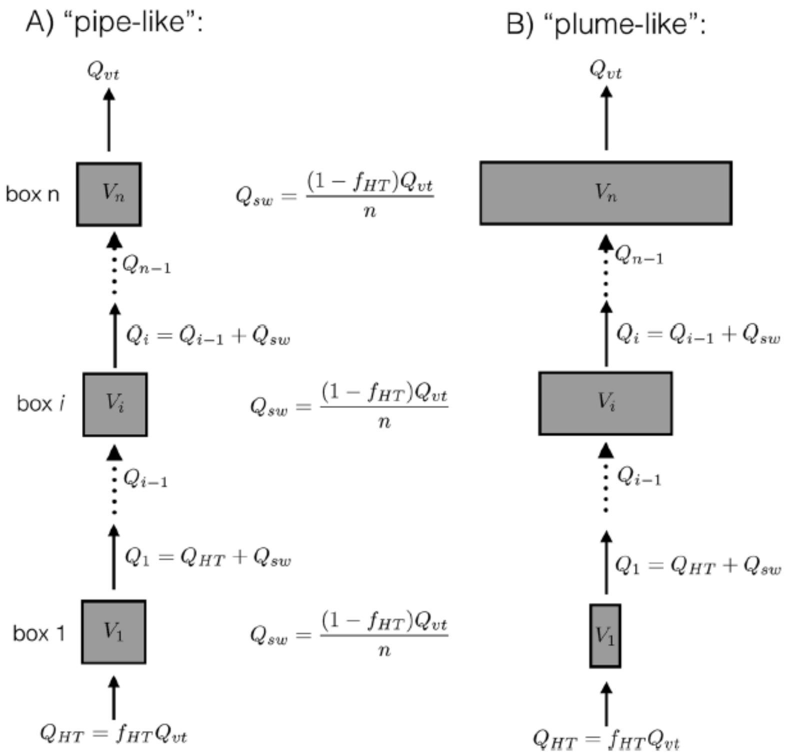
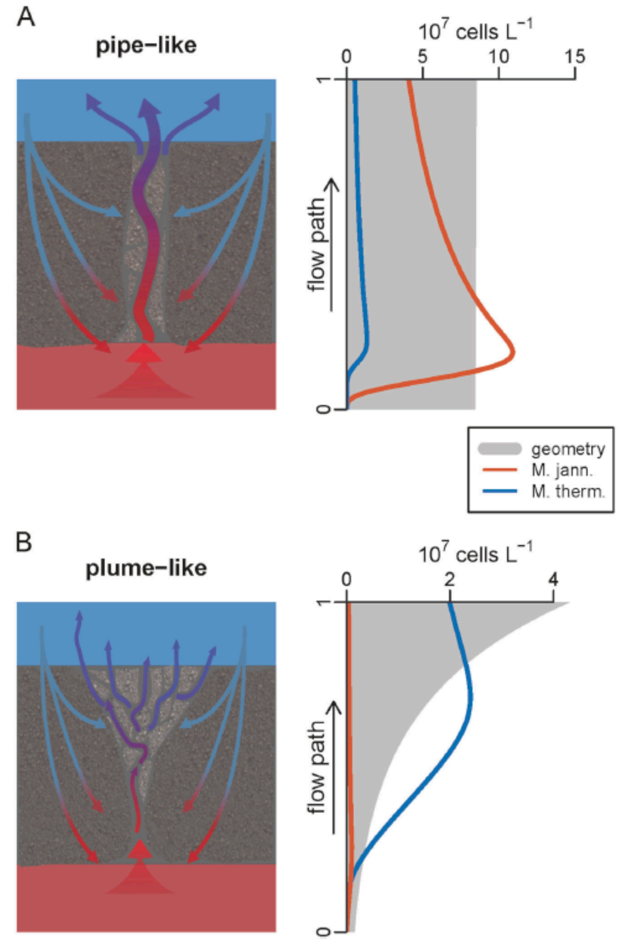
Fluid geochemistry, local hydrology, and metabolic activity define methanogen community size and composition in deep-sea hydrothermal vents

The ISME Journal (2019) 13:1711–1721
https://doi.org/10.1038/s41396-019-0382-3

Lucy C. Stewart[1,7] · Christopher K. Algar[2] · Caroline S. Fortunato[3] · Benjamin I. Larson[4] · Joseph J. Vallino[5] · Julie A. Huber[6] · David A. Butterfield[4] · James F. Holden[1]

Reactive transport model





- Fluid Residence Time: 29-33 h
- 10^{11} methanogens occupying as little as 2 m^3 pf ocean crust needed to create CH_4 anomalies
- Small, but very active subseafloor biosphere

Outstanding Questions

Mode of growth in subseafloor?

In situ **rates?**

Flow path and plumbing?

Permeability of ocean crust?

Fluid mixing?

Fluid residence time?

Fluid volume?

Flow rate?