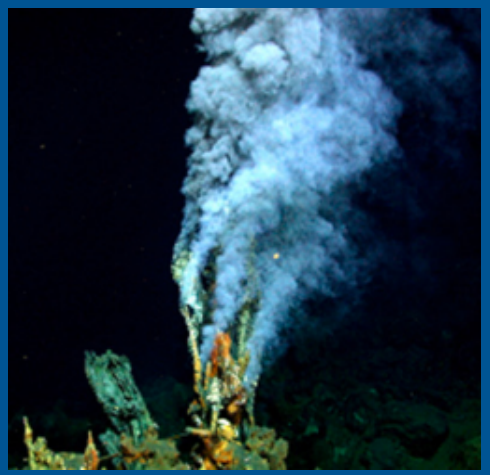
Hydrothermal Systems I

History, technology, structure, chemistry



OCN 623 - 22 March 2018

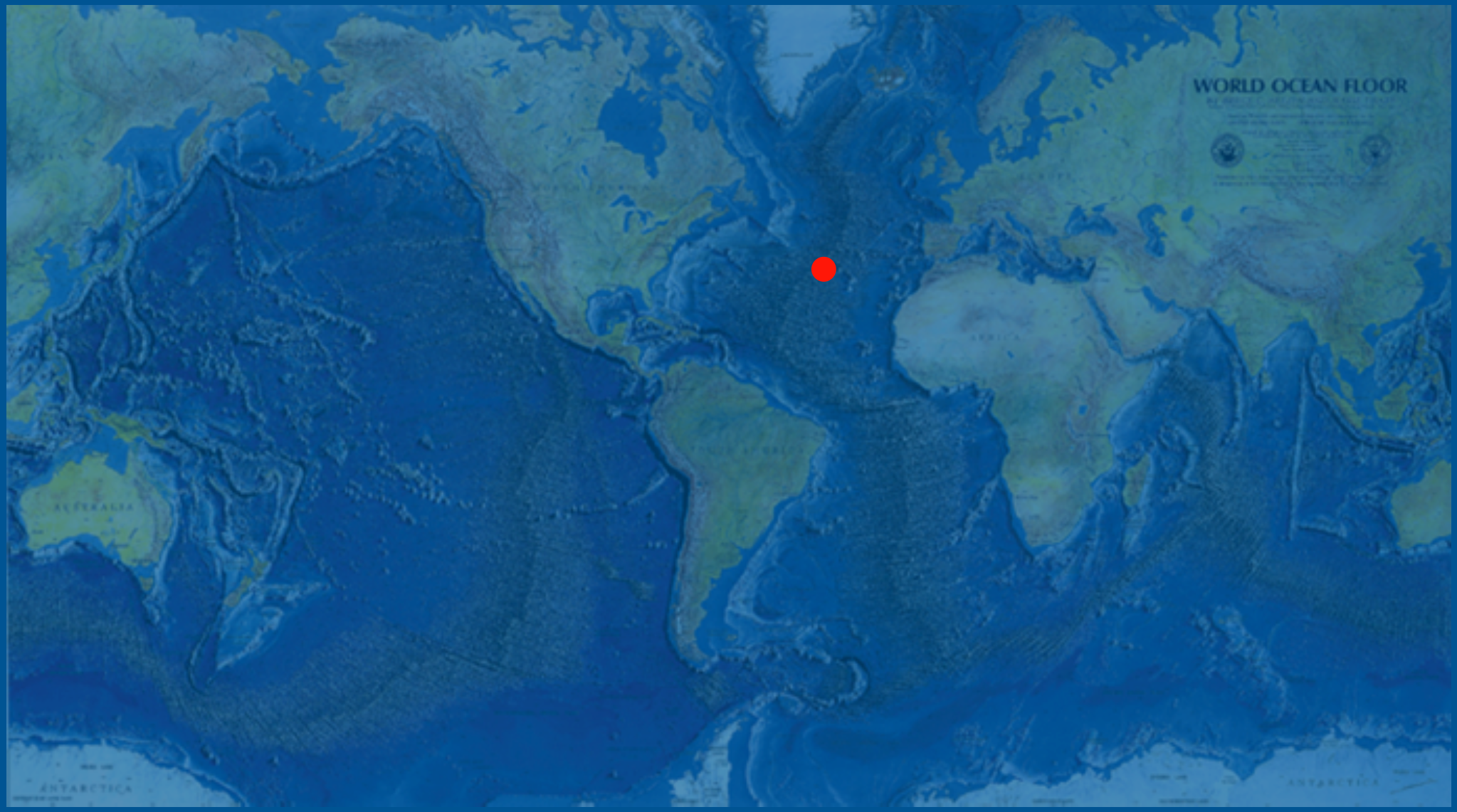
Brian Glazer

Hydrothermal Systems II

Chemosynthesis & symbioses,
fluxes, ridge flanks & the deep subsurface

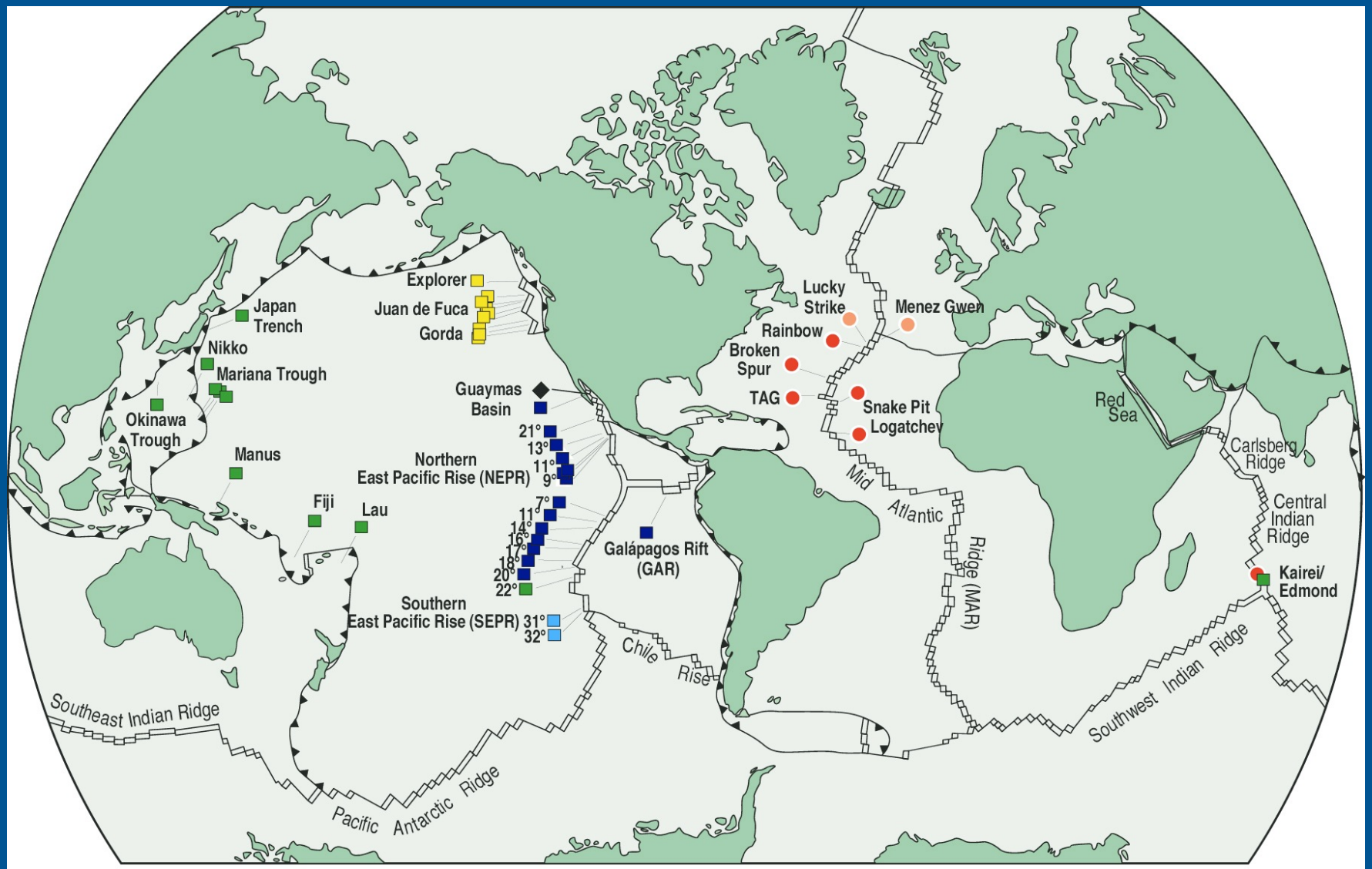
Project FAMOUS - 1974

First direct observations and mapping of MoR



Mid Atlantic Ridge 36°N

Earth’s largest mountain chain



The Mid-Ocean Ridge System

Alvin Dive 713
Feb 17, 1977

Pilot – Jack Donnely

Observers – Jack Corliss. Tjeerd van Andel

First vent discovered – Clambake I (8ºC)

"Isn't the deep ocean supposed to be like a desert?" Corliss asked. When Stakes answered, "Yes," Corliss replied: "Well, there's all these animals down here."

"But we were not biologists. We were supposed to be finding warm water." Bob Ballard

“It Was Like Columbus”

- “A whole lot of things sort of fell into place,” said John Edmond, a geochemist from MIT, in Victoria Kaharl’s book *Water Baby.* “About halfway into the cruise, we realized that regular seawater was mixing with something. It was a unique solution I had never seen before.

  “We all started jumping up and down. We were dancing off the walls. It was chaos. It was so completely new and unexpected that everyone was fighting to dive (in *Alvin*). There was so much to learn. It was a discovery cruise. It was like Columbus.”

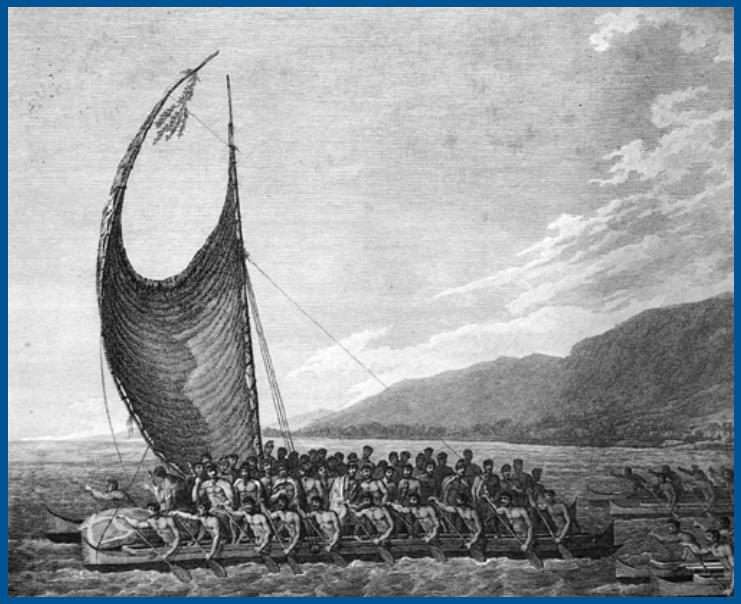
“In the spring of 1979—after geologists had discovered dense populations of strange new animals clustered around hydrothermal vents in an area north of the Galápagos Islands—a group of biologists took Alvin back to the same site.

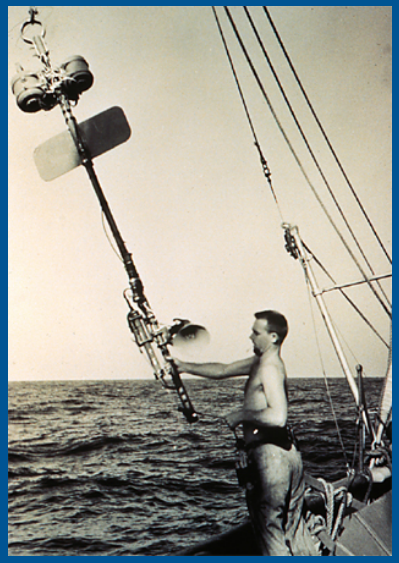
“It was an overwhelming experience to ‘fly,’ 2,550 meters deep, over dense beds of large mussels or even larger (up to 30 centimeters long) white clams, or stands of hundreds of snow-white tubeworms (up to two meters long) crowned with feather-like blood-red plumes.

“We were struck by the thought, and its fundamental implications, that here solar energy, which is so prevalent in running life on our planet, appears to be largely replaced by terrestrial energy —chemolithoautotrophic bacteria taking over the role of green plants. This was a powerful new concept and, in my mind, one of the major biological discoveries of the 20th century.”

Holger Jannasch
Annual Review of Microbiology
Vol. 51

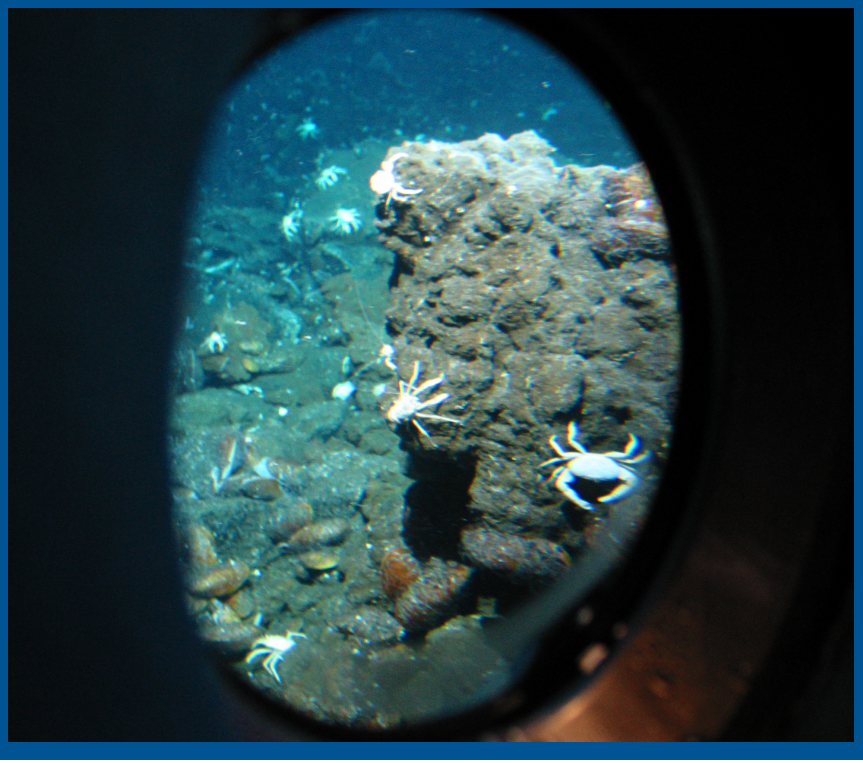
Technology and exploration enable innovative science





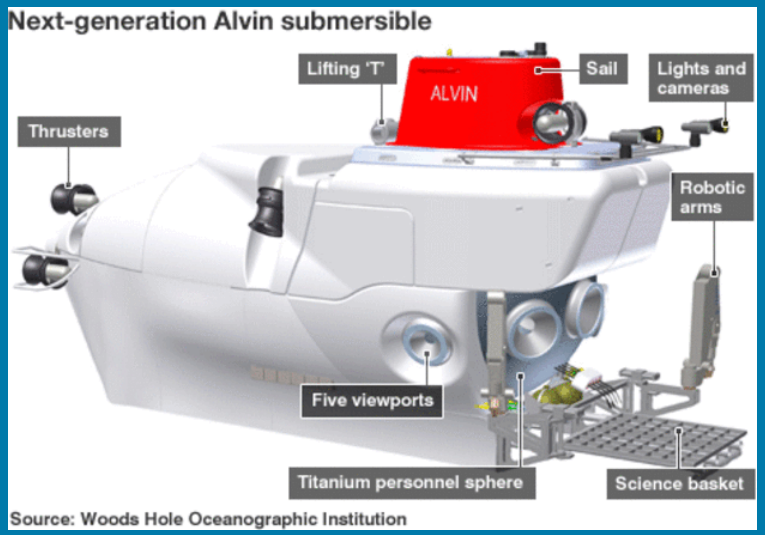
DSV *Alvin* *before the $50M refit*

- 3-person submarine
- 3700+ dives since ‘60s
- 2 in thick titanium
- 3 viewports (12”)
- Down to 4500 m (450atm=6600 psi)
- ~2 hr descent, 4 hrs bottom time, 2 hrs ascent

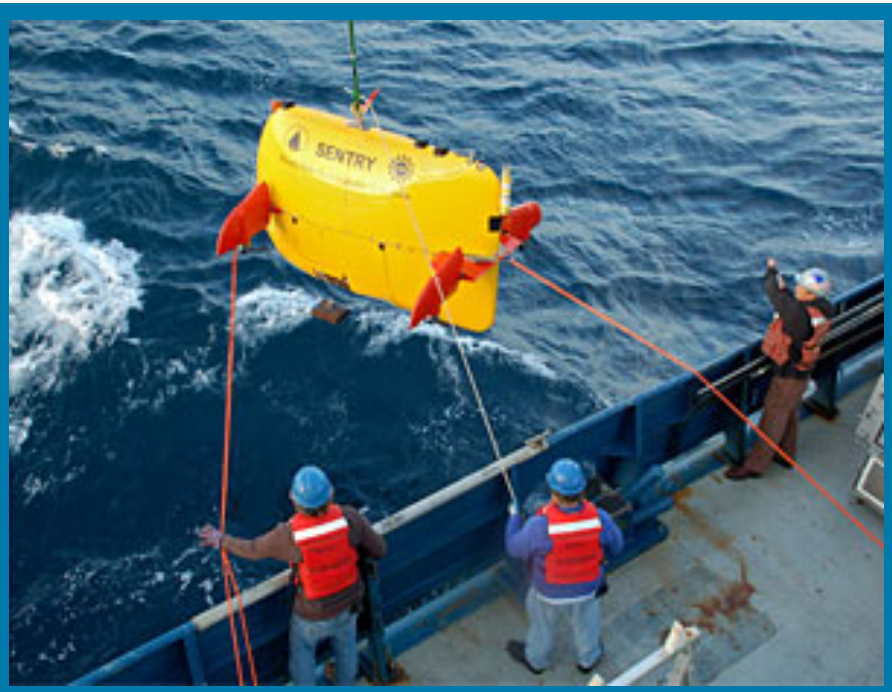


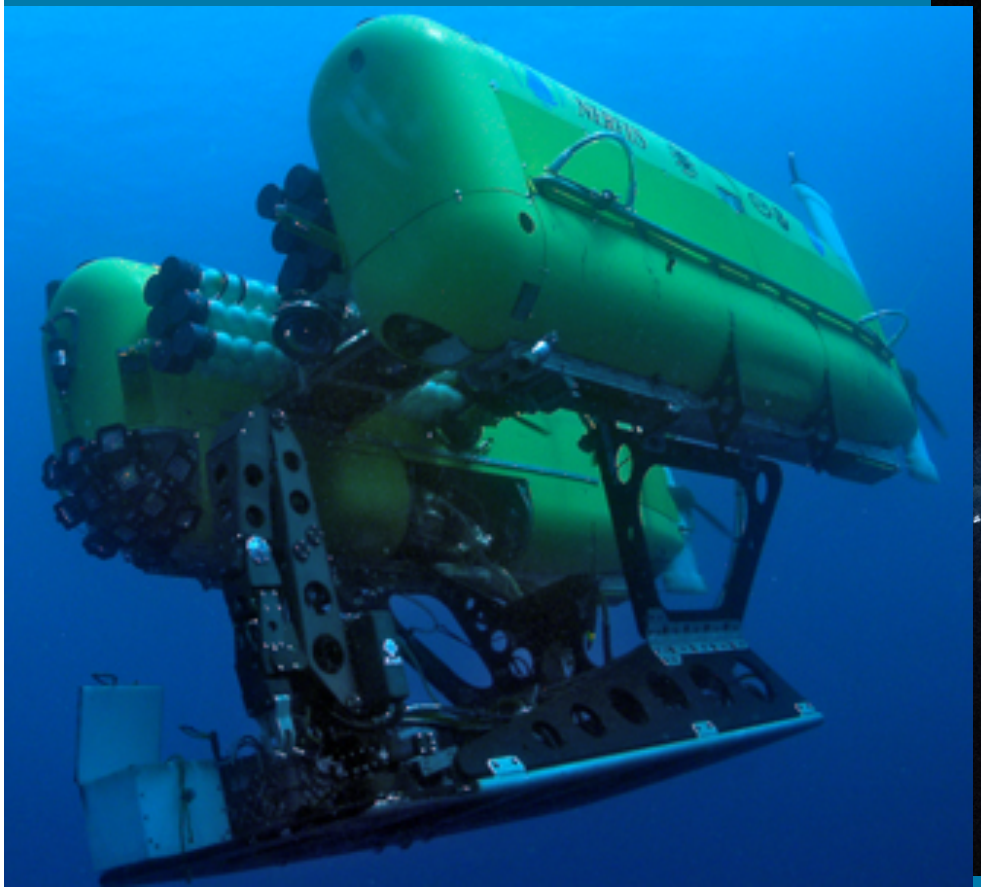
DSV *Alvin* upgrade

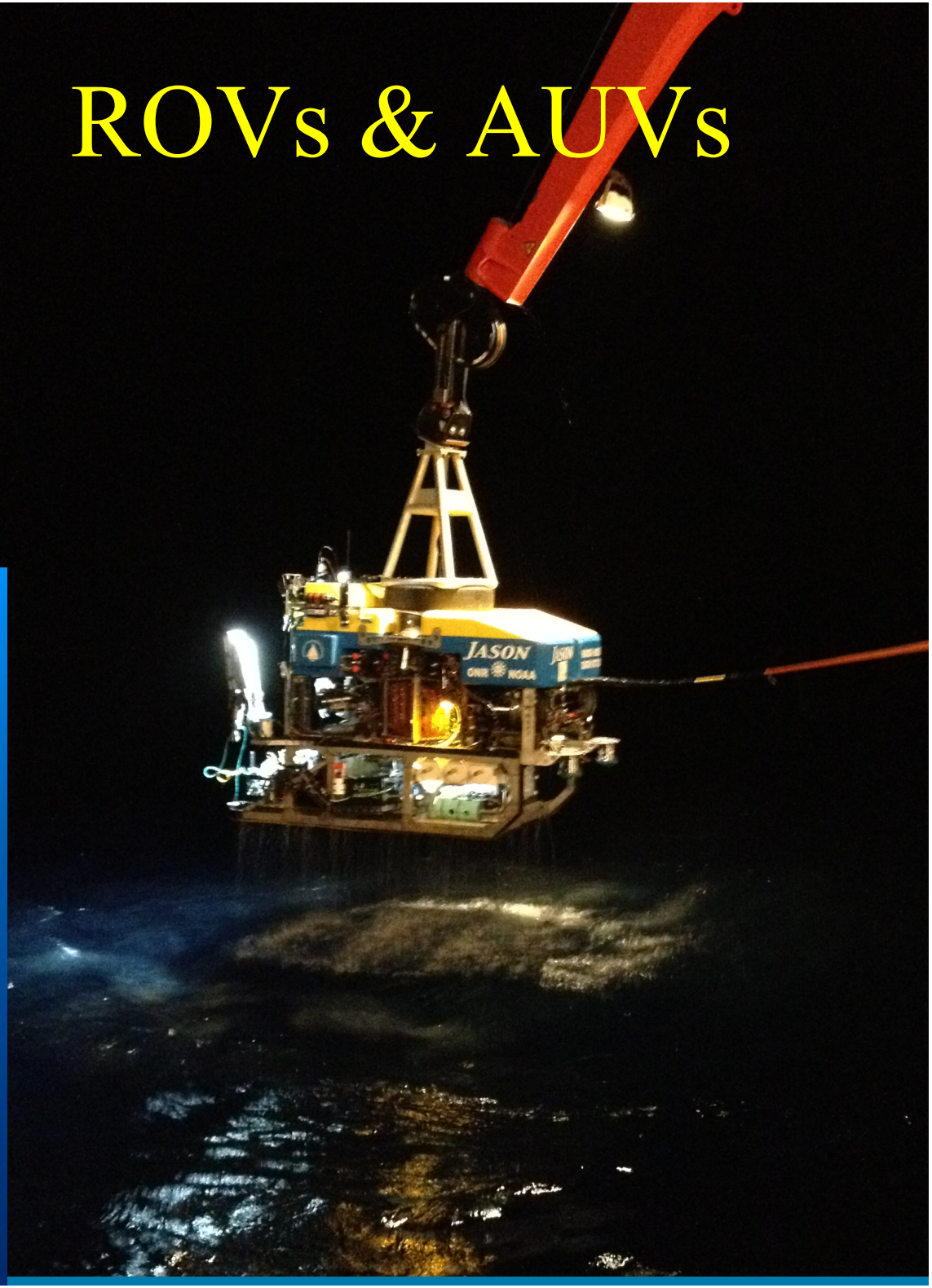
- New Ti sphere
- 3 in thick titanium
- 5 viewports
- 4.6” wider (18% vol)
- Down to 6500 m*
- 400 lb payload



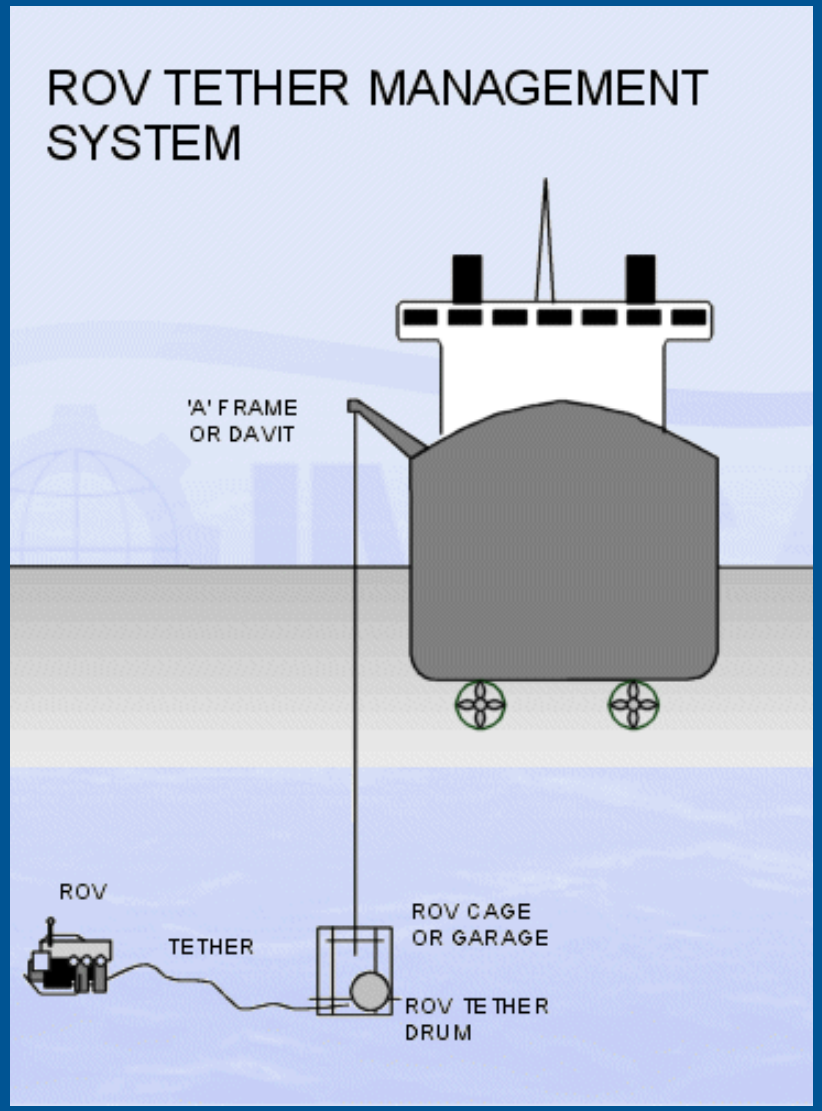
ROVs & AUVs

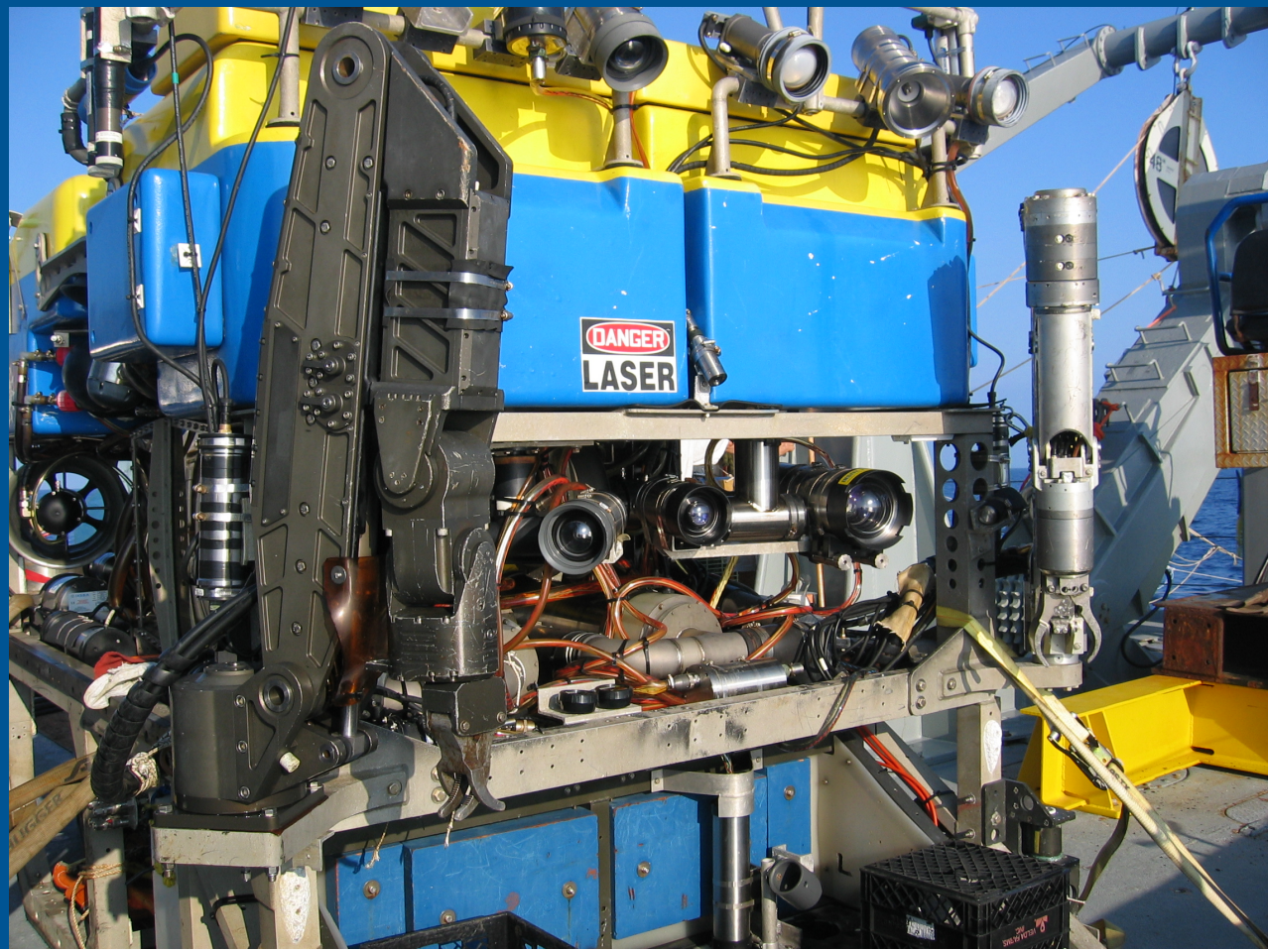






ROV *Jason-II*

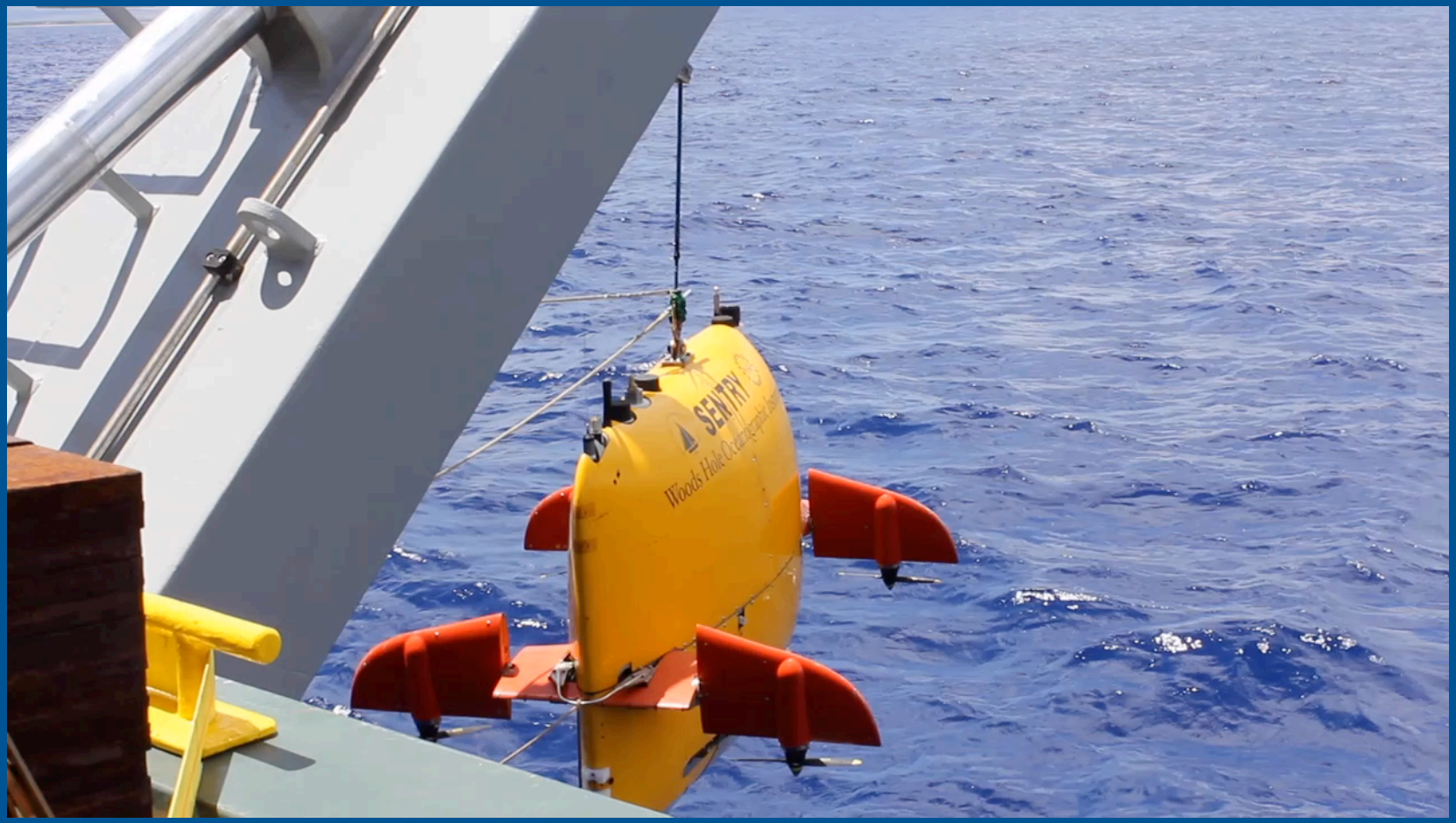

ROV TETHER MANAGEMENT SYSTEM
'A' FRAME OR DAVIT
ROV
TETHER
ROV CAGE OR GARAGE
ROV TETHER DRUM


DANGER
LASER

ROV *Jason-II…what's it like?*

ROV *Jason-II…what's it like?*

AUV *Sentry*



Depths of 6,000m

2.9m long X 2.2m wide X 1.8m high, 1250kg

70-100km range @ 0-1.2m/s

20-40 hrs endurance & 10hrs recharge time

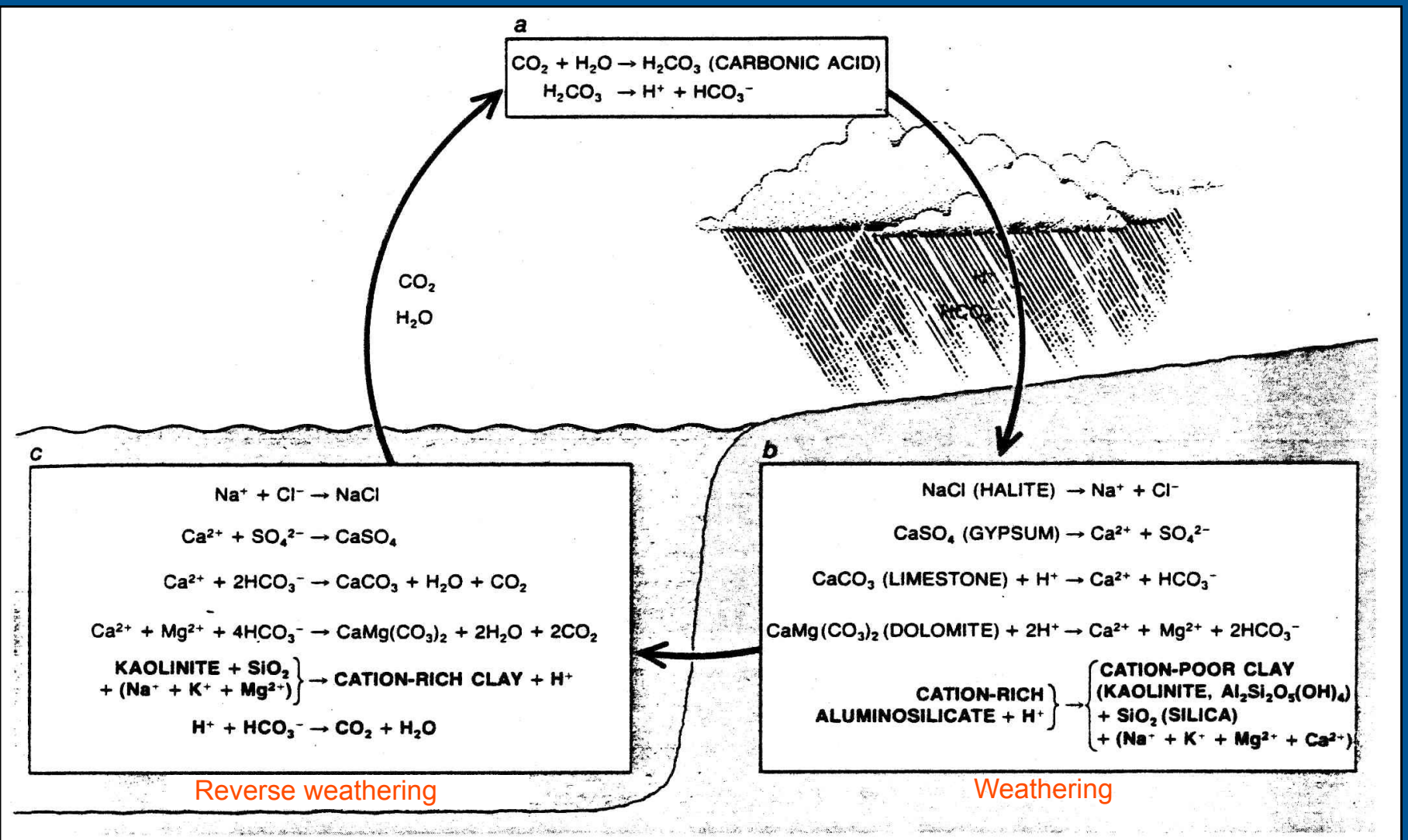
The Mass-Balance Problem

Seawater *vs.* River Water

	Dominant ions	Subsidiary ions	Minor ions
Seawater	Na^+ Cl^-	Mg^{2+} SO_4^{2-}	Ca^{2+}, K^+ HCO_3^-
River water	Ca^{2+} HCO_3^-	Mg^{2+}, Na^+ SO_4^{2-}, Cl^-	K^+

How, in a steady-state ocean (with residence times short relative to the age of the earth), is seawater produced from the input of river water??

Weathering / Reverse weathering - 1



CHEMICAL BALANCE between the atmosphere, the continents and the oceans was hypothesized in the 1950's by Lars Gunnar Sillén of the Royal Institute of Technology in Stockholm and worked out in detail by Frederick T. Mackenzie and Robert M. Garrels of Northwestern University. In the atmosphere (*a*) carbon dioxide is dissolved in water vapor as carbonic acid. The water rains or snows on the continents (*b*), where hydrogen ions from the acid solution leach cations (positive ions) such as calcium, magnesium, sodium and potassium out of the continental rocks. Rivers carry the results of the continental weathering to the oceans (*c*). In the oceans, which are poor in hydrogen ions, the reactions reverse, creating sedimentary rock rich in cations and restoring carbon dioxide to the atmosphere.

Weathering / Reverse weathering - 2

Solves:

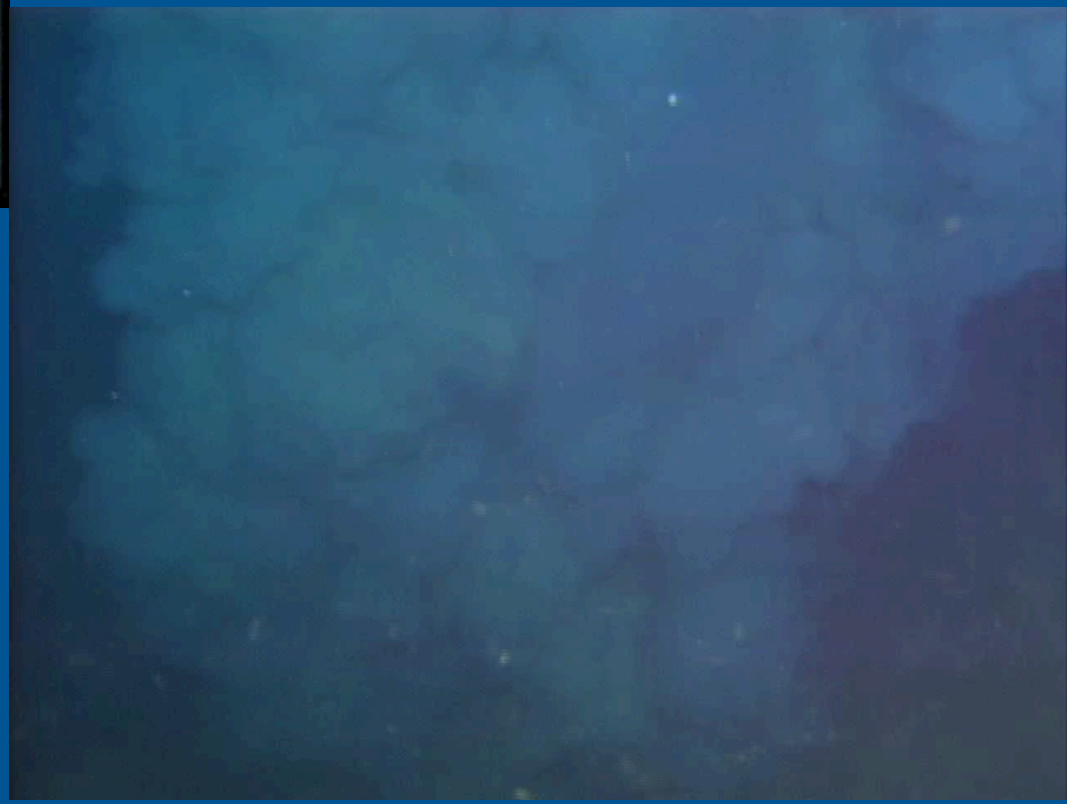
- Removes excess cations from seawater
- Provides H^+ to the ocean (prevents the ocean from becoming an “alkaline lake” due to high ion content)
- Solves the CO_2 problem

Problems:

- Can’t remove all of the HCO_3^- entering the ocean
- Need additional sink(s) for Mg^{2+} in order to close the budget

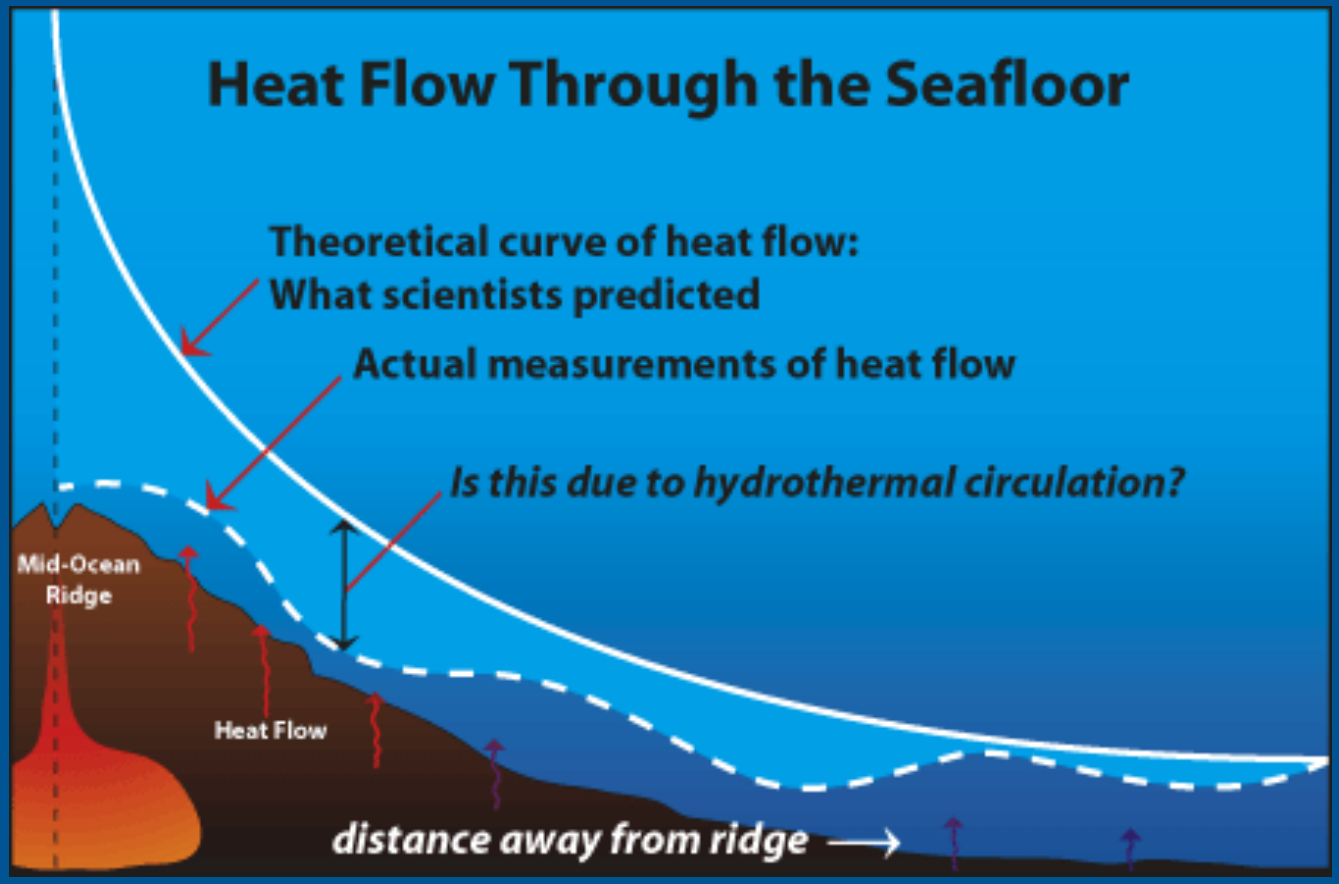
Edmond & Von Damm, 1983

Seafloor volcanism



Heat Flow From the Ocean Floor

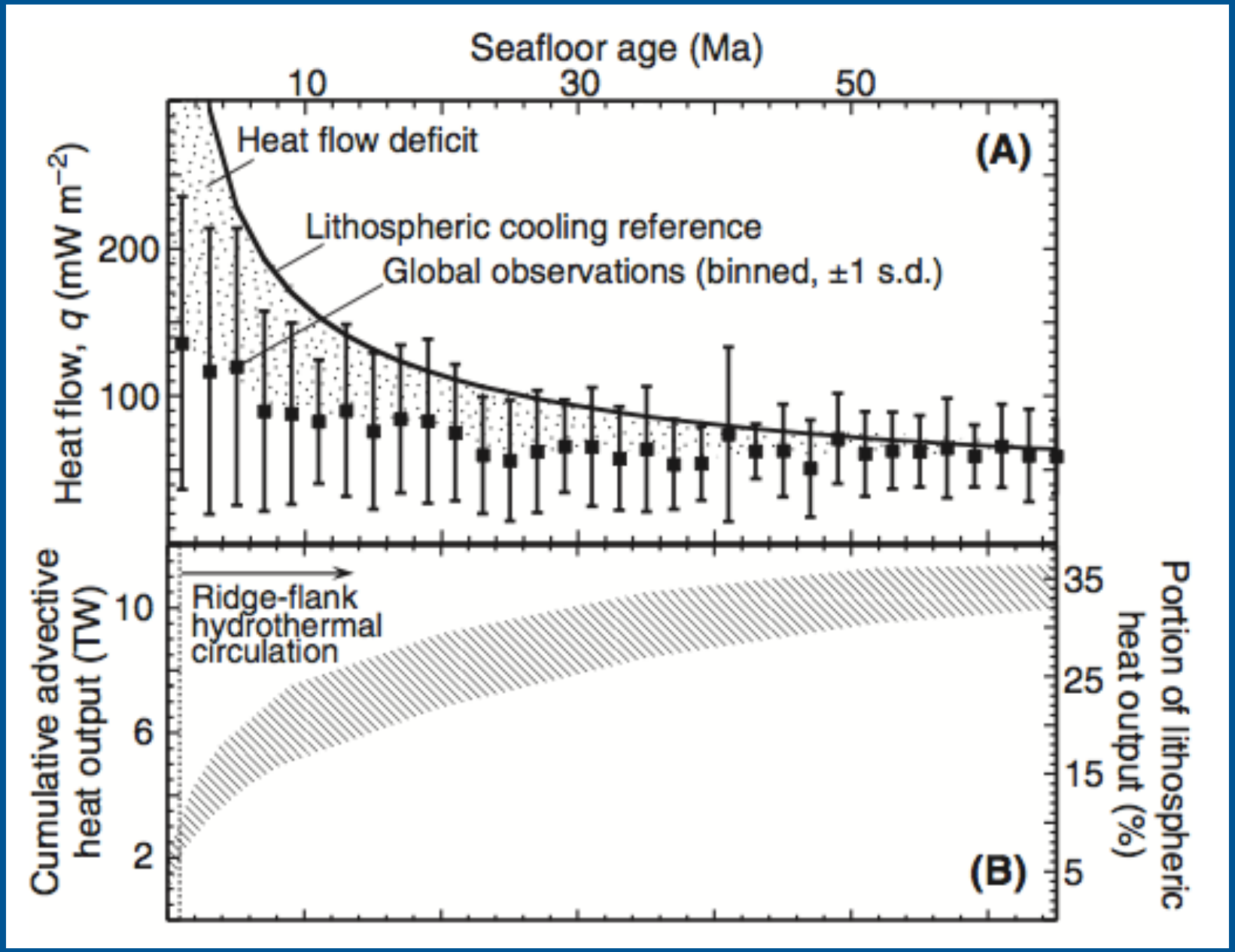
An indication of the importance of hydrothermal flow



Scientists predicted that the flow of heat through the seafloor should decrease farther away from the ridge. Although this is true, the measured values of heat flow near the ridge (dashed line) were lower than the predicted values (solid line). Could hydrothermal circulation explain the difference?

Edmond & Von Damm, 1983

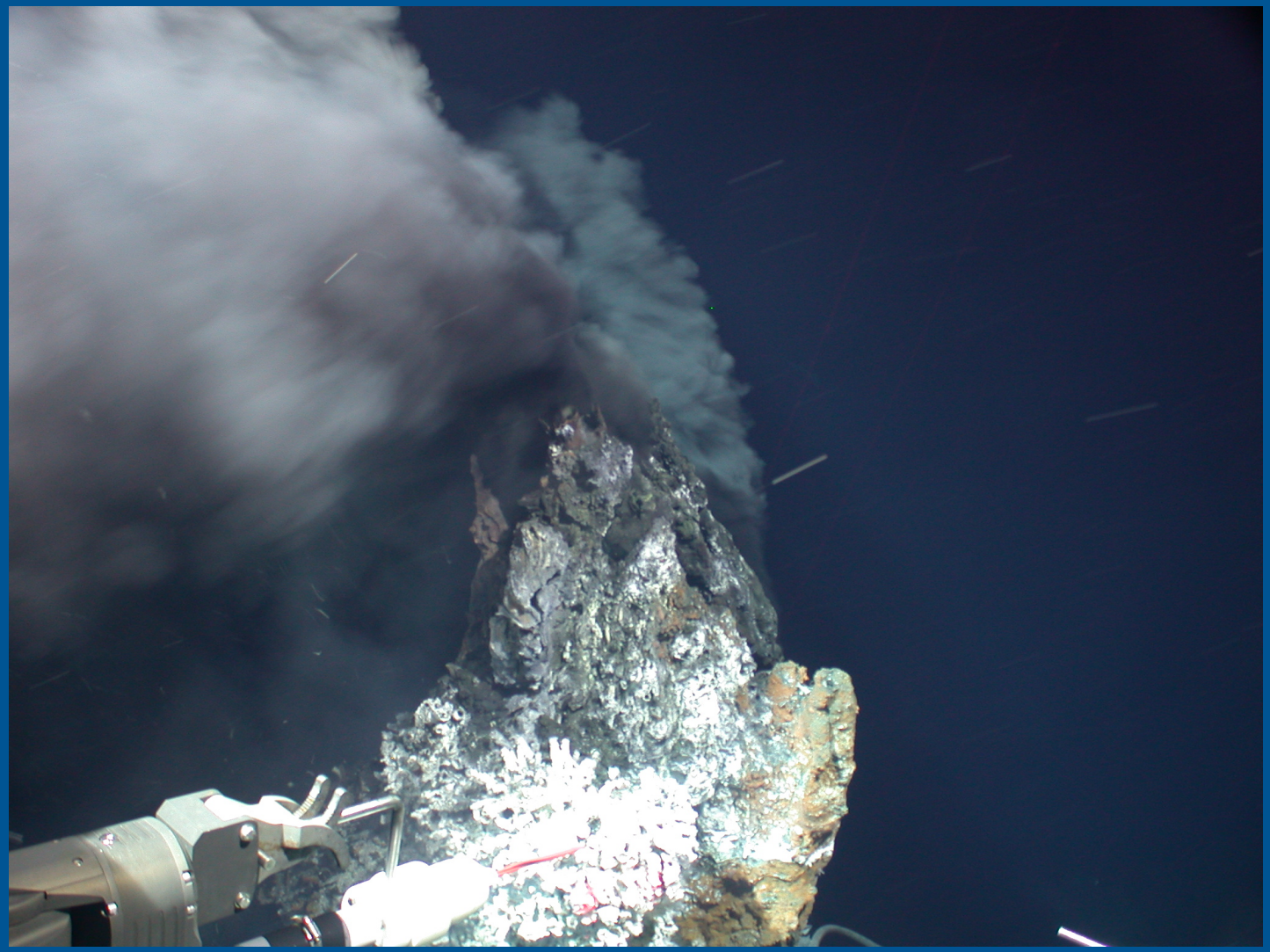
Oceanic Heat Flow



Fisher and Harris 2010

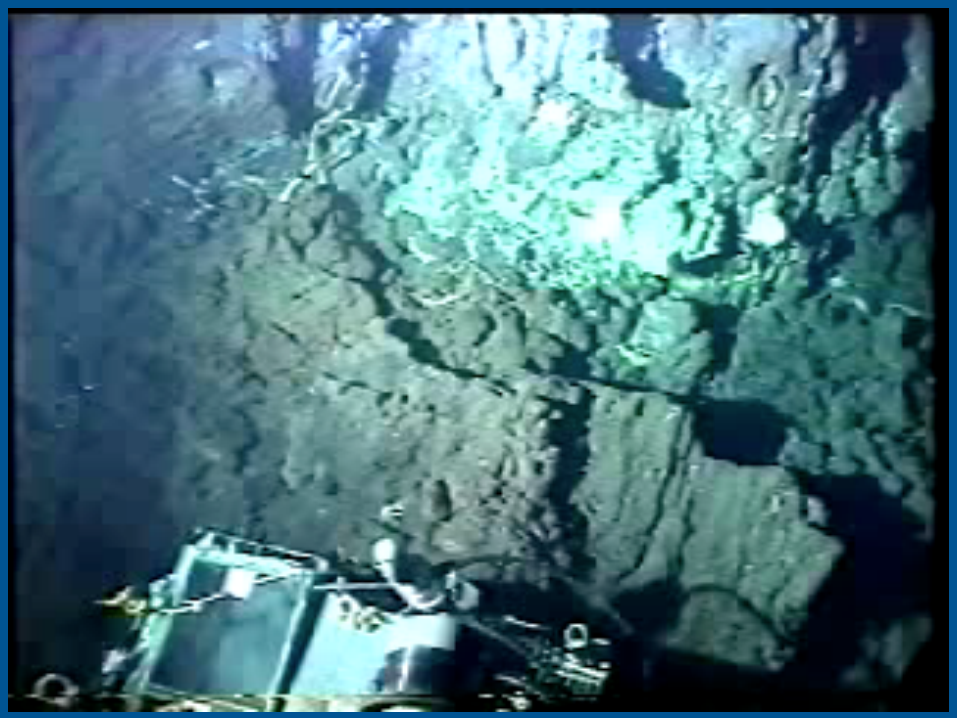
Mid-Ocean Ridge Hydrothermal Circulation

Another mechanism for significant seawater alteration

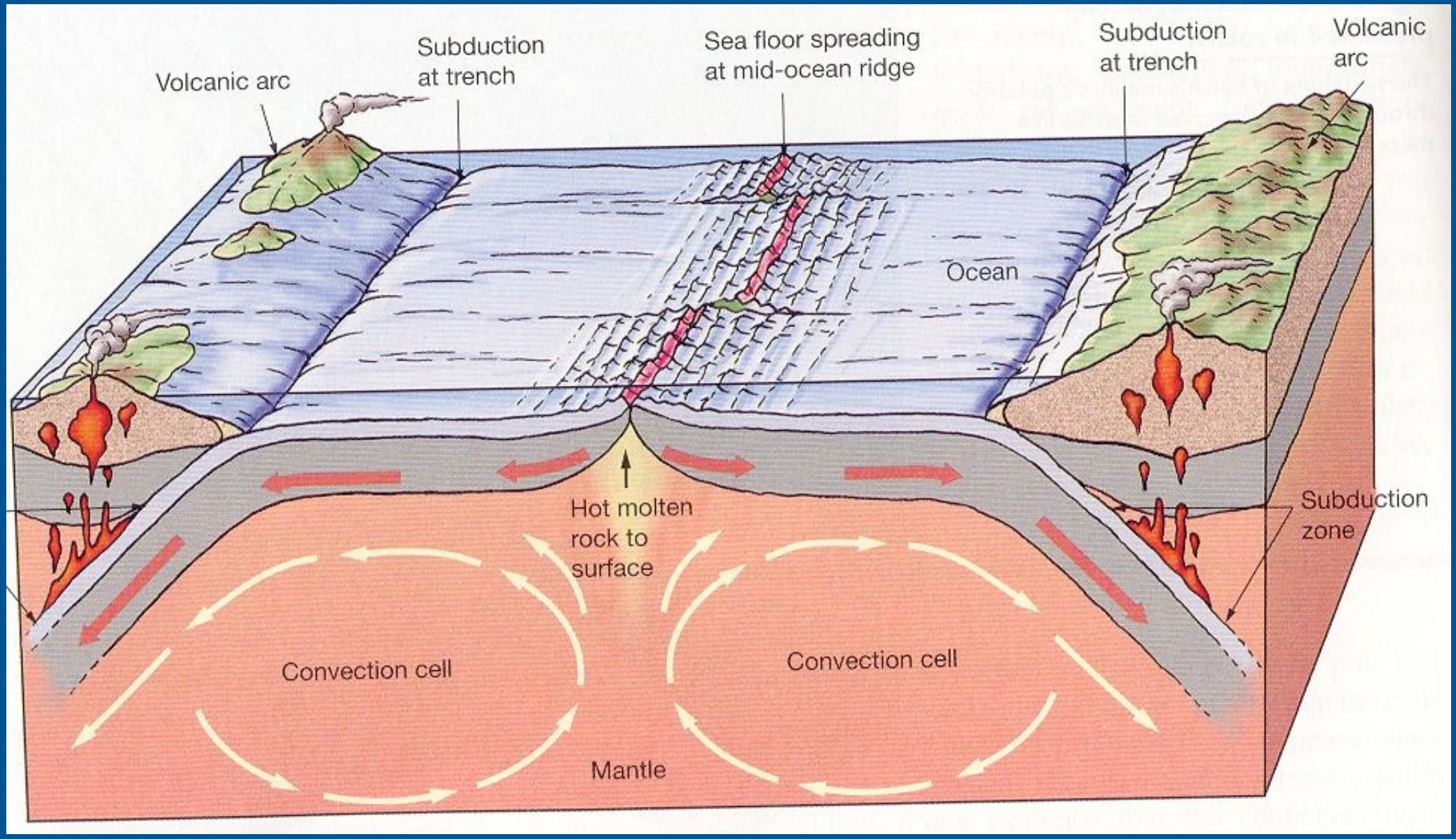


Hydrothermal Vents

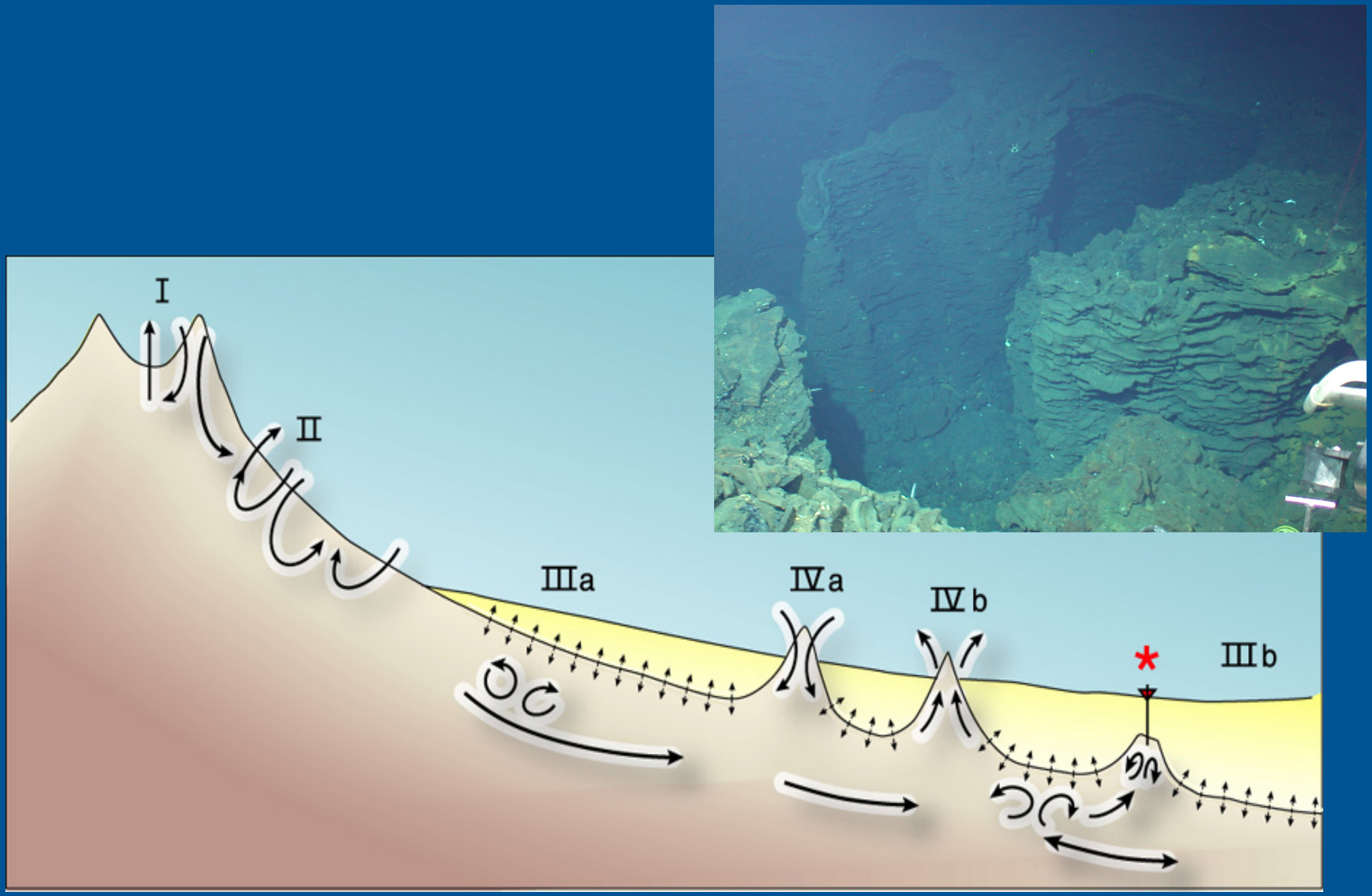
- Discovered in 1977, black smokers in 1979
- Important for origins of life?
- Heat escapes from Earth's interior
  - T = ~400°C
  - Abundant source of electron donors (H_2S)



Anatomy of an ocean basin

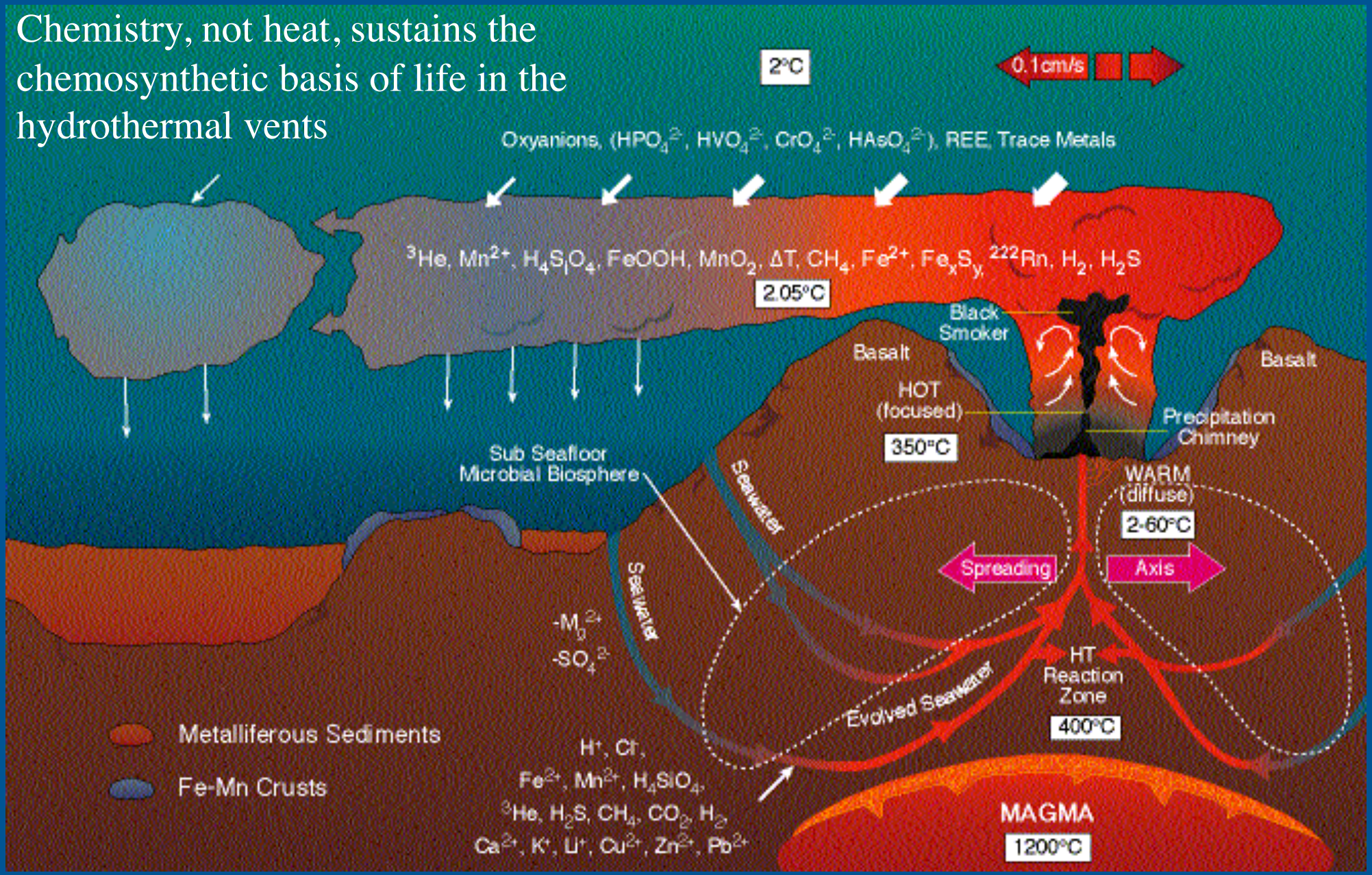


Anatomy of the ridge

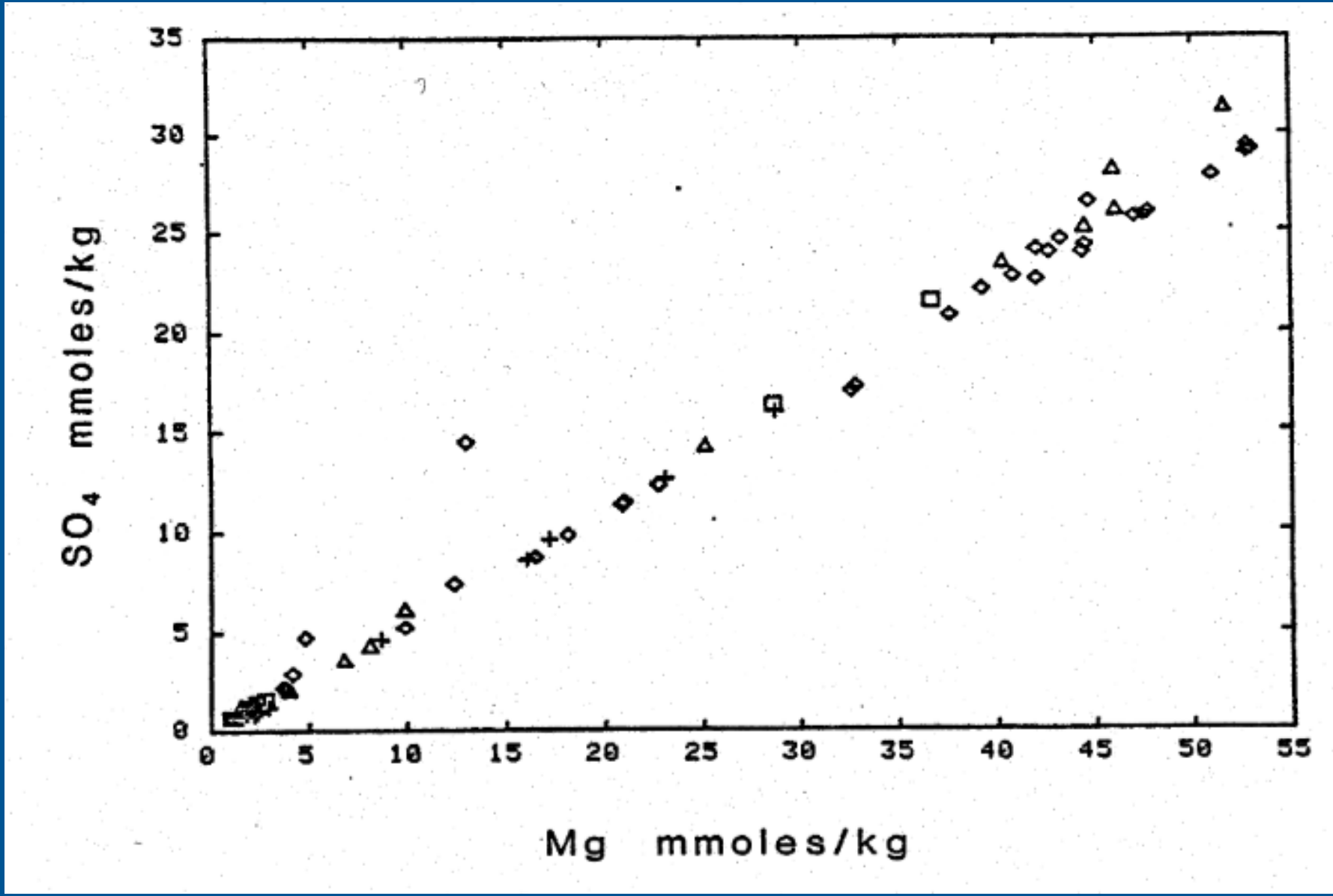


Anatomy of the ridge

Chemistry, not heat, sustains the chemosynthetic basis of life in the hydrothermal vents



Anatomy of vent fluid



Karen Von Damm thesis, 1983

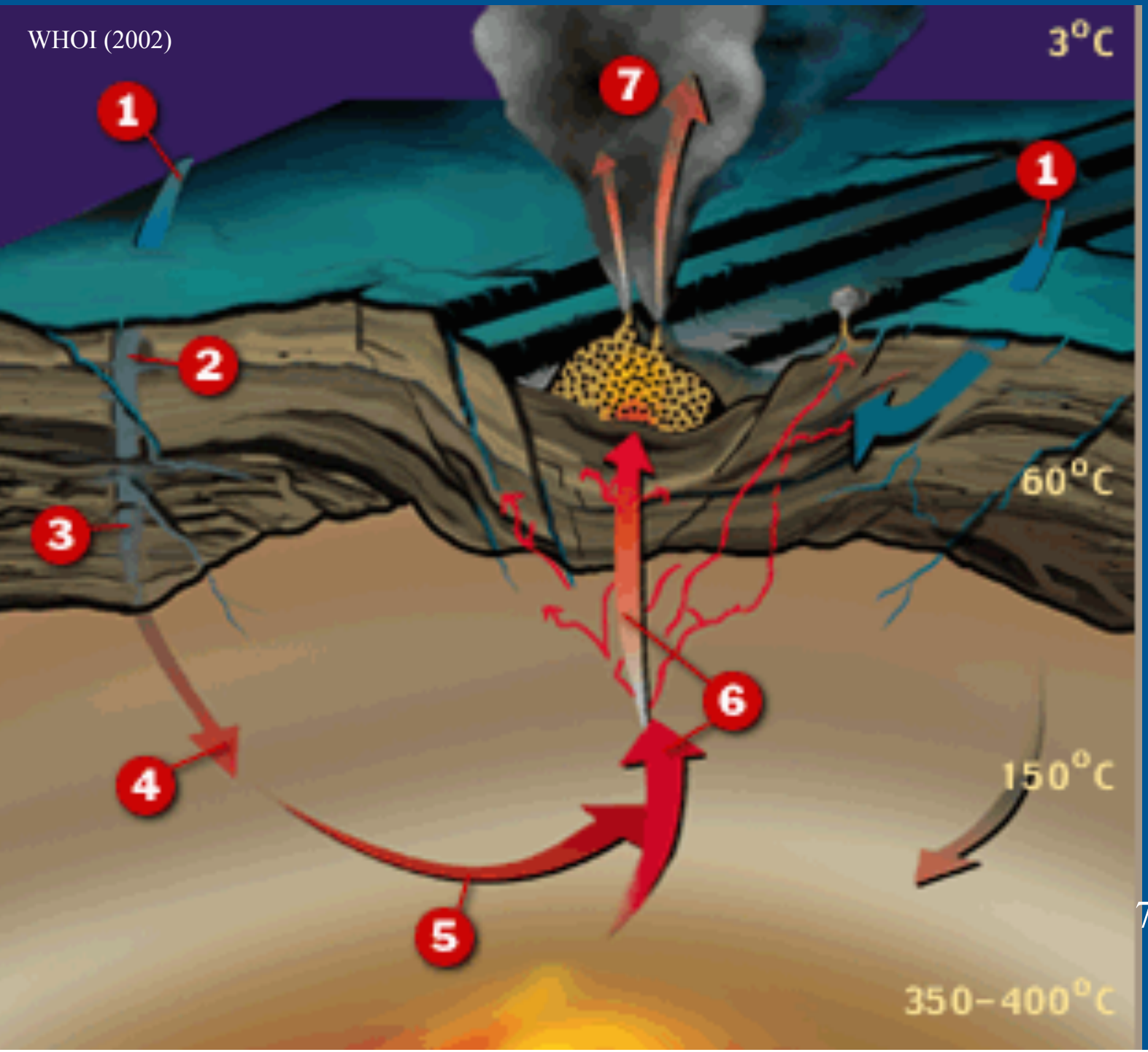
Anatomy of vent fluid

21°N EPR

		Max	Min	Avg	Sea water
Depth	meters			2600	
Spread. Rate	cm/yr			6	
Temp.	°C	370	112	317	2
NaCl	Wt %	3.38	2.62	2.91	3.2
Cl	mmol/kg	579	388(475)	491	540
SiO_2	mmol/kg	21.4	0.0	16.8	0.16
H_2S	mmol/kg	8.69	3.3	6.8	0
Max H_2S	mmol/kg	13	3.5	7.5	0
Na-CB	mmol/kg	510	411	446	464
K	mmol/kg	27.9	18.3	23.4	10
Li	umol/kg	1448	716	948	26
Rb	umol/kg	43.4	18.8	28.3	1.3
Cs	nmol/kg	246	136	207	2
Ca	mmol/kg	21.4	10.9	15.0	10
Sr	umol/kg	97	62	78	87
B	umol/kg	520	500	515	415
Fe	umol/kg	2429	232	985	0
Mn	umol/kg	1030	313	676	0
Tot. Cu	umol/kg	47	0	20	0.006
Tot. Zn	umol/kg	128	26	89	0.01
Al	umol/kg	10.1	0.0	6.6	0
SO_4	mmol/kg	1.36	-2.7	-0.22	28.2
Br	umol/kg	929	612	790	840
pH	25 °C, 1 atm	4.9	3.3	3.83	7.8
Alk	meq/kg	1.56	-1.92	-0.07	2.4
CO_2	mmol/kg	10.8	5.7	8.2	2.4
H_2	mmol/kg	3.13	0.03	1.02	$3x10^{-7}$
CH_4	mmol/kg	0.096	0.051	0.070	$3x10^{-7}$

Karen Von Damm thesis, 1983

Hydrothermal circulation



1) Cold water sinks

2) Removal of oxygen and potassium

3) Removal of calcium, sulfate & magnesium

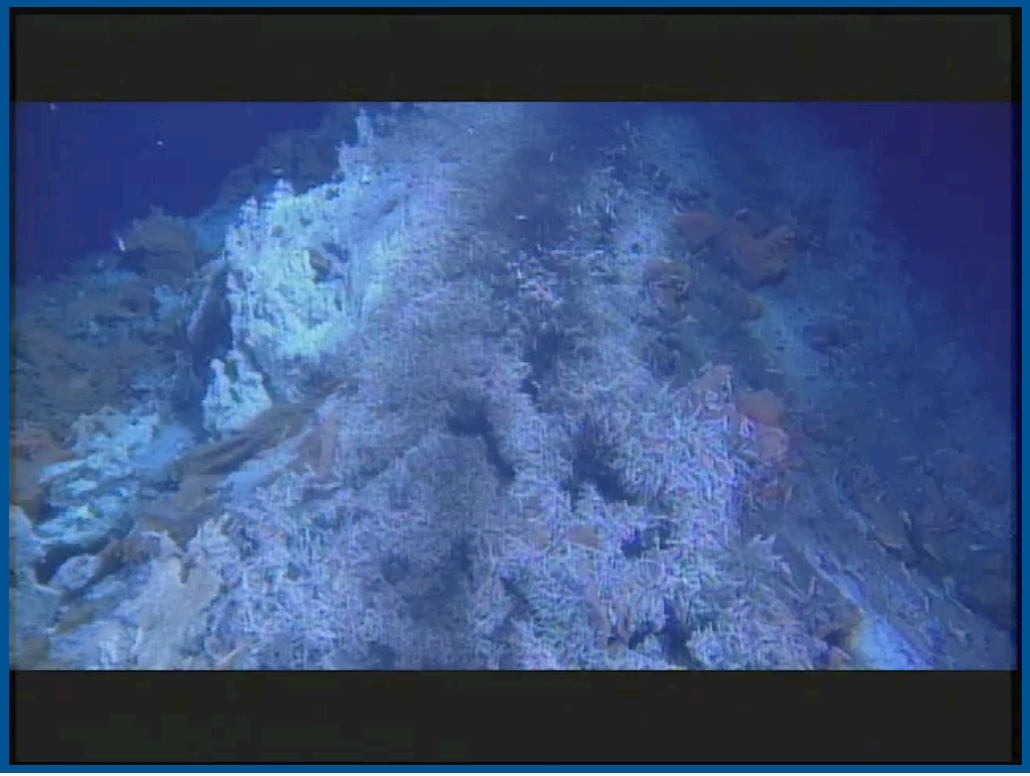
4) Addition of sodium, calcium & potassium

5) Lots of heat; addition of copper, zinc, iron and sulfur

6) Hot fluids rise

7) Hot fluids mix with seawater; metals & sulfides combine

Anatomy of a vent field

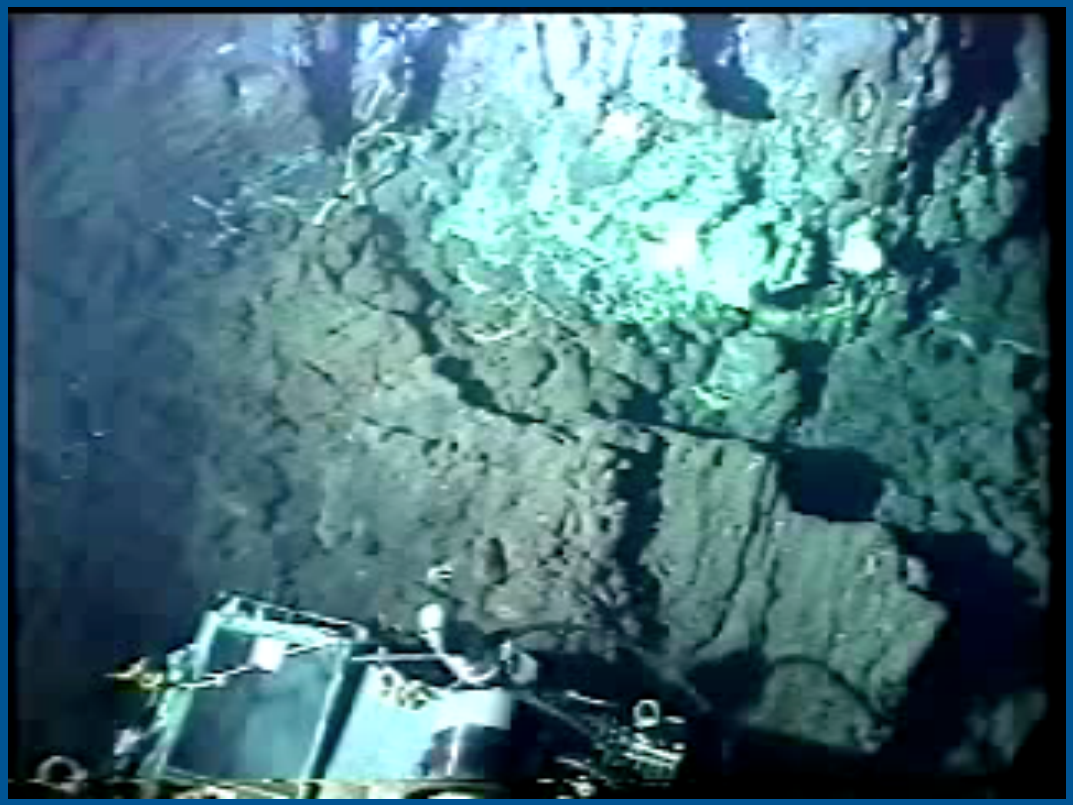


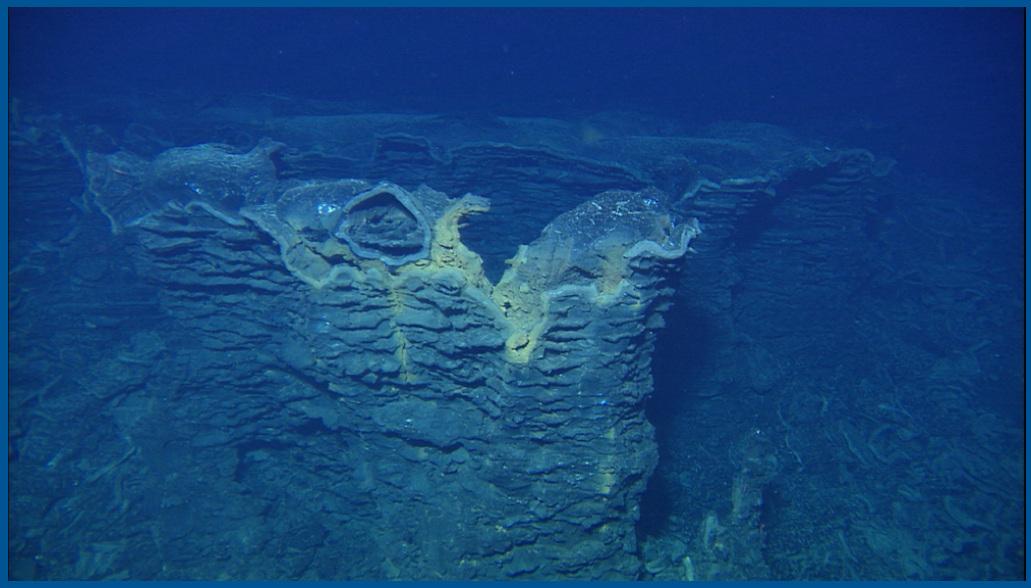
Anatomy of a chimney

- Major sulfide minerals
  - Pyrite – FeS_2
  - Marcasite – FeS_2
  - Pyrrhotite - FeS
  - Chalcoptrite – $CuFeS_2$
  - Sphalerite – ZnS
  - Magnetite – Fe_3O4

On-axis Vent chemistry recap

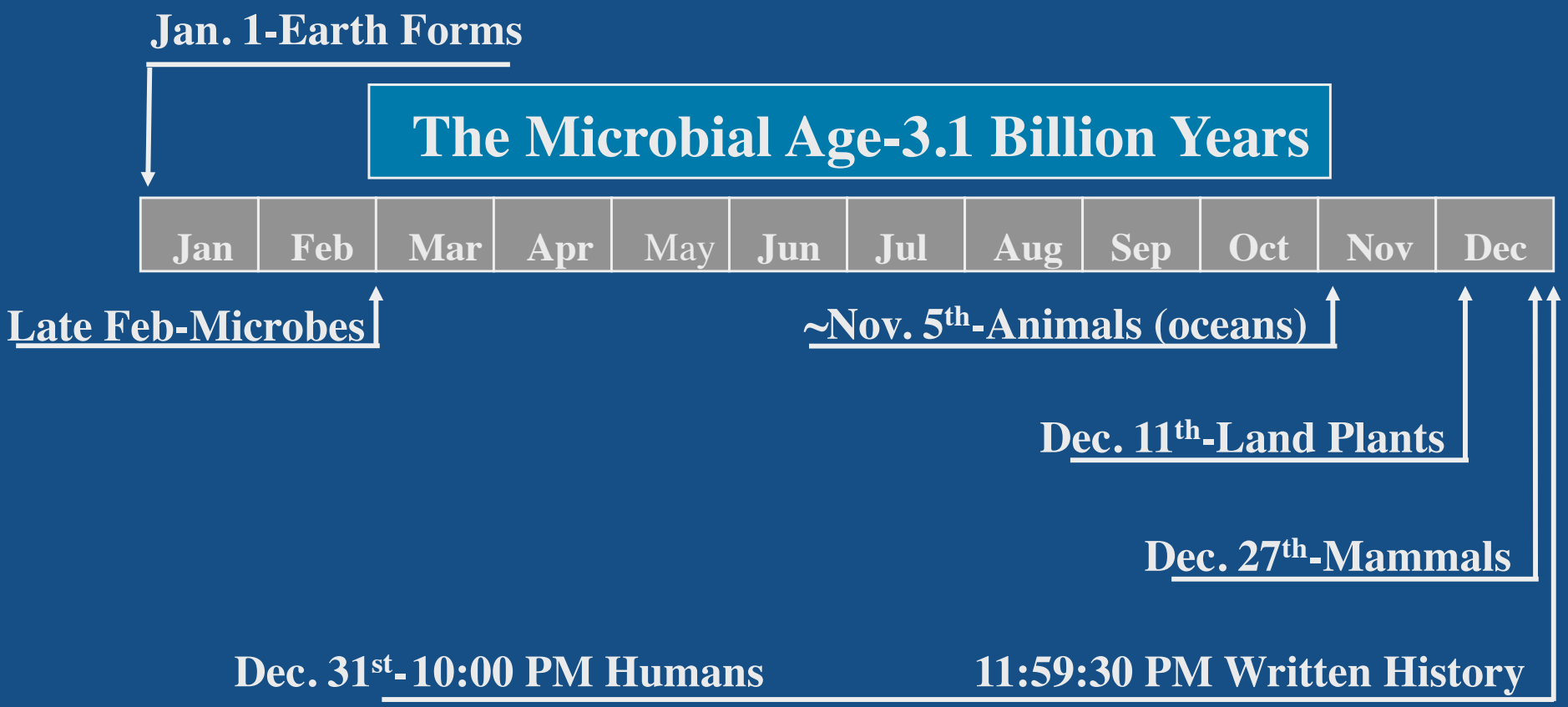
- Hydrothermal plumes - chronic vs. event
- Fluxes to global ocean
- Ephemeral nature of (micro)environment



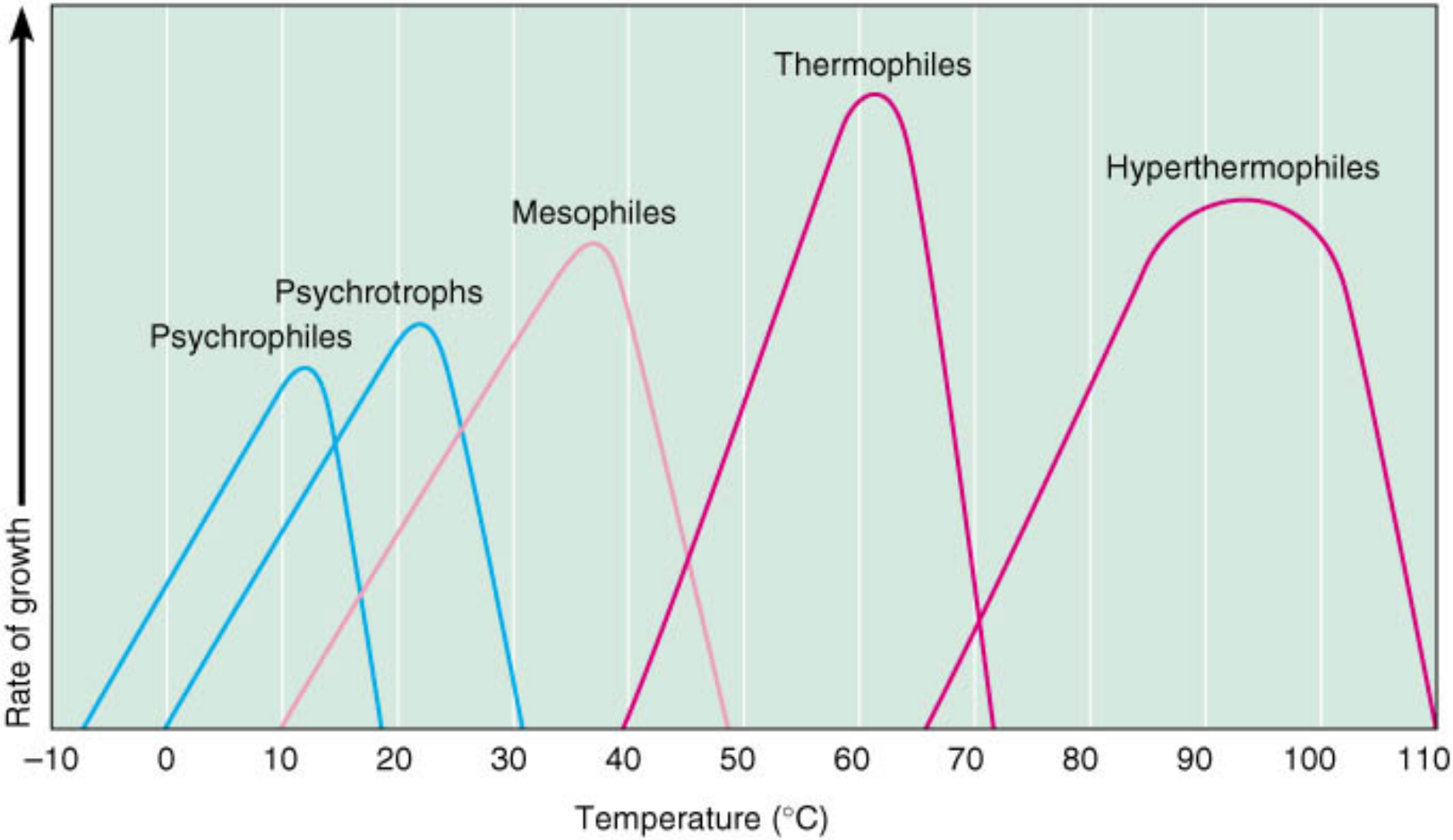


So, some microbial perspective

- The history of life on earth is overwhelmingly microbial
- The earth is ~4.5 billion yrs old,
  - microbes arose 3.8 billion years ago (bya)
  - animals-0.7 bya -- humans-0.001 bya



Microbes ~are chemistry



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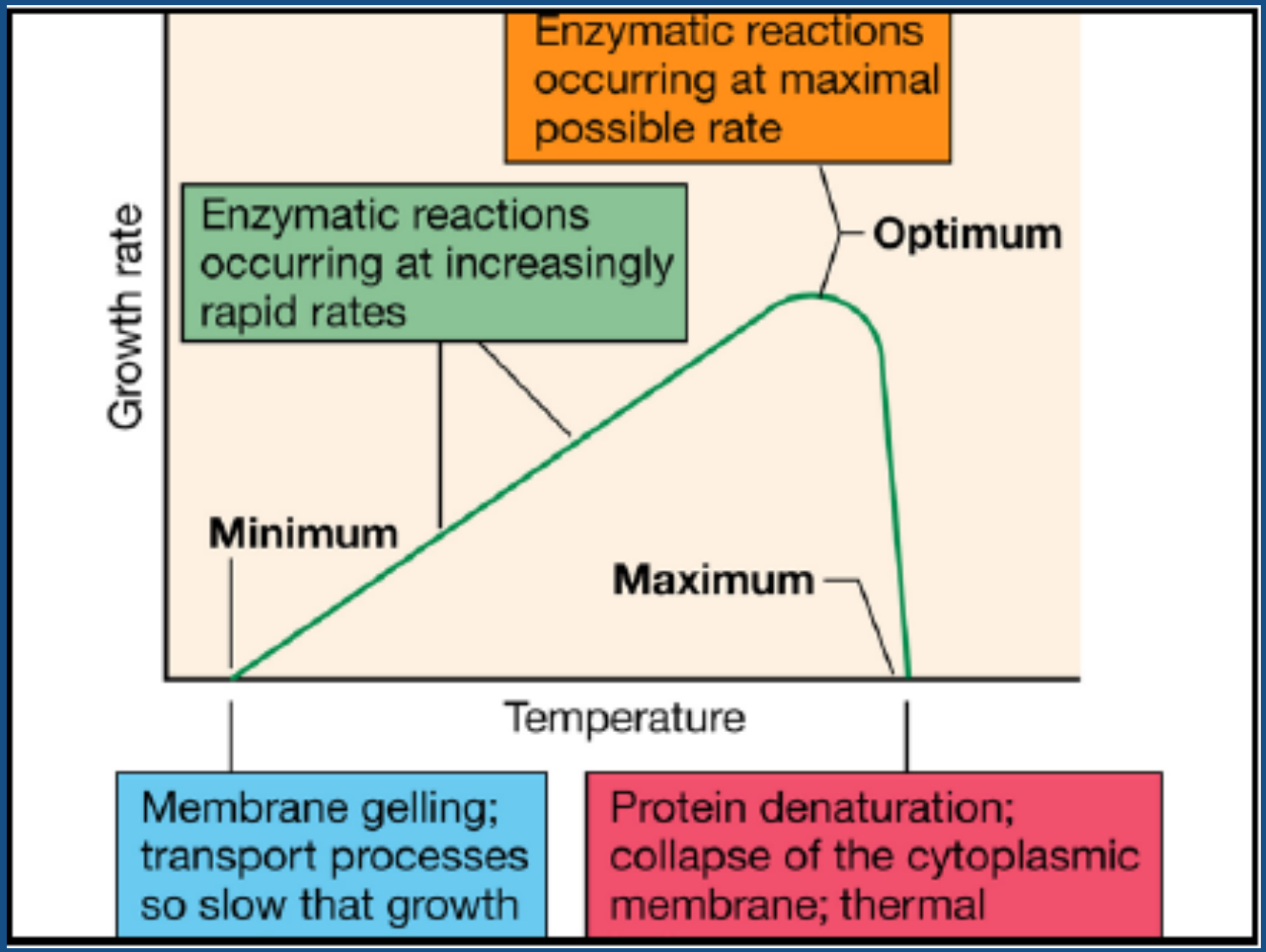
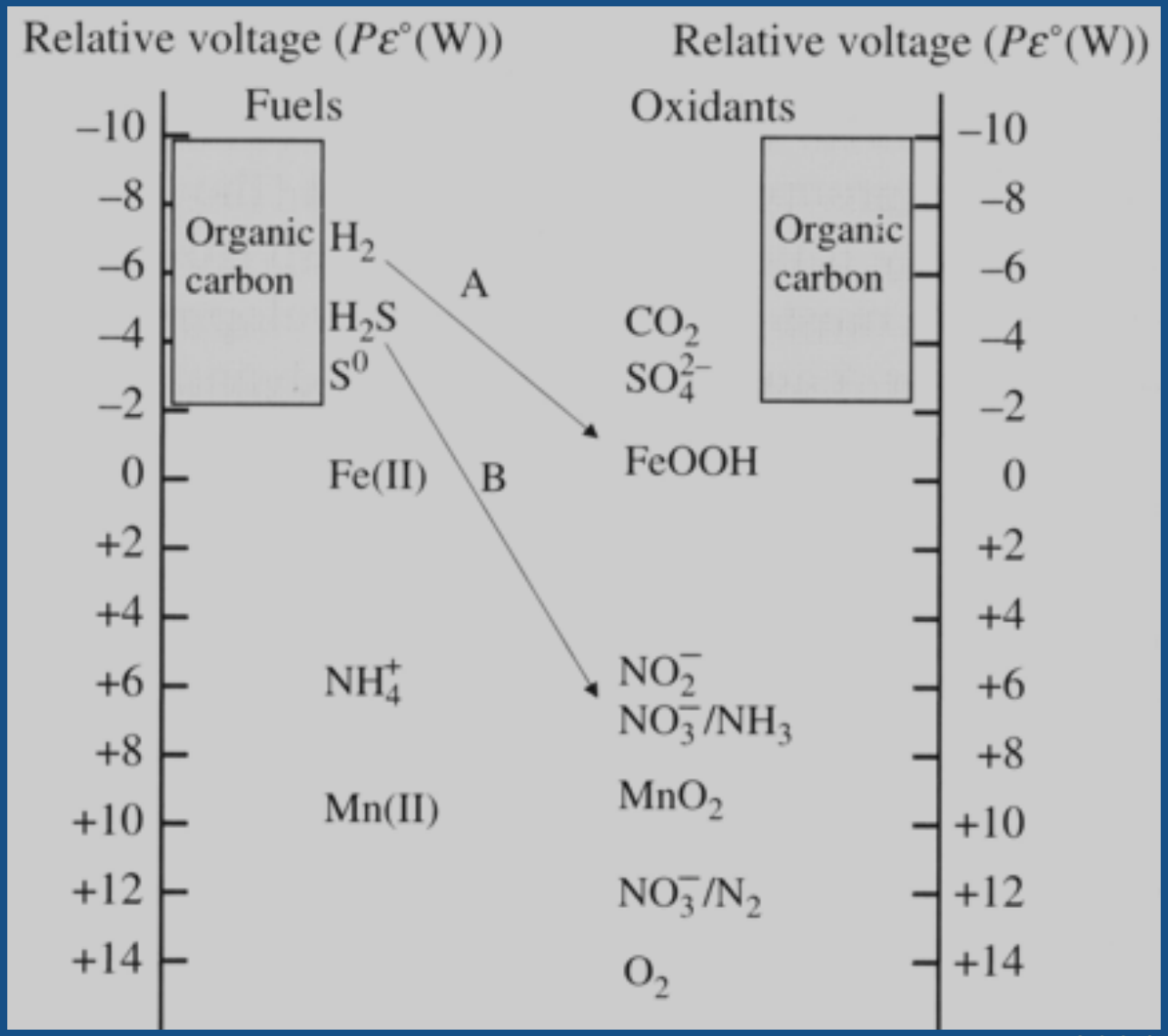
Microbes ~are chemistry



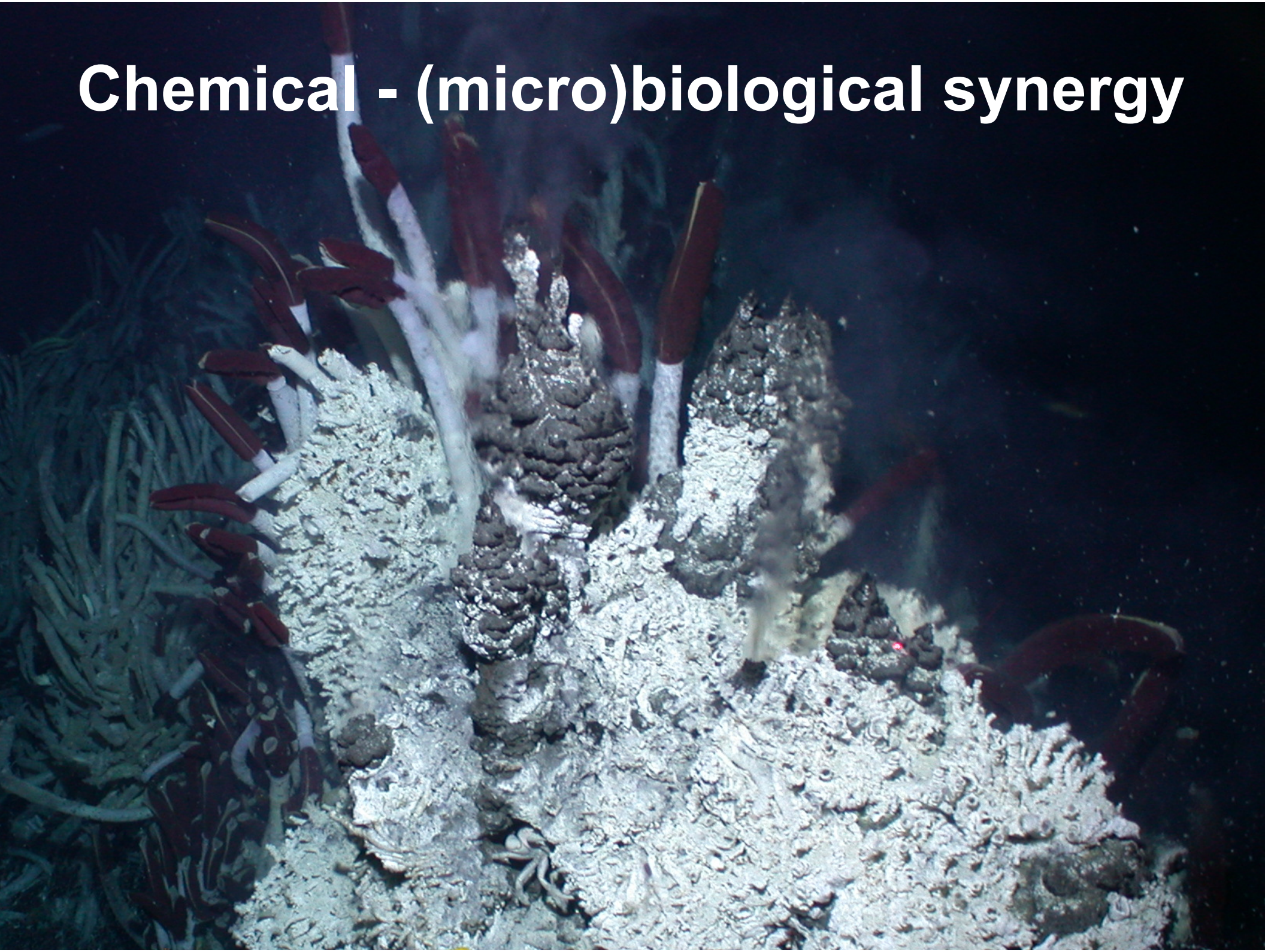
Microbes ~are chemistry



Nealson and Rye 2004

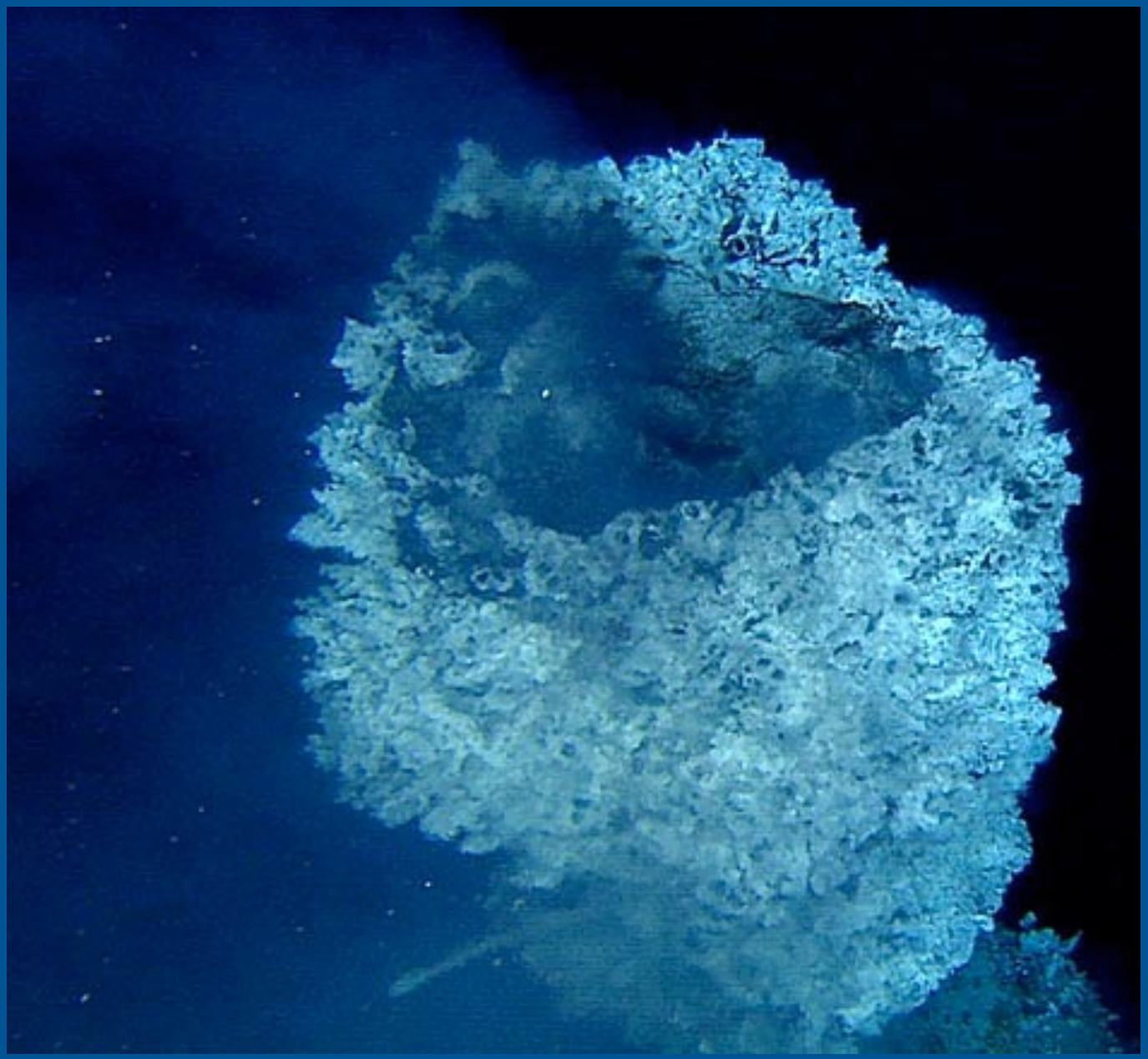
C, H, O, N, P, S, Fe…

Chemical - (micro)biological synergy



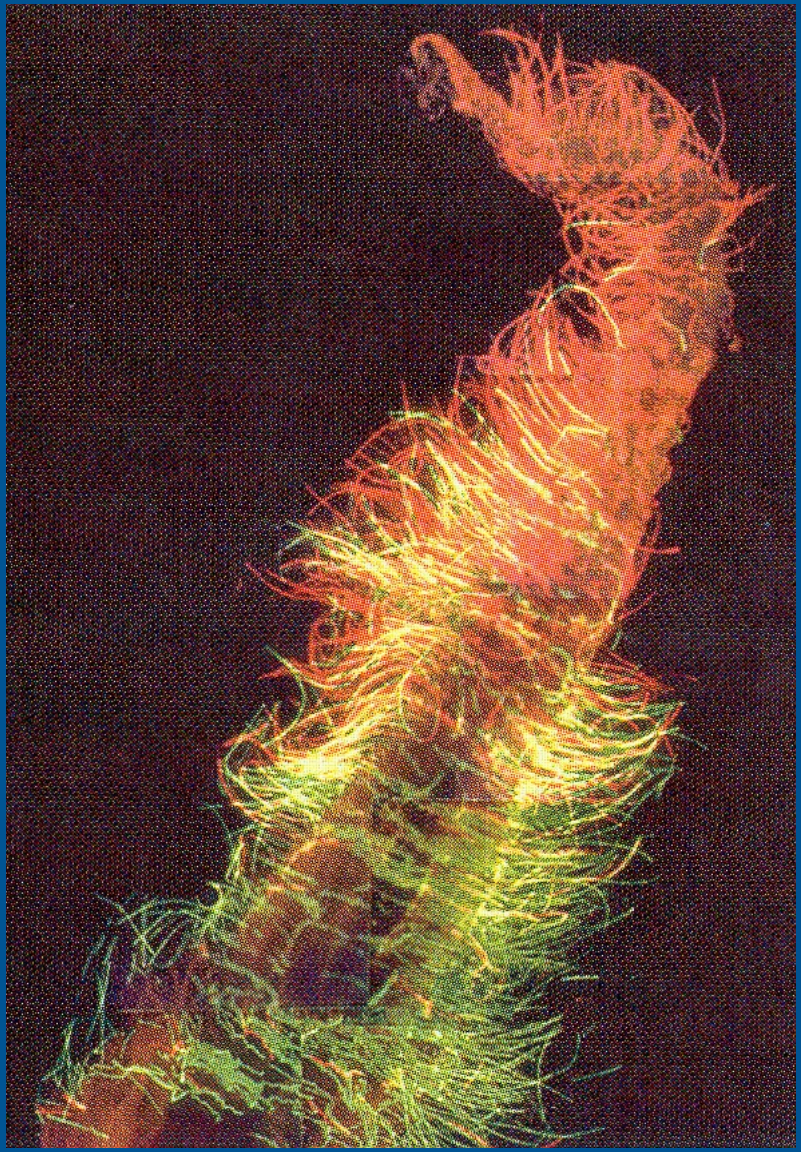
W. Lange - WHOI

Alvinella pompejana



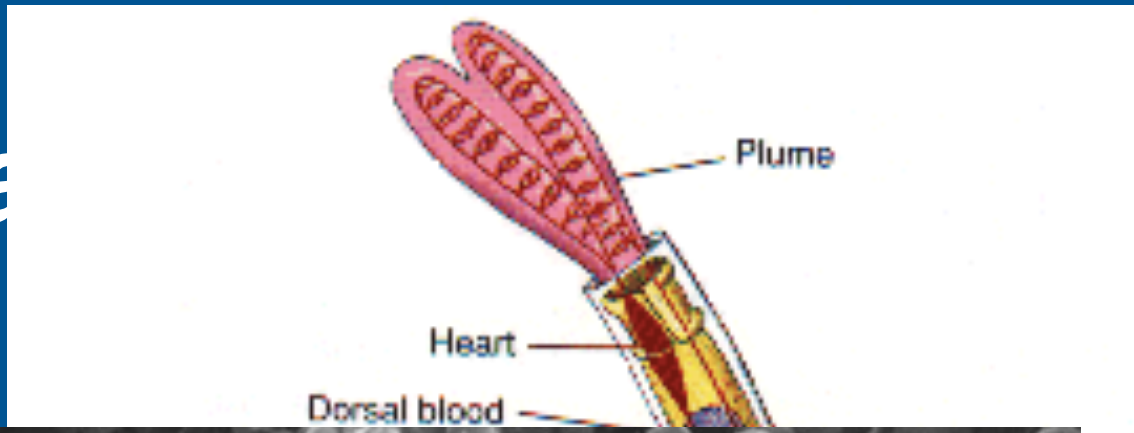
Alvinella pompejana

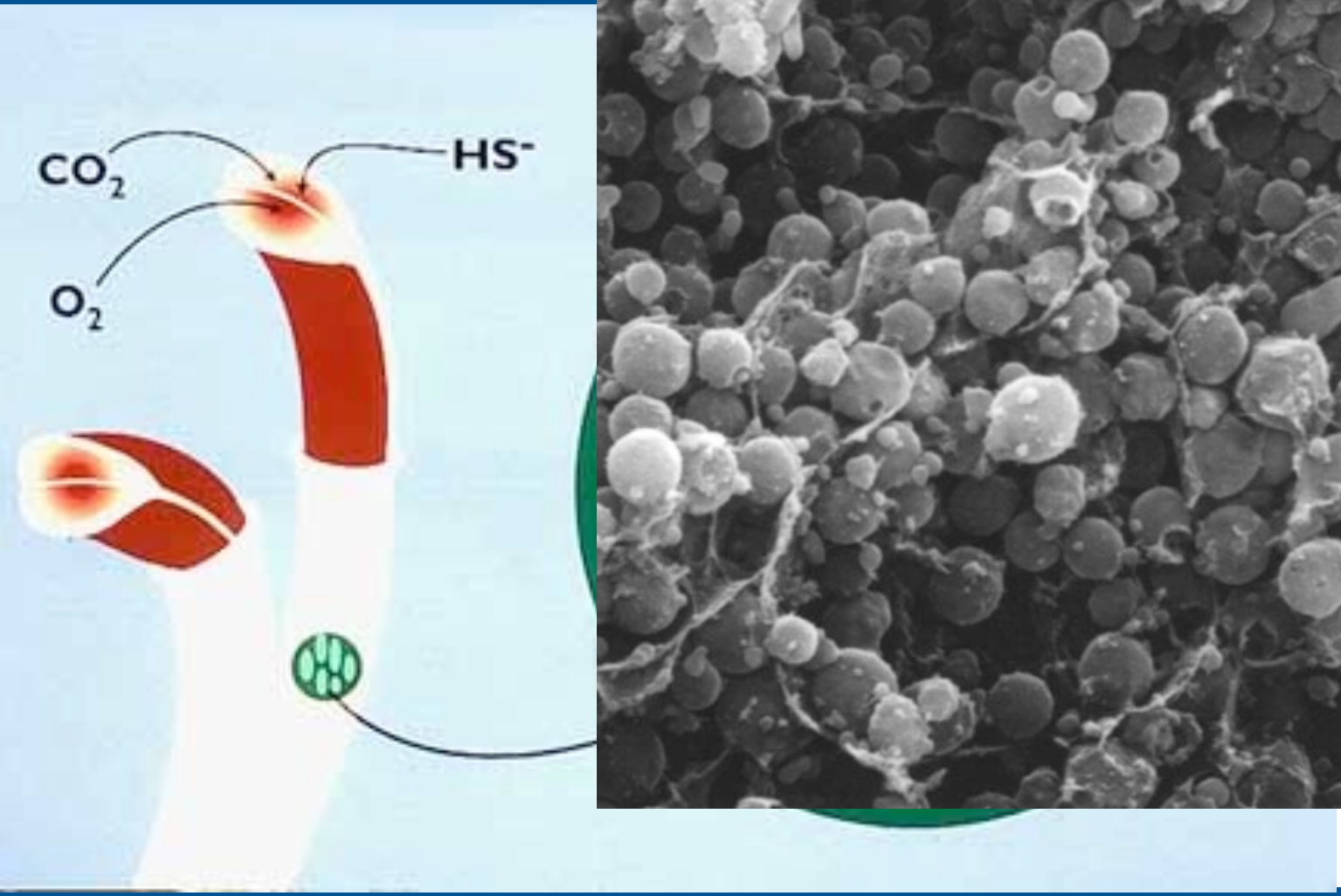
Alvinella pompejana ectosymbiosis



Riftia pachyptila

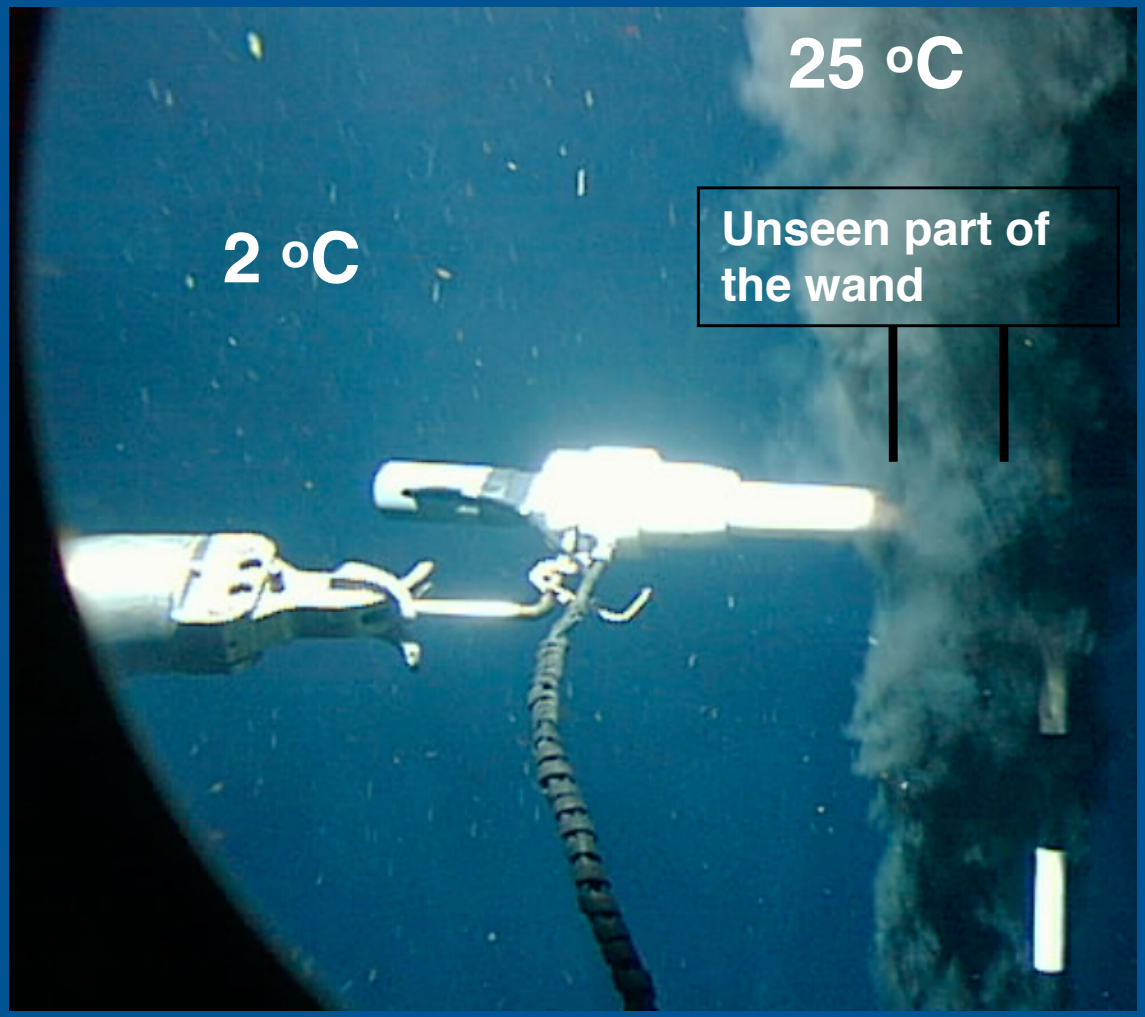
Riftia pachyptila endosymbiosis





Chemical speciation drives the (micro)biology

Chemical speciation: active vent

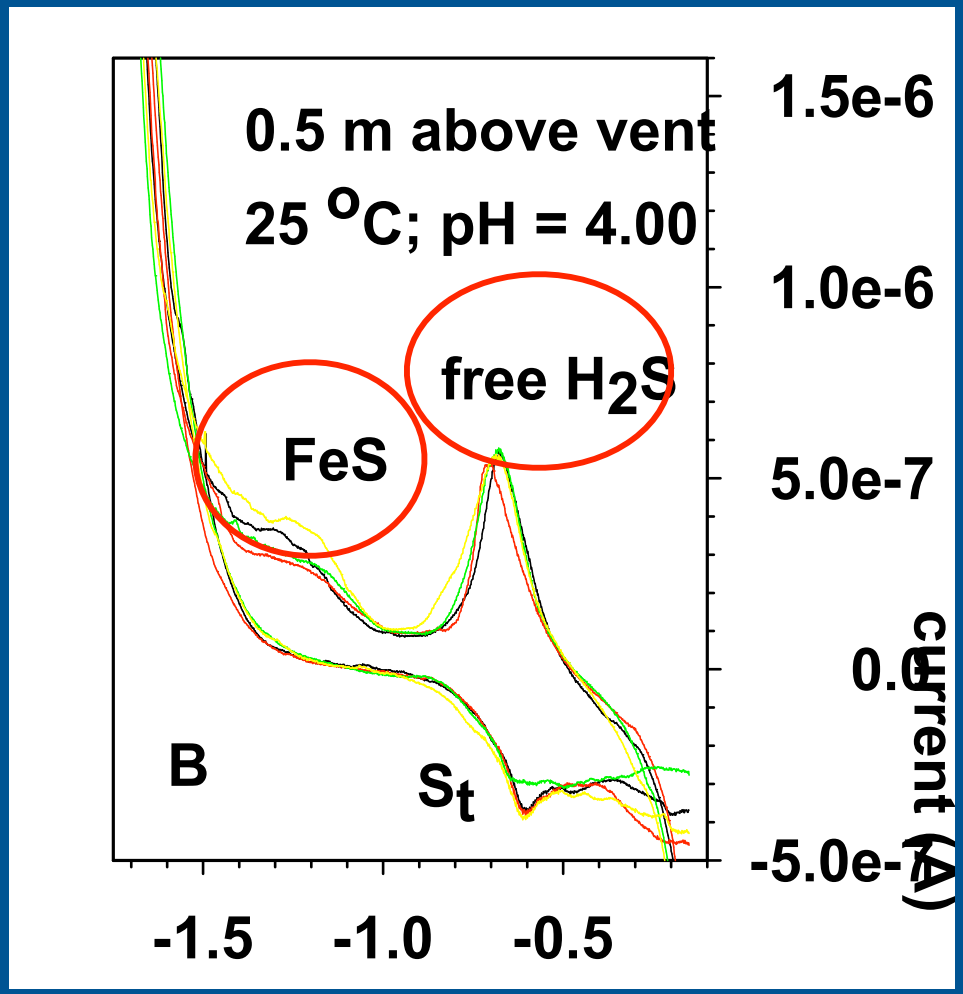


Chemical speciation: active vent

Major signals due to FeS & free H_2S

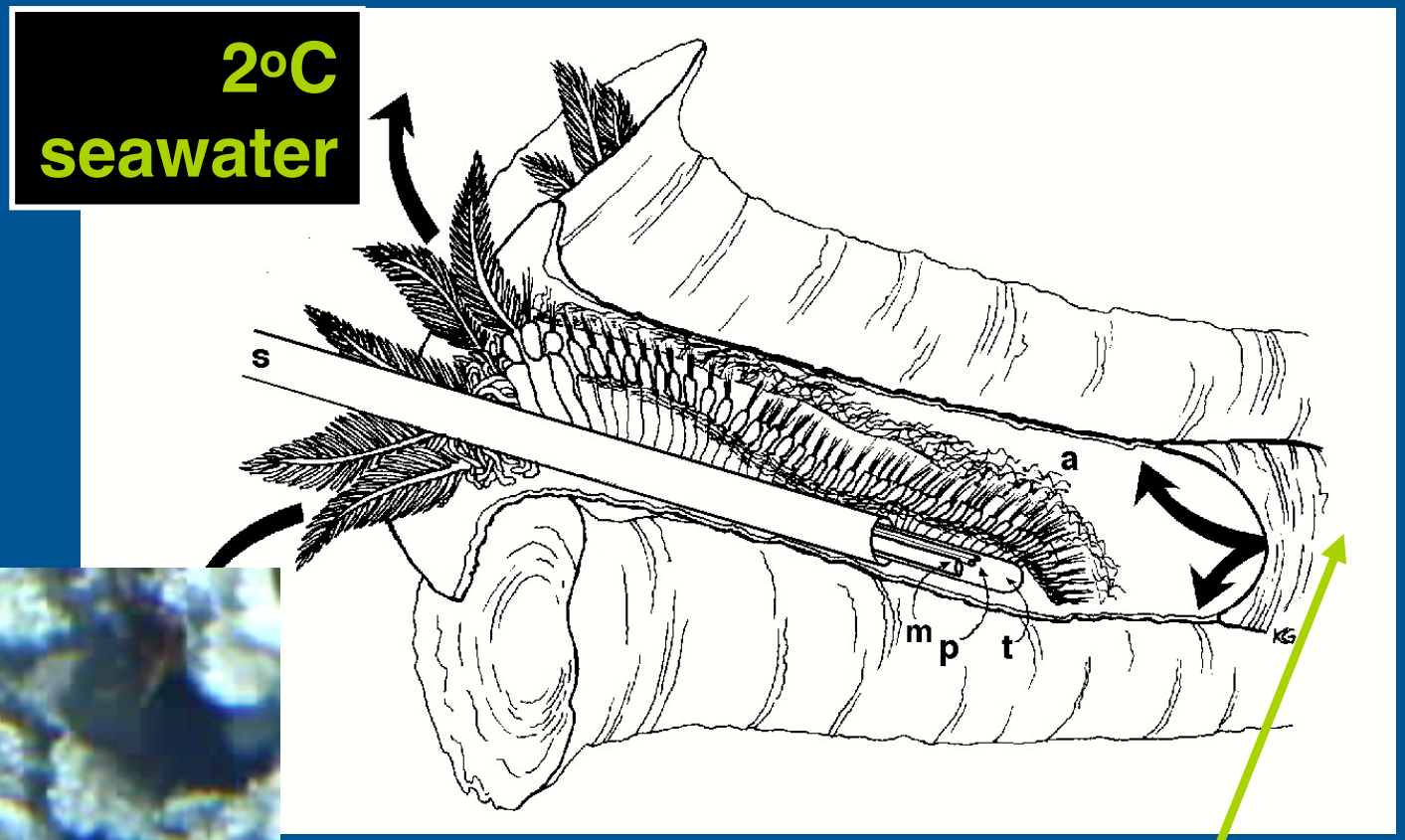
No O_2

No free Fe(II)



Volts vs Ag / AgCl

Chemical speciation: *Alvinella*



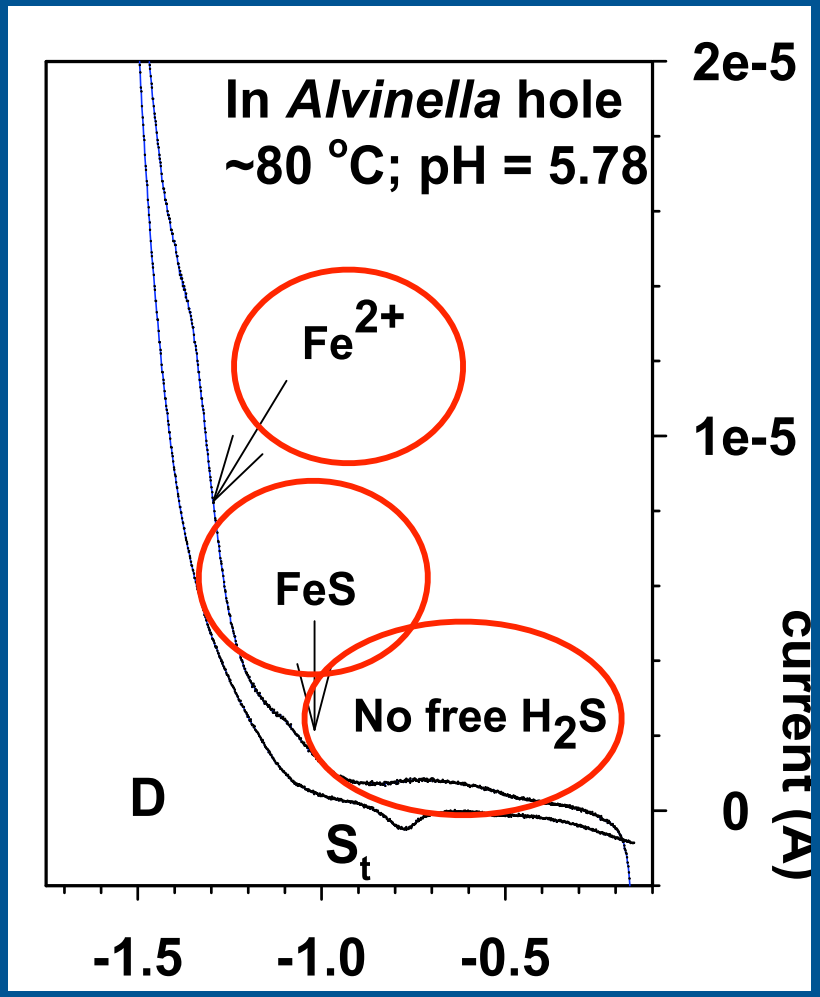
> 80°C
where tube
meets
chimney

Chemical speciation: *Alvinella*

Major signals due to FeS & Fe(II)

No O_2

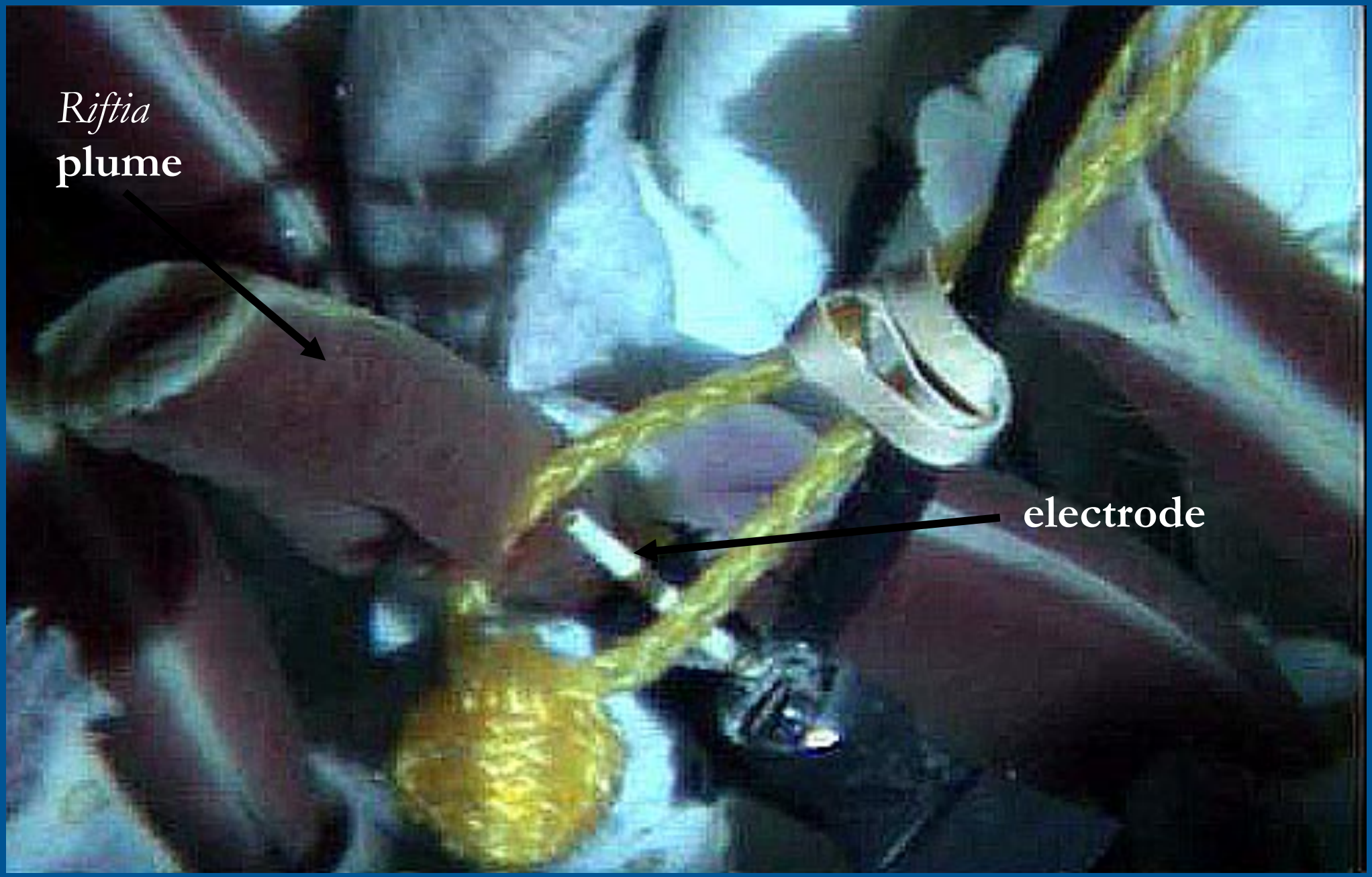
No free H_2S



Volts vs Ag / AgCl

Current (A)

Chemical speciation: *Riftia*

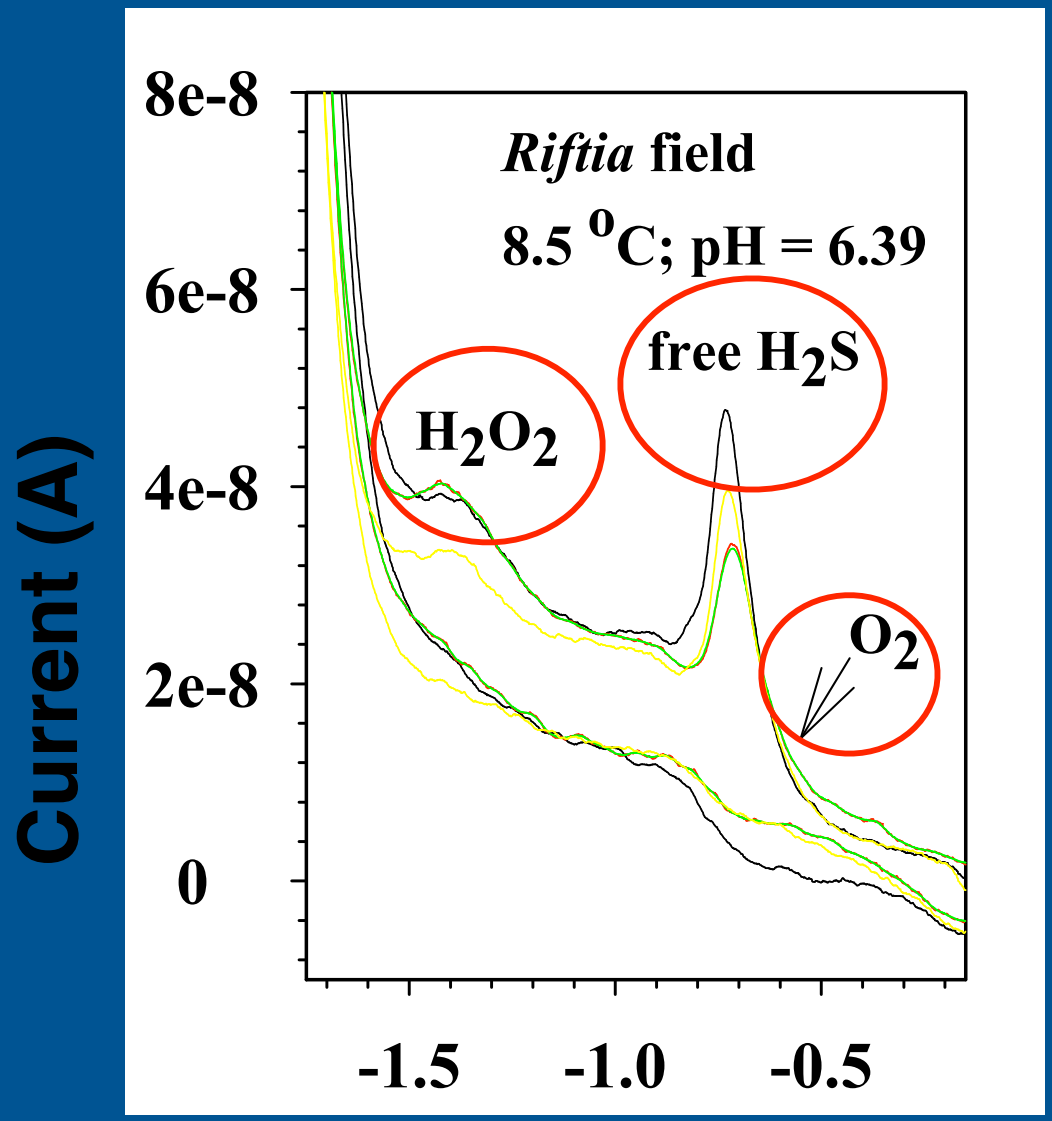

Riftia
plume
electrode

Chemical speciation: *Riftia*

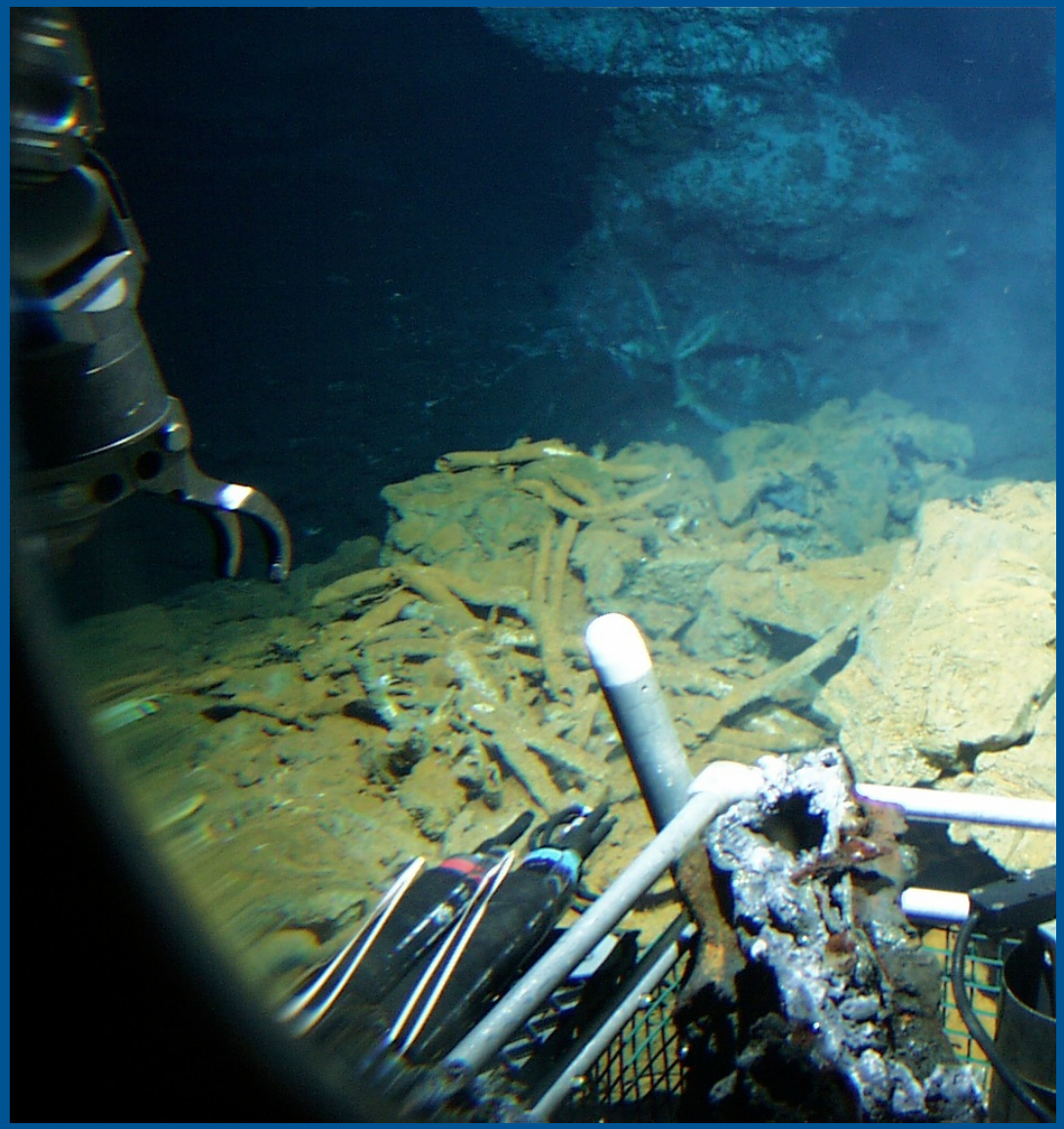
Major signals due to O_2 & free H_2S

No FeS or Fe(II)

Free H_2S required by chemoautrophic symbionts



Chemical speciation: “rusty” *Riftia*



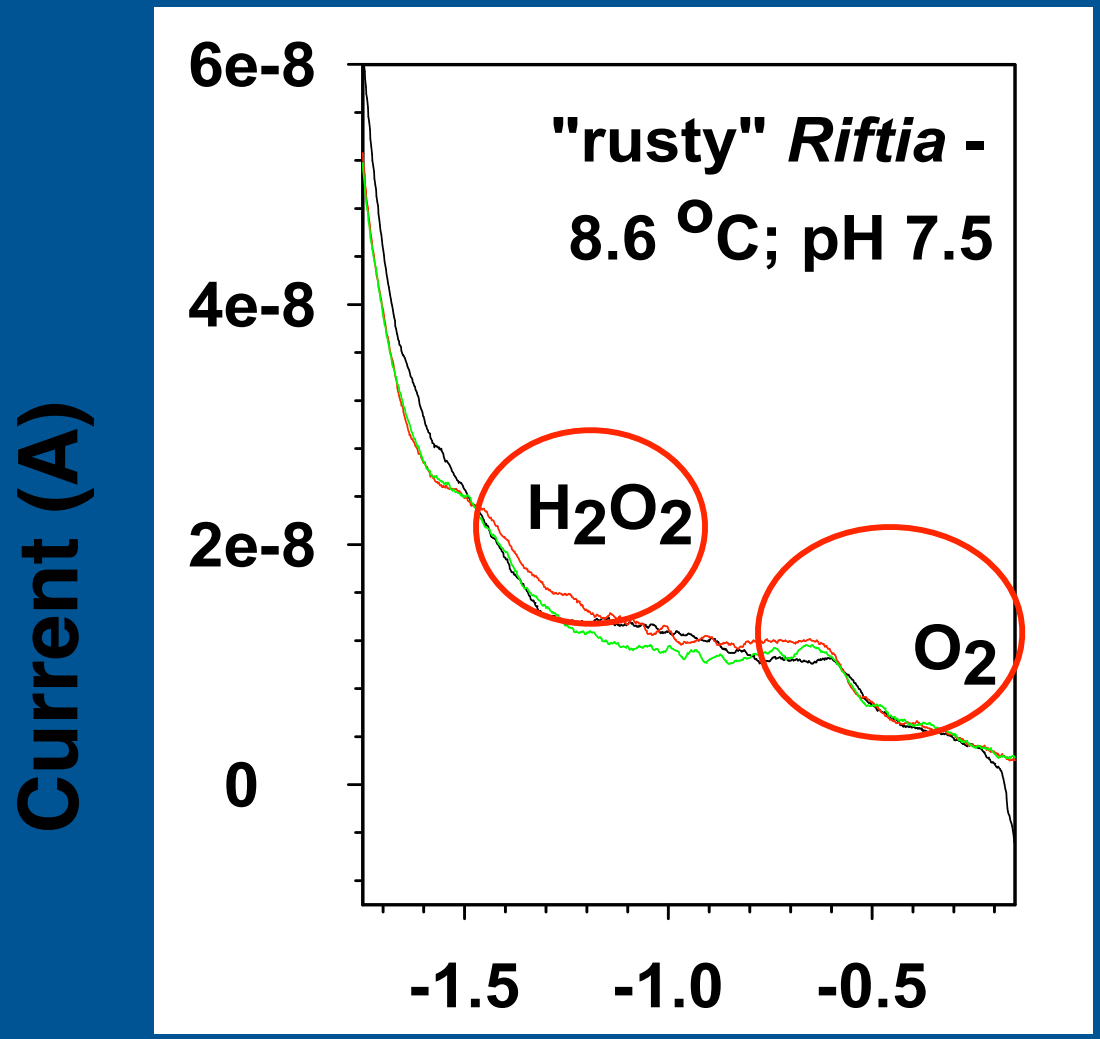
Chemical speciation: "rusty" *Riftia*

Major signal due to O_2

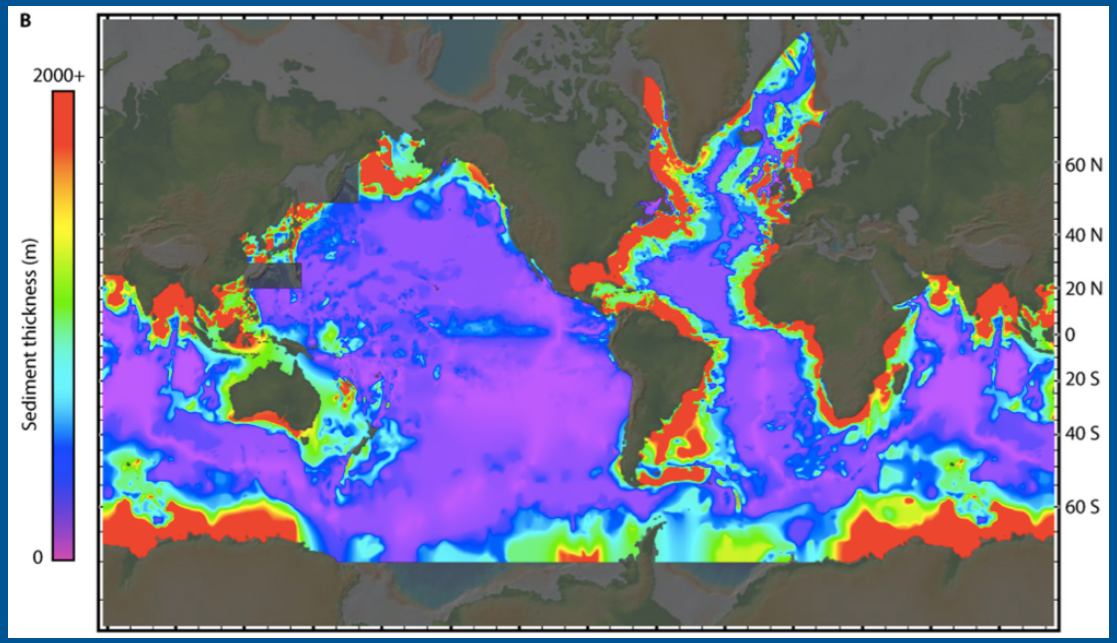
No FeS or Fe(II)

No free H_2S

Tubes encrusted with Fe(III)



…the subseafloor (the next frontier)

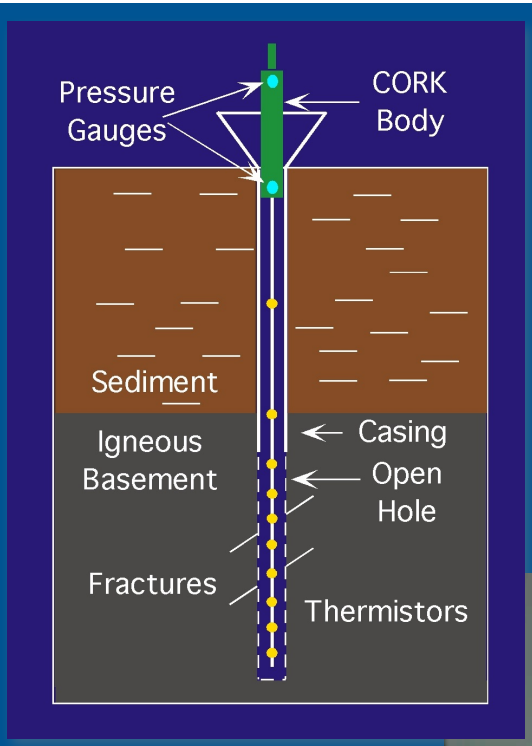


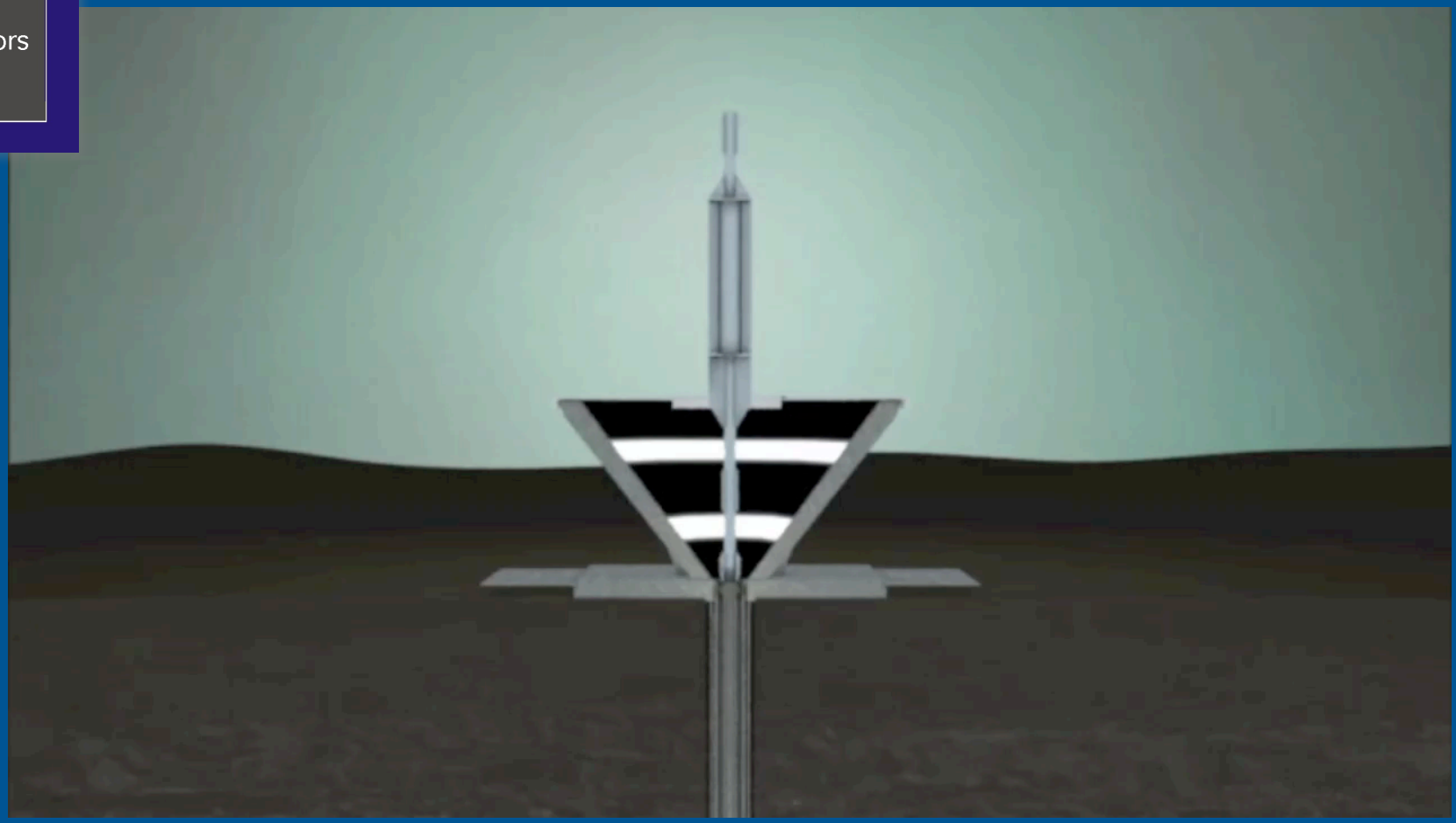
Are they alive?
Who is there?
What are they doing?
What are the rates?
C, N, Fe, S, etc…

Does their influence scale to this vast habitat size?

A hidden majority in the ocean crust?

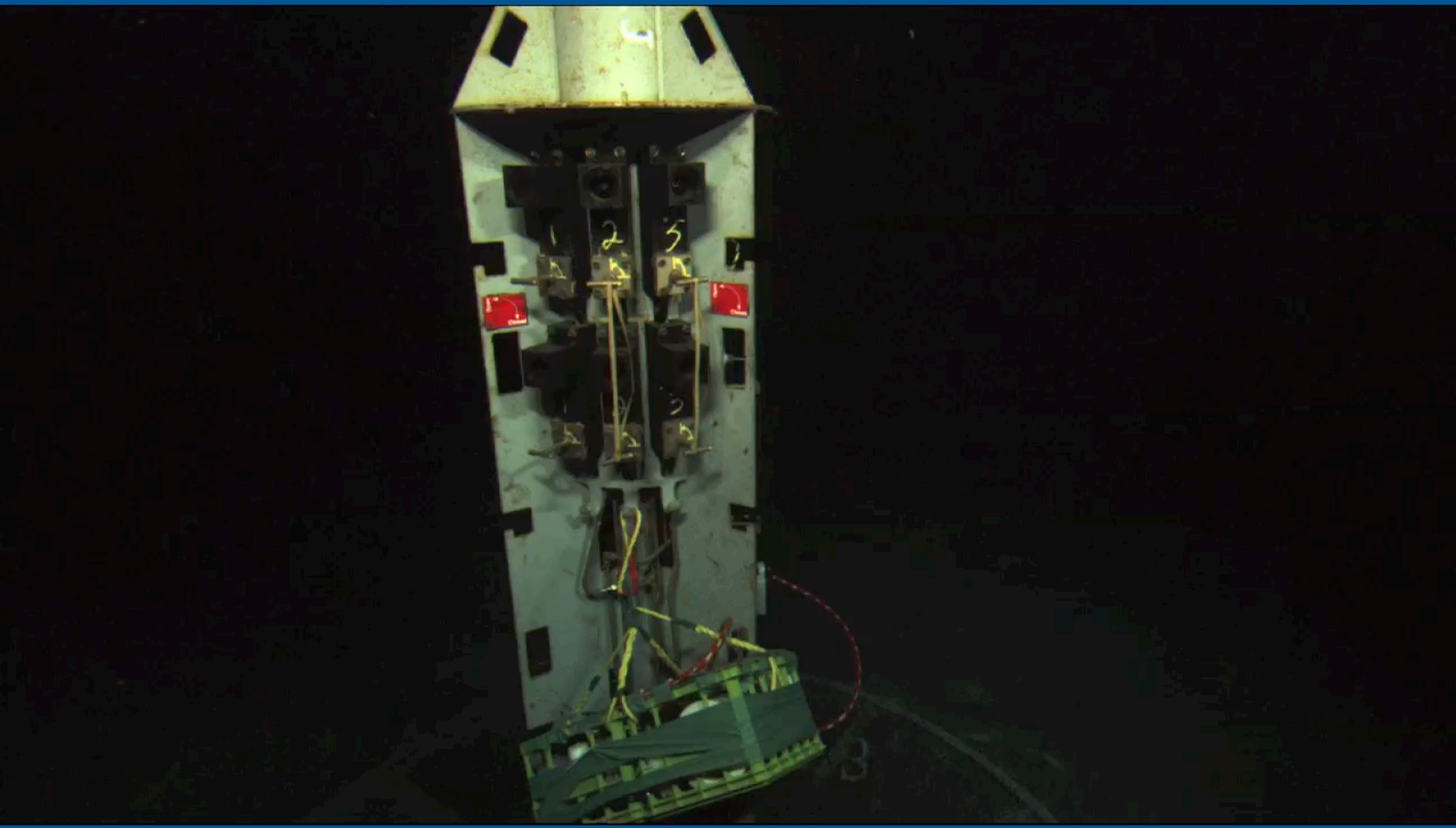
Accessing the deep subsurface





Animation from A. Fisher

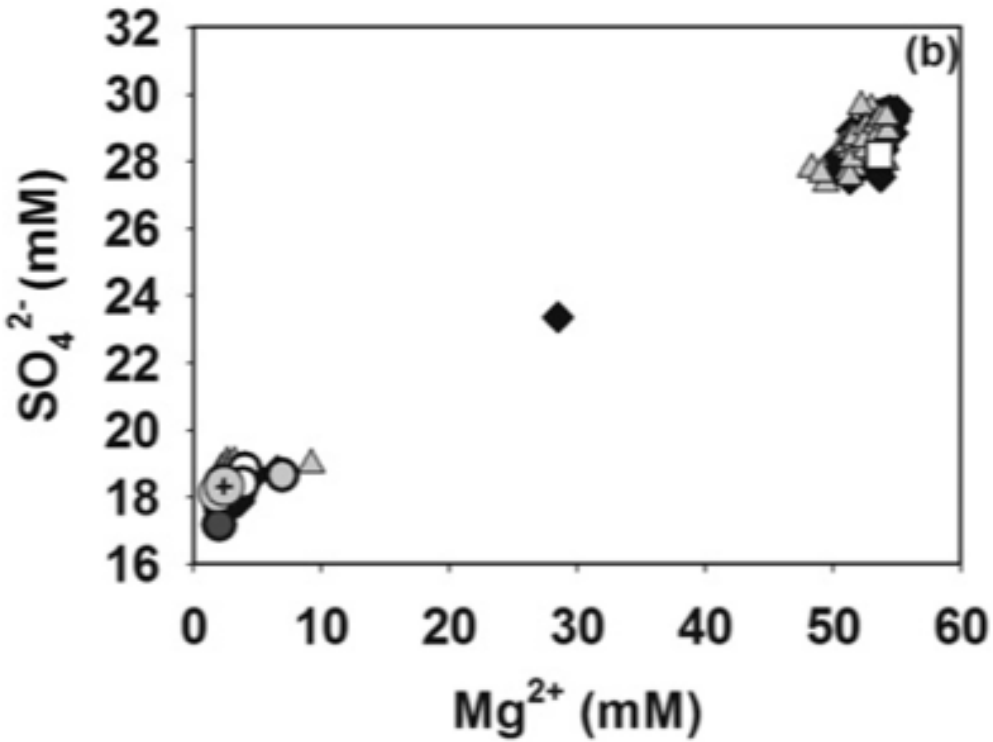
Accessing the deep subsurface

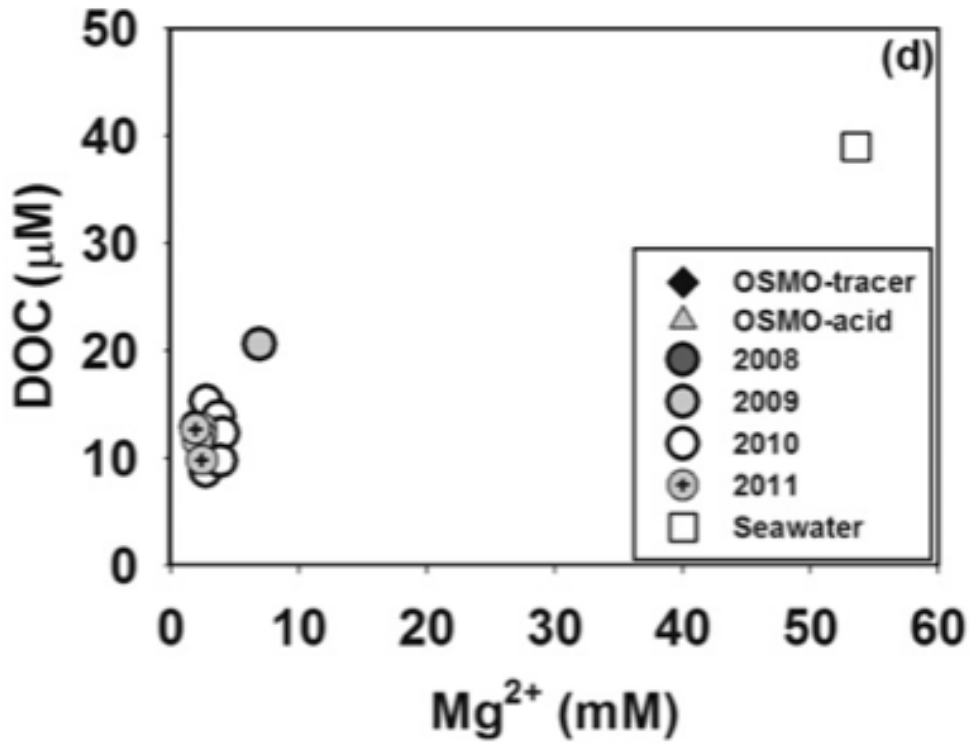


Accessing the deep subsurface

Video courtesy K. Becker

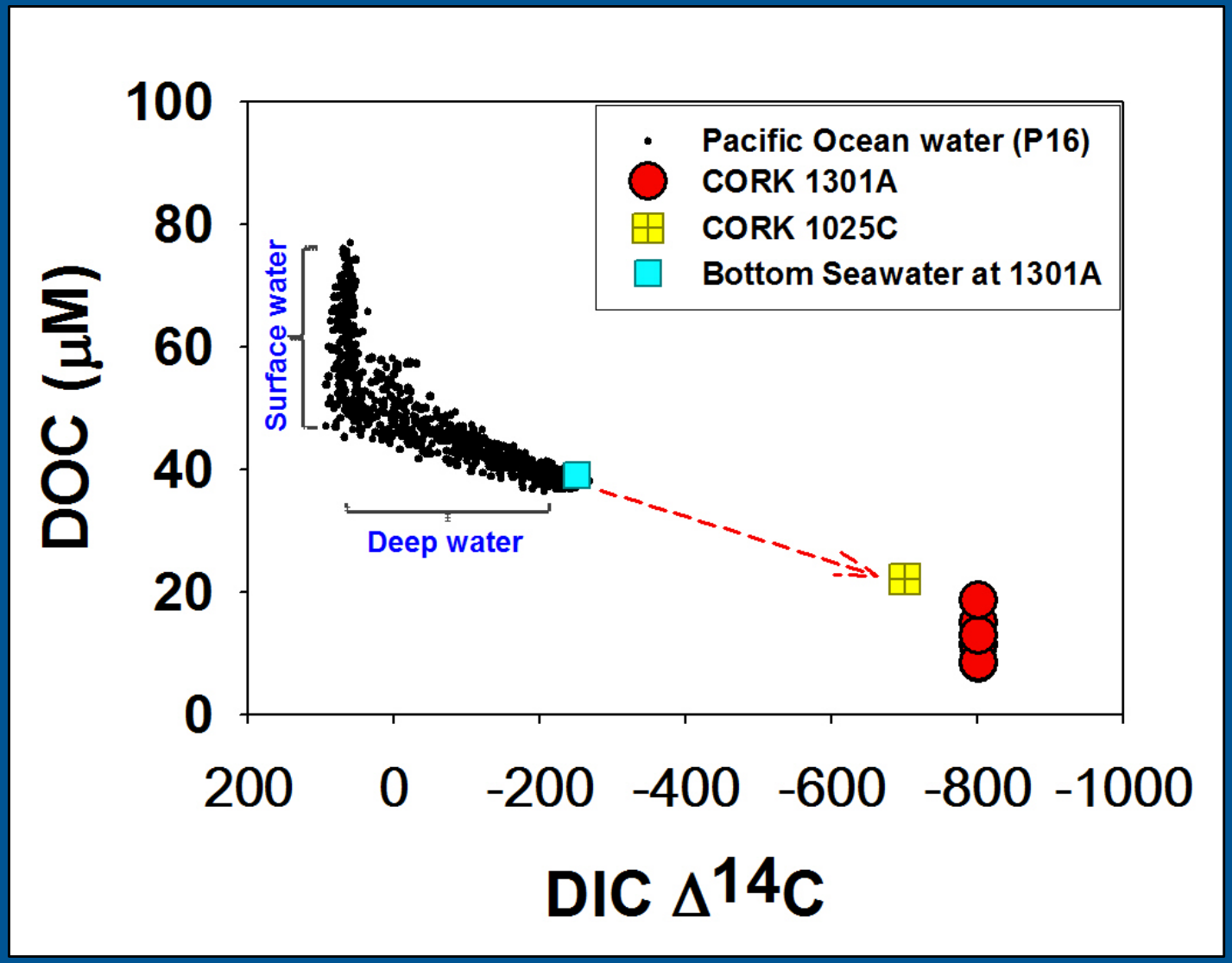
Subseafloor chemistry





Lin et al. 2011

Subseafloor chemistry



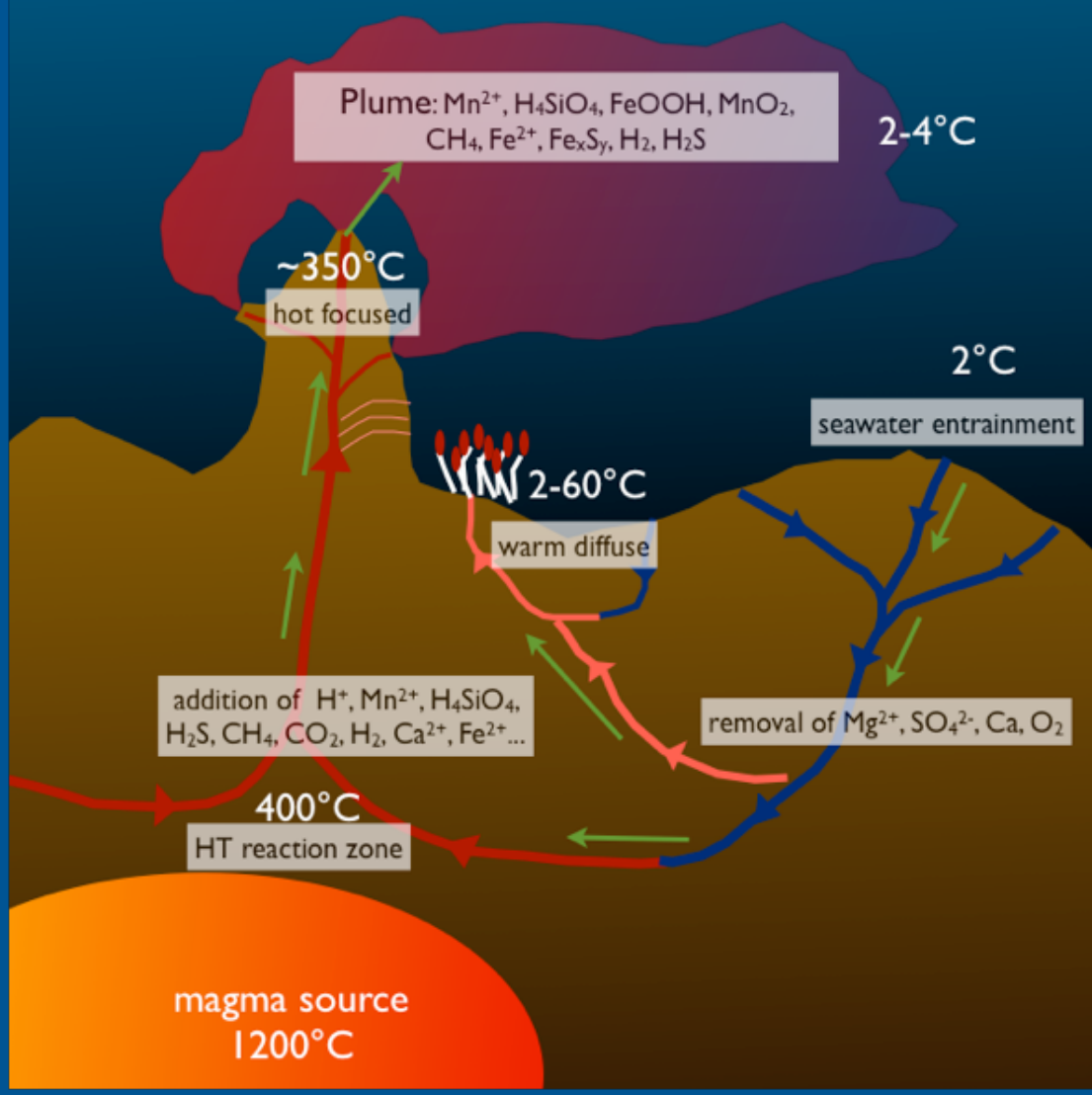
Fluids sampled from CORKs using new pumping systems

- DOC in Hole 1301A ~1/3 of bottom seawater, net removal ~ 2.4 nmol/L/yr (similar to deep ocean)
- Actual rate of DOC removal in the crust likely to be higher because of sources (e.g., diffusion from overlying sediment)

Lin et al. 2011

Deep-sea hydrothermal systems

Seawater changes into hydrothermal fluid



	Hydro-thermal Fluid (MOR)	Sea-water
Temp (°C)	~400	2
pH (at 25°C)	2.8-4.5	8
H_2S (mmol/kg)	0-19.5	0
Na (mmol/kg)	10.6-983	464
SO_4 (mmol/kg)	0	28
Cl (mmol/kg)	30.5-1245	545
Mg (mmol/kg)	0	53
Methane (uM)	978	<<1
CO_2 (uM)	5753	31
H_2 (uM)	78	<<1

After Reysenbach & Cady 2001.
CH_4, CO_2, H_2 data from Wankel et al 2011,
other data from Tivey, 2007