Characterization of Methane Degradation and Methane-Degrading Microbes in Alaska Coastal Waters

DE-NT0005666

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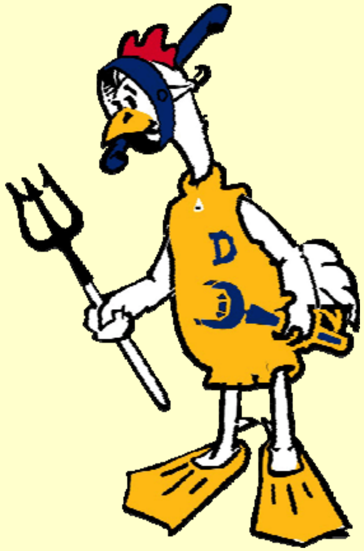
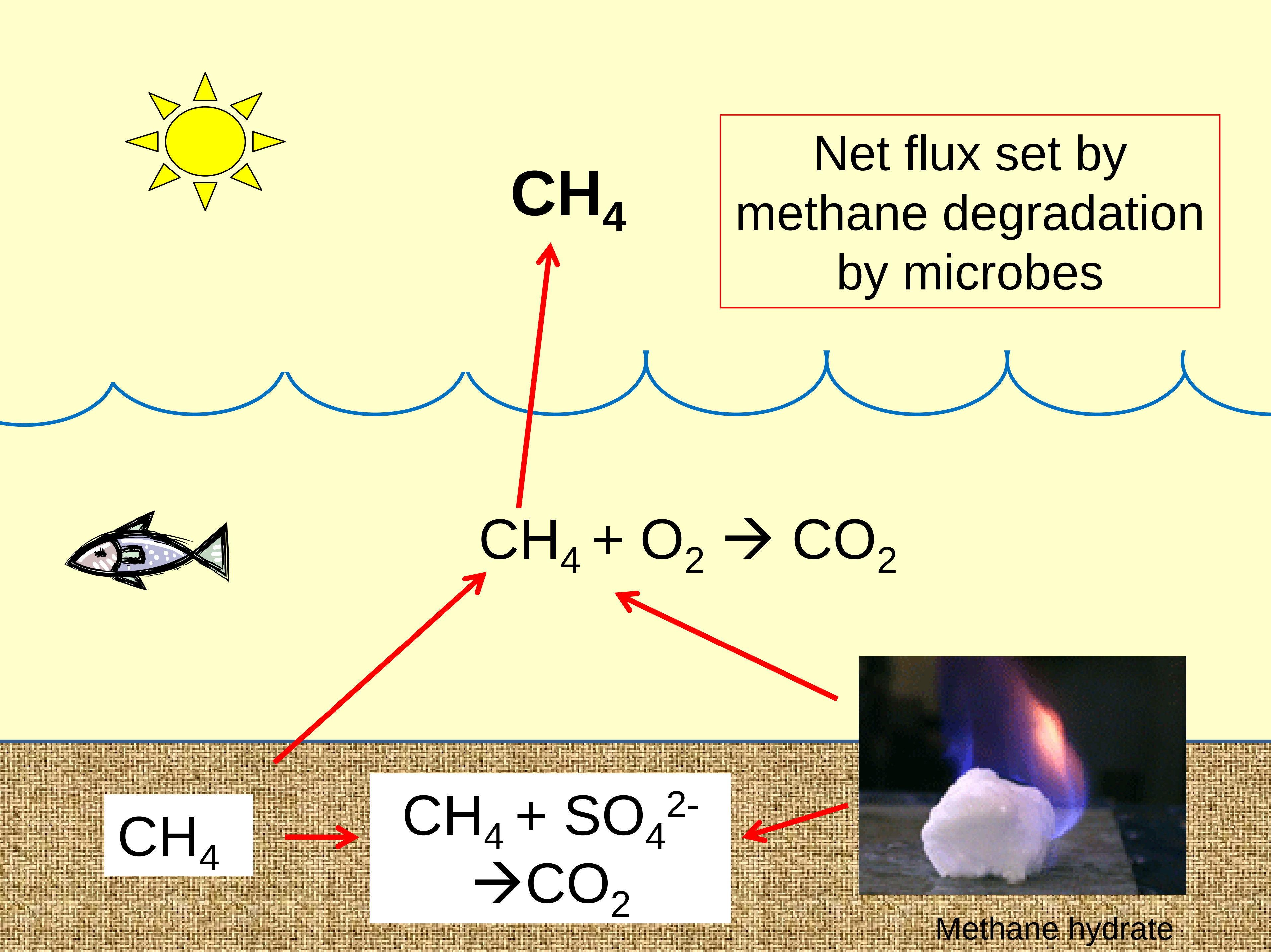
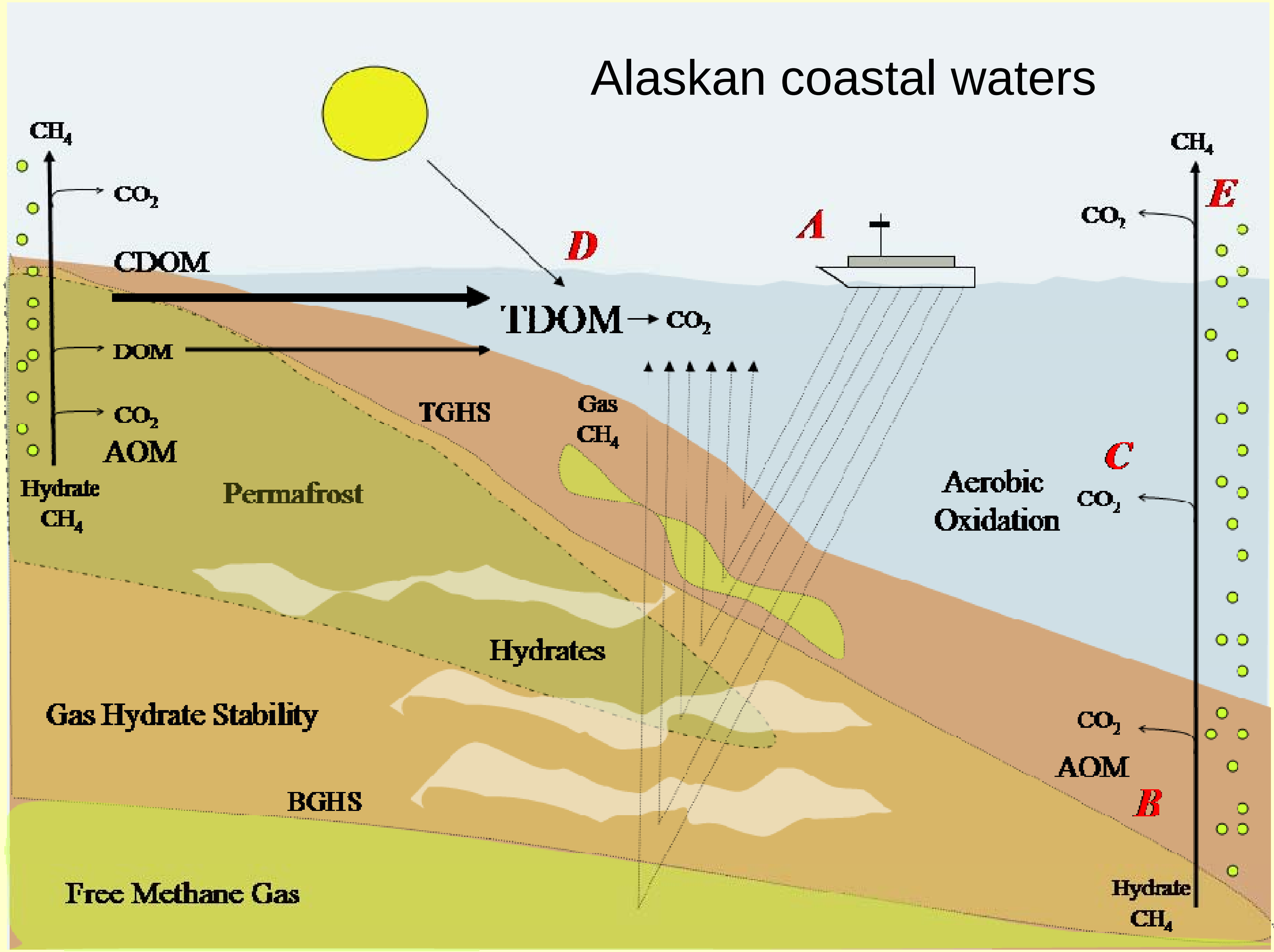


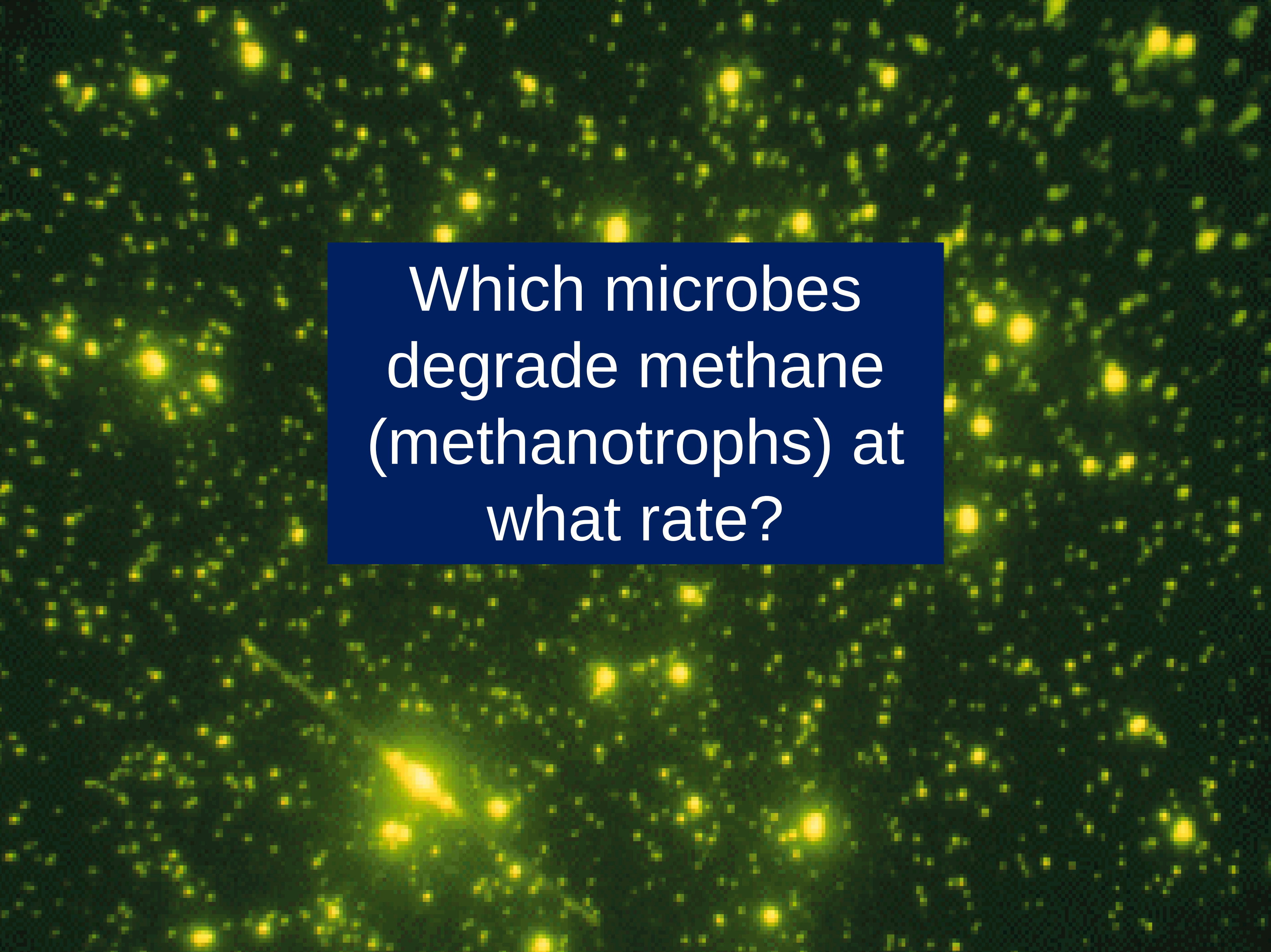

Net flux set by methane degradation by microbes
CH_4
$CH_4 + O_2 \rightarrow CO_2$
CH_4
$CH_4 + SO_4^{2-} \rightarrow CO_2$
Methane hydrate



AOM = Anaerobic oxidation of CH_4

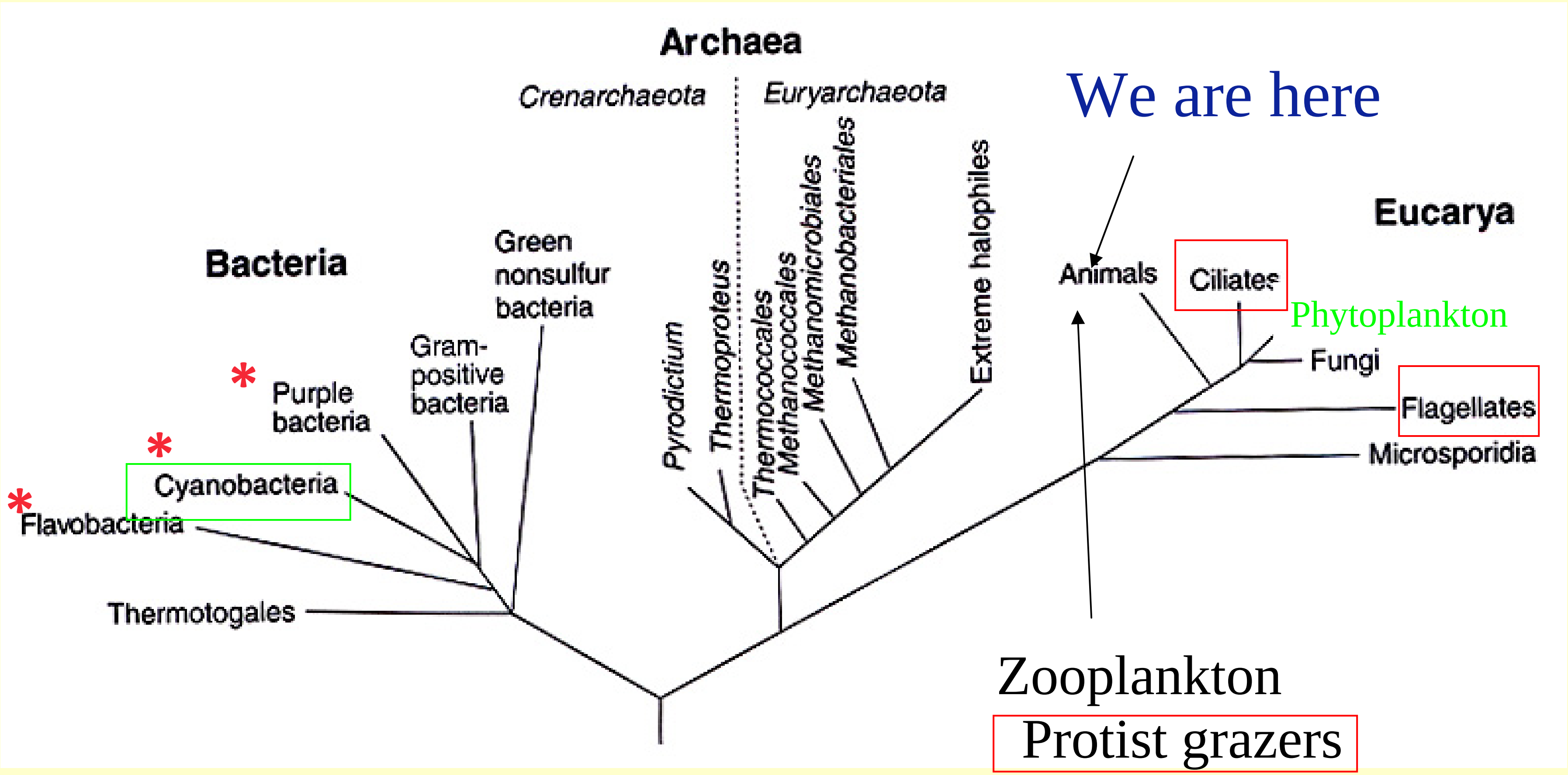
CDOM= colored dissolved organic material

GHS= gas hydrate stability



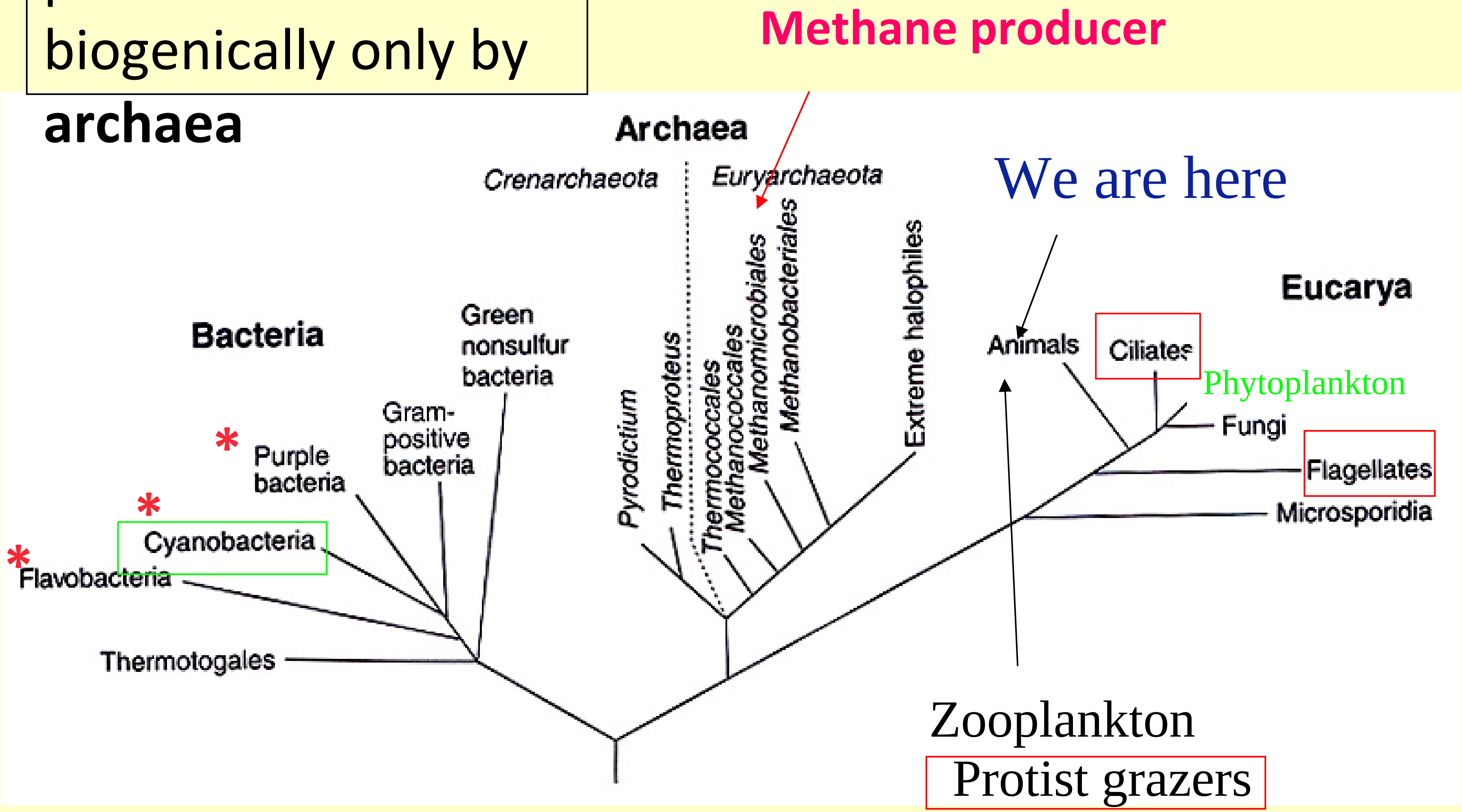
Which microbes degrade methane (methanotrophs) at what rate?

Simple tree of life



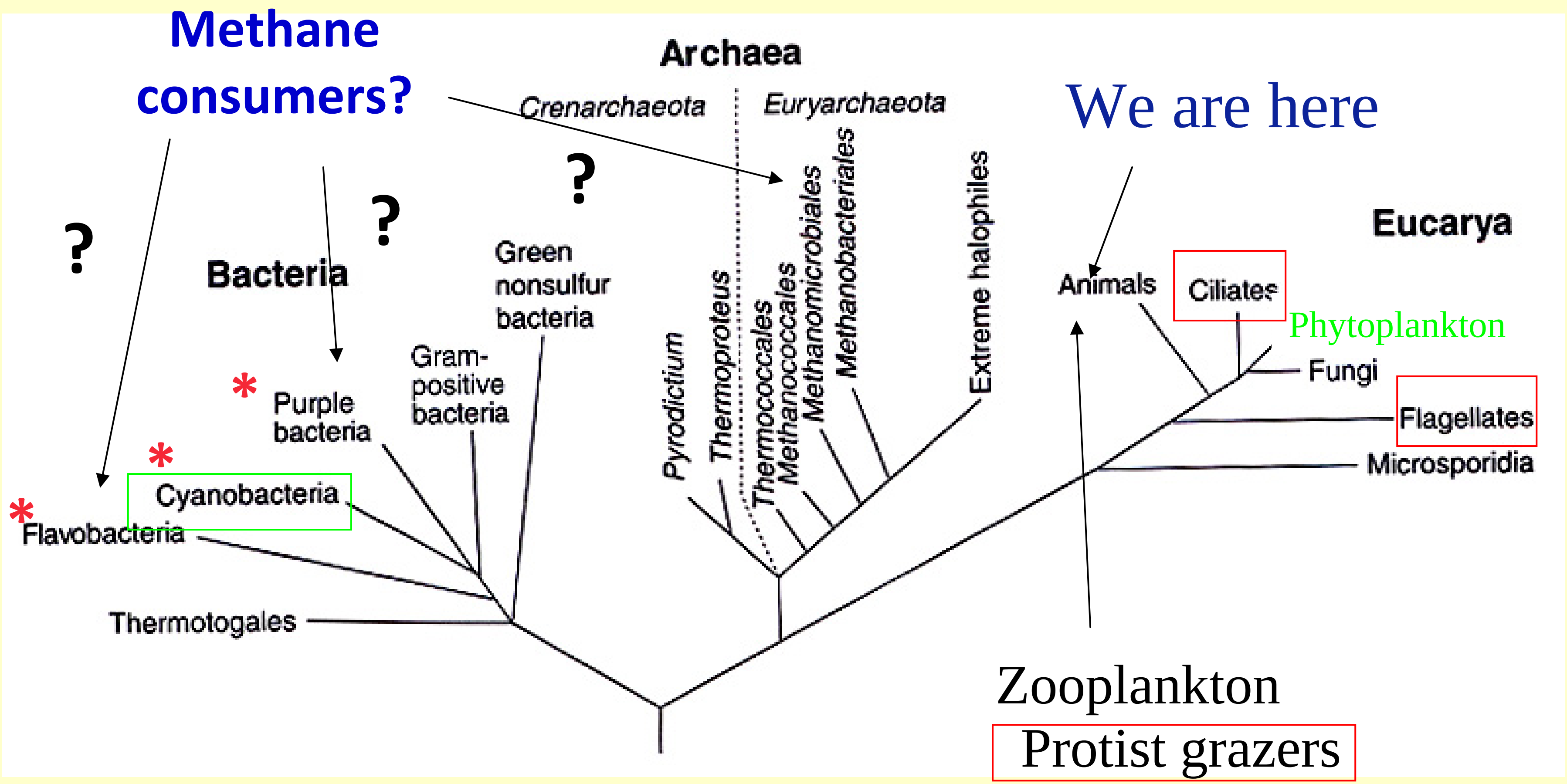
*Abundant groups in the ocean

Methane is produced biogenically only by **archaea**



*Abundant groups in the ocean

But who are the methane consumers?



*Abundant groups in the ocean

Arctic Ocean Methane Hydrate Exploration: Energy and Climate Change

Cruise scheduled for August-September 2009

Richard Coffin, Naval Research Lab, Washington, DC

Jens Greinert, Royal Netherlands Institute for Sea Research, The Netherlands

Ingo Pecher, Heriot-Watt University, UK

Thomas Lorenson, USGS, Menlo Park, CA

Senior Scientists for Methane Hydrate Expedition

1. Thomas Bianchi, Texas A&M University, College Station, TX, USA
2. Richard Coffin, Naval Research Laboratory, Washington, DC, USA
3. Roswell Downer, Milibar Hydrotest Inc., Shreveport, LA, USA
4. Jens Greinert, University of Ghent, Ghent, Belgium; NIOZ, The Netherlands
5. Leila Hamdan, Naval Research Laboratory, Washington, DC, USA
6. David Kirchman, University of Delaware, Lewes, Delaware, USA
7. Thomas Lorenson, USGS, Menlo Park, CA, USA
8. Ingo Pecher, Heriott-Watt University, Edinburgh, Scotland
9. Christopher Osburn, North Carolina State University, Raleigh, NC, USA
10. Kelly Rose, National Energy Technology Lab, Morgantown, WV, USA
11. Joseph Smith, Naval Research Laboratory, Washington, DC, USA
12. Tina Treude, IFM-GEOMAR, Germany
13. Shari Yvon-Lewis, Texas A&M University, College Station, TX, USA
14. Warren Wood, Naval Research Laboratory, Stennis, MS, USA
15. Brandon Yoza, University of Hawaii, Honolulu, HI, USA

Some goals and research topics

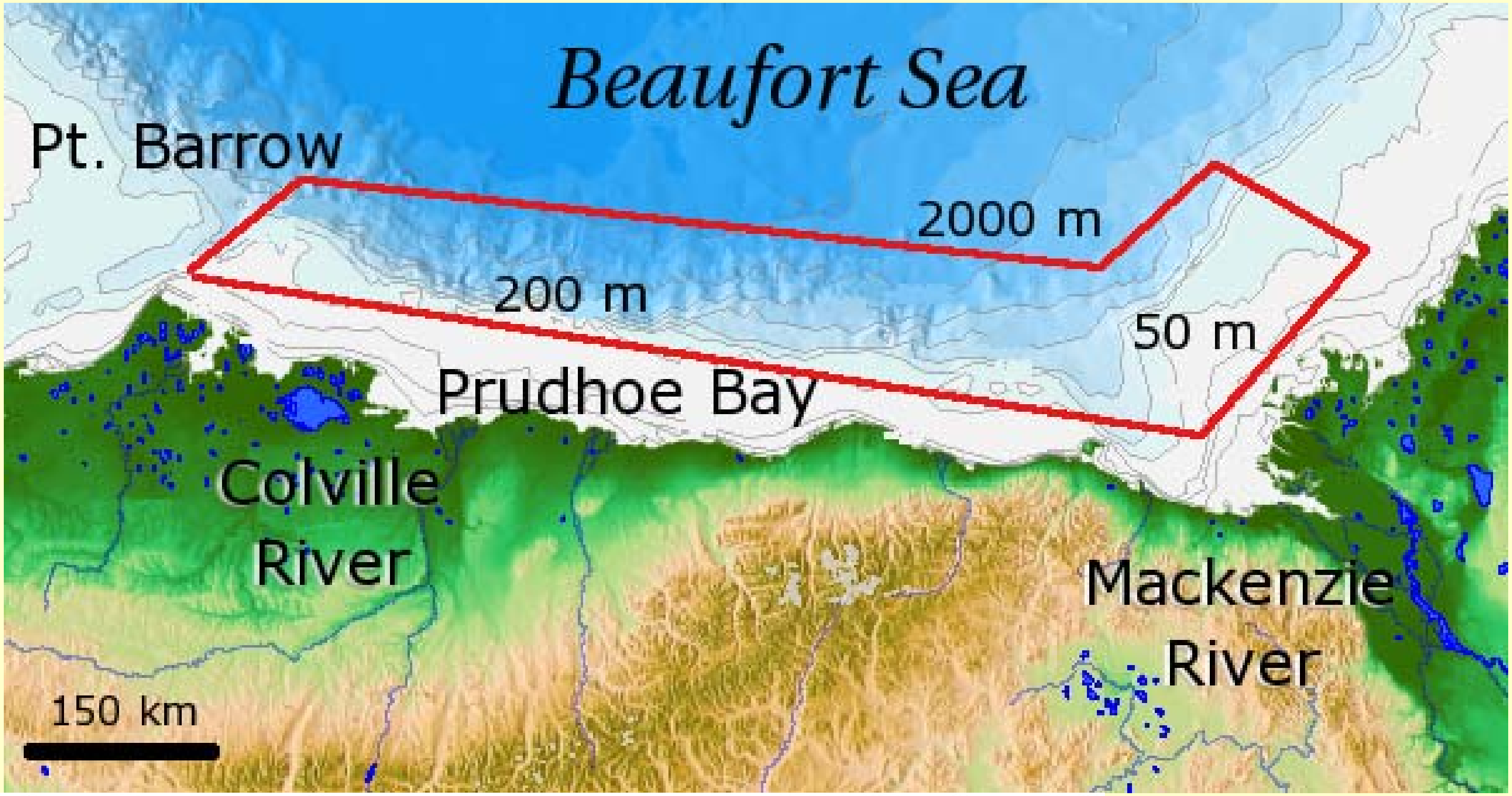
- Acquire seismic, heatflow and geochemical data for **evaluation of deep sediment hydrate distributions**.

- Estimate spatial variation in the **vertical methane diffusion** in sediment and water column.

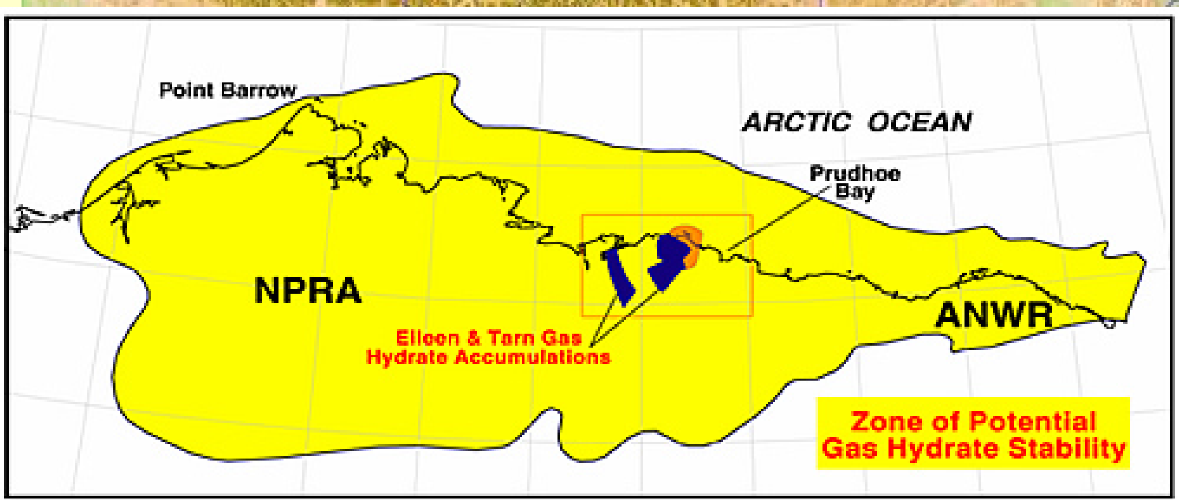
- Develop and calibrate **models to evaluate sediment hydrate** loading, hydrate destabilization through warming, and the **fate of methane after hydrate destabilization**.

- Determine and **model the transport of methane** from the sediment through the water column into the atmosphere.

- Study the control of total methane emissions by **microbial methane consumption**.

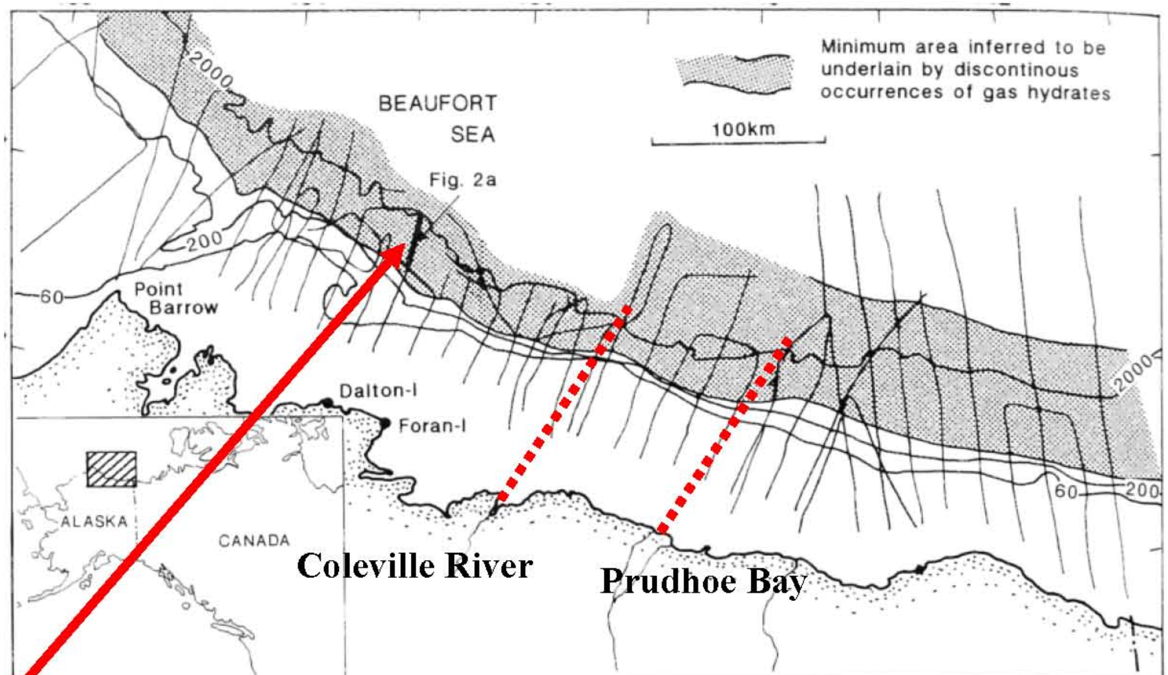

Beaufort Sea
Pt. Barrow
2000 m
200 m
50 m
Prudhoe Bay
Colville
River
Mackenzie
River
150 km

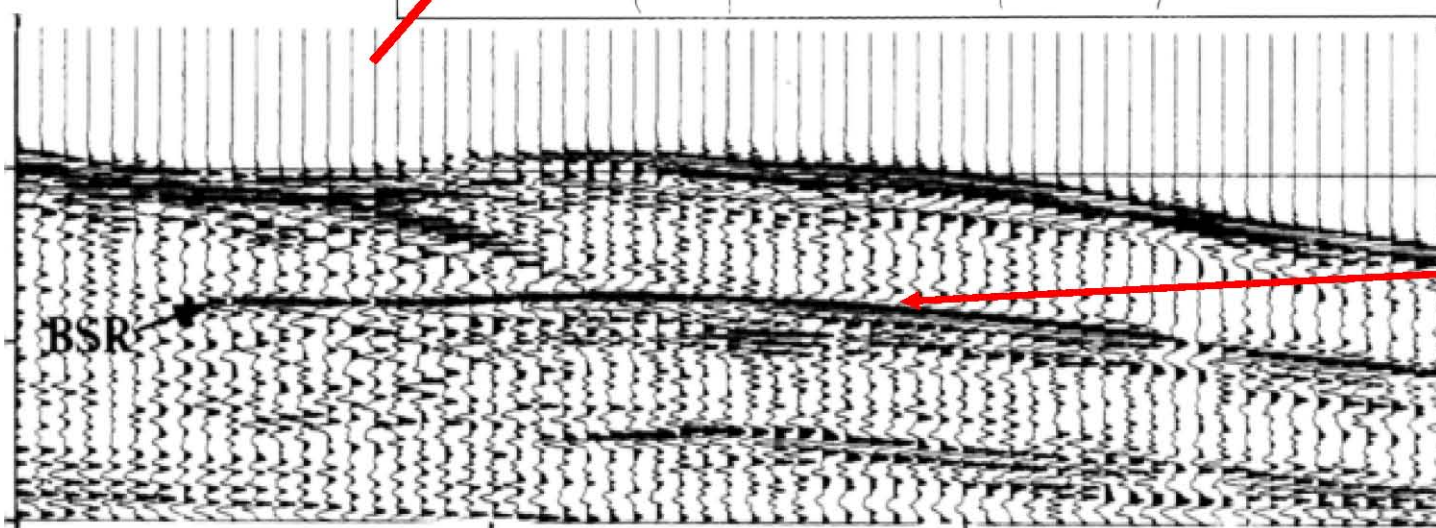
Study Area


Point Barrow
ARCTIC OCEAN
Prudhoe
Bay
NPRA
ANWR
Eileen & Tarn Gas
Hydrate Accumulations
Zone of Potential
Gas Hydrate Stability


RUSSIA
ARCTIC
OCEAN
GREENLAND
ICELAND
CANADA
UNITED STATES OF AMERICA

Existing Seismic Data





Bottom Simulating Reflector Indicating potential gas hydrate beds

Work to be done on the US Coast Guard ice breaker, **Polar Sea**

399 feet
25 scientists

Questions to be addressed by Kirchman's group

1.How does methane degradation depend on methane concentrations and methane hydrates?

Measure ^{14}C-methane degradation in various regions with and without methane hydrates

Few previous direct estimates of methane degradation

Regime	Concentration (nmol cm^{-3})	Degradation Rate (nmol cm^{-3} d^{-1})
Water column		
Bering Sea	2-21	0.007-0.07
→ Chukchi Sea	0.2-1	0.04-0.3
Kara Sea	1.3-16	0.009-4.5
Barents Sea	0.05-0.15	0.0002-0.006
Skan Bay, Aleutian Is.	0-2500	0-10
Sediments		
Bering Sea	n.d.	0.2-117
→ Chukchi Sea	1-15	0.002-0.015
Kara Sea	10-27	0.3-222
Barents Sea	0.75-2	0.07-2.2
Terrestrial		
Siberia permafrost	50-1000	5-50


Beau 1
Chuk 1
Chuk 2
Beau 2
Beau 3
Chuk 3
Image © 2008 DigitalGlobe
© 2008 National Geographic Society
Image © 2008 TerraMetrics
Image NASA
Google™
Pointer 71°24'05.70" N 156°24'35.31" W
Streaming ||||||||| 100%
Eye alt 40.97 km


Welcome to Barrow
Paġlagivsigiñ
Utqiaġvigmun
America's Northernmost City
Barrow
Alaska
Top of the World!

Methane degradation in the coastal Chukchi Sea (Barrow, Alaska)

Date	Uptake (pmol/L/h)	SD	Respiration (pmol/L/h)	SD	Uptake/ Respiration	SD
1/27/08	1.63	0.09	44.2	9.4	0.038	0.006
1/29/08	0.76	0.15	62.0	12.0	0.012	0.001
1/31/08	0.58	0.08	54.0	55.1	0.019	0.012
8/2/08	1.05	0.71	13.62	1.6	0.077	0.446
8/2/08	0.16	0.04	17.16	4.4	0.010	0.009
8/4/08	0.27	0.16	9.41	1.9	0.028	0.086
8/4/08	0.69	0.19	11.57	4.1	0.060	0.046
8/8/08	0.52	0.15	8.49	1.9	0.062	0.076
8/8/08	0.40	0.17	7.68	1.5	0.052	0.118

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Uptake = ^{14}C incorporation into cells

Respiration = ^{14}C- methane → $^{14}CO_2$

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Methane degradation in the coastal Chukchi Sea (Barrow, Alaska)

Nearly 5-fold higher rates in the winter!

Date	Uptake (pmol/L/h)	SD	Respiration (pmol/L/h)	SD	Uptake/ Respiration	SD
1/27/08	1.63	0.09	44.2	9.4	0.038	0.006
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All other properties higher in summer—except methane oxidation

	Summer	Winter
Methane oxidation (pmol L^{-1} h^{-1})	11.8 $\pm$ 3.6	54.3 $\pm$ 8.5
Chlorophyll (μg L^{-1})	1.23	0.061
Total microbes (10^9 L^{-1})	1.12	0.55
Growth Rate (d^{-1})	0.0303 $\pm$ 0.0055	0.00752 $\pm$ 0.0.0032

Questions……

2.What is the time-dependent response of methanotrophic microbes and methane degradation to changes in methane fluxes?

How do microbes respond to changes in methane fluxes on both short and long time scales?

Follow degradation rates and methanotrophic genes over time (days)

Methanotrophic enzymes and genes

Methanotrophic Process	Enzyme	Gene
Aerobic	Particulate methane monooxygenase	*pmoA*
Aerobic	Soluble methane monooxygenase	*mmoX*
Aerobic	Methanol dehydrogenase	*mxaF*
Anaerobic	Methyl-coenzymeM reductase	*mcrA*

Following methanotrophic microbes

Isolate DNA and mRNA (= active genes)

PCR for specific methanotroph genes

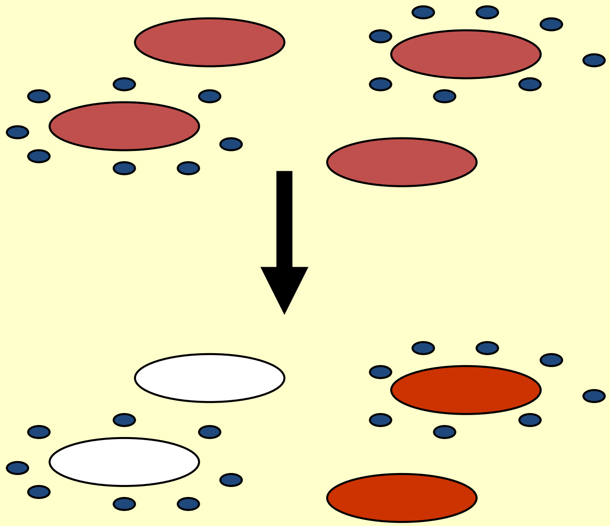
Sequence

Identify microbes and compare

Quantitative PCR for specific methanotroph genes and mRNA

Abundance of methanotroph genes and mRNA

Microautoradiography with FISH



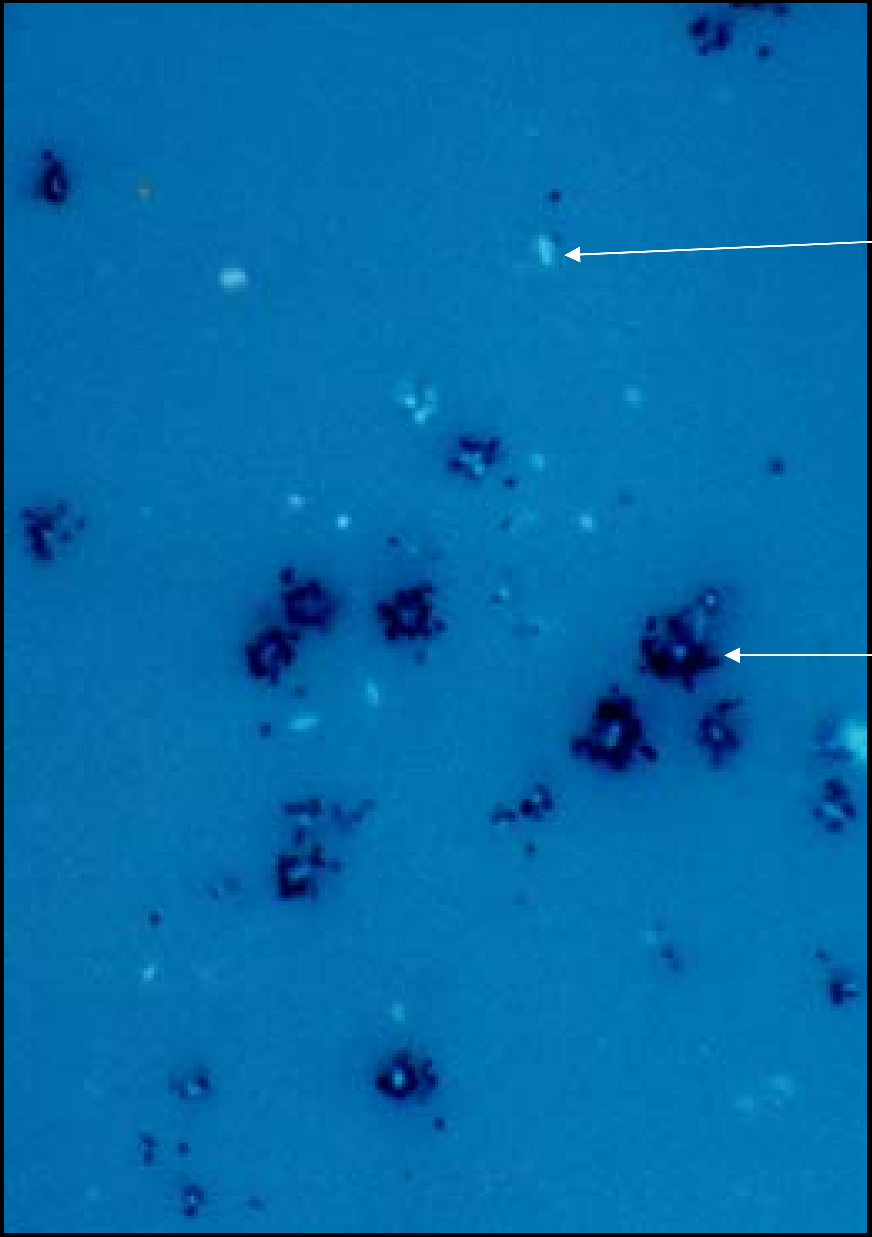
Cells radioactive from taking up ^{3}H-organics and $^{14}CH_4$

Identify bacteria by FISH

MAR-FISH Lee et al. (1999)

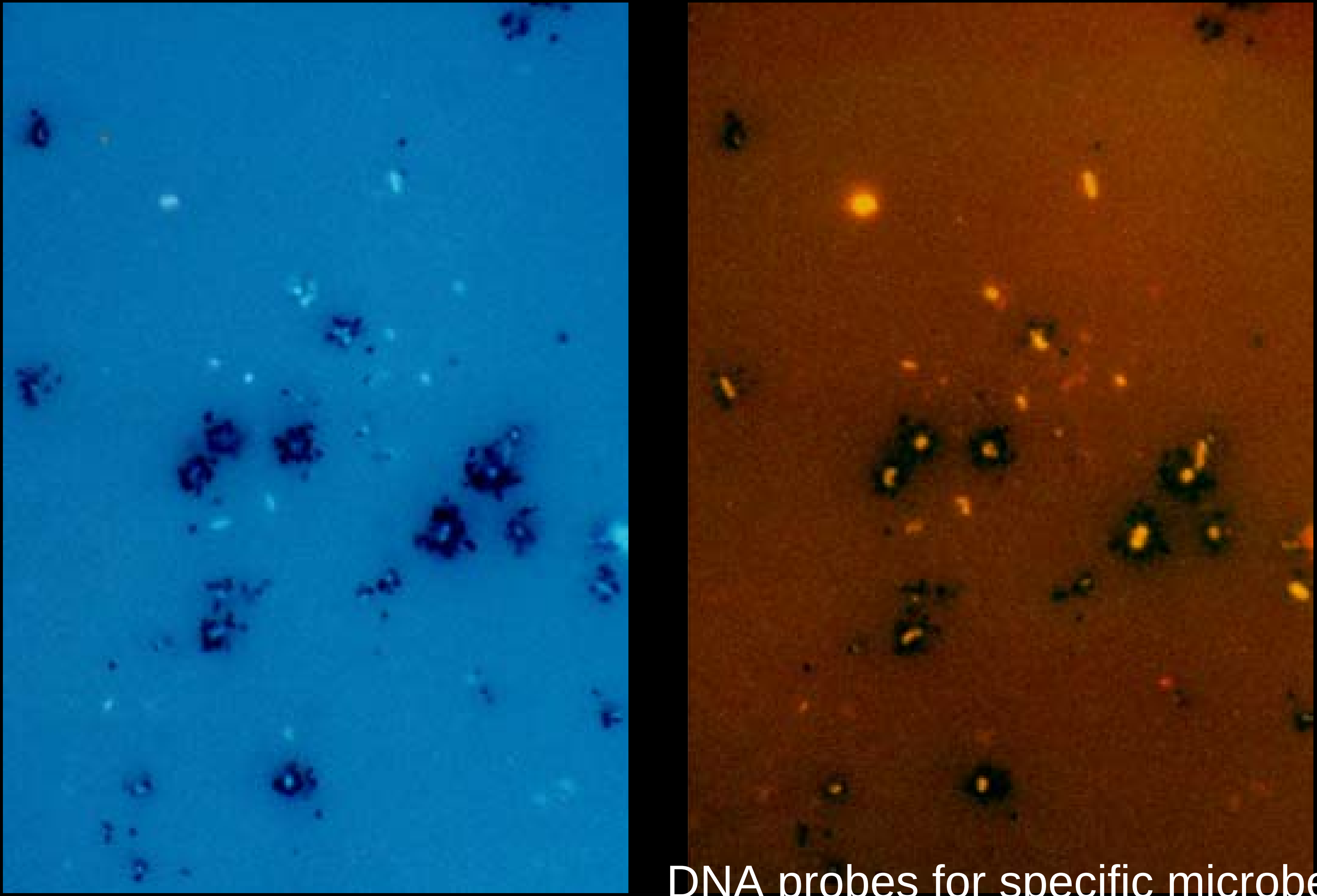
STARFISH Ouverney and Fuhrman (1999)

Micro-FISH Cottrell and Kirchman (2000)



Cells stained for DNA (0.5 μm)

Silver grains, indicating uptake of radioactive compounds



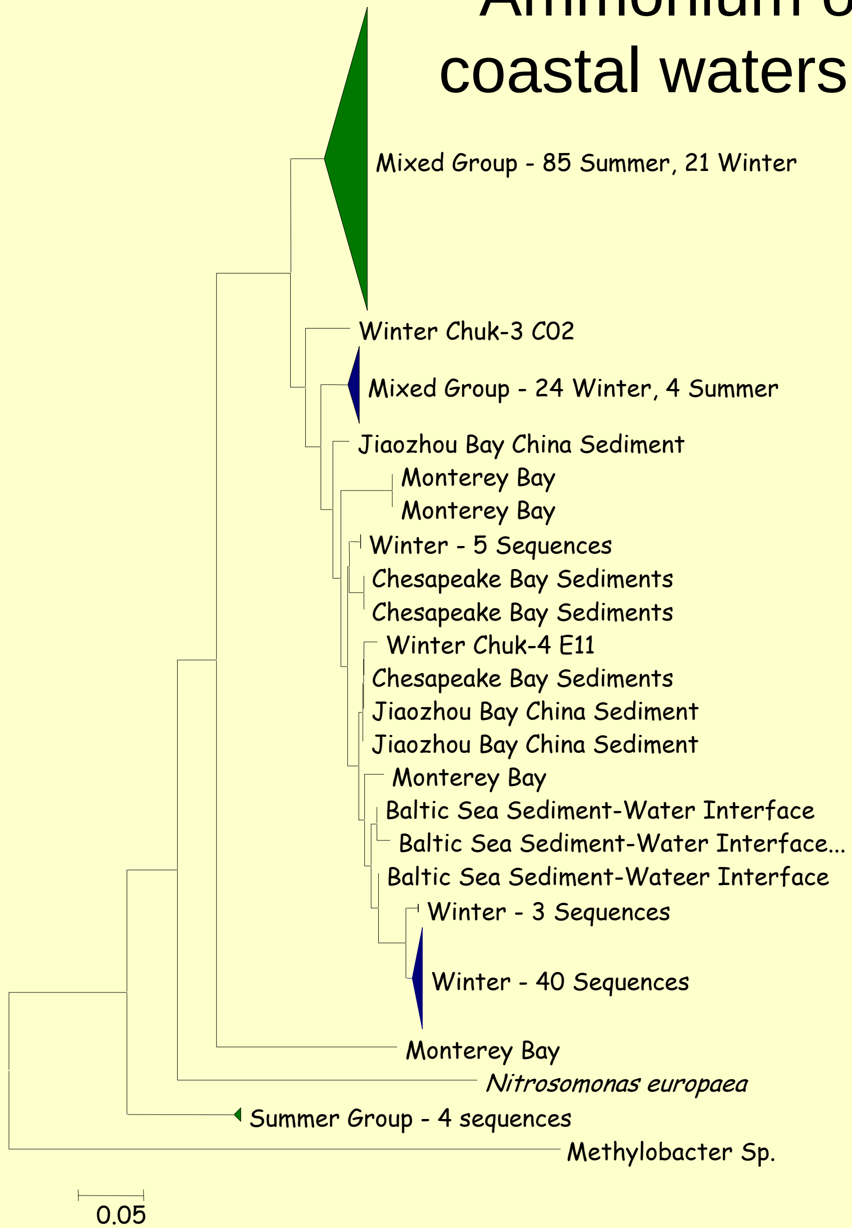
DNA probes for specific microbes

Questions…..

3.How do methane degradation rates and key methane degradation genes (pmoA and mcrA) in the Arctic and low latitudes compare?

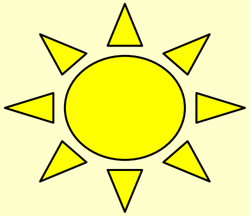
Are there unique “Arctic” genes?

Ammonium oxidation gene(*amo*A) in Barrow coastal waters: same as seen in lower latitudes



Connections between ammonium and methane oxidation

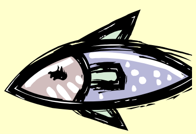
- Ammonium oxidizers can degrade methane (and visa versa).
- Key genes for both processes are similar (*amoA* and *pmoA*).



CH_4

- What controls methane emissions to the atmosphere?

- How will degradation and emission rates vary in response to climate change?



CH_4 → $CH_4 \rightarrow CO_2$ ←

Methane hydrate