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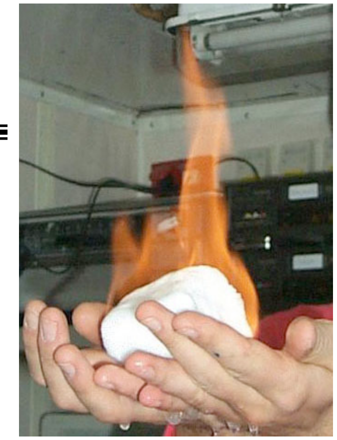

methane hydrate settings off North Carolina and hydrate-dependent habitats

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A Presentation to the Subcommittee on Offshore Energy Exploration

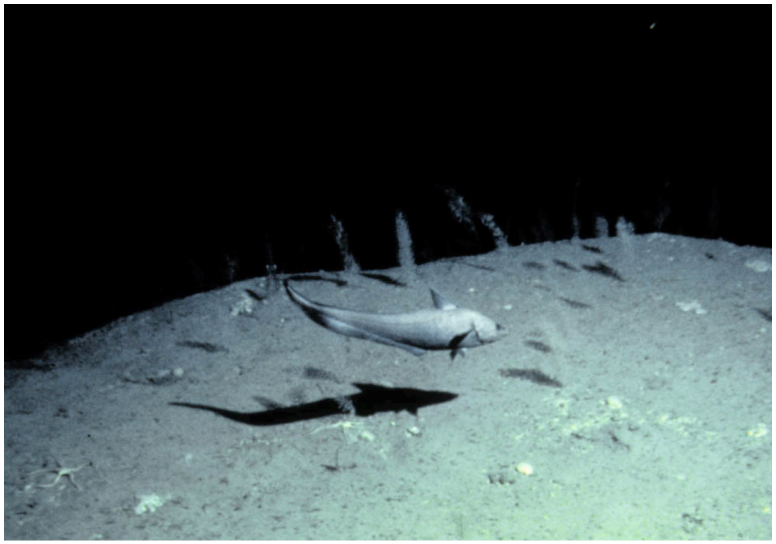
15 April 2009

Raleigh NC

Outline

- Deep Sea Overview
- Methane Hydrate Overview
- Blake Ridge Methane Hydrate Province
  - Resource Estimates
  - Methane Dynamics and Concentration
  - Blake Ridge Depression and Sediment Wave Field
  - Blake Ridge Diapir (BRD) and Subsurface Structure
  - BRD Seep
    - Chemosynthesis
    - Sulfate Reduction

Brief Introduction to the Deep Sea



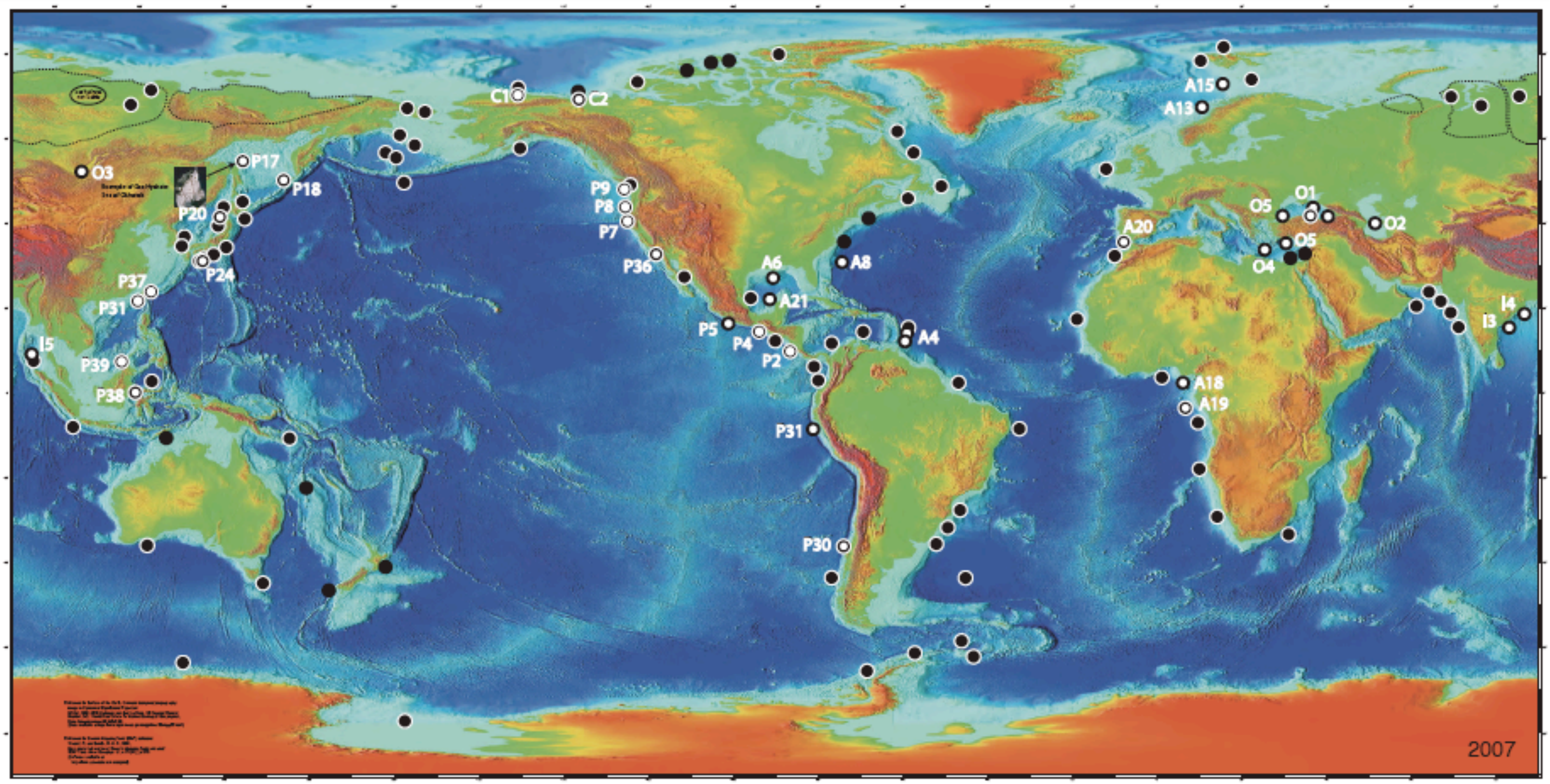
Sediment
- low sedimentation rates
- low organic carbon content in sediment

Pressure
- 1 atm every 10 m water depth (1500 m = 150 atm)

Temperature
- 1 to 2 °C (just above freezing)

Fauna
- low biomass
- low abundance
- high biodiversity

another kind of seabed environment: global distribution of methane hydrates

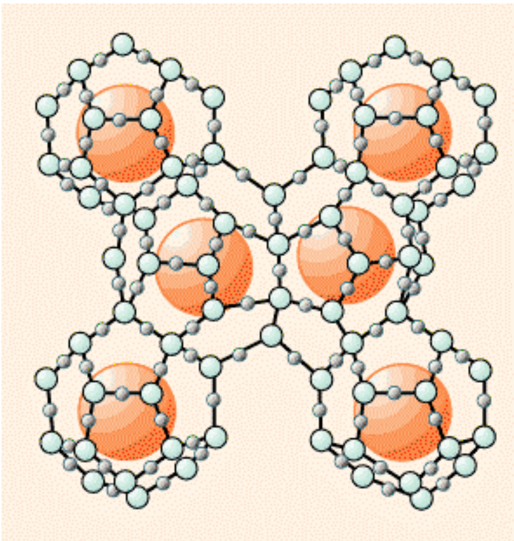


http://walrus.wr.usgs.gov/globalhydrate/poster.pdf

Thomas D. Lorenson and Keith A. Kvenvolden

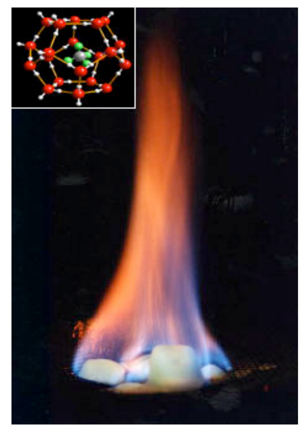
white circles: sampled hydrate
black circles: inferred hydrate

What is methane hydrate?



QUICK FACTS

- methane hydrate: water lattice (H2O) and swamp gas (CH4)
- methane composes >99% of the hydrocarbon gas (BR)
- stable at low temperature and pressure
- occurs in deep-sediments, polar permafrost, deep lakes
- clathrate: water lattice with trapped gas molecules

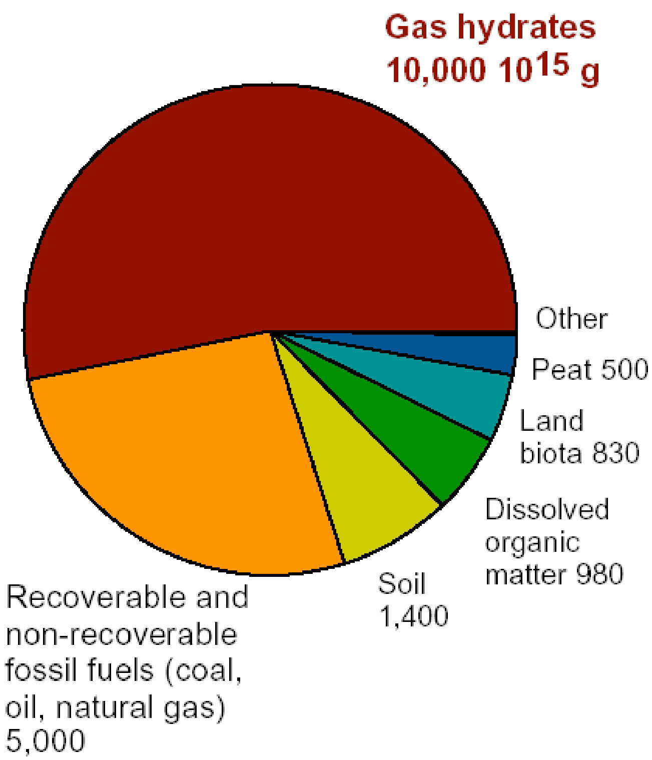


"ice that burns"

gas hydrates:

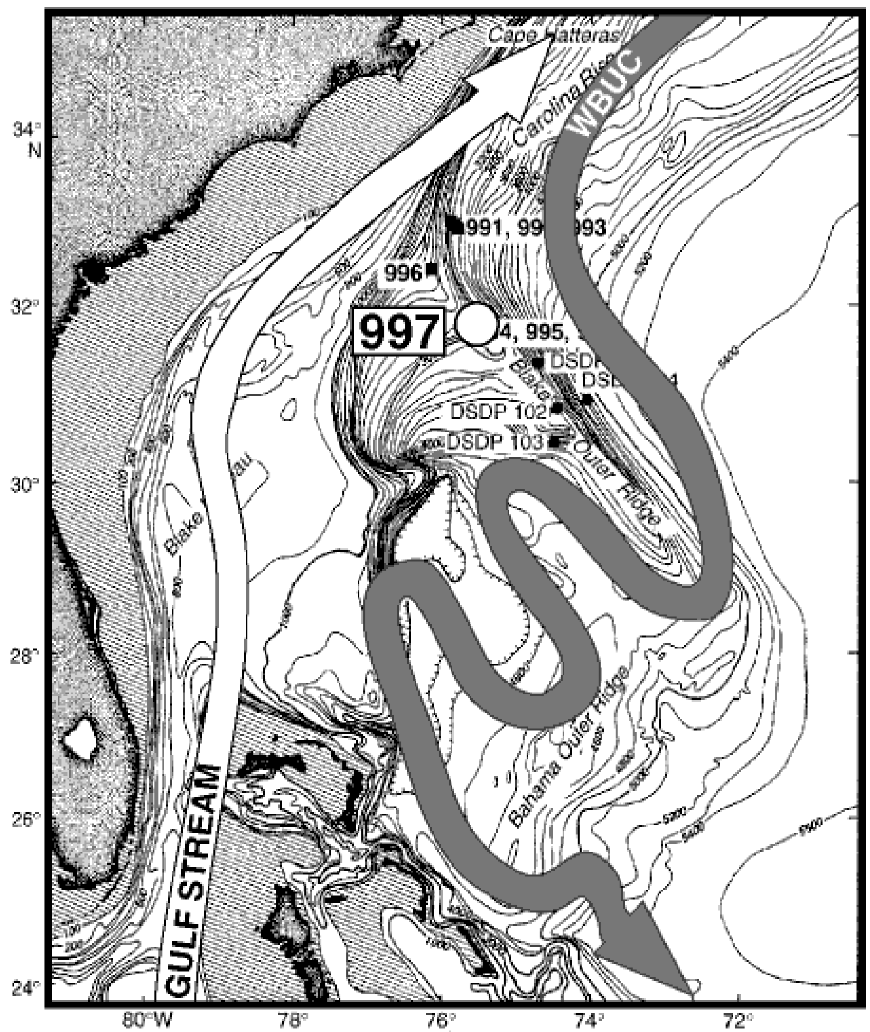
largest reservoir of organic carbon on the planet

Organic carbon in the earth



after Kvenvolden

http://gsc.nrcan.gc.ca/gashydrates/canada/index_e.php

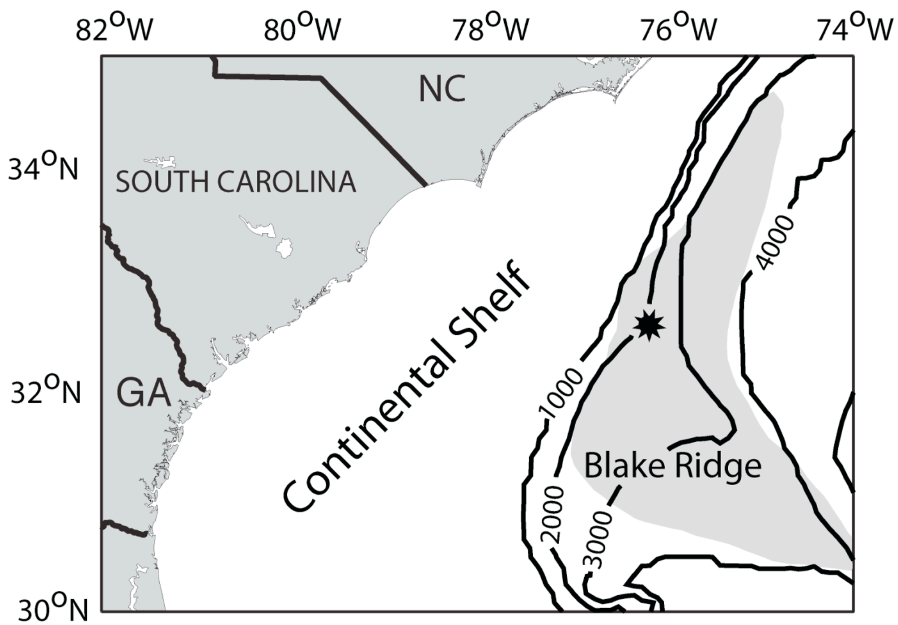


Faugères et al. (1993)

www-odp.tamu.edu/.../ 164_SR/chap_35/ch35_f1.htm

The Blake Ridge Contourite

- passive continental margin
- interaction of Gulf Stream and WBUC*
- depositional feature (2900 m max)
- Miocene and younger (< 23 Ma)
- Western Boundary Under Current*
  - erodes sediment E flank
  - deposits sediment W flank



Blake Ridge Basic Specs

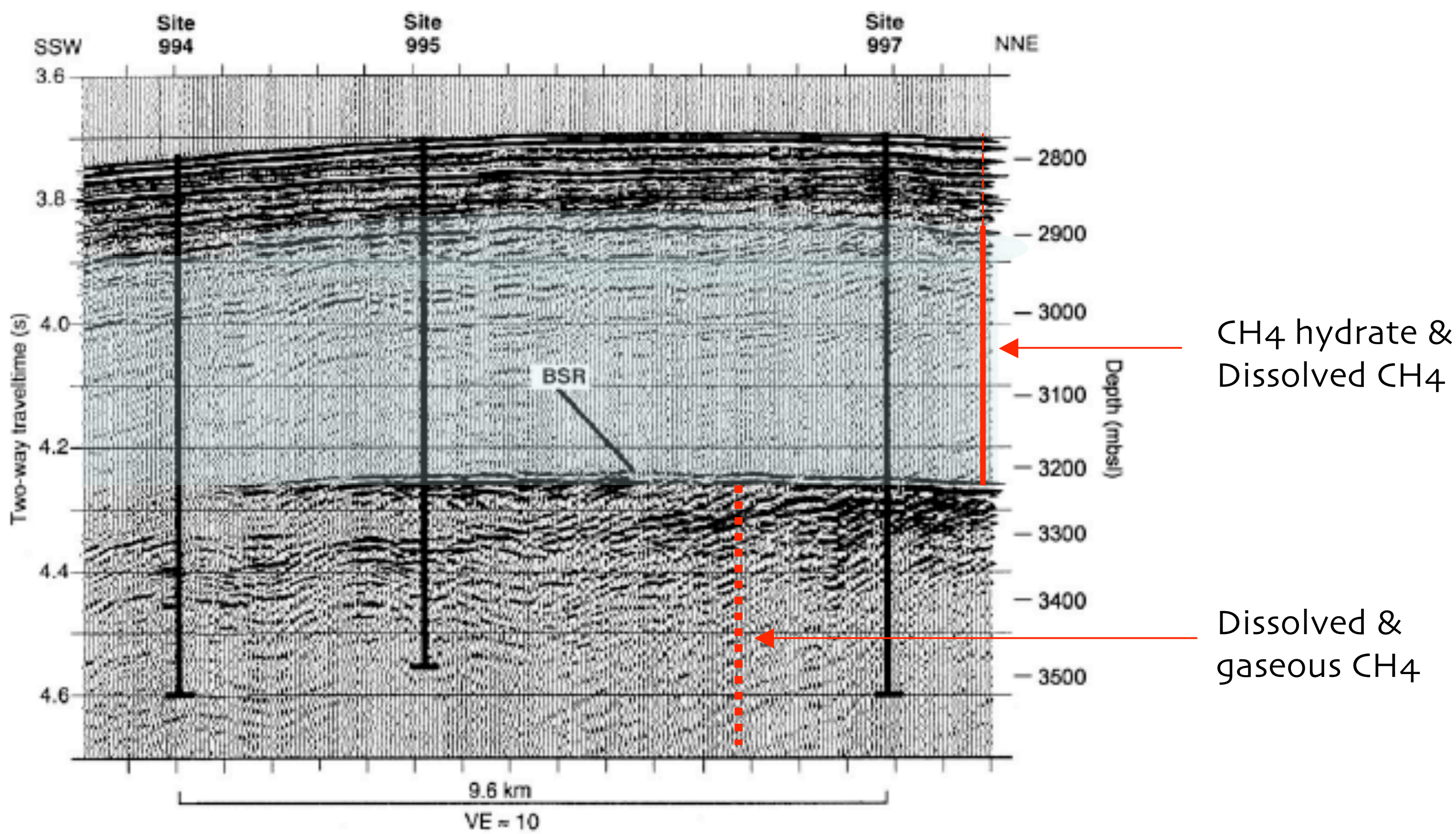
- 2000-4800 m
- ~500 km length
- BSR reported in 1970

asterisk: Blake Ridge Diapir

BSR = contrast in sound velocity created by hydrate-cemented zone above water-saturated sediments with trapped gas

- BSR encloses 55,000 km^2; high amplitude BSR: 26,000 km^2

What is a bottom-simulating reflector (BSR)?



Paull et al. 1996; Holbrook et al. 1996; Borowski 2004

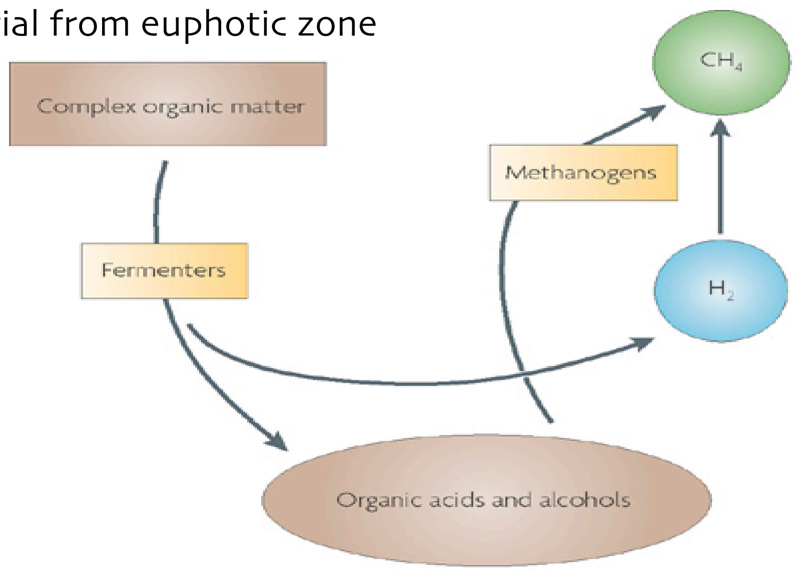
- Gas hydrates between 190 and 450 m in sediment column
average sediment pore space occupied by methane gas hydrates: 5.4%

What is the methane source?

microbial methanogenesis (biogenic methane)

$$Co_2 + 4\ H_2O \rightarrow CH_4 + 2H_2O$$

burial from euphotic zone



Rittman et al 2008

Basic Blake Ridge Methane Statistics

from Borowski 2004

1. methane hydrate: 67-406 Gt or 9-53 Gt methane

2. methane gas (below BSR): 2.6 to 27 Gt methane

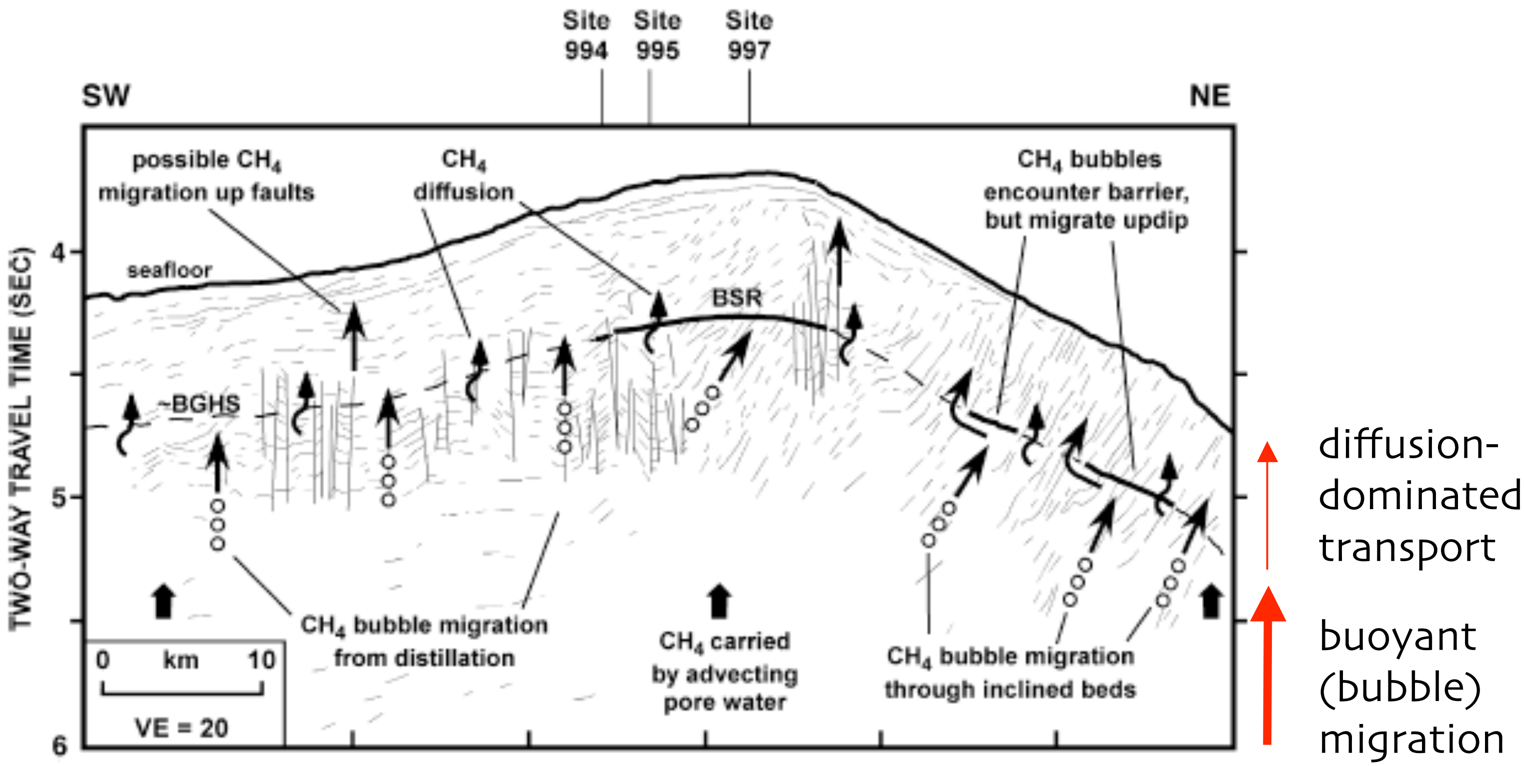
3. current methane losses from system:
   - point source seeps
   - diffusion and consumption at sulfate-methane interface by anaerobic methane oxidation (2.8×10^8 mol yr^{-1})

4. methane enters gas hydrate stability zone at rate of 1.3×10^9 mol yr^{-1}

5. ⇒methane trapping efficiency ~85%

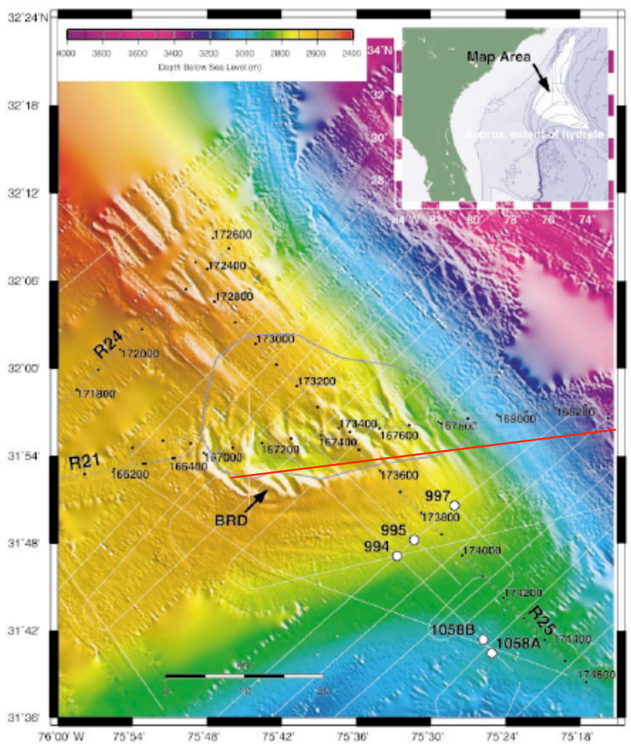
6. gas hydrate in Blake Ridge system has accumulated over ≥55 MY

methane movement and concentration mechanisms



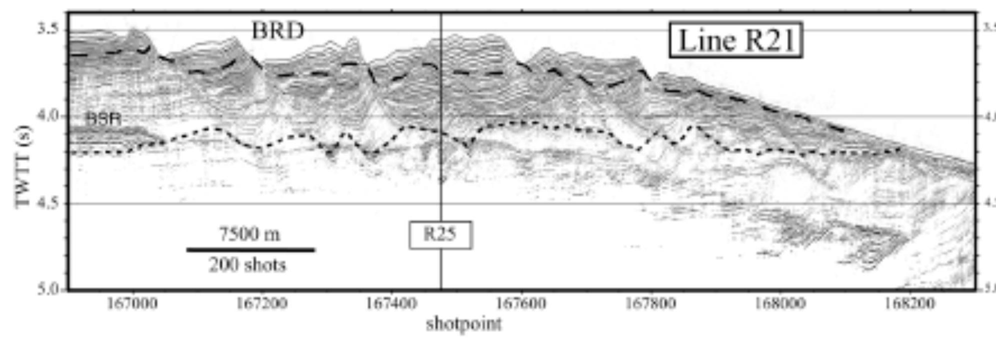
Borowski 2004

BGHS: base of gas hydrate stability zone



Holbrook et al. 2002

blake ridge depression and sediment wave fields

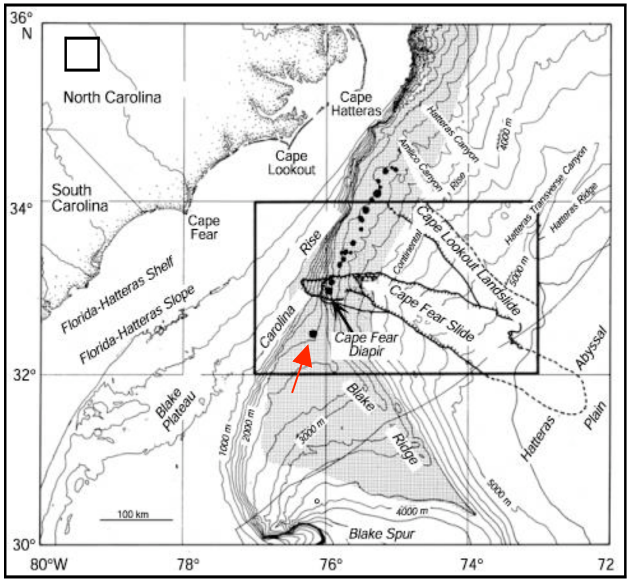


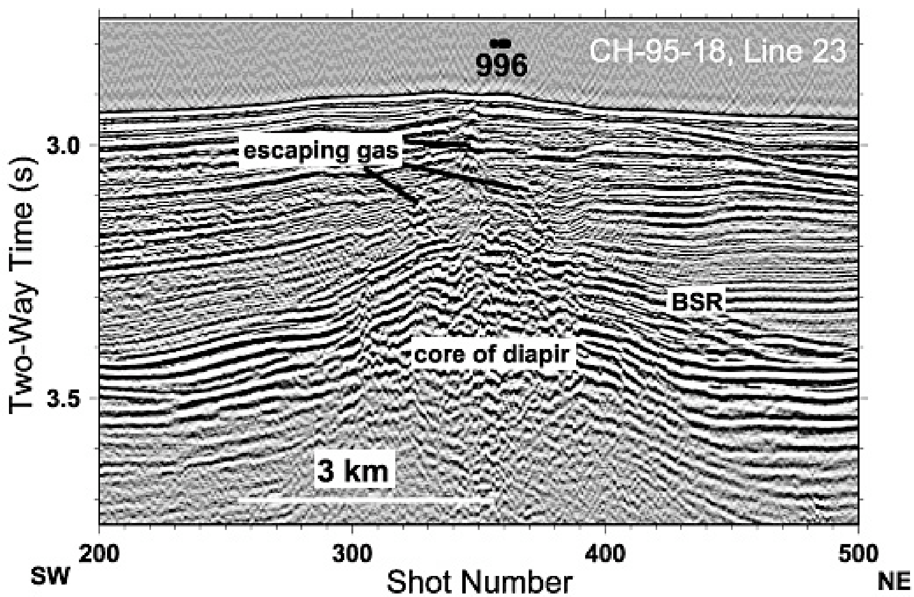
- waves: 5-10 km long, 1-3 km separation
  - 75-50 m height
- erosional and depositional regime
- weak or absent BSR; not due to structural collapse
- escape of 0.6 Gt methane; timing and rate unknown

  12% of present day atmospheric methane

sustained, morphologically driven advection through erosional features

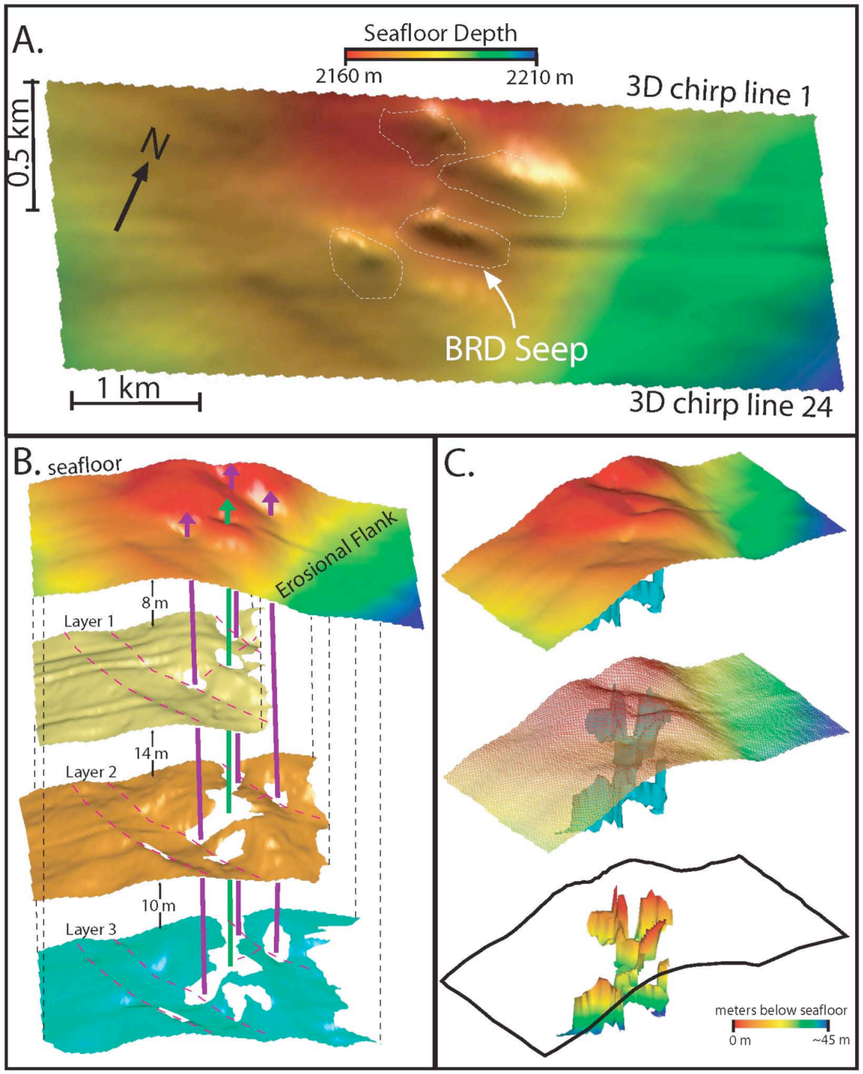
blake ridge diapir





focused advection

Blake Ridge Diapir Subsurface Structure



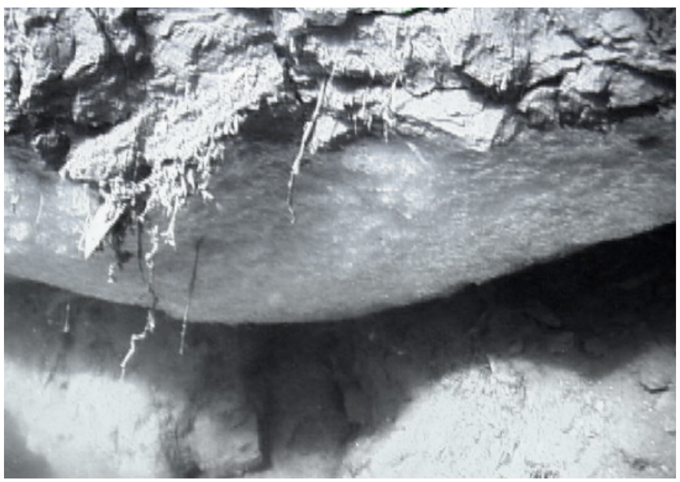
Hornbach et al. 2005

3.5 kHz echo sounder
24 lines, 6 km long
40 m spacing

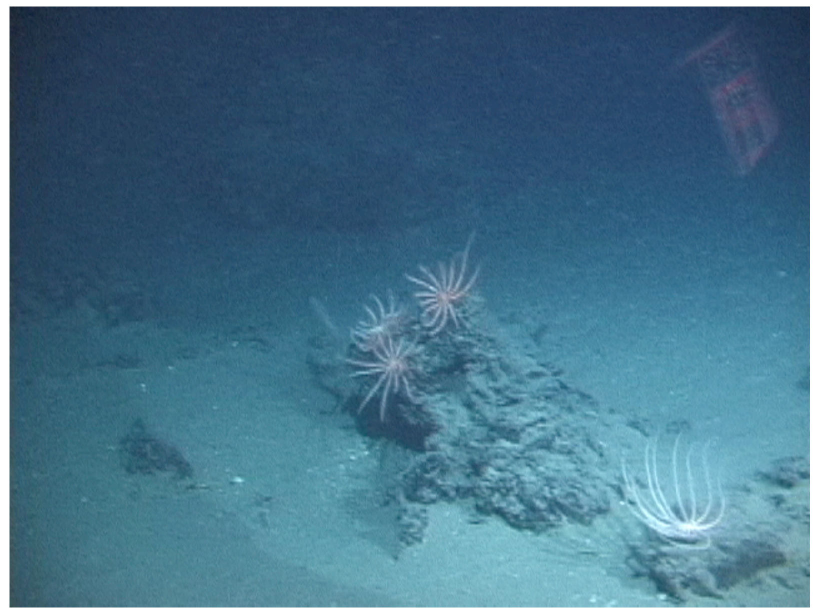
- "holes" in layers = potential conduits
  i.e., seep sites
- holes are associated with faults

blake ridge seep setting

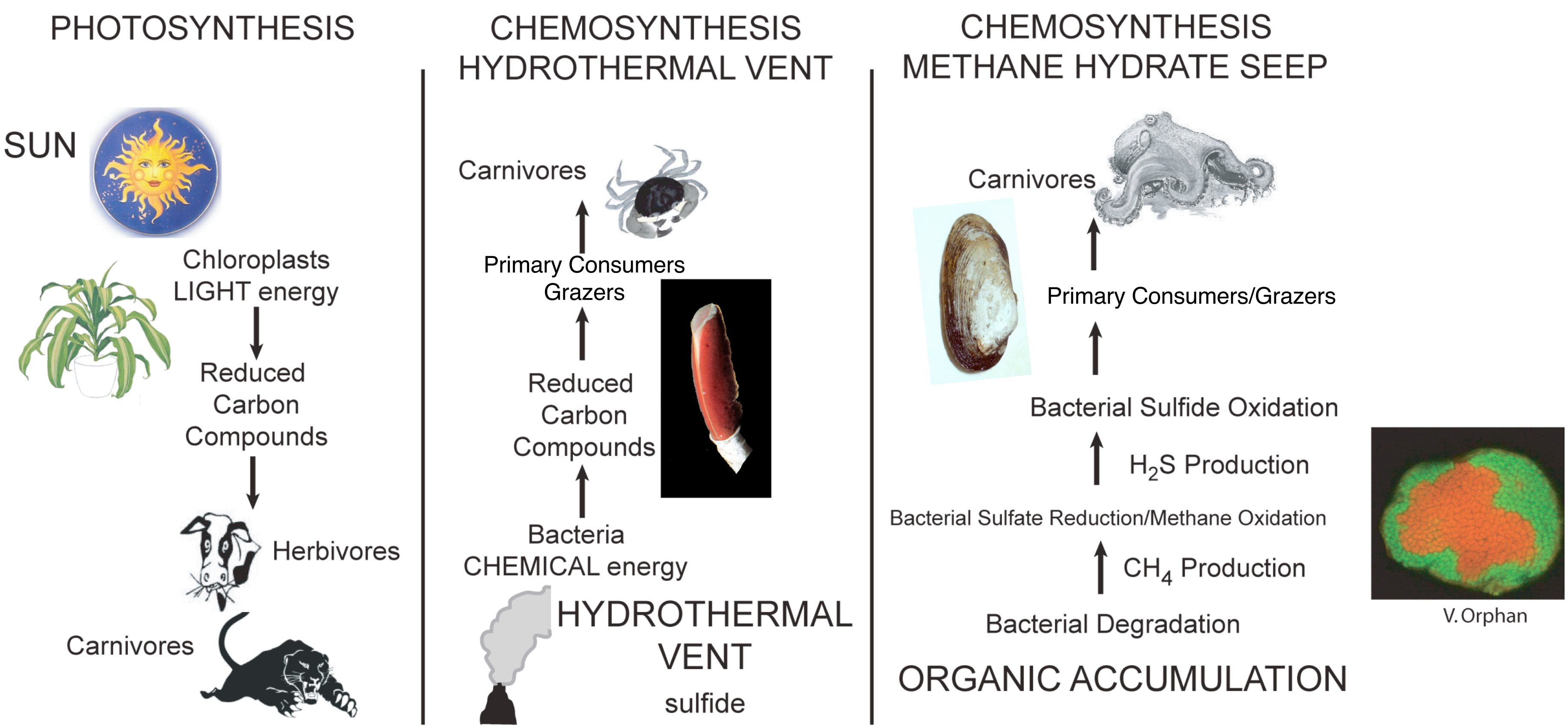
Van Dover et al. 2003



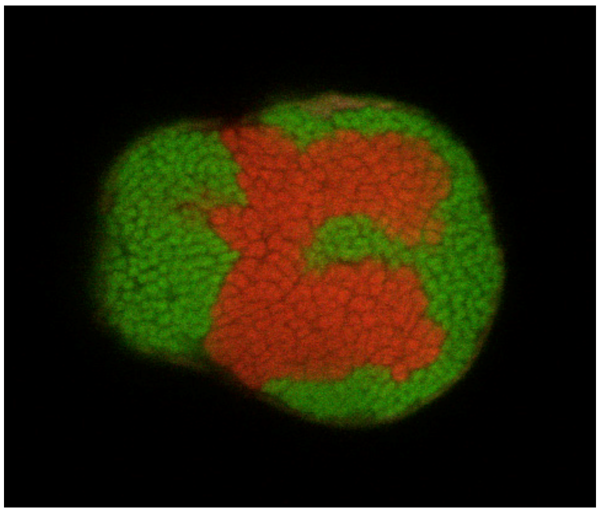
methane-hydrate outcrop



authigenic carbonate outcrop


PHOTOSYNTHESIS
SUN
Chloroplasts
LIGHT energy
Reduced
Carbon
Compounds
Herbivores
Carnivores
CHEMOSYNTHESIS
HYDROTHERMAL VENT
Carnivores
Primary Consumers
Grazers
Reduced
Carbon
Compounds
Bacteria
CHEMICAL energy
HYDROTHERMAL
VENT
sulfide
CHEMOSYNTHESIS
METHANE HYDRATE SEEP
Carnivores
Primary Consumers/Grazers
Bacterial Sulfide Oxidation
H_2S Production
Bacterial Sulfate Reduction/Methane Oxidation
CH_4 Production
Bacterial Degradation
ORGANIC ACCUMULATION
V. Orphan

microbial consumption of methane in porewaters



www.amethox.com/ principal.htm

sulfate-dependent methane oxidation

PROPOSED REACTION (of several possible)

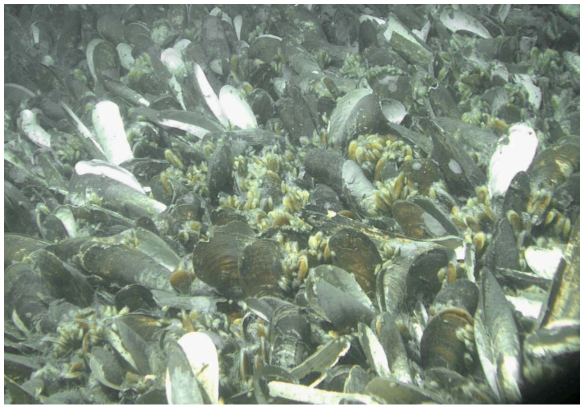
$CH_4 + 3H_2O \rightarrow HCO_3^- + H^+ + 4H_2$

$4H_2 + SO_4^{2-} \rightarrow S^{2-} + 4H_2O$

TOTAL REACTION:

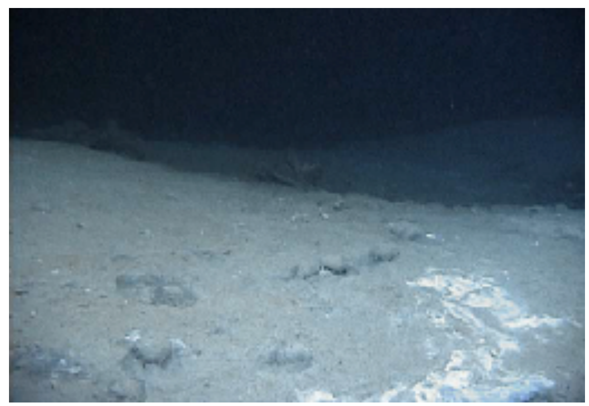
$CH_4 + SO_4^{2-} \rightarrow HCO^{3-} + HS^- + H_2O$

dominant megafauna



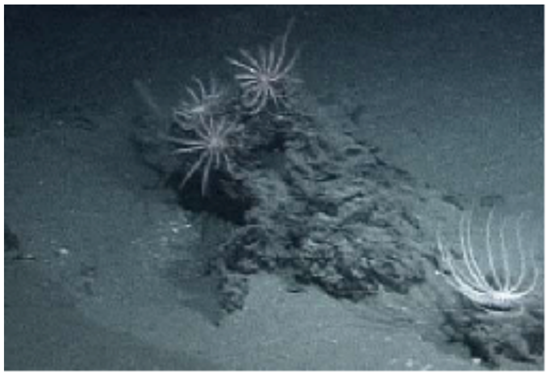

Bathymodiolus heckerae
mussels


Vesicomyidae n. gen. n. sp.
clams

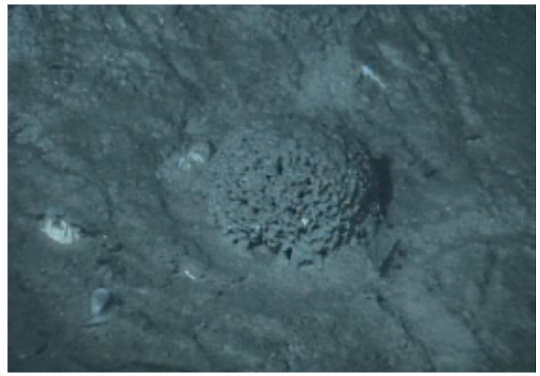



Sarsiaster greigi
cake urchin

other megafauna



brisingid seastar



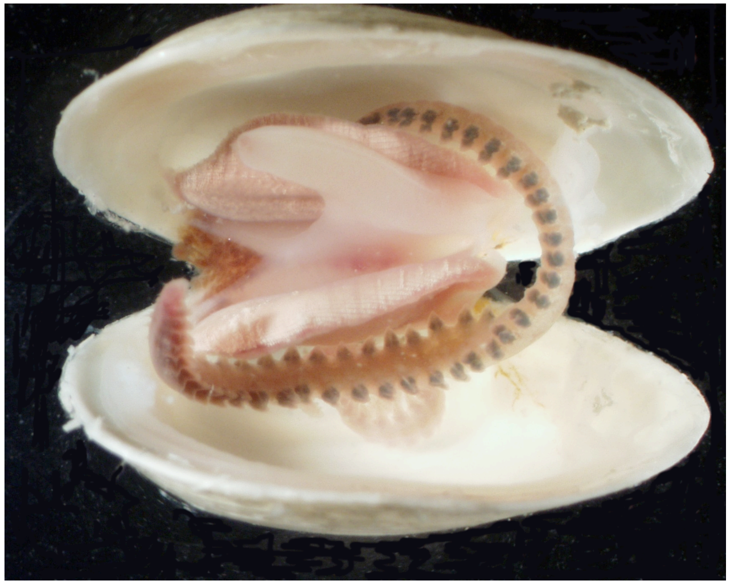
Syringammina
xenophyophore
(Protozoa)

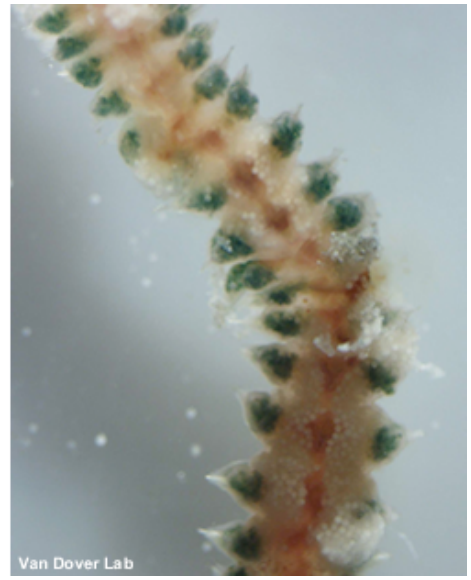
"tubeworms"
pogonophorans
or
vestimentiferans?

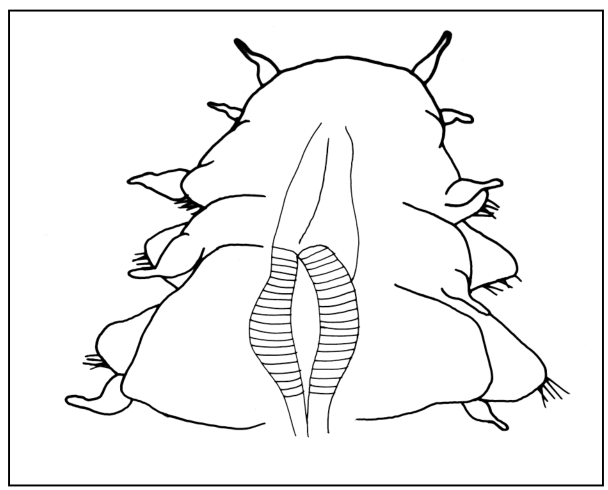
Alvinocaris muricola

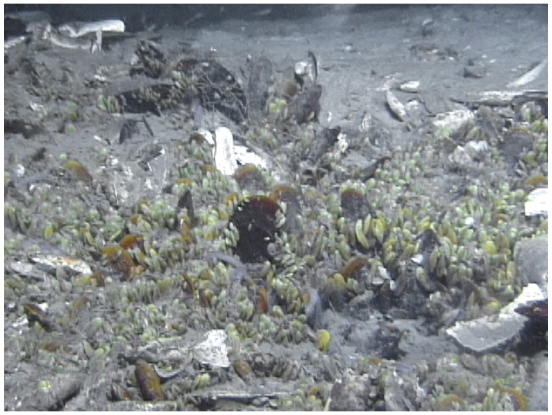
A. methanophila

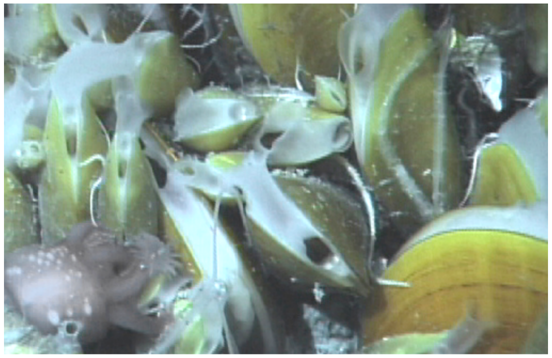
Vesicomyicola trifurcatus



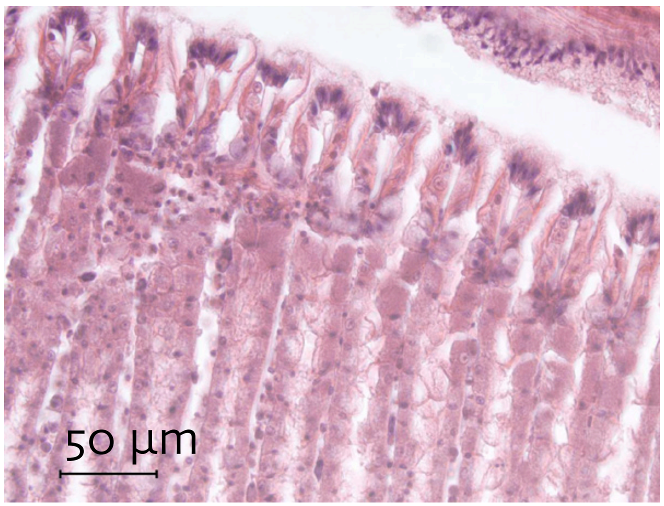




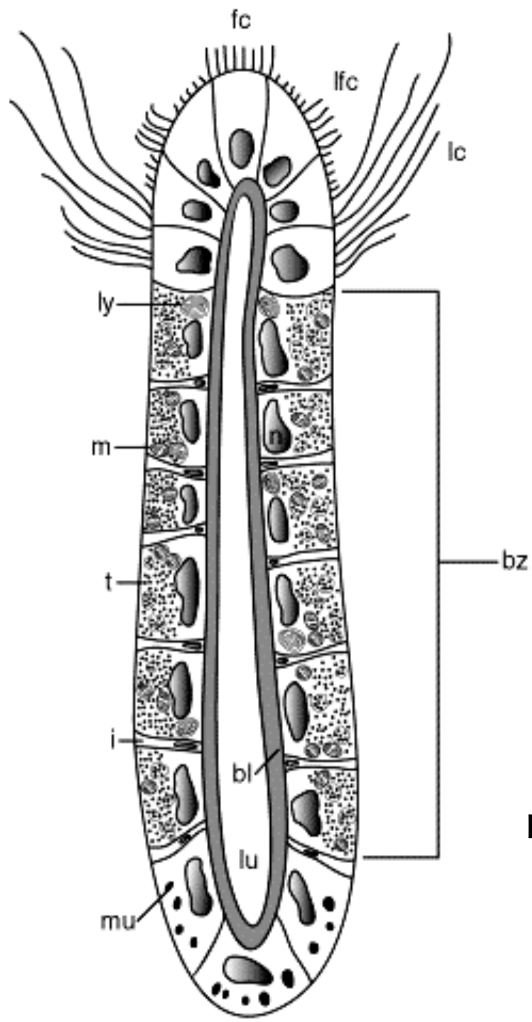


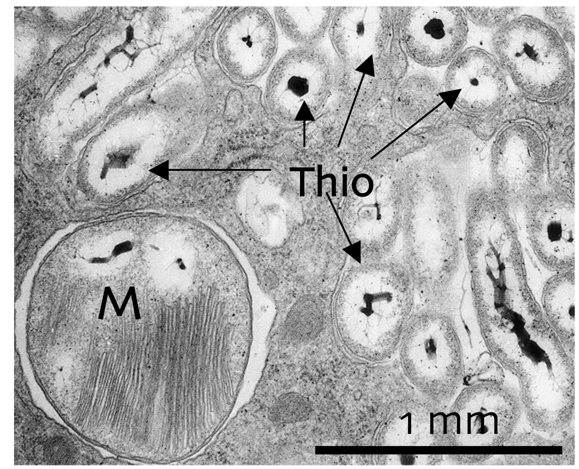


Bathymodiolus heckerae



gill tissue

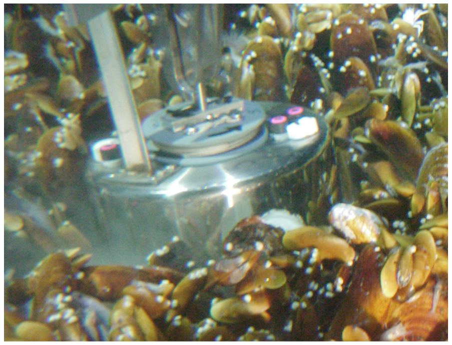




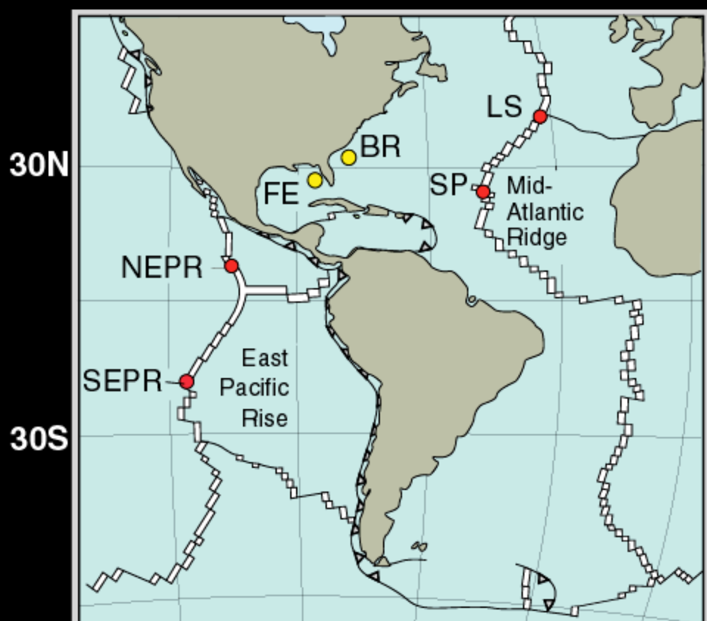
"dual" symbiosis:
methanotrophs and thiotrophs

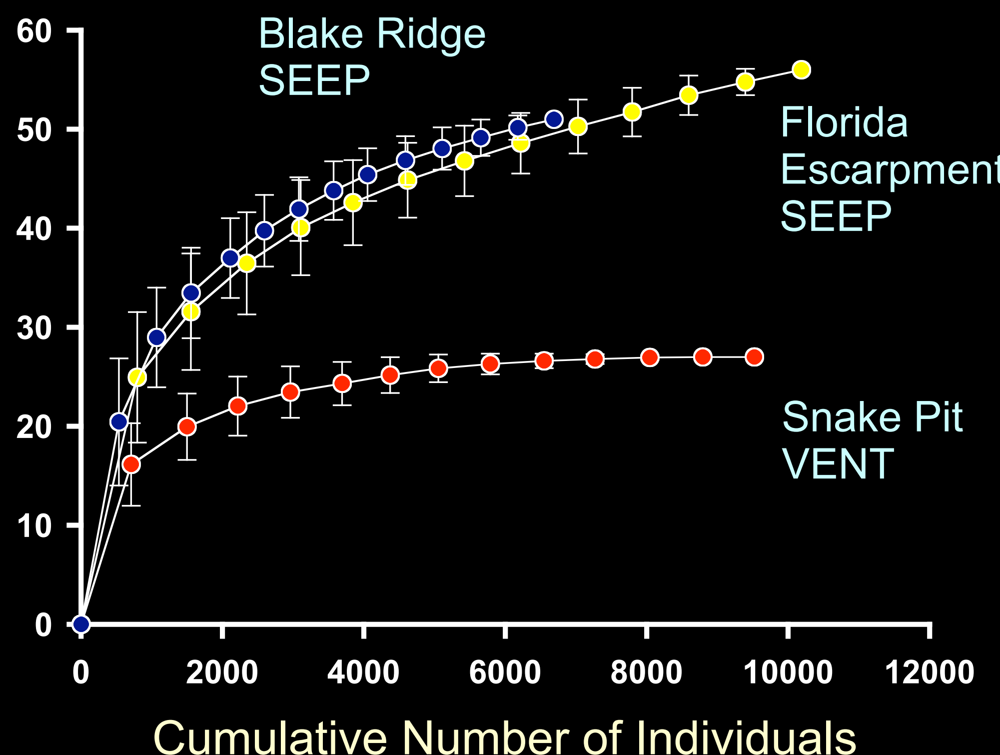
Van Dover et al. 2003

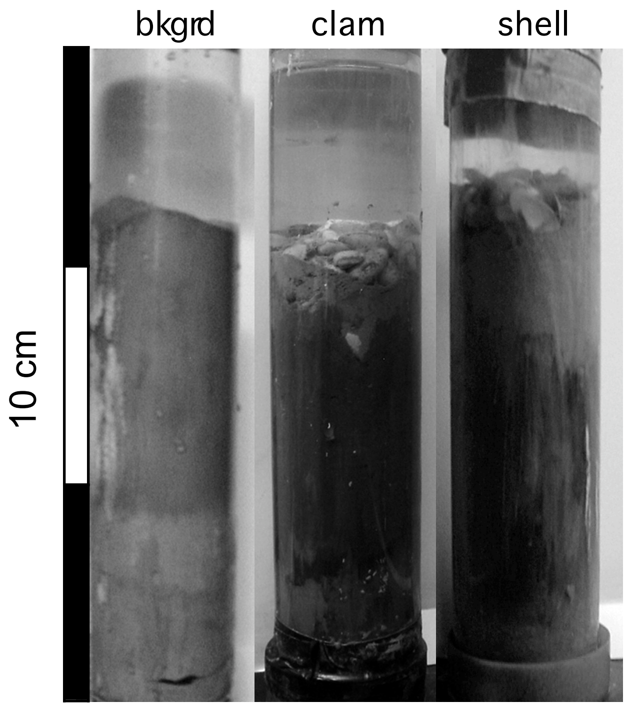
Bathymodiolus heckerae



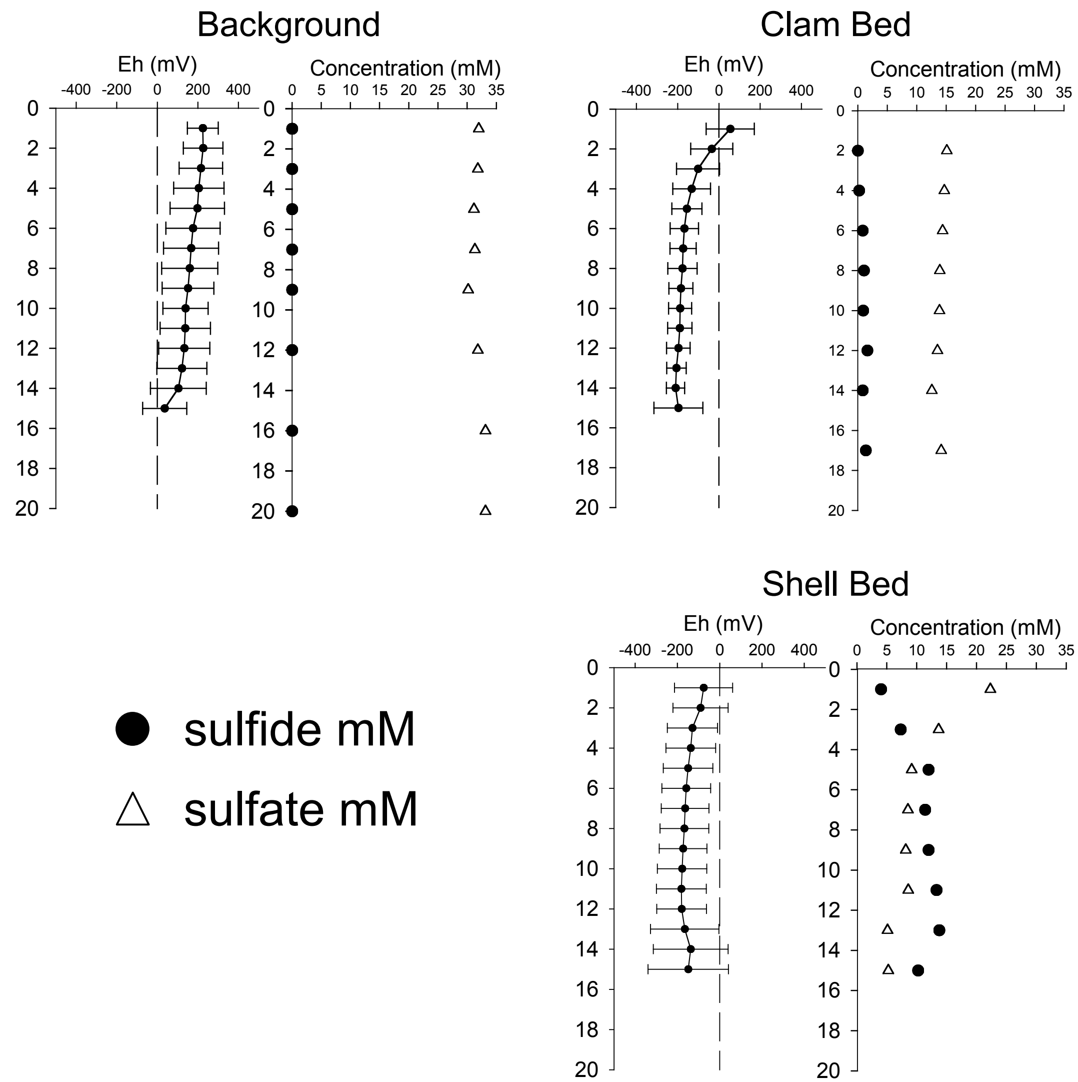
quantitative studies of biodiversity in mussel beds







Heyl et al. 2007



conservation challenges

- distribution and variety of chemosynthetic habitats in the region is unknown
- seep fauna likely to have very slow growth rates, extended longevity
- numerous rare and undescribed species
- no knowledge of location of brood stocks or population connectivity
- mitigation, remediation, restoration strategies difficult to imagine or implement