Biogeochemistry, Microbial Activity, and Microbial Distributions in Sediments of the Deep Slope

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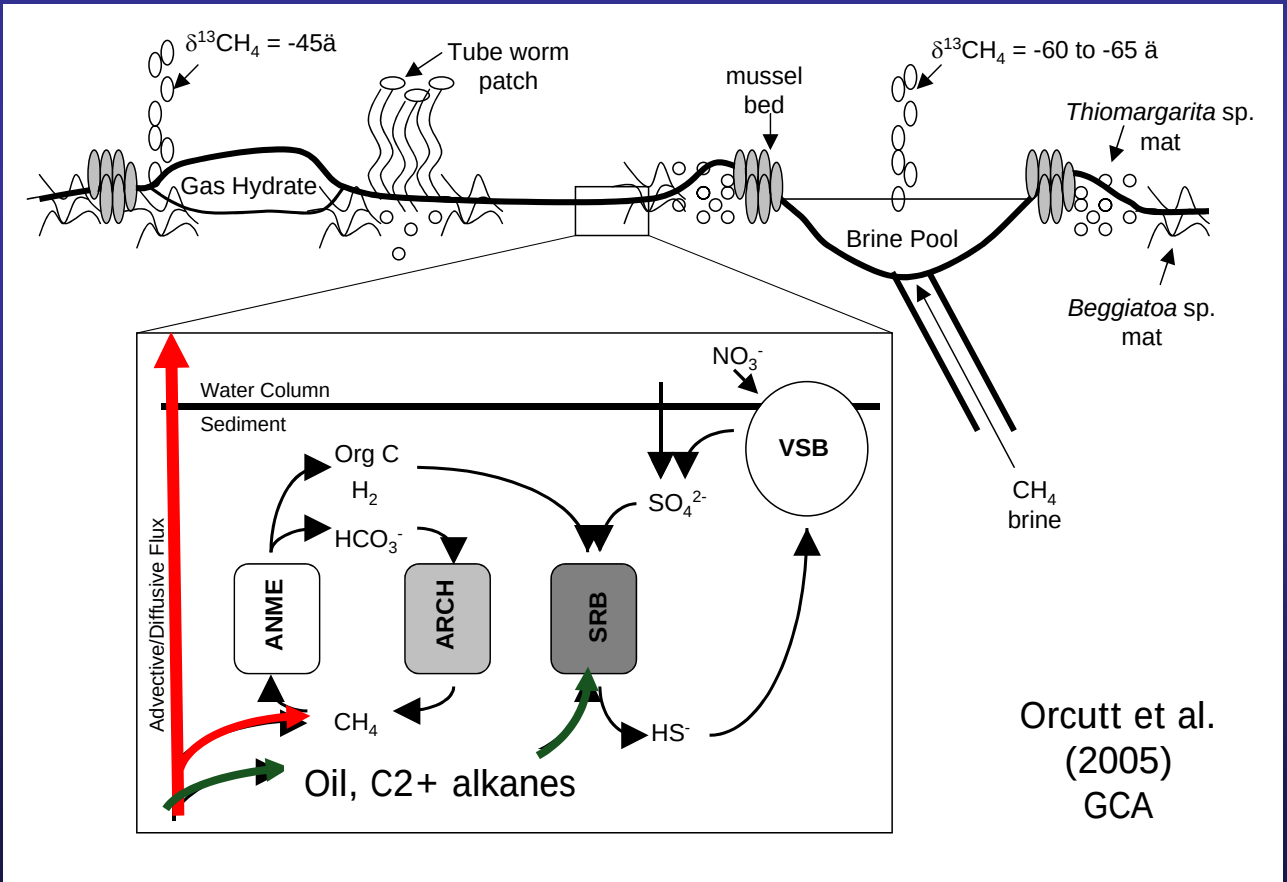
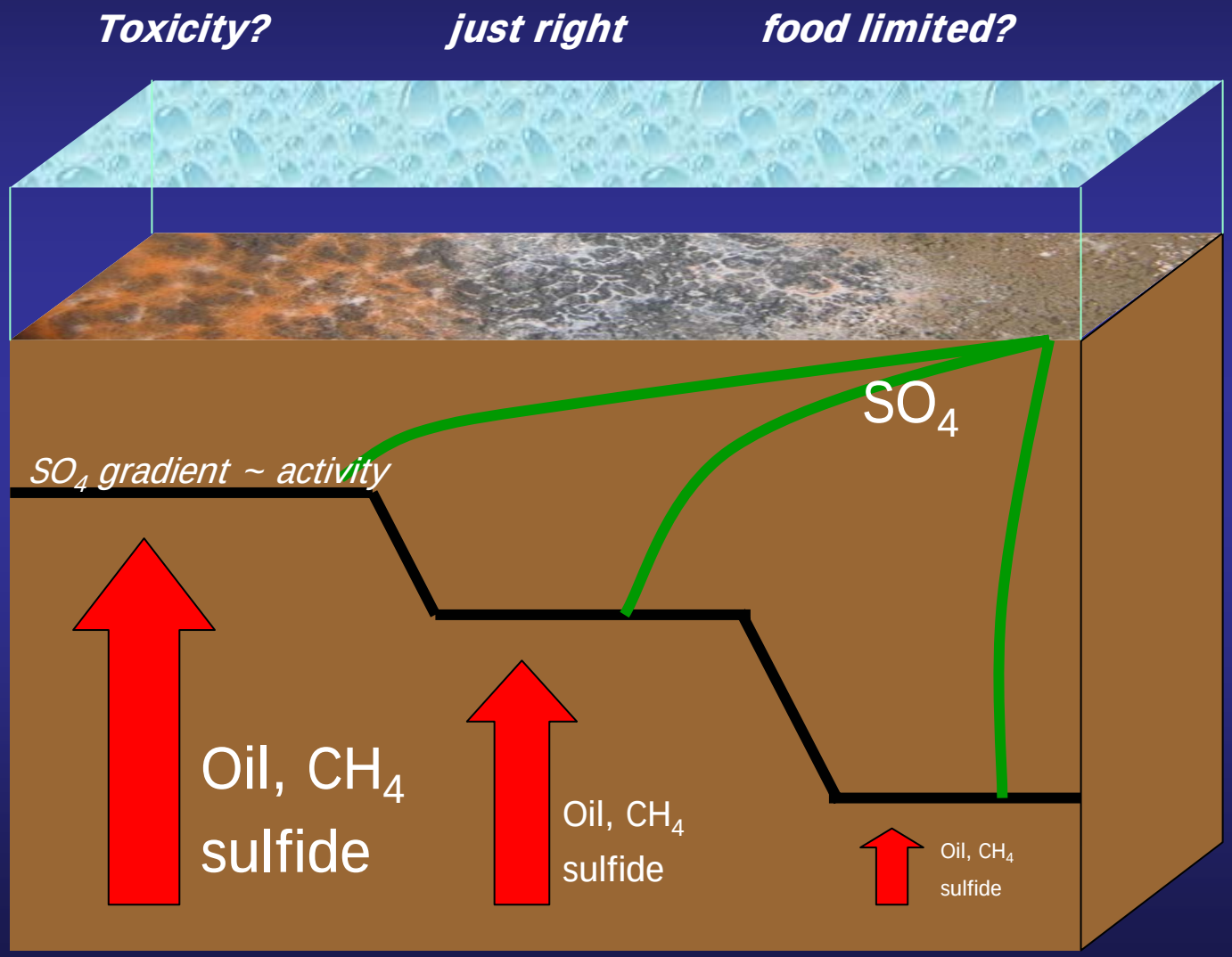
The Geobiological Engine

Seepage of reductant (oil, alkanes) rich fluids fuels microbial activity, which generates metabolic substrates (H_2S) for macrofaunal production.



The Geobiological Engine



Joye et al. (2004)
Chem. Geol.

Biogeochemistry and Microbiology

Water Column:

** 7 CTD casts @ 3 different sites*

- hydrography (temperature, salinity, nutrients, oxygen)
- methane concentration and consumption (oxidation)

Sediment:

* *29 cores processed from 9 different sites*

- biogeochemistry
  - -salts, dissolved gases, nutrients, organic matter
- sulfate reduction rates
- methane oxidation rates
- methane production rates
- microbiology and molecular biology

Biogeochemistry and Microbiology

Molecular Biology (on-going)

- DNA extraction and clone libraries
- abundance quantification of specific groups by FISH

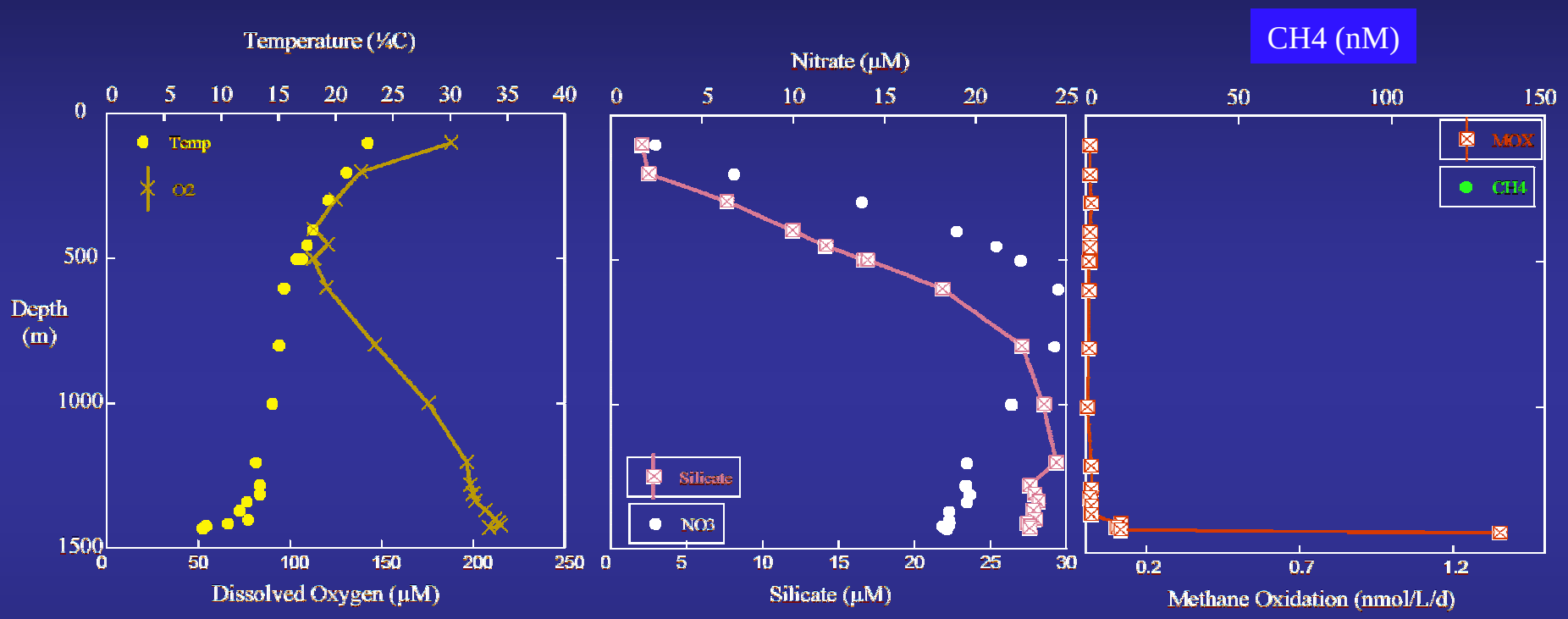
Organic Geochemistry (on-going)

- biomarkers

Classic Microbiology (on-going)

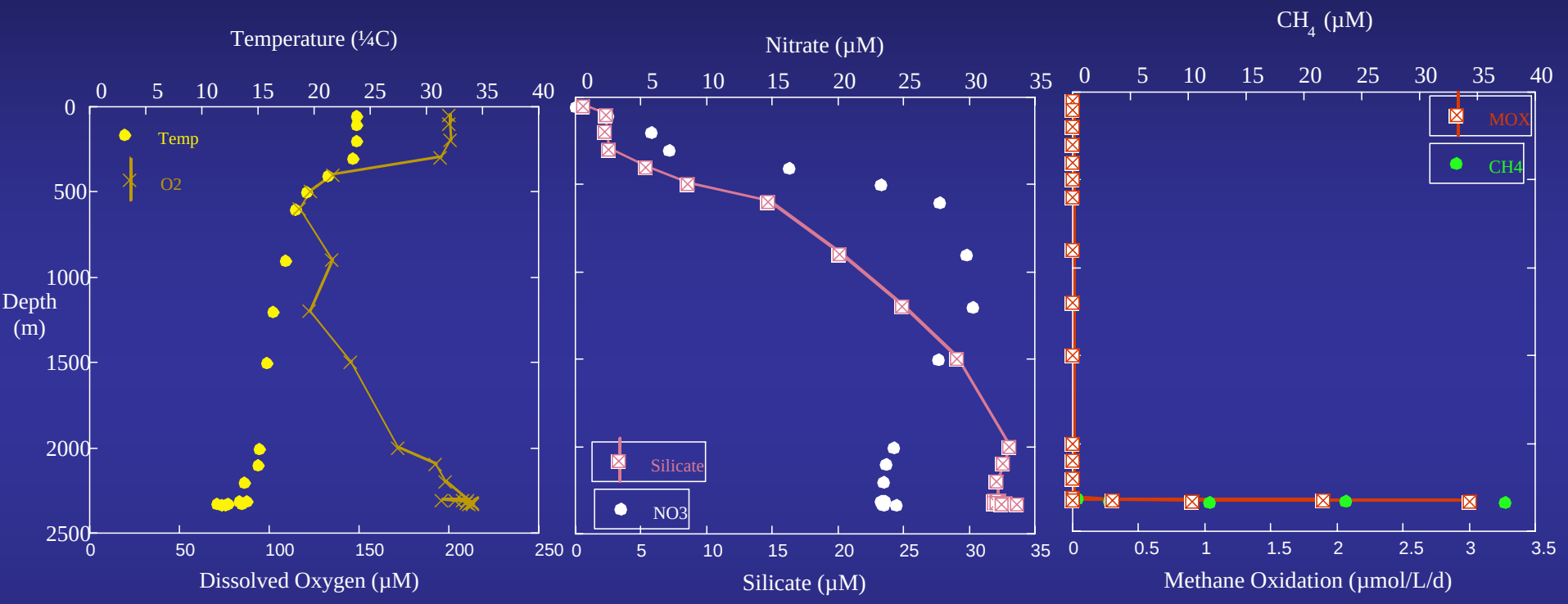
- cell counts
- culture/isolations
- physiology (lab experiments)

Water Column-GC852



- pronounced mid-water O_2 minimum (nitrification)
- CH_4 concentration similar to other GOM sites (nM) (>100 nM near bottom)
- CH_4 oxidation rates fairly high (1% per day)

Water Column-AC601



✓ pronounced mid-water O_2 minimum (nitrification)

✓✓ CH_4 concentration high throughout water column (up to 40 µM near bottom)

✓✓ CH_4 oxidation rates similarly high

Water Column Summary

Highest water column CH_4 concentrations at AC601 (Brine Pool)

Surface water is supersatured with CH_4 (>5 nM)

Methane oxidation rates comparable to (or greater than) rates at shallower GOM seep sites >this is surprising<

Geochemistry and Activity

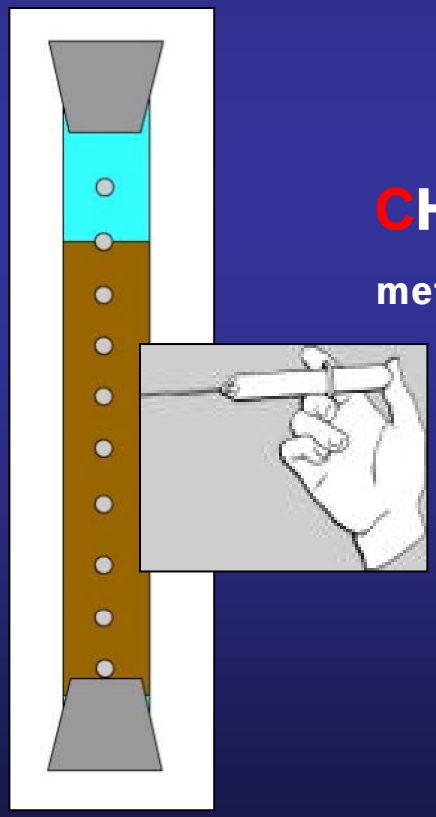
Measuring microbial activity with radiotracers:

^{14}C carbon

^{35}S sulfur

$$CH_4 + SO_4^{2-} \rightarrow CO_3^{2-} + H_2S + H_2O$$

methane sulfate bicarbonate hydrogen sulfide water



push core

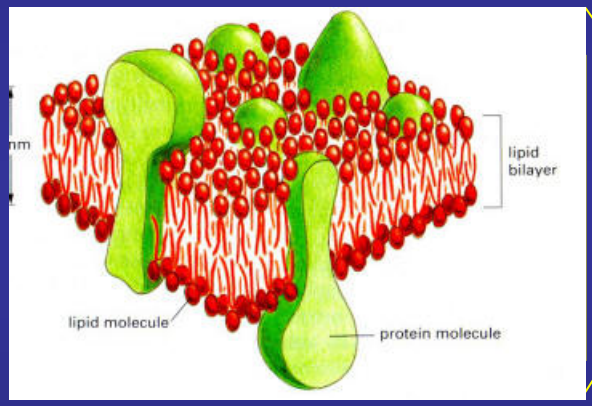
The microbial turnover of radioactive methane and sulfate is a tool to measure anaerobic oxidation of methane (AOM) and sulfate reduction (SR)

Methods to Target 'Live' Biomass

Who is there and what are they doing ?

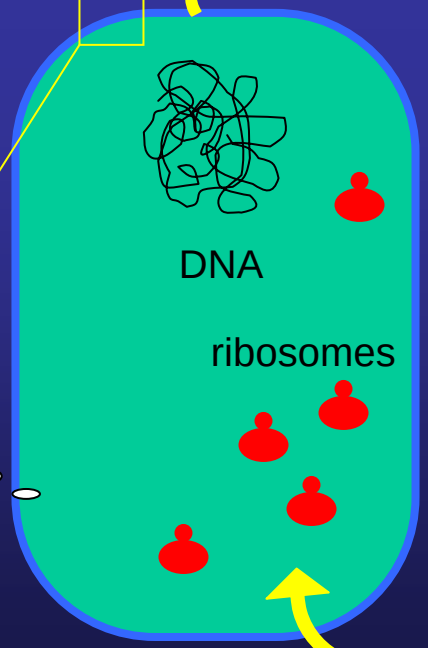
Identification by lipid biomarkers

cell wall



What do I eat?

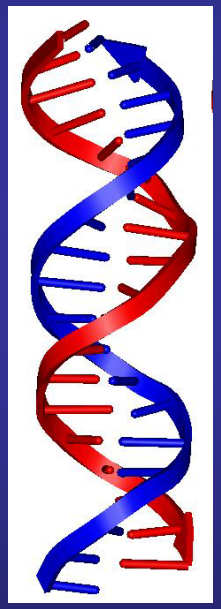
$\delta^{13}C$ composition of cell material



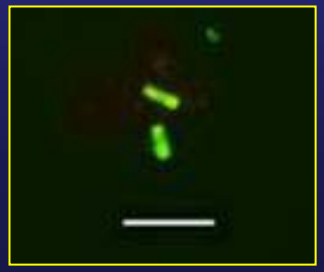
Identification by molecular phylogeny

Amplify 16S rDNA genes from environmental samples

Develop markers for specific groups of organisms

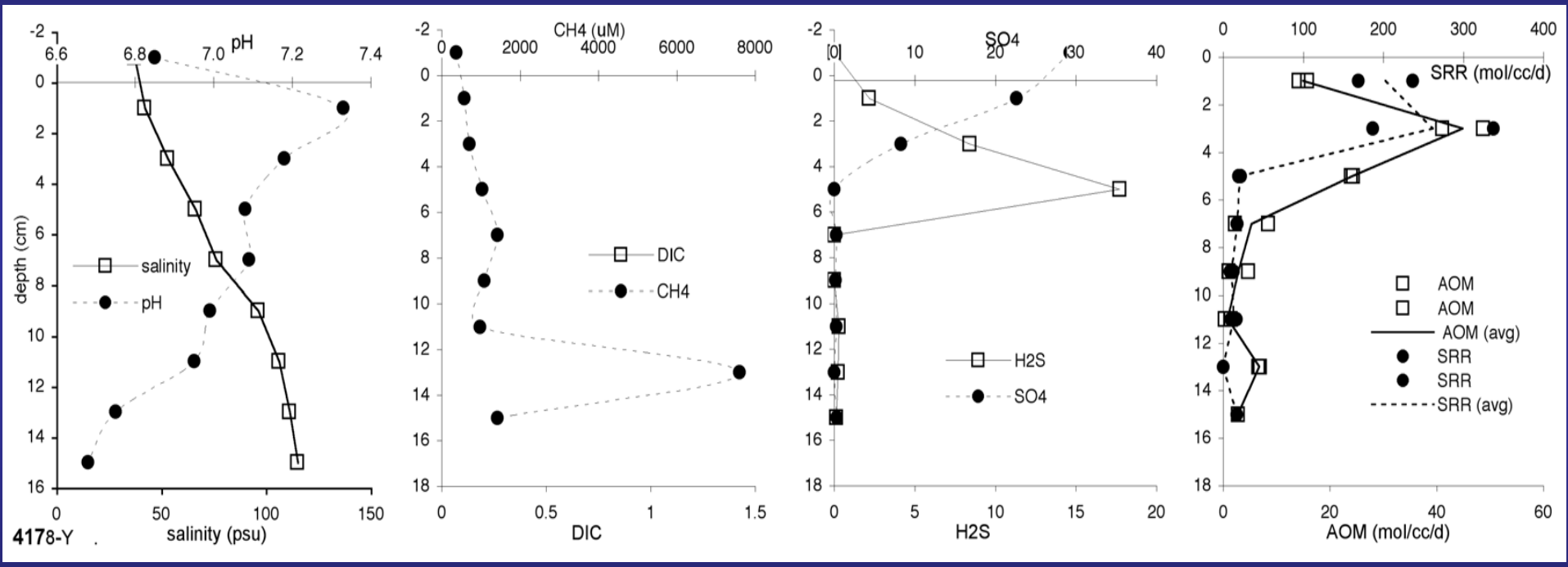


Hybridize ribosomes in intact cells with fluorescent markers (FISH)



Geochemistry and Activity

MC853, 1070m, **oily** white mat, **brine**



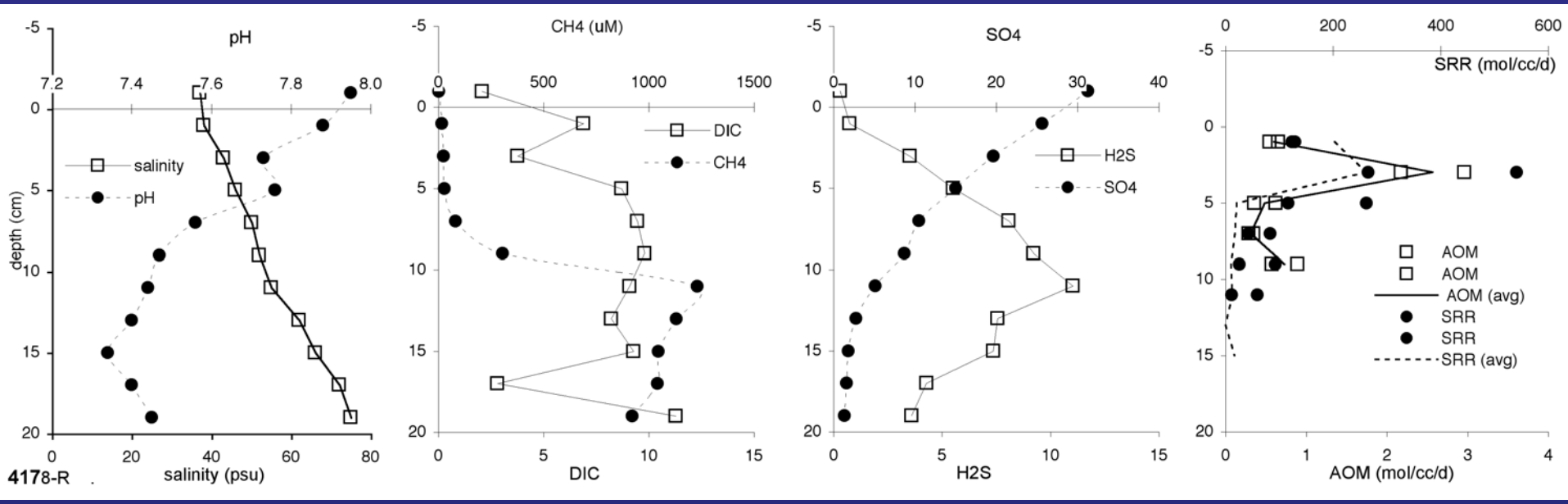
Brine Advection: complete SO_4 depletion, thin H_2S zone

High AOM (relative to other sites)
SR > > AOM

Geochemistry and Activity

MC853, 1070m, **oily** white mat, **brine**

> Mats not nearly as lush as in z<1000m

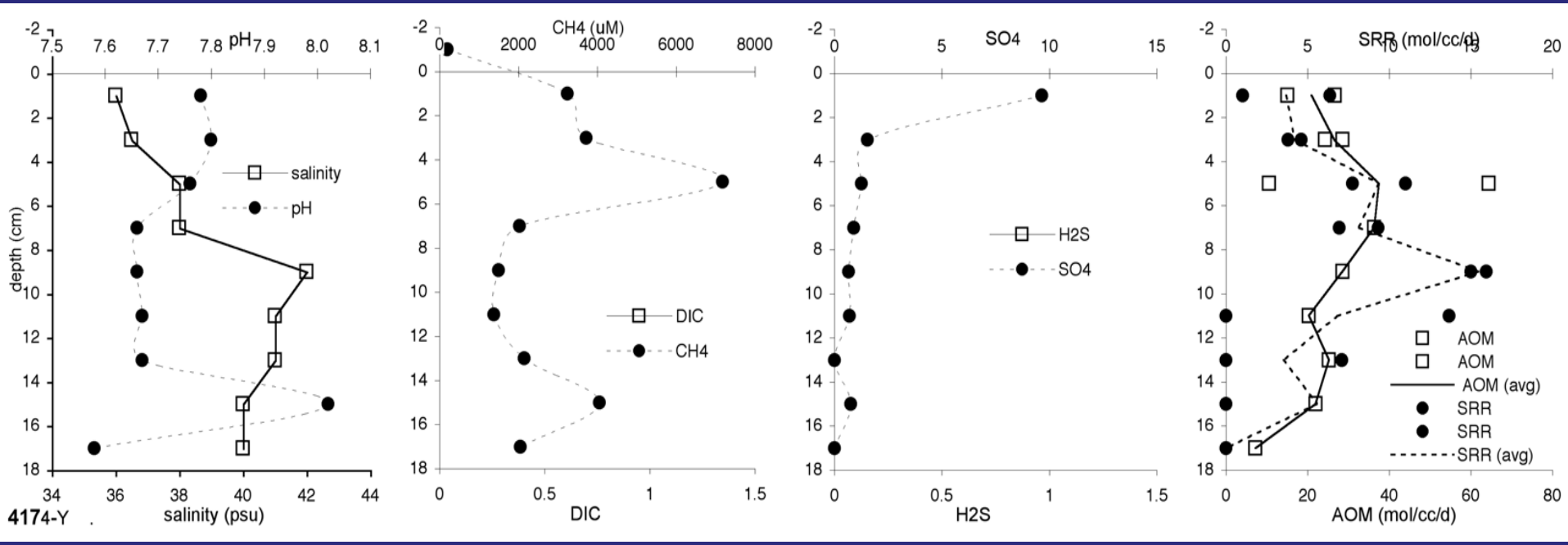


Less brine advection: deeper SO_4 depletion, higher H_2S

Lower AOM (oil) (SR >>> AOM)

Geochemistry and Activity

GC600, 1250m, **oily** core

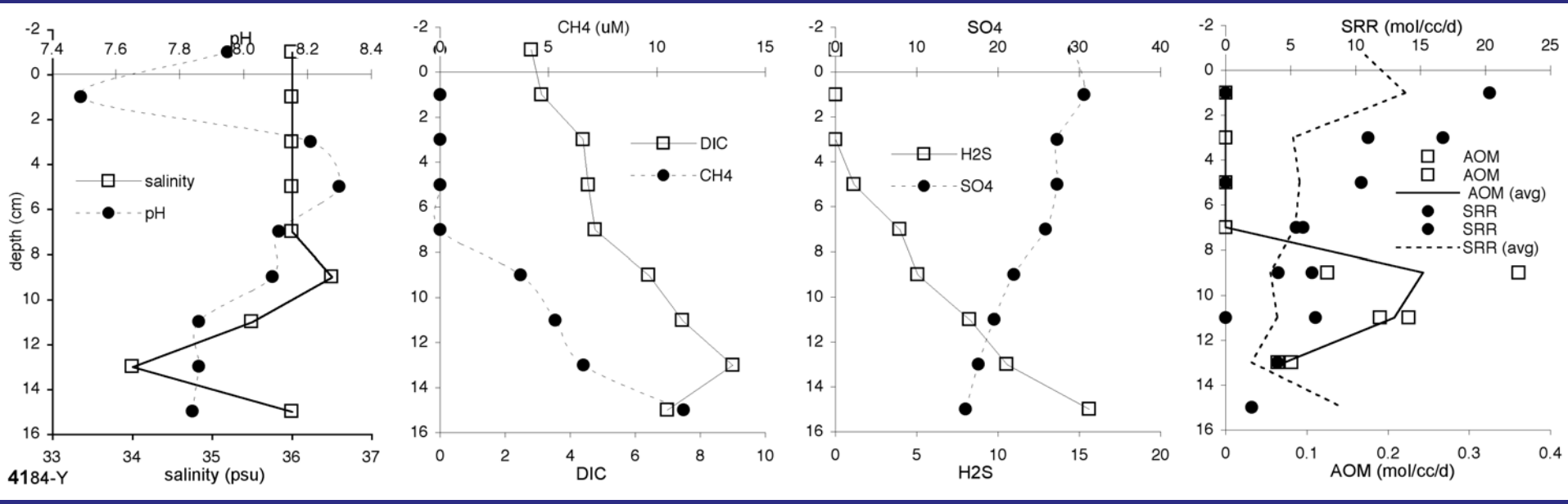


Sulfate limited sulfate reduction

Rather high AOM (relative to SR)

Geochemistry and Activity

GC600, 1250m, clam bed

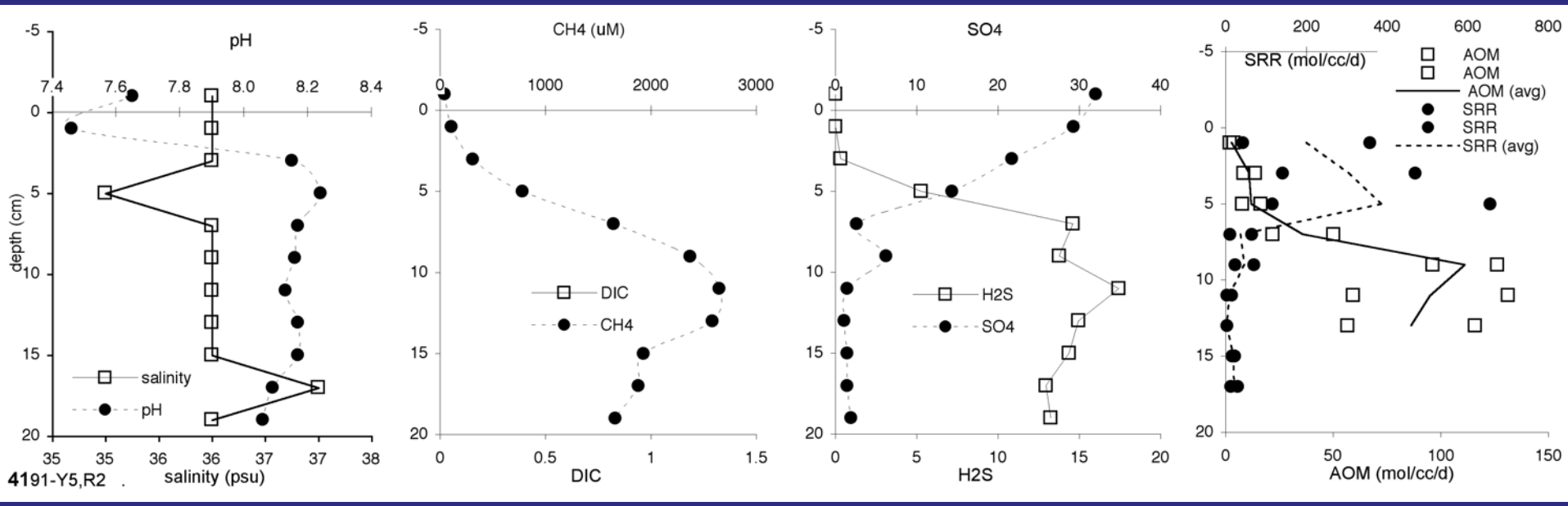


SR > AOM rates

gradual SO_4 depletion and H_2S accumulation

Geochemistry and Activity

WR269/270, 1953m, pogo

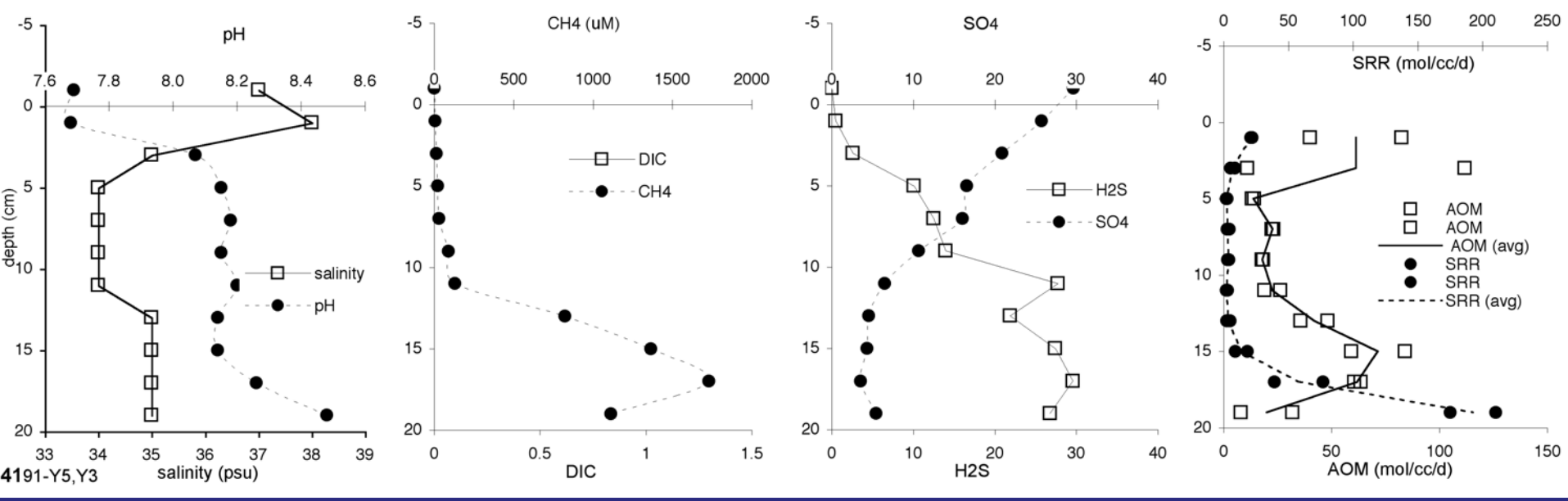


Variable but high rates of SR and AOM
– poor correlation b/t rates –

highest AOM rates measured

Geochemistry and Activity

WR269/270, 1953m, pogo

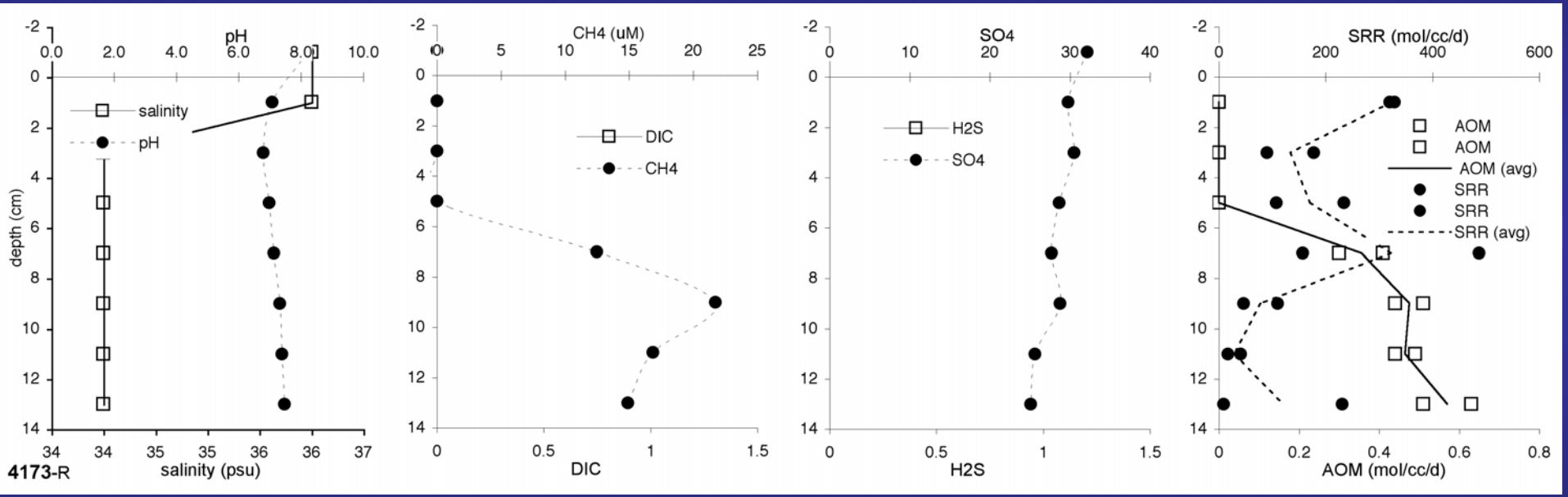


Good replication between cores (esp. rates)

***different depth profile of activity (SR highest at bottom)**

Geochemistry and Activity

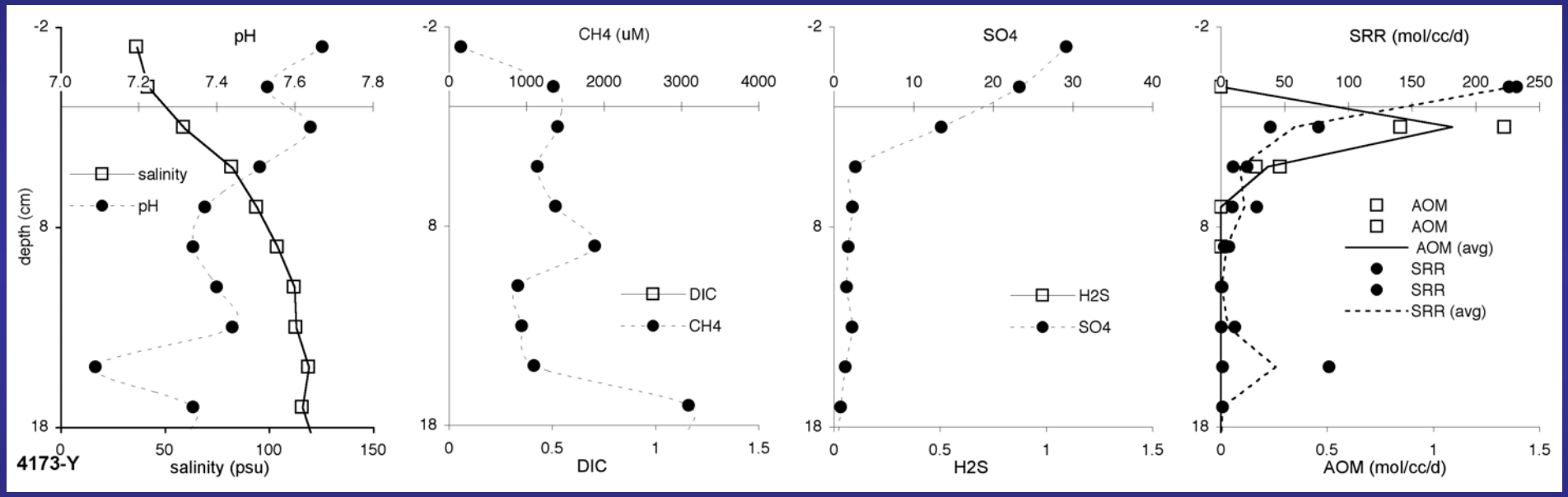
AT340, 2180m, beside tube worm bush



Negligible SO_4 gradient; high SR rate but very LOW AOM (low CH_4)

Geochemistry and Activity

AT340, 2180m, white mat (?), **brine**

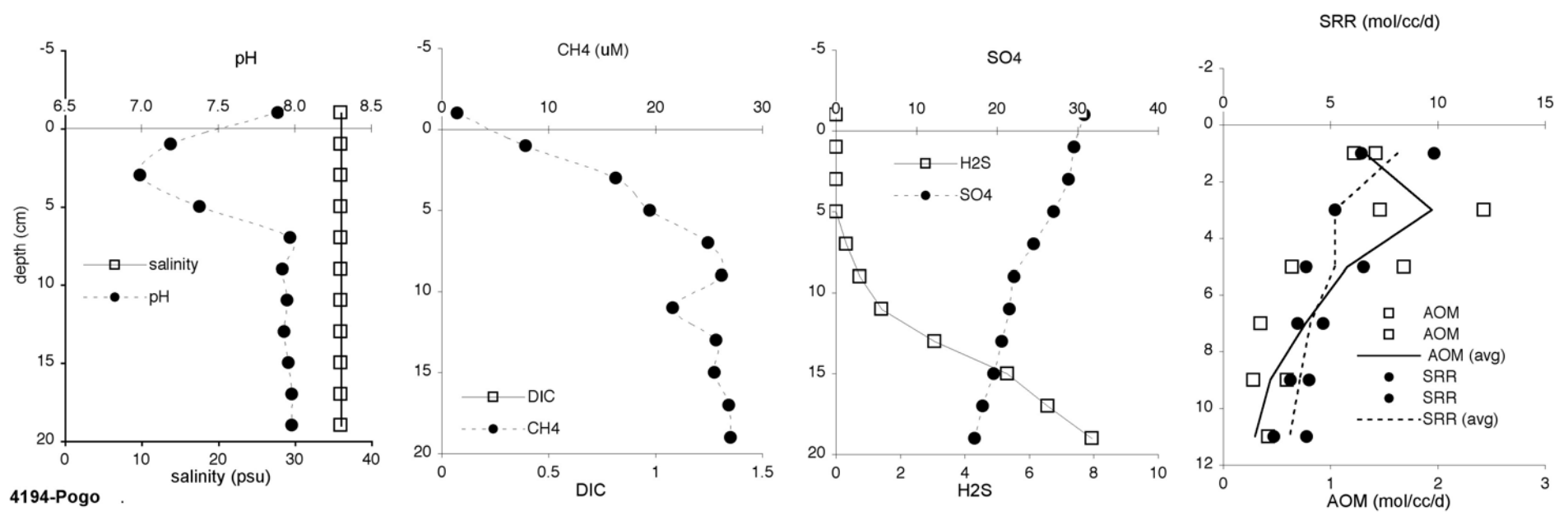


Sulfate limitation of SR

Very LOW AOM

Geochemistry and Activity

AC645, 2210m, pogo



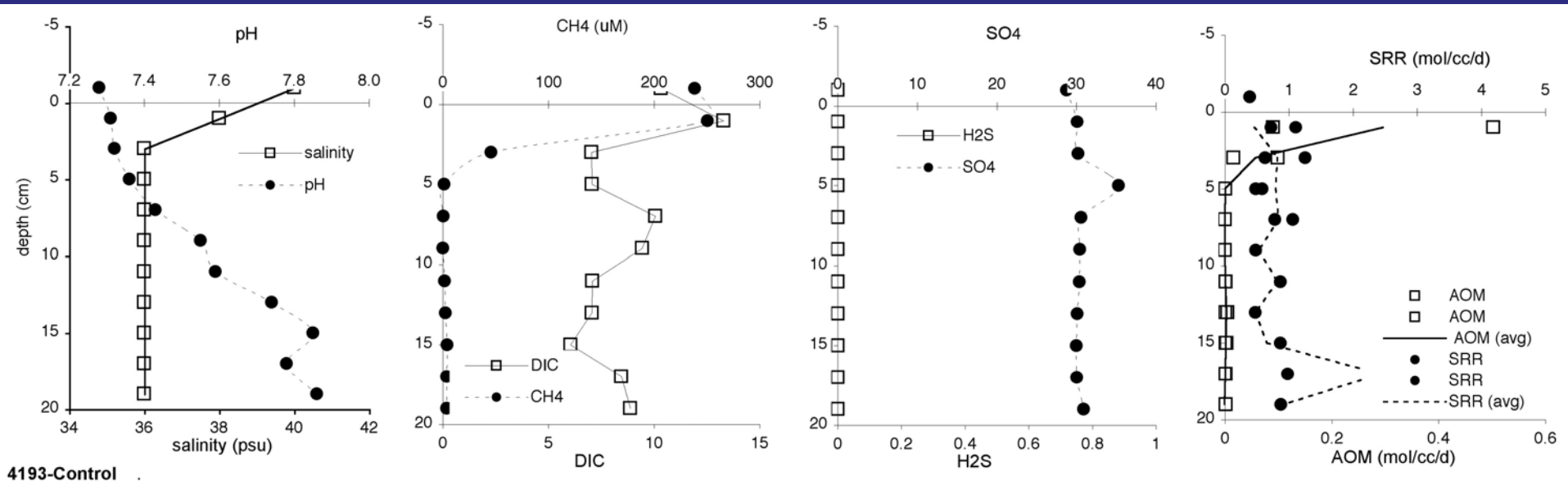
Very low SR and AOM rates

gradual SO_4 depletion; more rapid H_2S accumulation

pH minimum denotes H_2S oxidation

Geochemistry and Activity

AC601, 2330m, control-away from brine lake

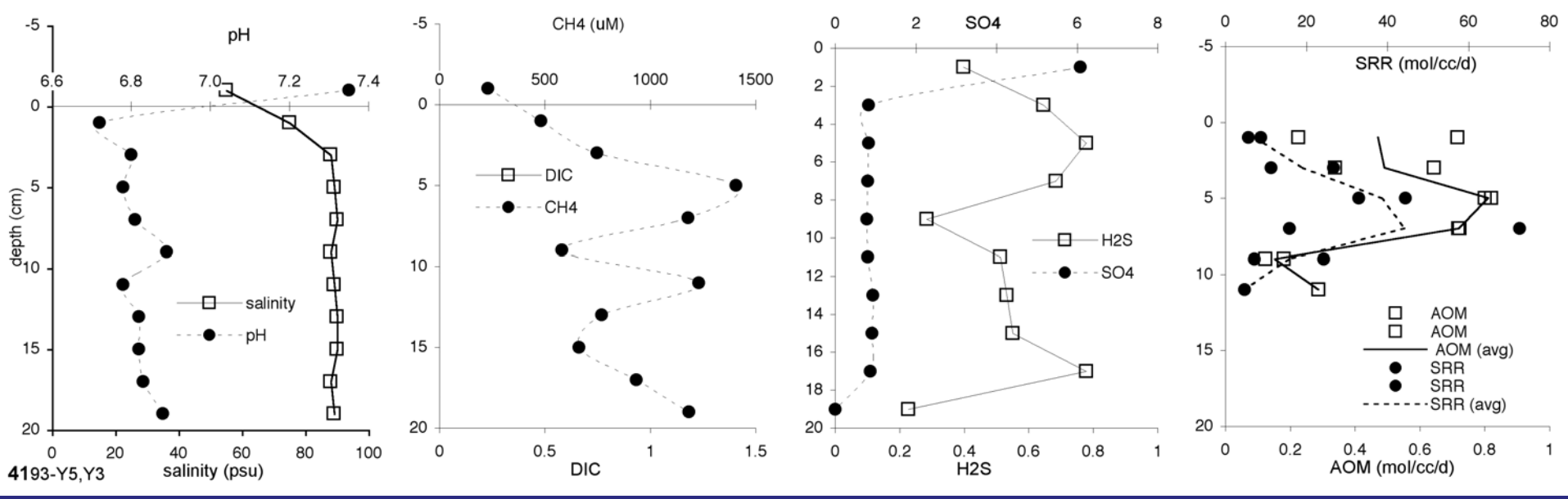


Very low SR rates; no SO_4 depletion

AOM rates extremely low in comparison

Geochemistry and Activity

AC601, 2330m, bottom of **brine** lake



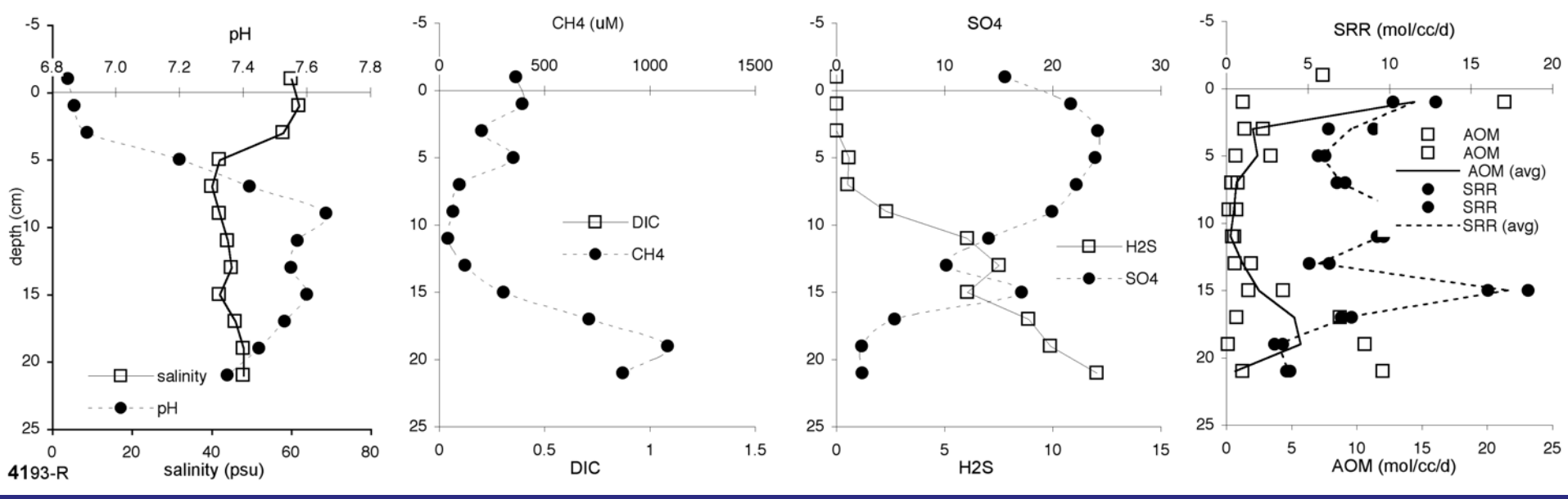
Low SR rates

AOM rates extremely low

<degassing>

Geochemistry and Activity

AC601, 2330m, urchin field at edge of **brine** lake

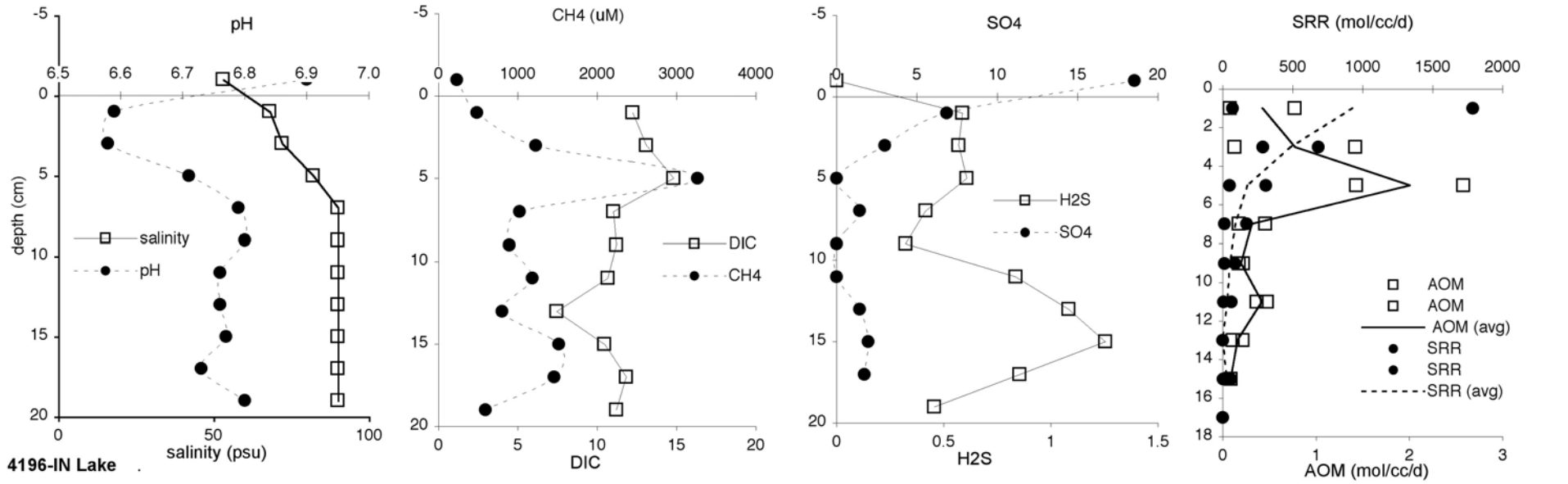


Strange SR rates profile; rapid SO_4 depletion and H_2S accumulation

AOM rates higher here

Geochemistry and Activity

AC601, 2330m, inner edge of **brine** lake



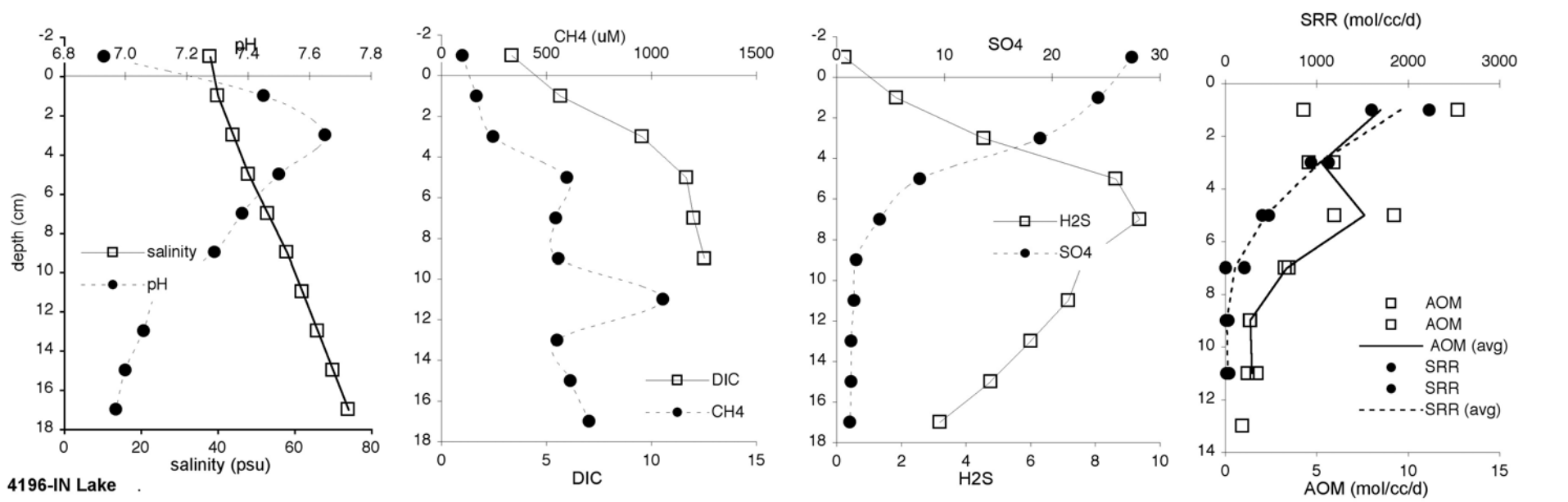
High SR rates at top; rapid SO_4 depletion

****Highest SR rates measured****

AOM rates extremely low in comparison

Geochemistry and Activity

AC601, 2330m, outer edge of **brine** lake

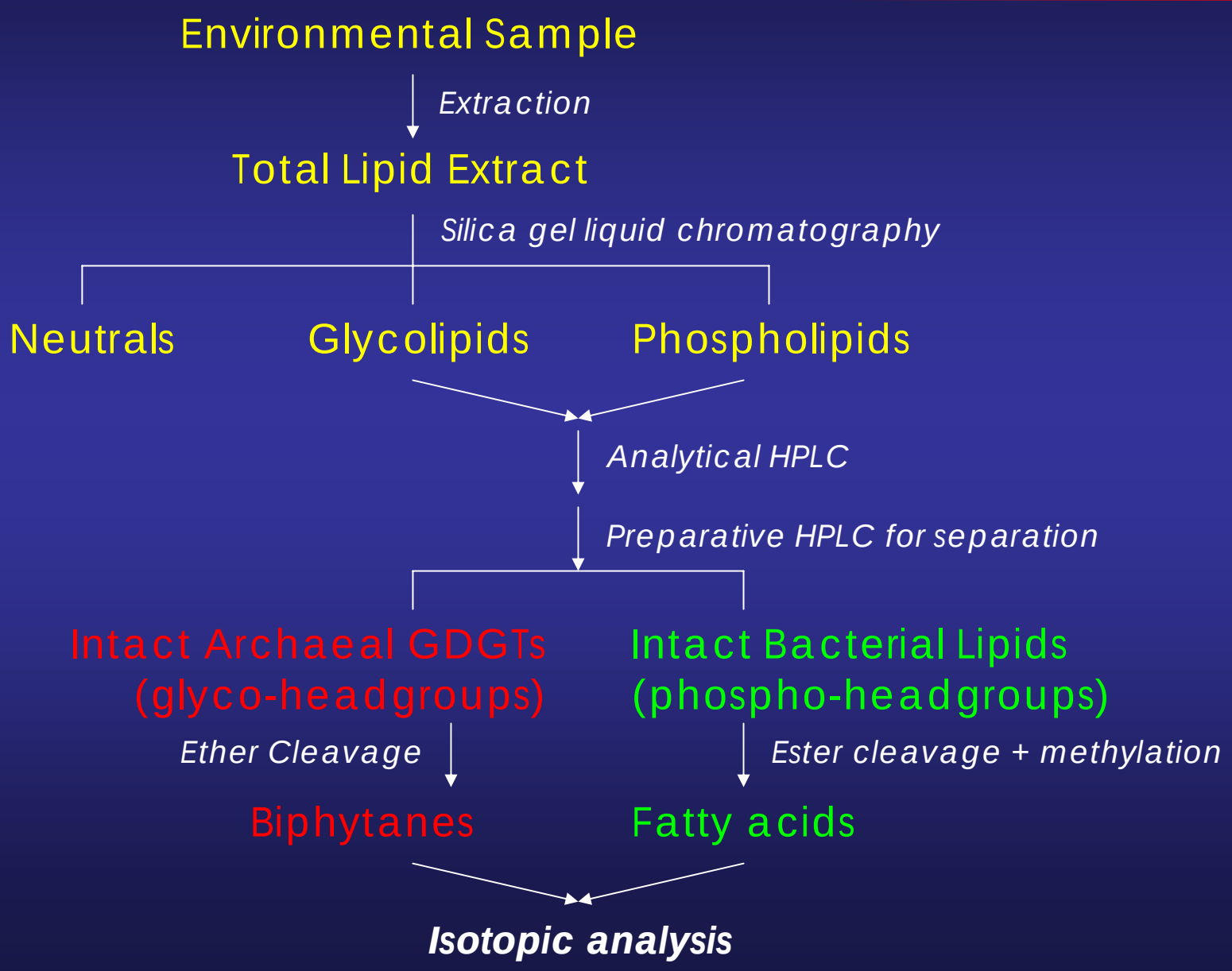


High SR rates track SO_4 depletion (higher H_2S)

****Highest SR rates measured****

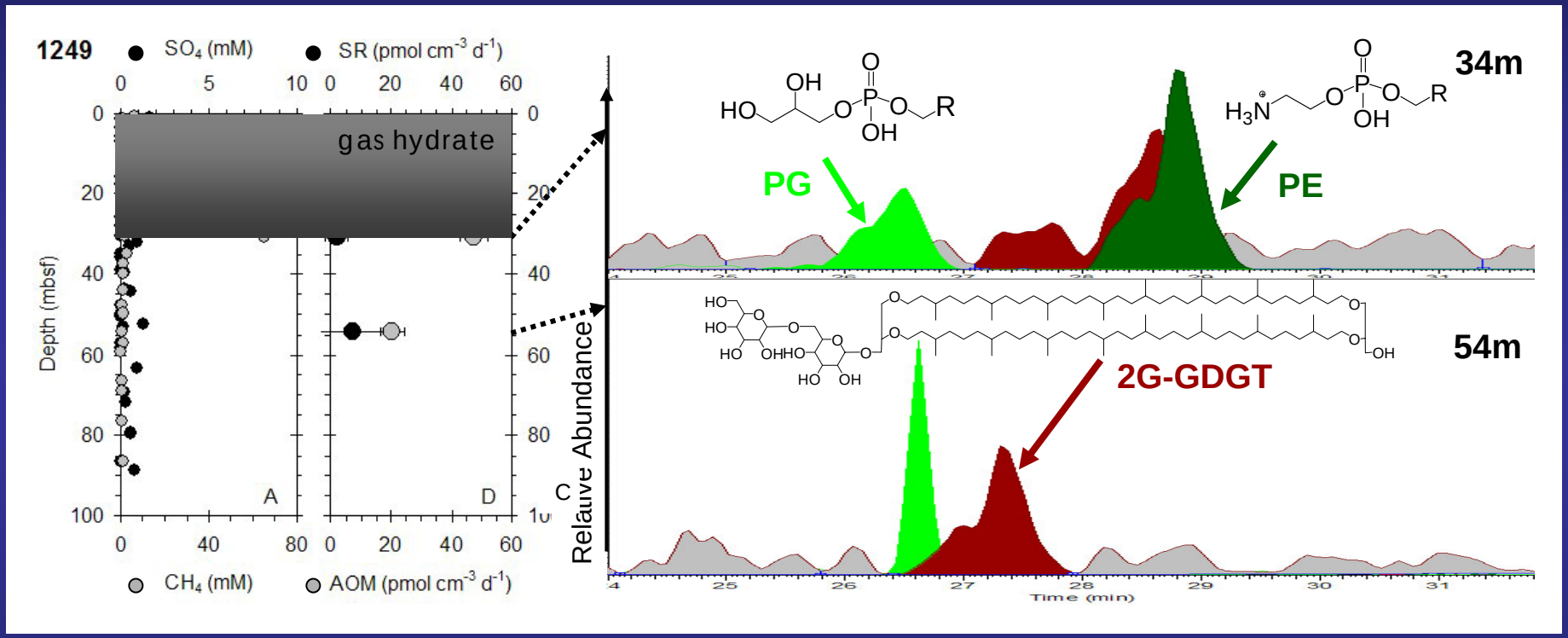
AOM rates low (but higher than inside pool)

Analysis of Intact Polar Lipids



Example: Hydrate Ridge Site 1249

Summit site with gas hydrate



- Bacterial phospholipids with PE and PG headgroups
- Archaeal GDGTs with 0-3 rings with different sugar headgroups; no diethers

Brine Biomarkers

Sulfate Reducing Bacteria

SRB	i-$C_{15:0}$	ai-$C_{15:0}$	$C_{16:1\omega5}$	cy$C_{17:0\omega5,6}$	$C_{17:1\omega6}$
Seep-SRB1 (ANME-1)	++	(+)	(+)	-	-
Seep-SRB1 (ANME-2)	+	++	++	++	-
Desulfobulbus	+	++	-	-	-

Blumenberg et., 2004 & references therein, Elvert et al. 2003, Niemann et al. 2006

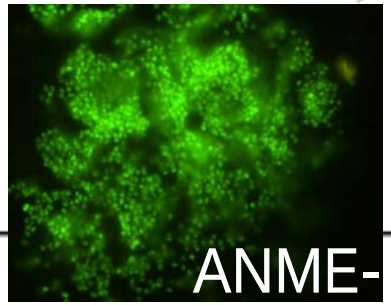
sample					
Brine 1	+	++	++	++	++
Brine 2	+	++	++	++	++
Brine 3	+	+	(+)	tr.	tr.
Brine 4	+	++	++	++	++
Brine 5	+	++	++	+	+

Brine Biomarkers

Methane Oxidizing Archaea

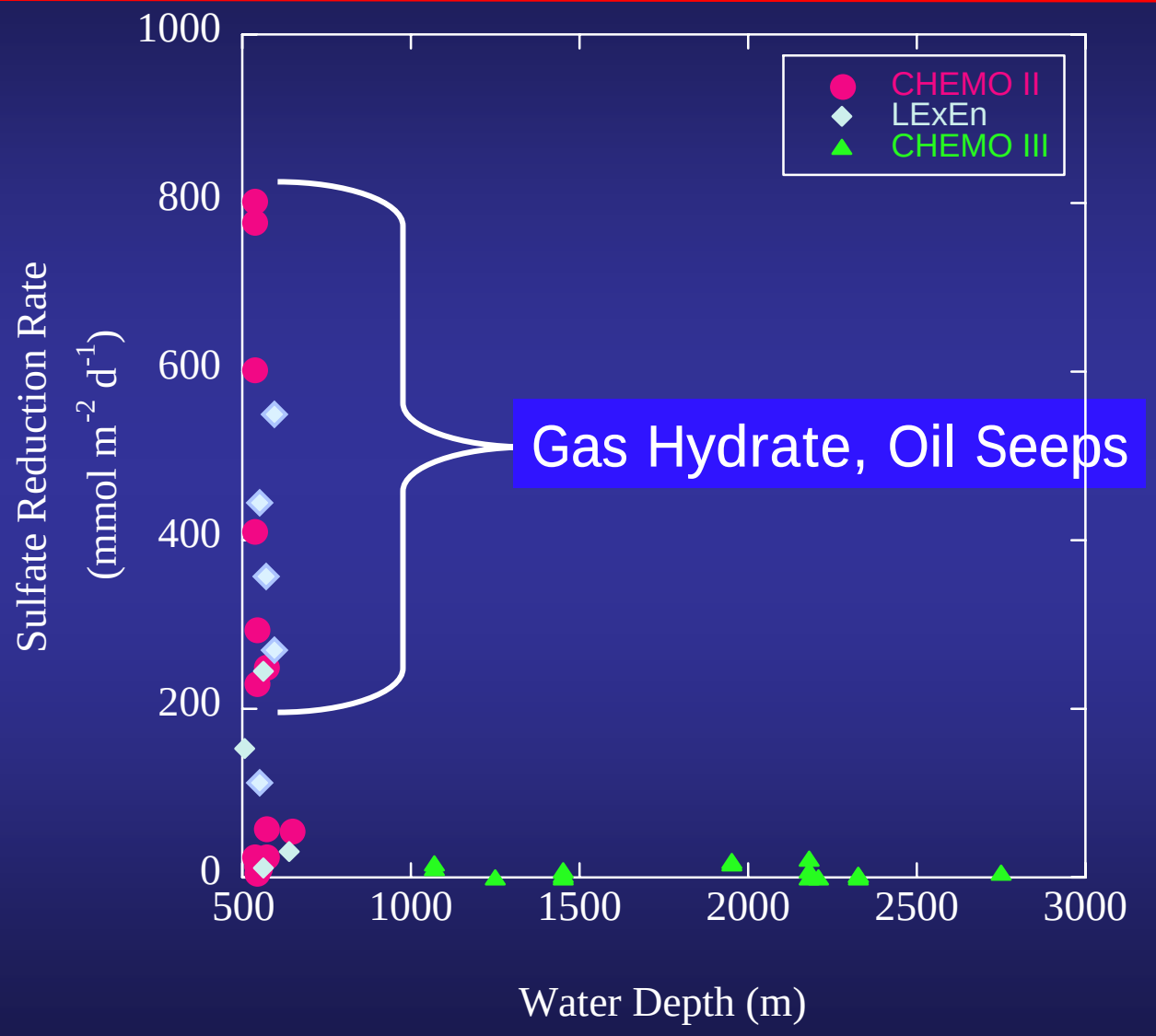
archaeon	archaeol	*sn2*-hydroxy-archaeol	crocetane	PMI Δ
ANME-1	++	(+)	(+)	0-5
ANME-2	+	++	++	0-4
ANME-3	+	++	-	4, 5

Blumenberg et., 2004 & references therein, Elvert et al. 2005, Niemann et al. 2006



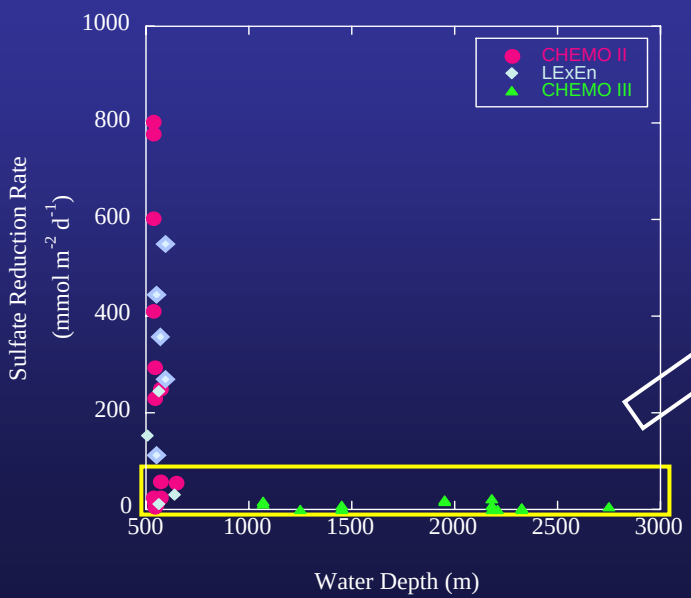
sample				
Brine 1	tr.	+	-	-
Brine 2	tr.	+	-	-
Brine 3	tr.	+	-	-
Brine 4	(+)	++	-	-
Brine 5	(+)	++	-	-

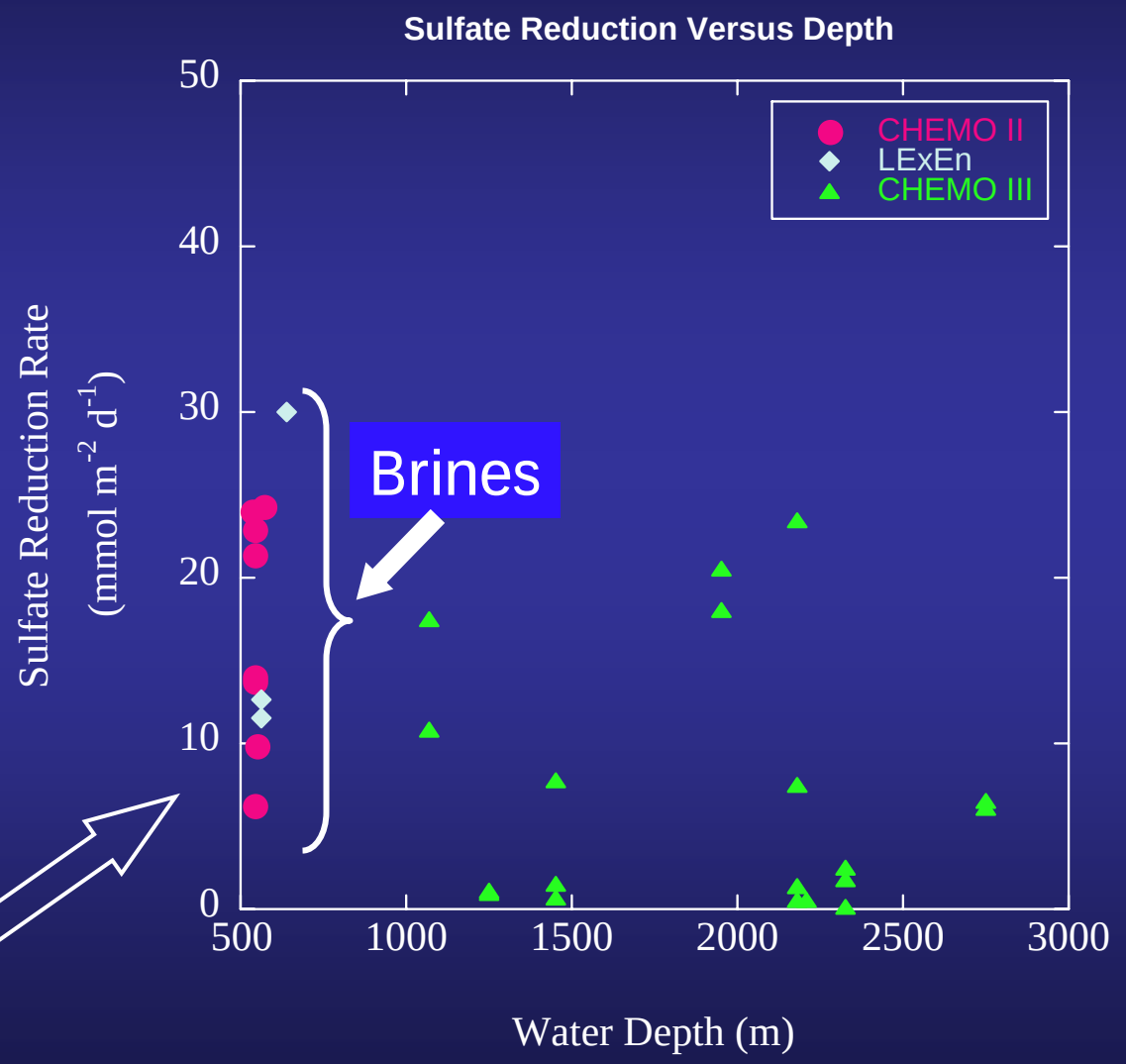
Sulfate Reduction Rates versus Water Depth



Data from: Arvidson et al. 2004, Joye et al. 2004, Orcutt et al. 2005, Joye unpublished

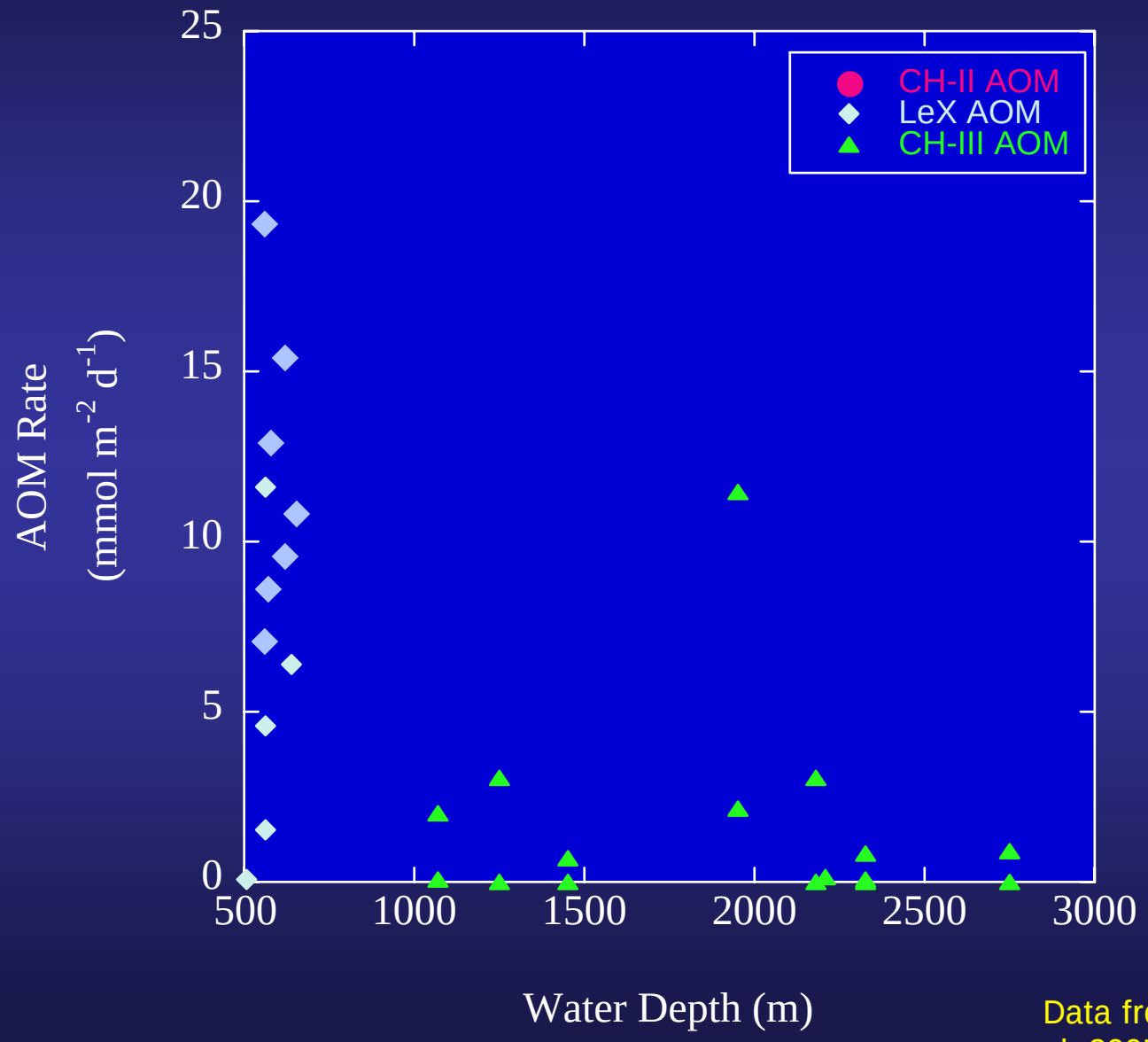
Sulfate Reduction Rates versus Water Depth





Data from: Arvidson et al. 2004, Joye et al. 2004, Orcutt et al. 2005, Joye unpublished

AOM Rates versus Water Depth



Methane limited AOM?

Need data from In situ pressure

Data from: Joye et al. 2004, Orcutt et al. 2005, Joye unpublished

Summary

1. ***Depth variability in SR rates***: Rates at sites >1000m are generally **lower** than those observed in <1000m for gas hydrate sites but are **comparable** to rates at <1000m brine seeps (<1000m brine seeps are SO_4 limited)

2. ***Depth variability in AOM rates***: Rates at sites >1000m are generally **lower** than those observed in <1000m for all sites (AOM rates are likely CH_4 limited)

3. ***Brine Sites*** *(MC853, GC600, AT340, AC601)*: Upward advection of brine (NaCl) limits SO_4 penetration and thus SR rates; AOM rates at brine sites are variable but often low

4. ***H_2S Oxidation*** *(esp. urchin, pogo)*: Most extreme pH anomalies, suggestive of H_2S oxidation; other evidence, elemental S (S^o) and polysulfide. *S^o disproportionation?*

Summary

5. **Coupling between SR and AOM**: Extremely loose coupling, as noted at sites <1000m (oil, alkanes serve as reductant for SR)

6. ***The brine lake***: Extremely high rates of SR; very low AOM. Edges seem to be the most active but bottom of the pool and away from the edge are less so. Novel SRBs and ANMEs here.

7. ***Microbiology***: Initial surveys suggest novel types of SRBs and ANMEs. Detailed surveys (FISH, clone libraries, and biomarker) work planned for the next few months (and continuing after the 2007 cruise).

Plans for 2007

1. More rates to better test depth vs. activity trends
2. Look for “microbial mats” and compare types of microorganisms, abundance and activity
3. Look for novel sulfur metabolisms (disproportionation)
4. *In situ* pressure incubations for AOM and SR
5. Quantify within- and between-site differences in activity and biogeochemistry

References

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