Ecology of Submerged Cenotes in Lake Huron: Players and Processes

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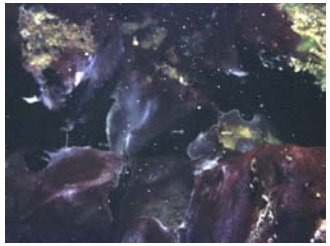
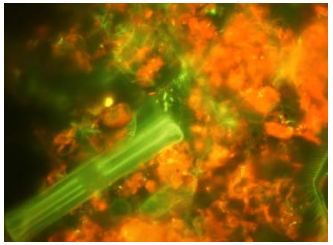
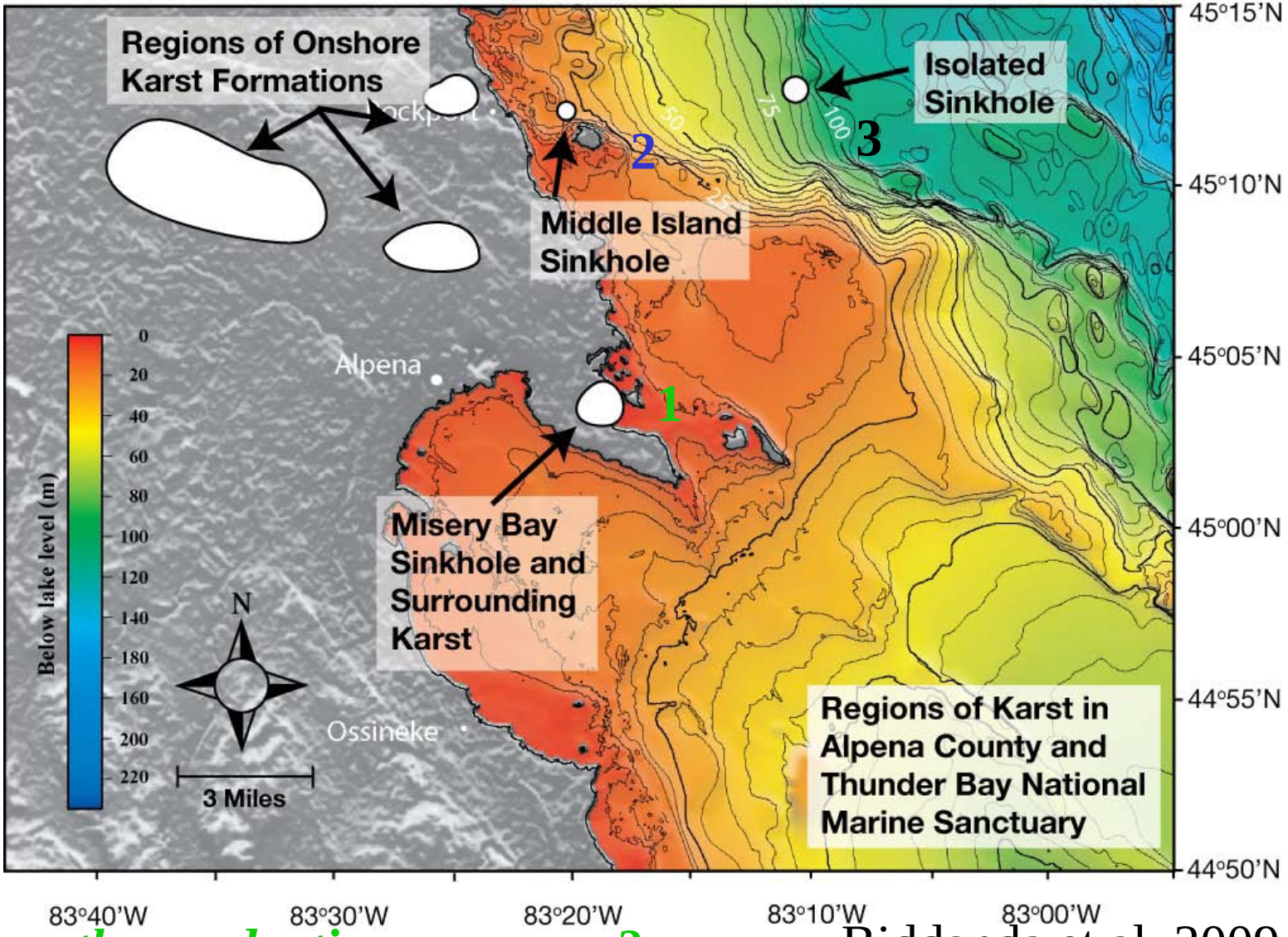


A NSF & NOAA funded, TBNMS & NOF supported study

Submerged sinkholes along a increasing depth/decreasing sunlight gradient

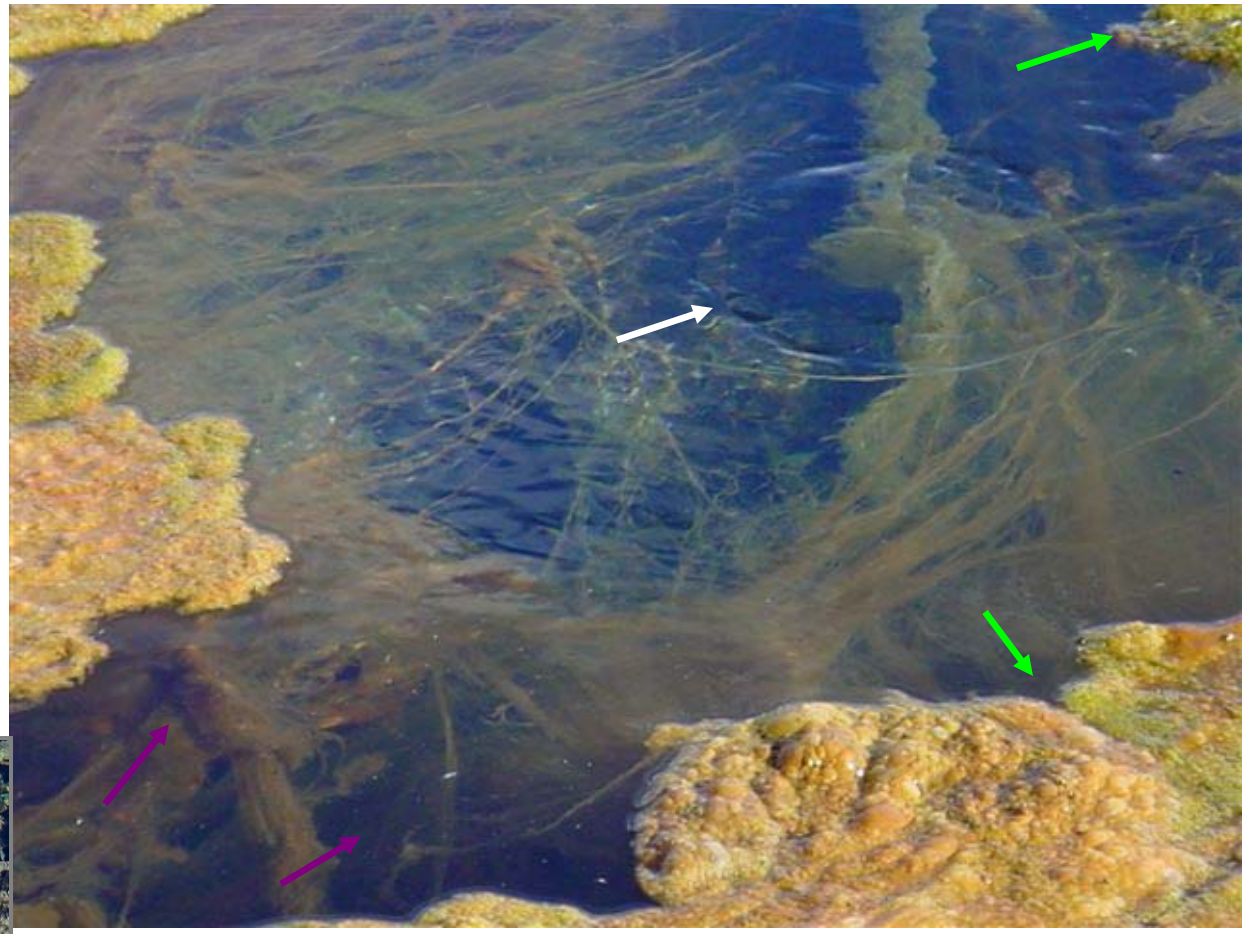


What are the production processes?

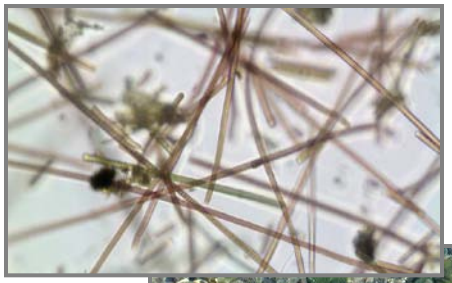
Biddanda et al. 2009 (Eos)

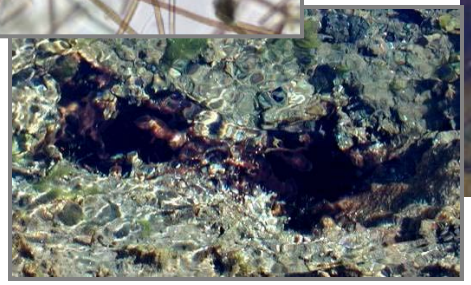
1. El Cajon Bay Springs (shallow)

Groundwater Emerging from Shallow Submerged Sinkhole Springs (White arrows) are characterized by green algae (Green arrows) and purple cyanobacteria (Purple arrows)



Green Algae



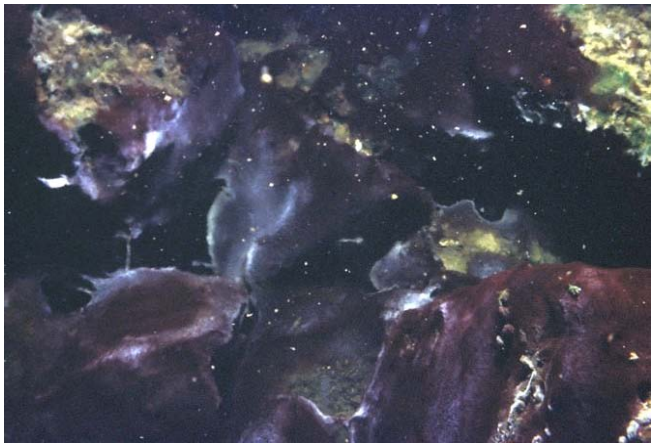


Purple Cyanobacteria

El Cajon Spring_0001.wmv

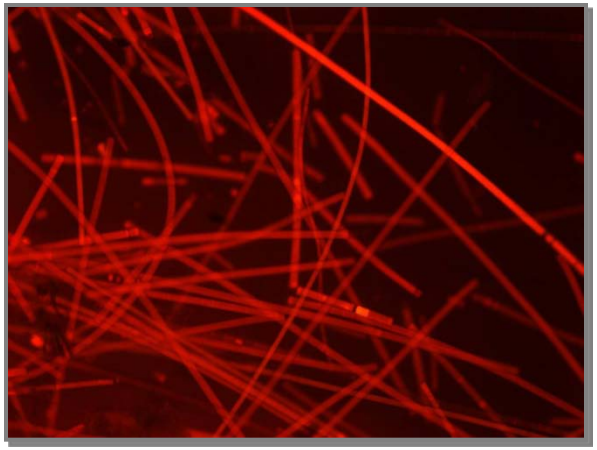
2. Middle Island Sinkhole (Low-Light: 5-23 m)

Benthic Cyanobacterial Mats

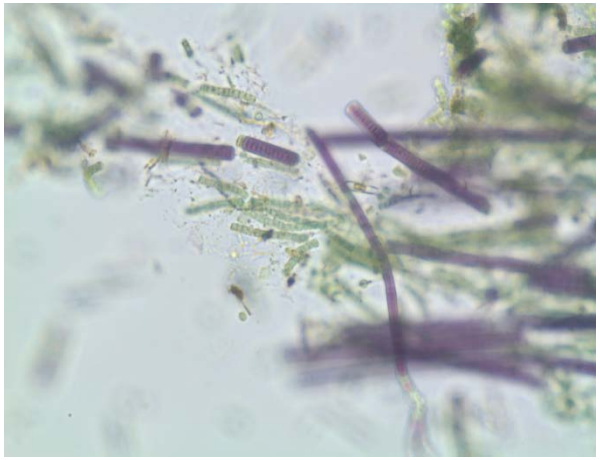


Dominant Purple Colored Mats

Cyanobacteria Under Microscope



Red autofluorescence of chlorophyll



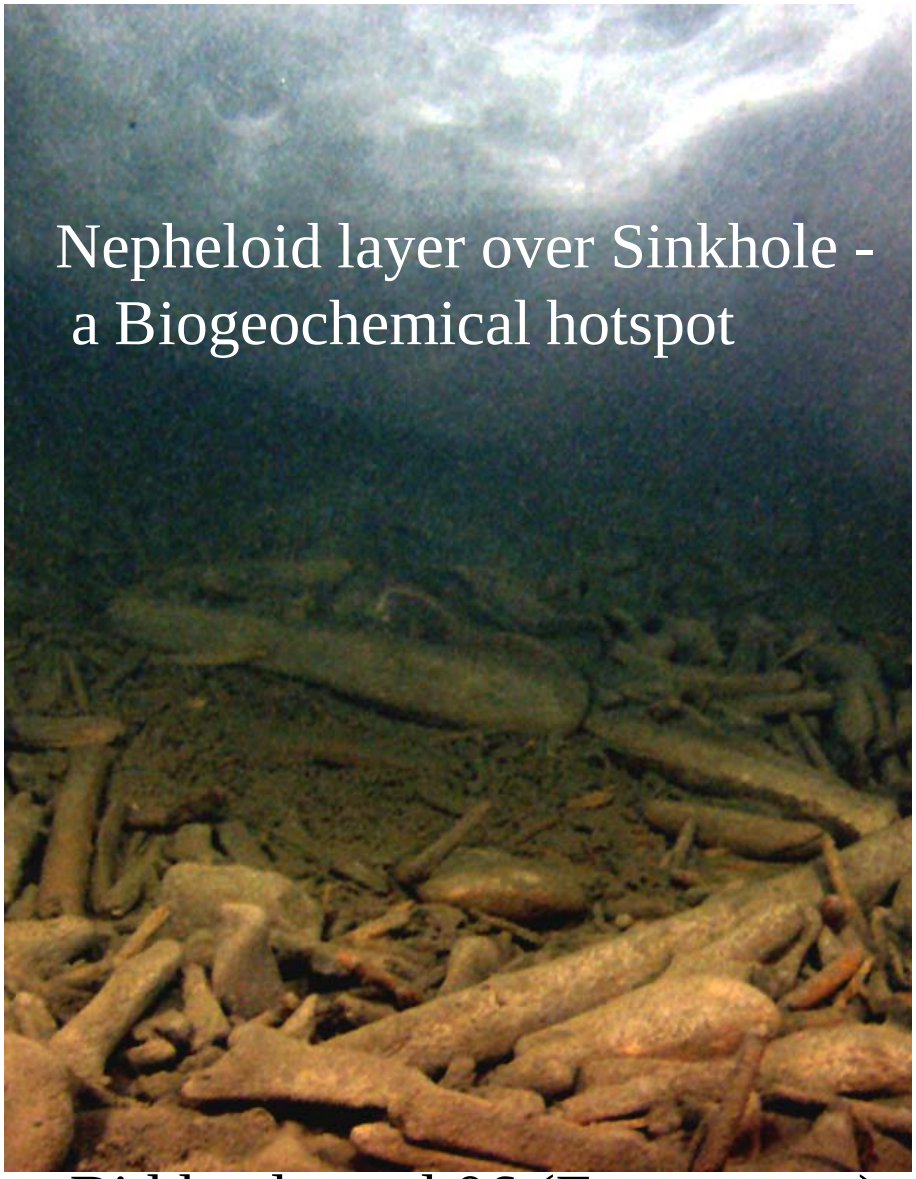
Purple and Green Filaments

Potential for both Oxygenic and Anoxygenic Photosyntheisis?

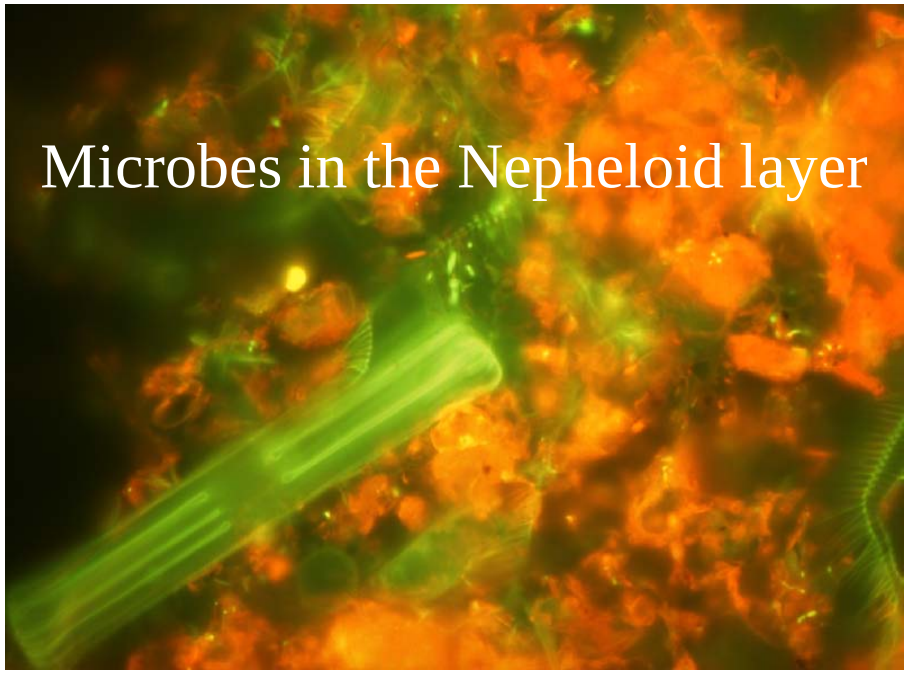
Anoxygenic Photosynthesis (Cyanobacteria)

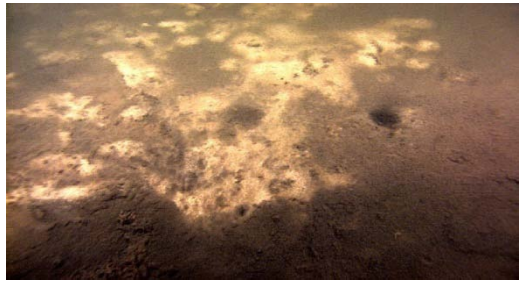
$$H_2S + CO_2 = CH_2O + SO_4^{2-}$$

3. Isolated Sinkhole (Aphotic) 93m



Biddanda et al 06 (Ecosystems)





White Benthic Mats on lake floor
(Similar to Marine Vents and Seeps!):
S-oxidizing chemosynthetic bacteria?

Isolated Clip_0001.wmv

Comparison of Lake Huron water and sinkhole vent water.

Parameter	Lake Huron	Venting GW
Conductivity (mS/cm)	0.2	2.3
Dissolved Oxygen (mg/L)	11	< 0.3
Temperature (^{o}C)	seasonal	~9
pH	8.3	7.1
Chloride (mg/L)	6	25
Sulfate (mg/L)	15	1250

Ruberg et al. 2009 (MTSJ)

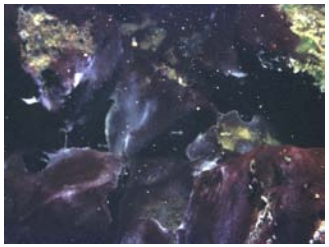
Microbial Processes in Huron Sinkholes:

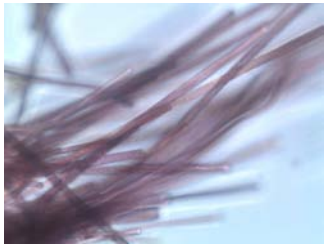
Changing Light Gradient

El Cajon sinkhole 1m
Full Sunlight

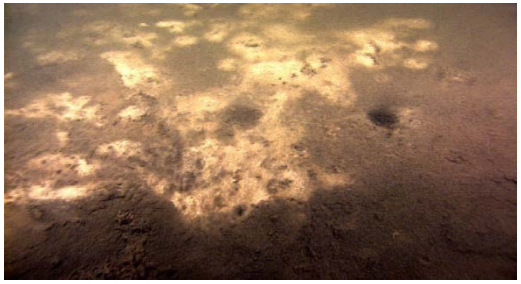
QUESTION/HYPOTHESIS

Photosynthesis in Shallow waters shifts to Chemosynthesis in Deep water(?).



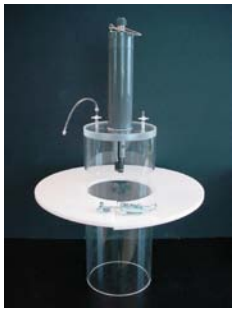


Middle Island Sinkhole 20 m
5-10% Sunlight



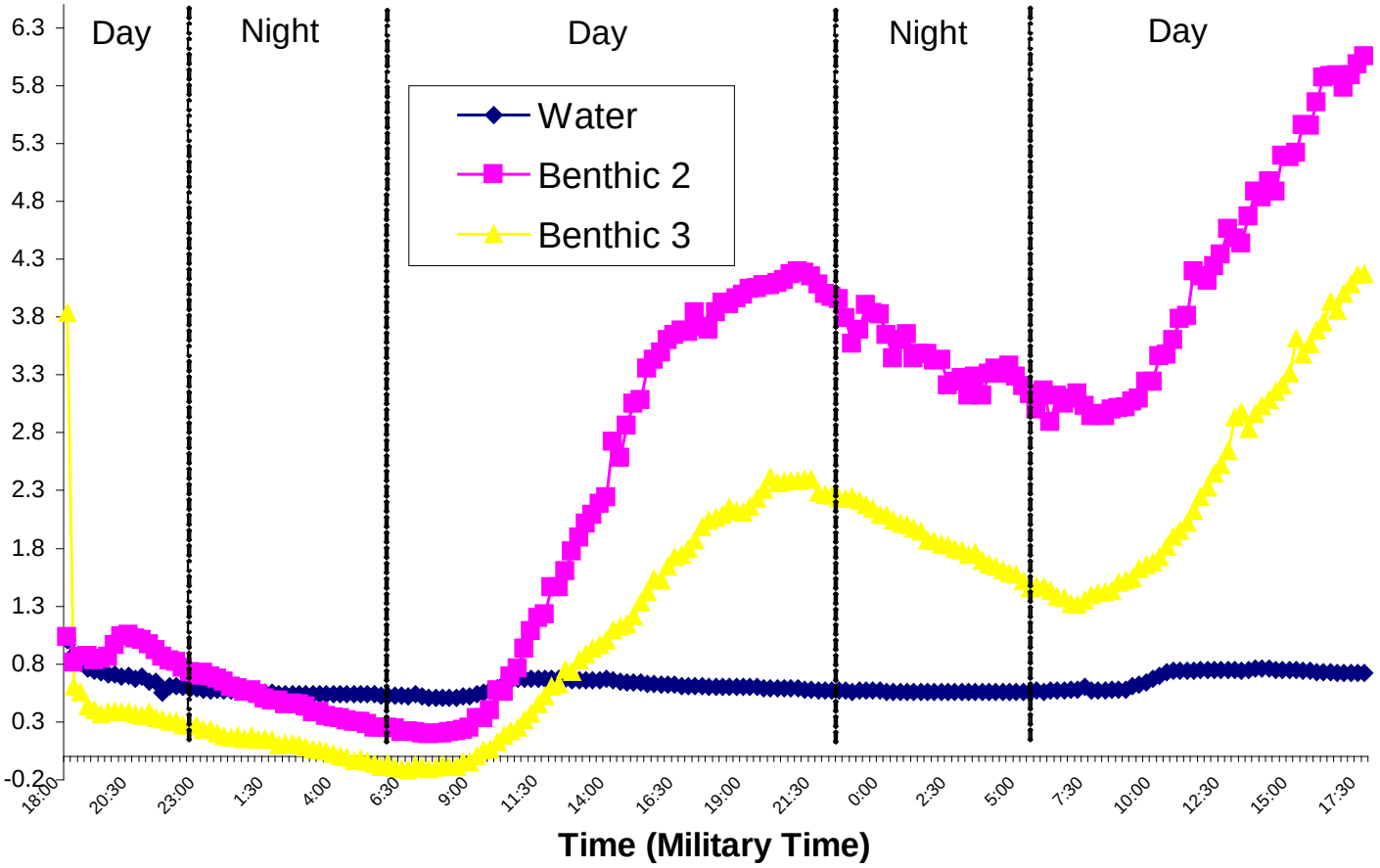
Isolated Sinkhole 93m
No Sunlight

Metabolic Studies in El Cajon

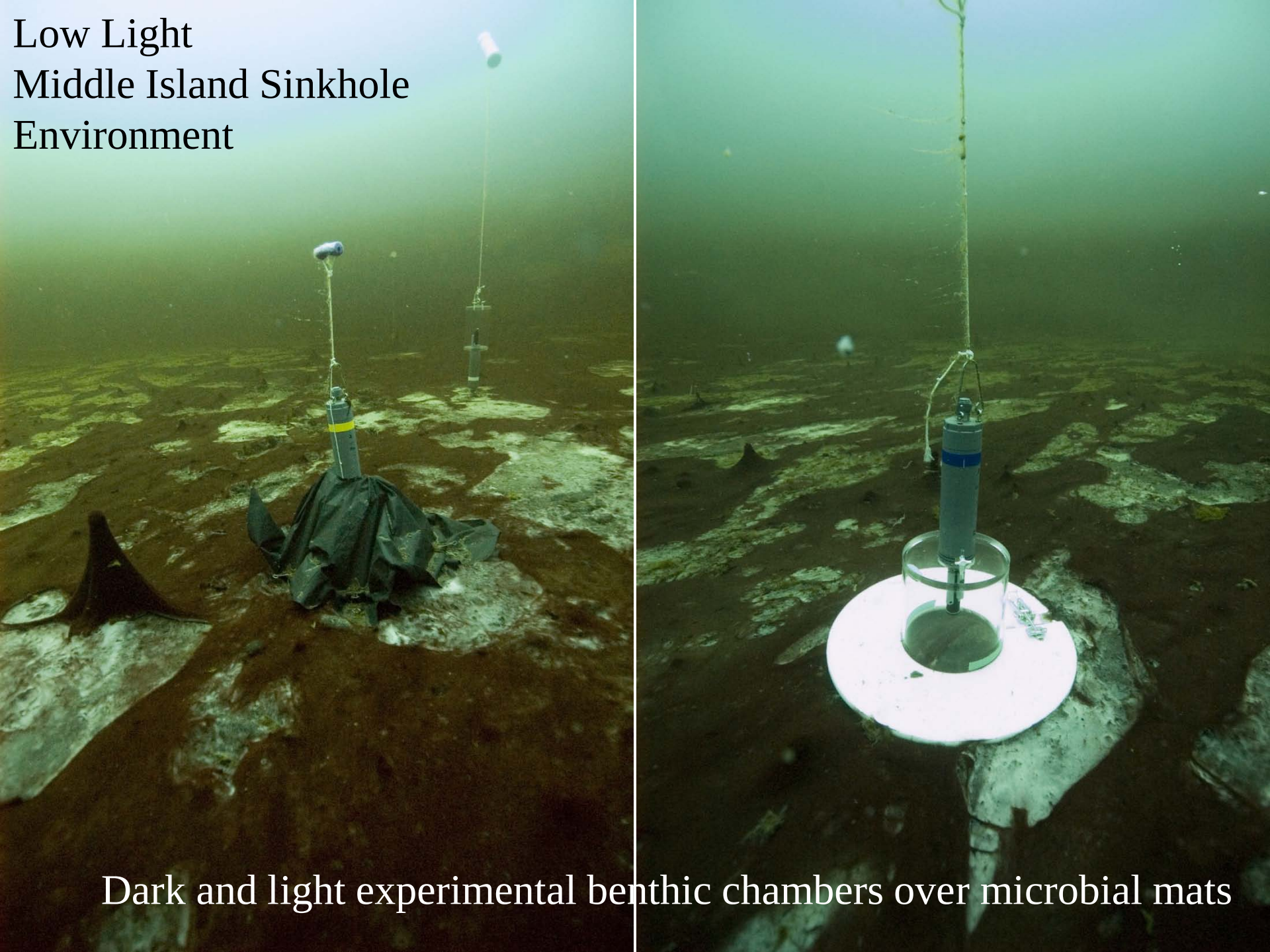


Preliminary Observations: Benthic photosynthesis is the major production process in shallow sinkholes

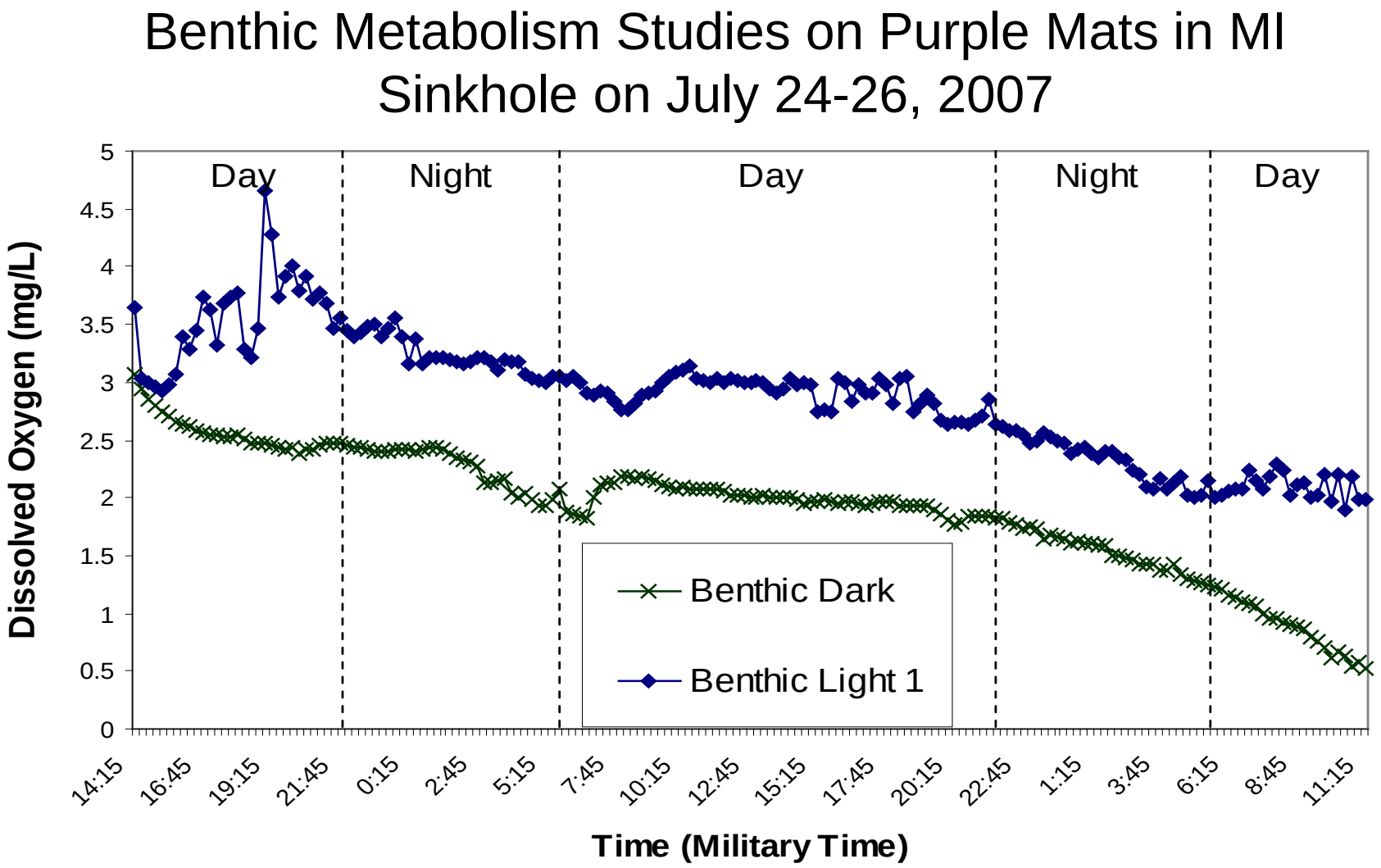
Metabolism Studies at El Cajon Spring from June 11-13, 2007



Question: What is the fate of the excess benthic primary production?

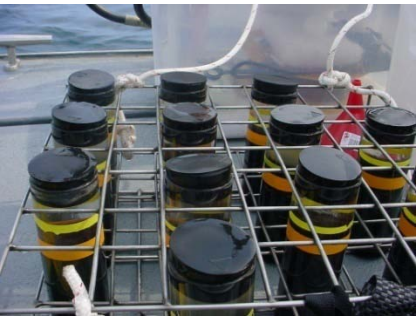

Low Light
Middle Island Sinkhole
Environment
Dark and light experimental benthic chambers over microbial mats

Preliminary Observations: Oxygenic Photosynthesis is not adequate to balance C in deeper sinkholes



Question: Can Anoxygenic Ps and Chemosynthesis account for the apparent C deficit in deeper sinkholes?

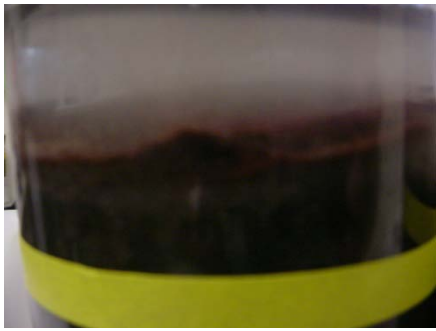
Production Processes Study: ^{14}C-Bicarbonate Incorporation into Benthic Mats-Sediment under *in situ* conditions



Sediment Cores

Experimental Design:

SUNLIGHT	DARK
Oxygenic Photosynthesis	Chemosynthesis
Anoxygenic Photosynthesis (+DCMU)	Live,DCMU and Killed Controls



Cyanobacterial Mat on sediment Surface

Incubation Chamber Over-view

Incubation Chamber Front View

DCMU inhibits Oxygenic Ps

Autotrophic Production Processes at Shallow and Deep Sinkholes:

Observation: Shift from Photosynthesis to Chemosynthesis

Production Process	El Cajon Spring µgC/L/d	Mid Island Sinkhole µgC/L/d	Isolated Sinkhole µgC/L/d
Oxygenic Photosynthesis	67 (24)	~30 (5)	NA
Anoxygenic Photosynthesis	0	22 (6)	NA
Chemosynthesis	21 (5)	10 (6)	20
Total Autotrophic Production	88	62	20

OBSERVATIONS

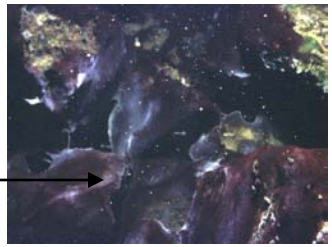
Dominant Autotrophic Production Process

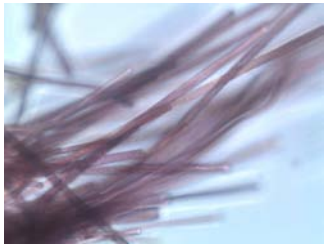
Changing Light Gradient

Oxygenic Photosynthesis

El Cajon sinkhole (1 m)
Full Sunlight

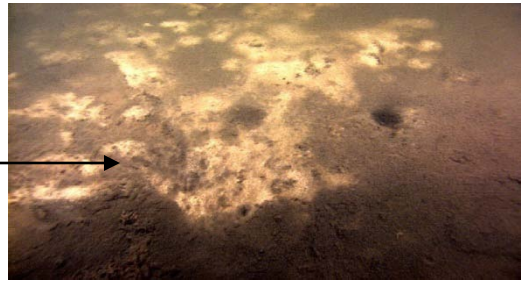
Oxygenic & Anoxygenic Photosynthesis





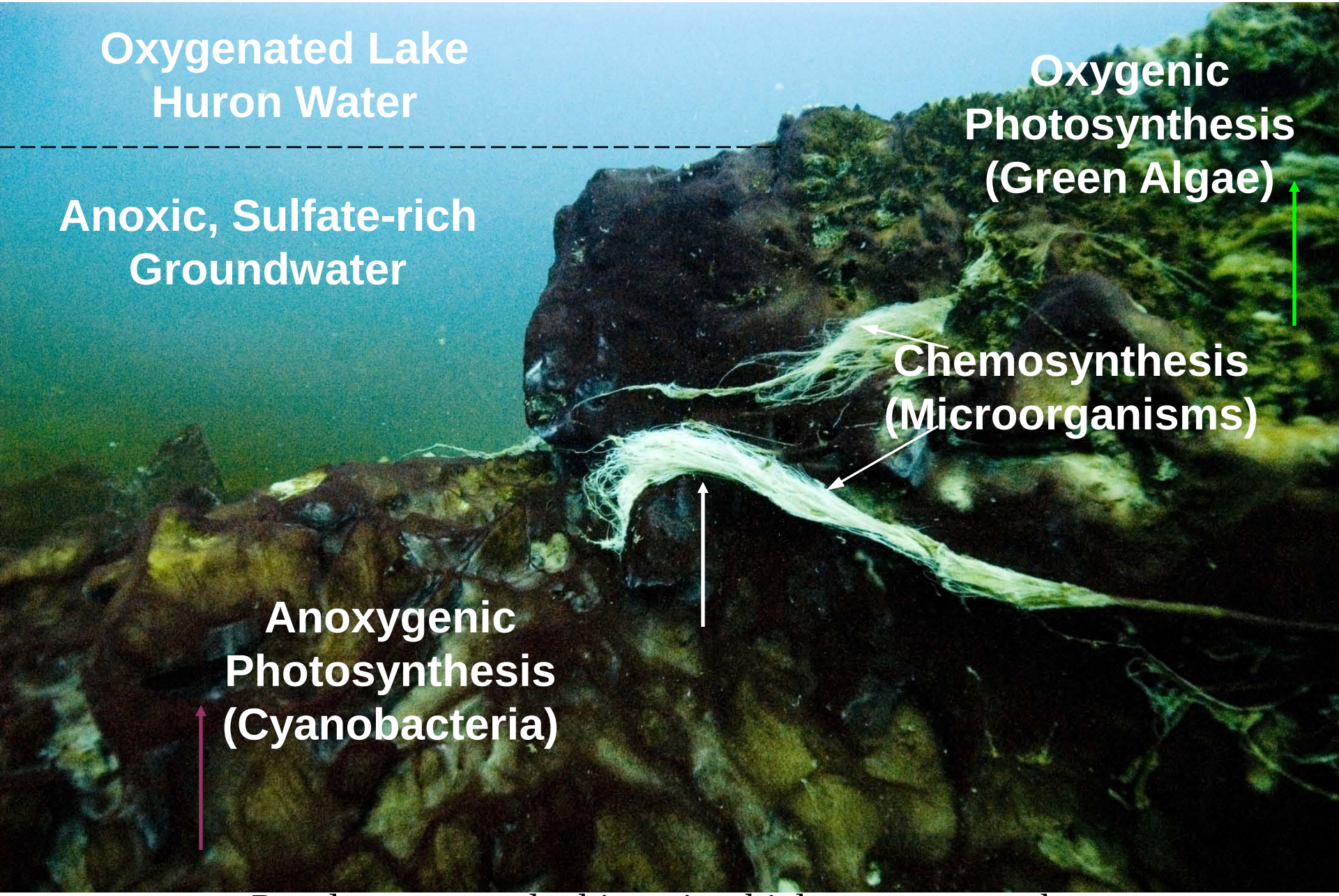
Middle Island Sinkhole (20 m)
5-10% Sunlight

Chemosynthesis

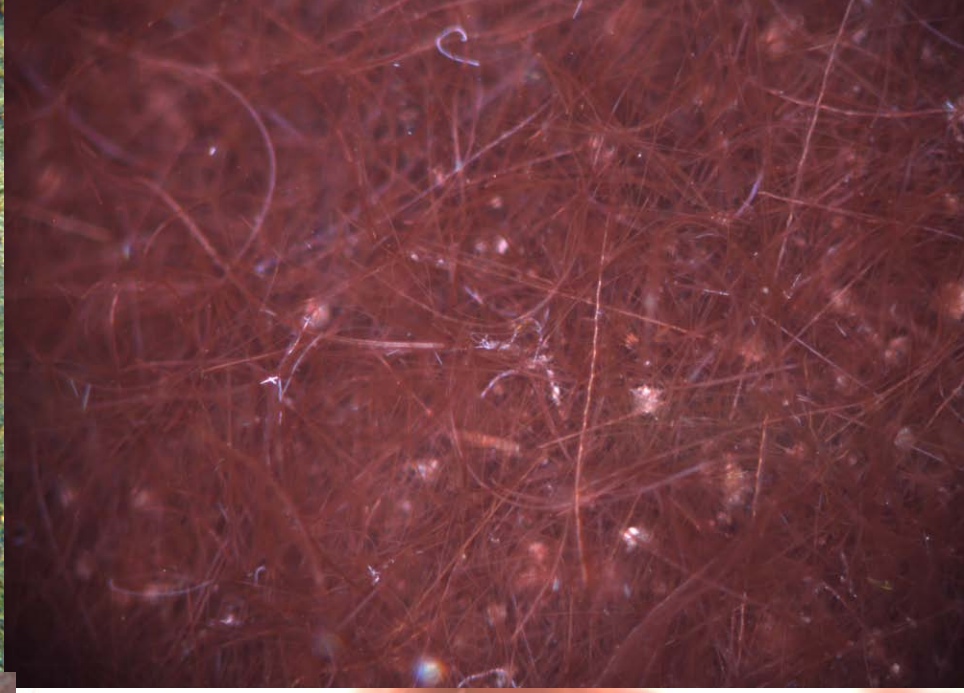
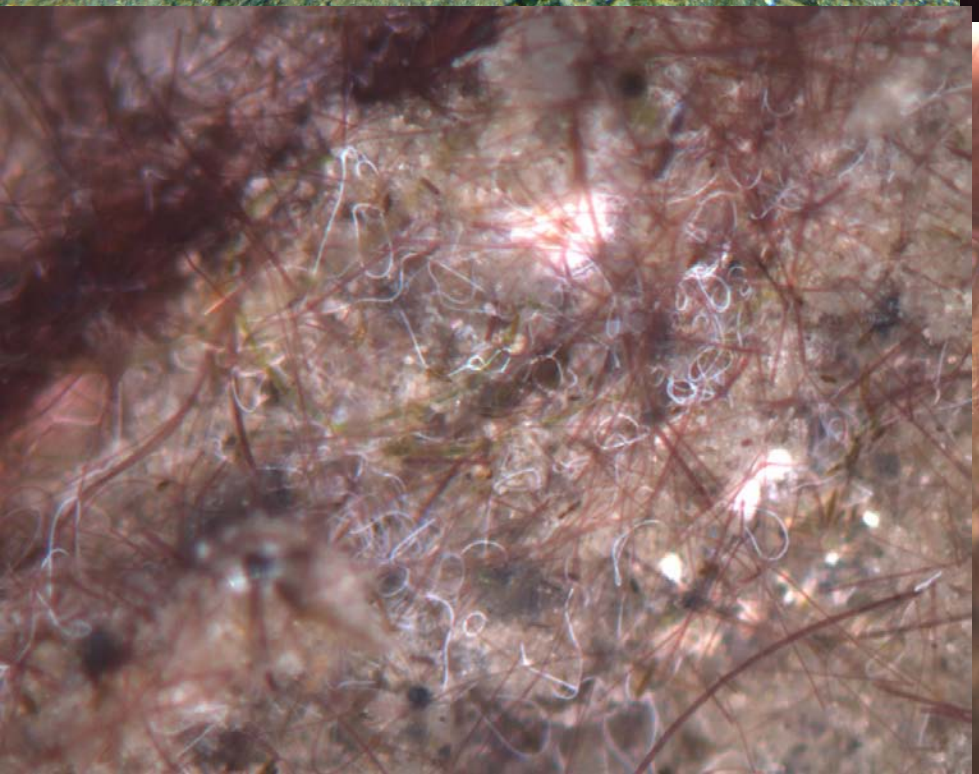
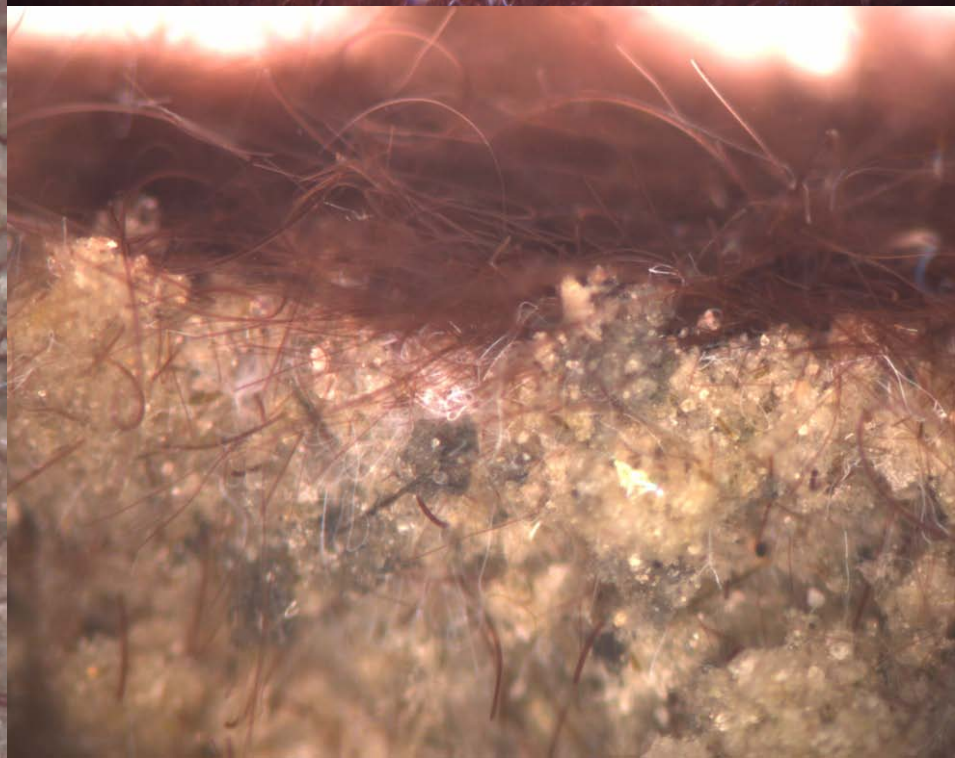


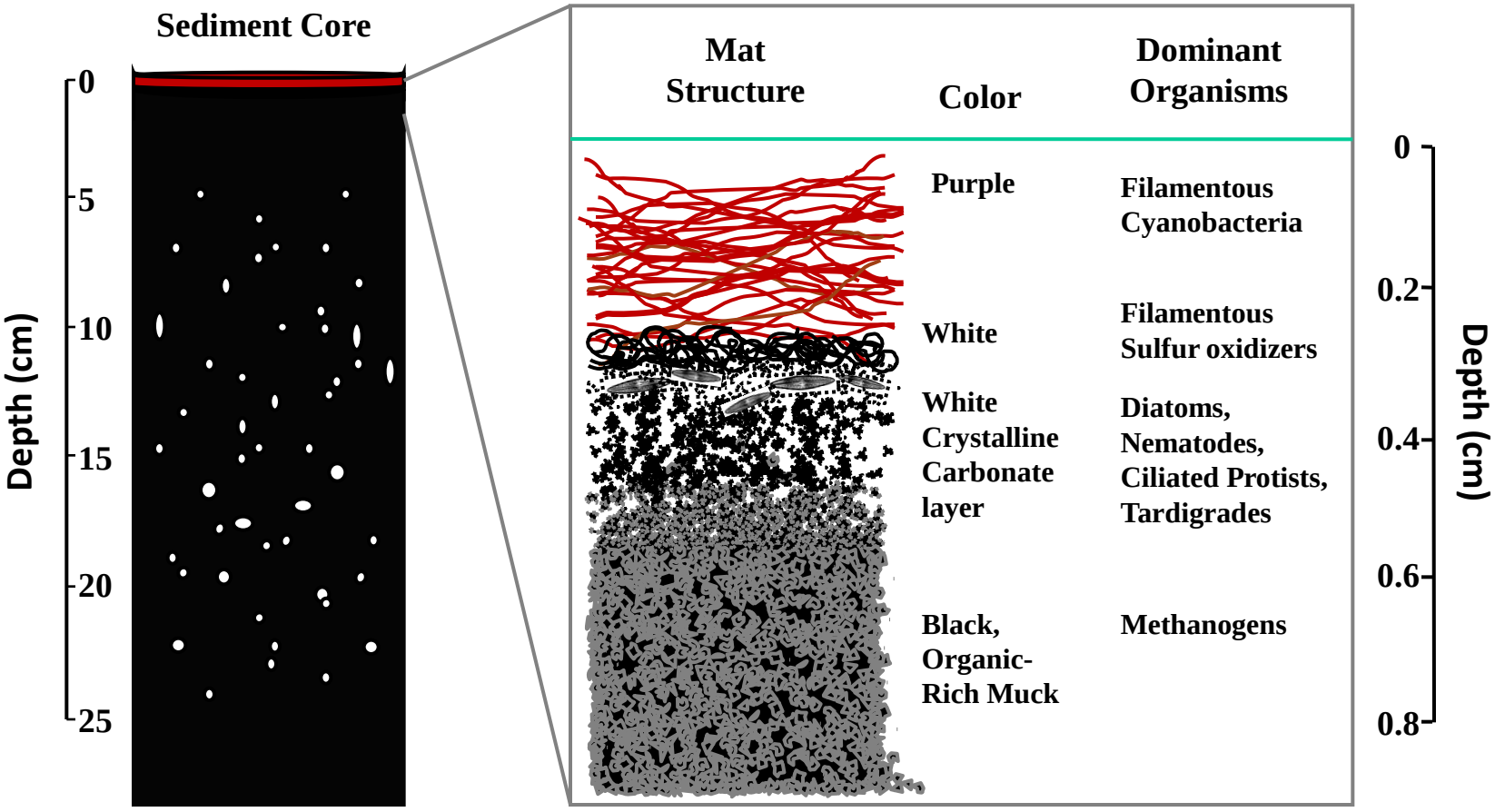
Isolated Sinkhole (93 m)
No Sunlight

Hypothesized Scenarios of Production Processes in Sinkholes

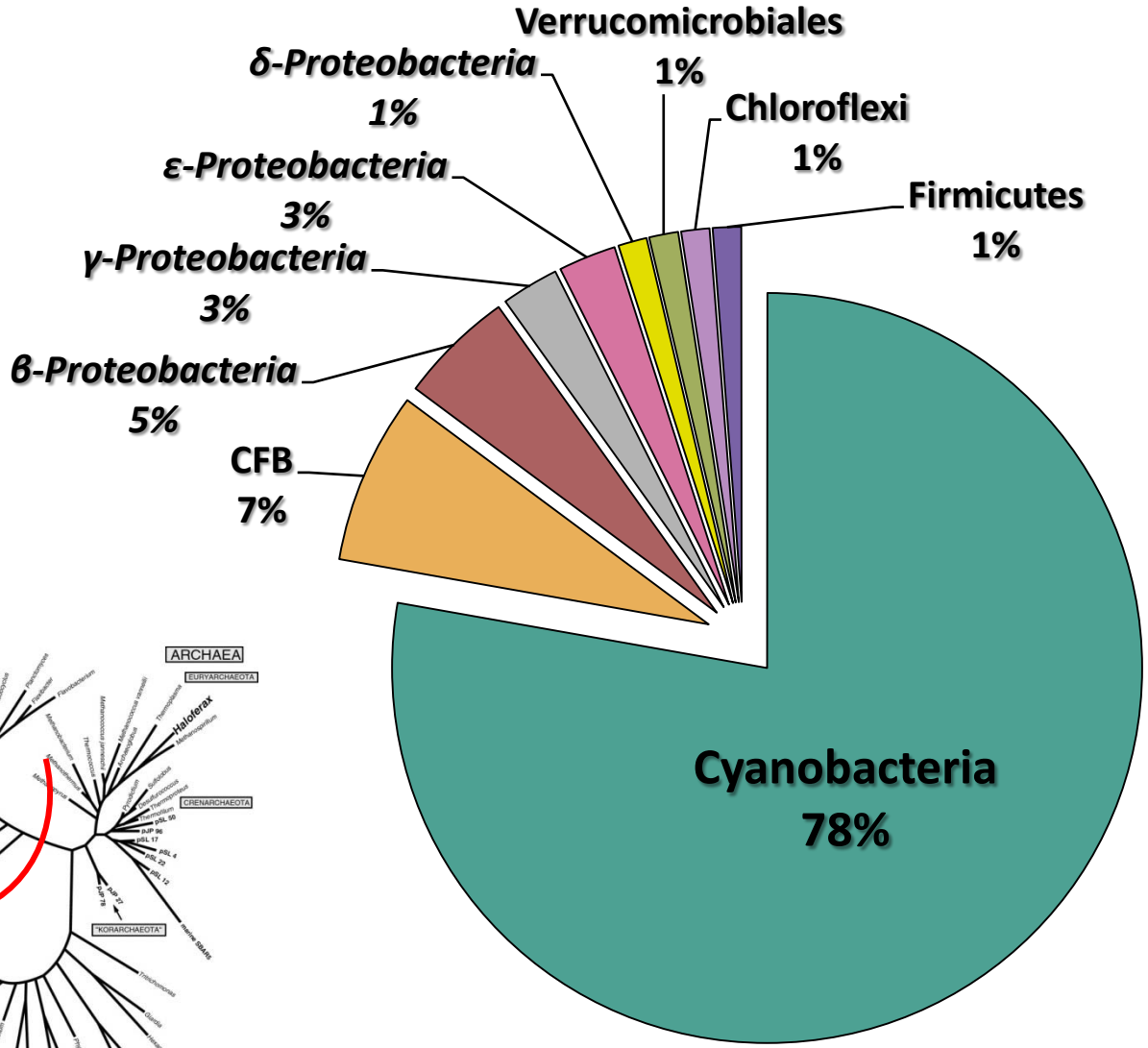


Purple, green and white microbial mats over rocks


Sediment Core
Depth (cm)
0
5
10
15
20
25
Mat Structure
Color
Dominant Organisms
Purple
Filamentous Cyanobacteria
White
Filamentous Sulfur oxidizers
White Crystalline Carbonate layer
Diatoms, Nematodes, Ciliated Protists, Tardigrades
Black, Organic-Rich Muck
Methanogens
0
0.2
0.4
0.6
0.8
Depth (cm)

Bacteria: 16S rRNA Clone Library Composition

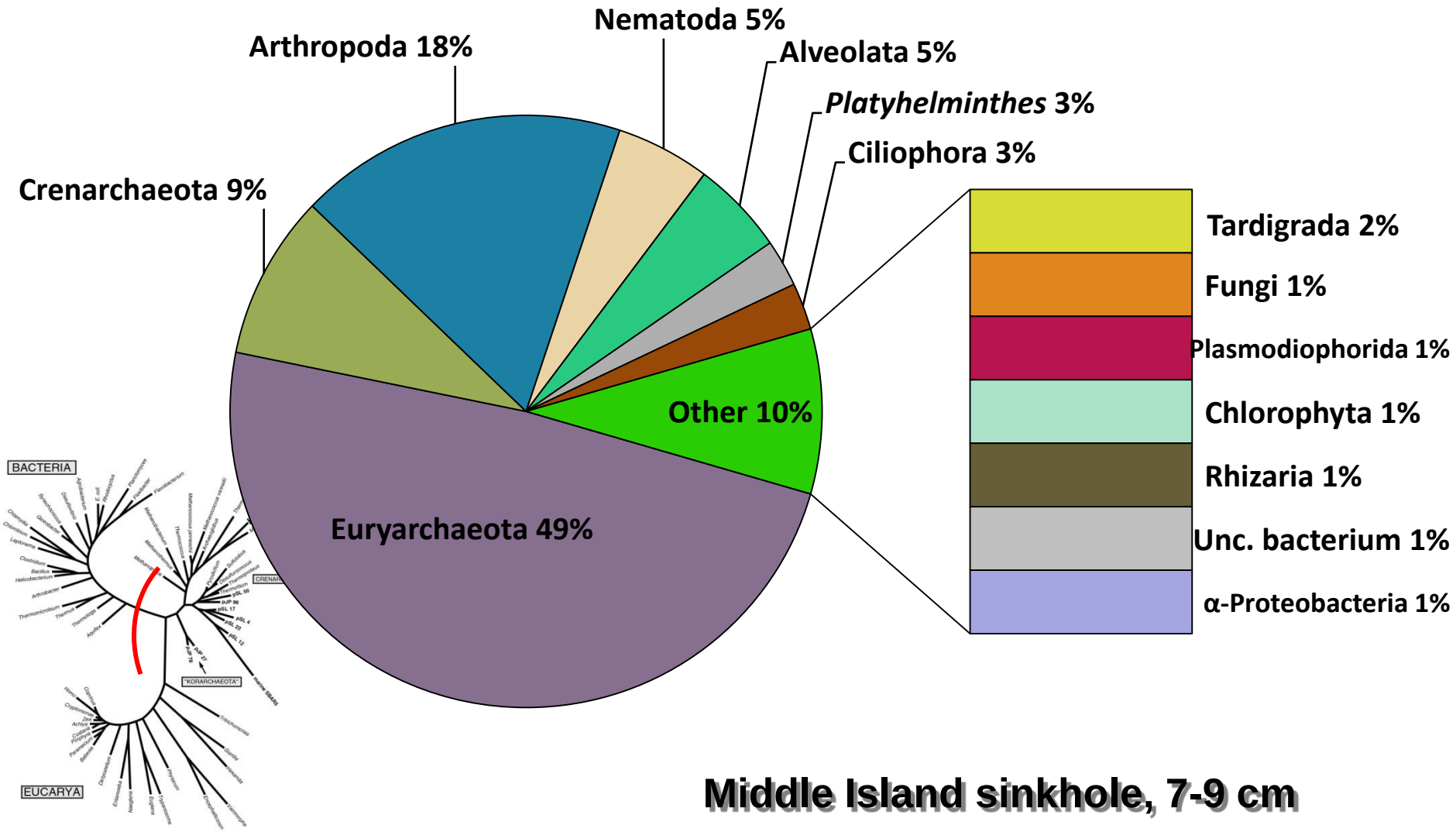


Middle Island sinkhole Mat (0-0.5 cm)

Archaea and Eukarya

C

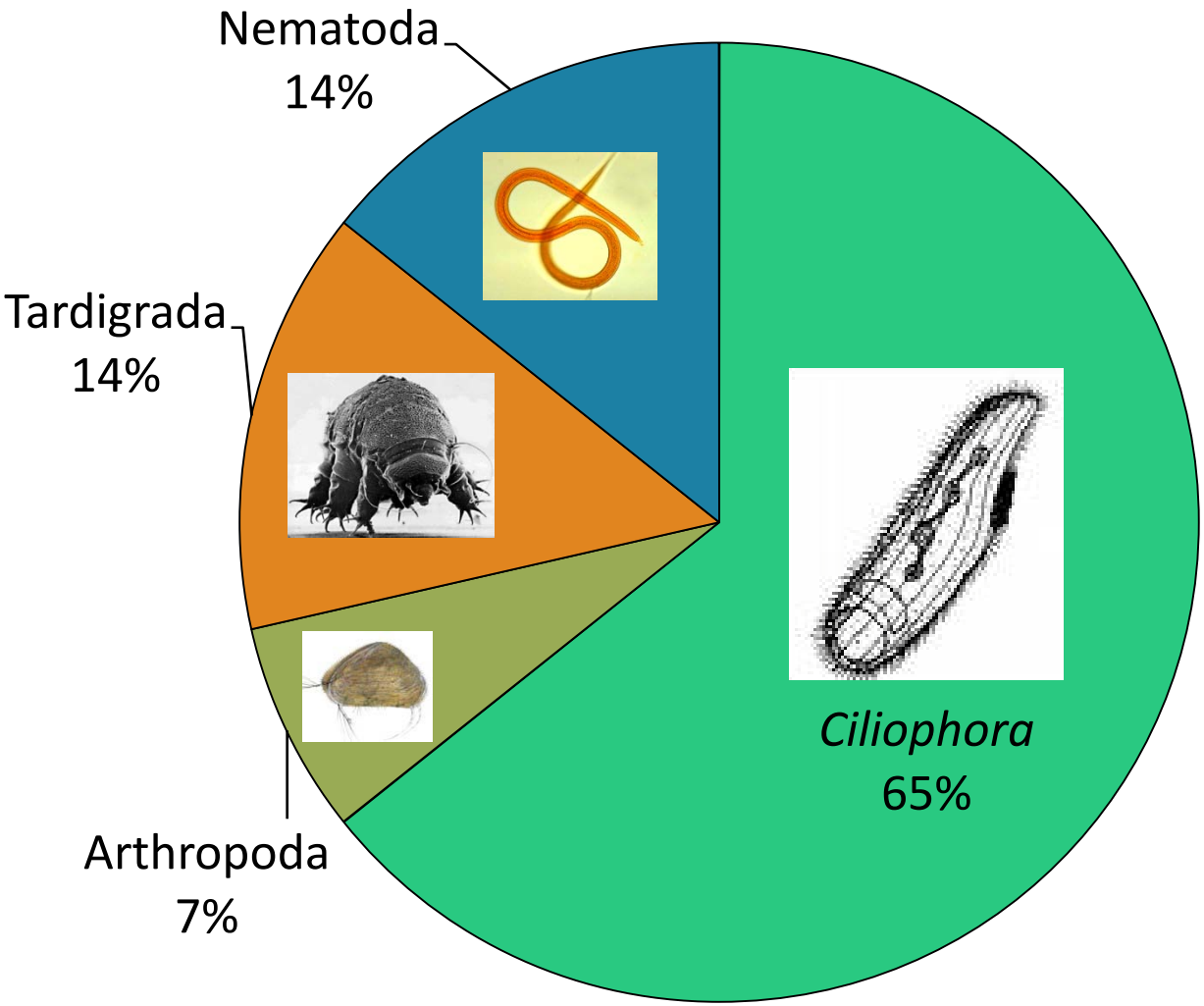
SSU rRNA clone library composition

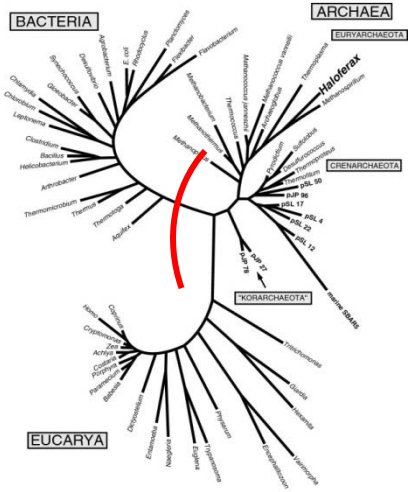


Middle Island sinkhole, 7-9 cm

MicroEukaryotes

SSU rRNA clone library composition





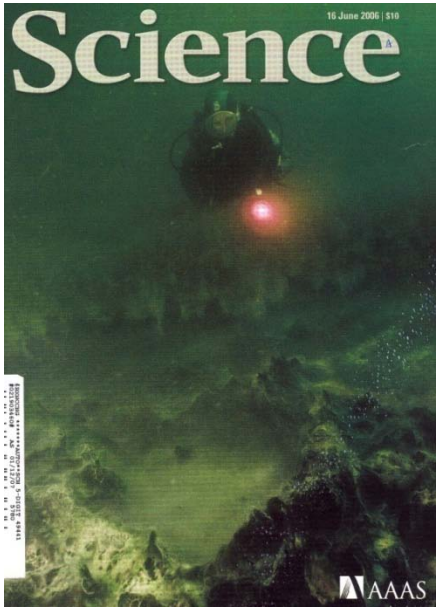
Middle Island sinkhole, 0-0.5 cm

Comparing Lake Huron Benthic Mats to Other Systems of the World

Lake Huron, Michigan

Lake Hoare, Antarctic Dry Valleys

Dale T. Andersen
images.spaceref.com/astro/lter/sm0207.JPG



Lake Cadagno, Switzerland.

A Submerged Cenote in Laguna Bacalar, Mexico

A Submerged Sinkhole in Lake Huron, Michigan

Look Similar?

Observations

- Submerged sinkhole ecosystems in Lake Huron are characterized by physicochemical gradients,and microbially dominated processes.

- There is emerging support for the "Variable Production Process Gradient Hypothesis" in sinkholes: Oxygenic Photosynthesis in sunlit shallow waters shift to Chemosynthesis in aphotic deep water sinkholes.

Questions

- With their low oxygen and high sulfur content, are Lake Huron's sinkhole ecosystems similar to marine vents, terrestrial S springs, submerged cenotes,and Antarctic lakes?

- What is the fate of benthic mat production and the source of sedimentary carbon?

- Potential for discovery of novel organisms and processes - Case for protection/preservation of these unique habitats?

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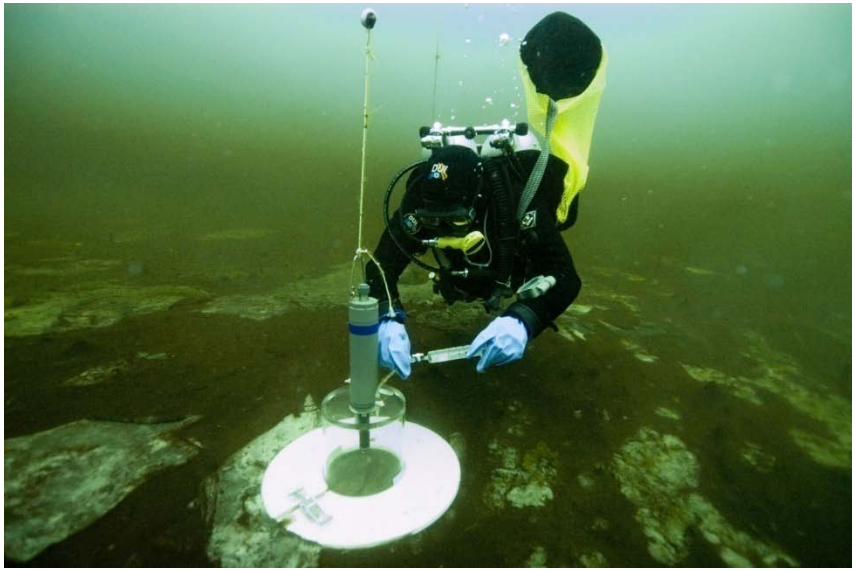
Underwater ROV videos: Steve Ruberg and Guy Meadows

Aerial photography: Scott Kendall and Bopi Biddanda

Grand Valley State University
Annis Water Resources Institute



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Where Discoveries Begin
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