Sinkholes to Stars: Exploring Microbial Ecosystems in Lake Huron's Sinkholes as Analogs of Life on Early Earth, and as a Model for Life in Extraterrestrial Waters

National Marine Sanctuaries
National Oceanic & Atmospheric Administration
THUNDER BAY NATIONAL MARINE SANCTUARY

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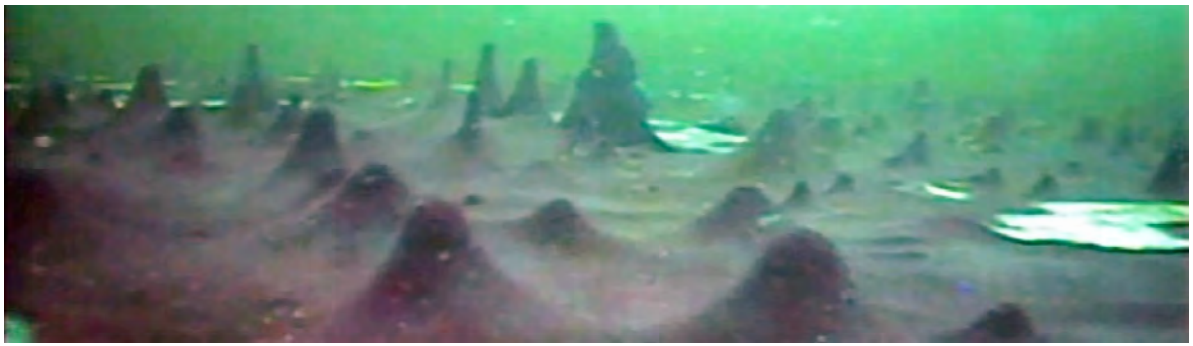



A NSF, NASA & NOAA funded and NOF & TBNMS supported study

National Science Foundation WHERE DISCOVERIES BEGIN
STOUT UNIVERSITY OF WISCONSIN
Thunder Bay National Marine Sanctuary
MICHIGAN

Things I'll cover in this Seminar

Objectives:

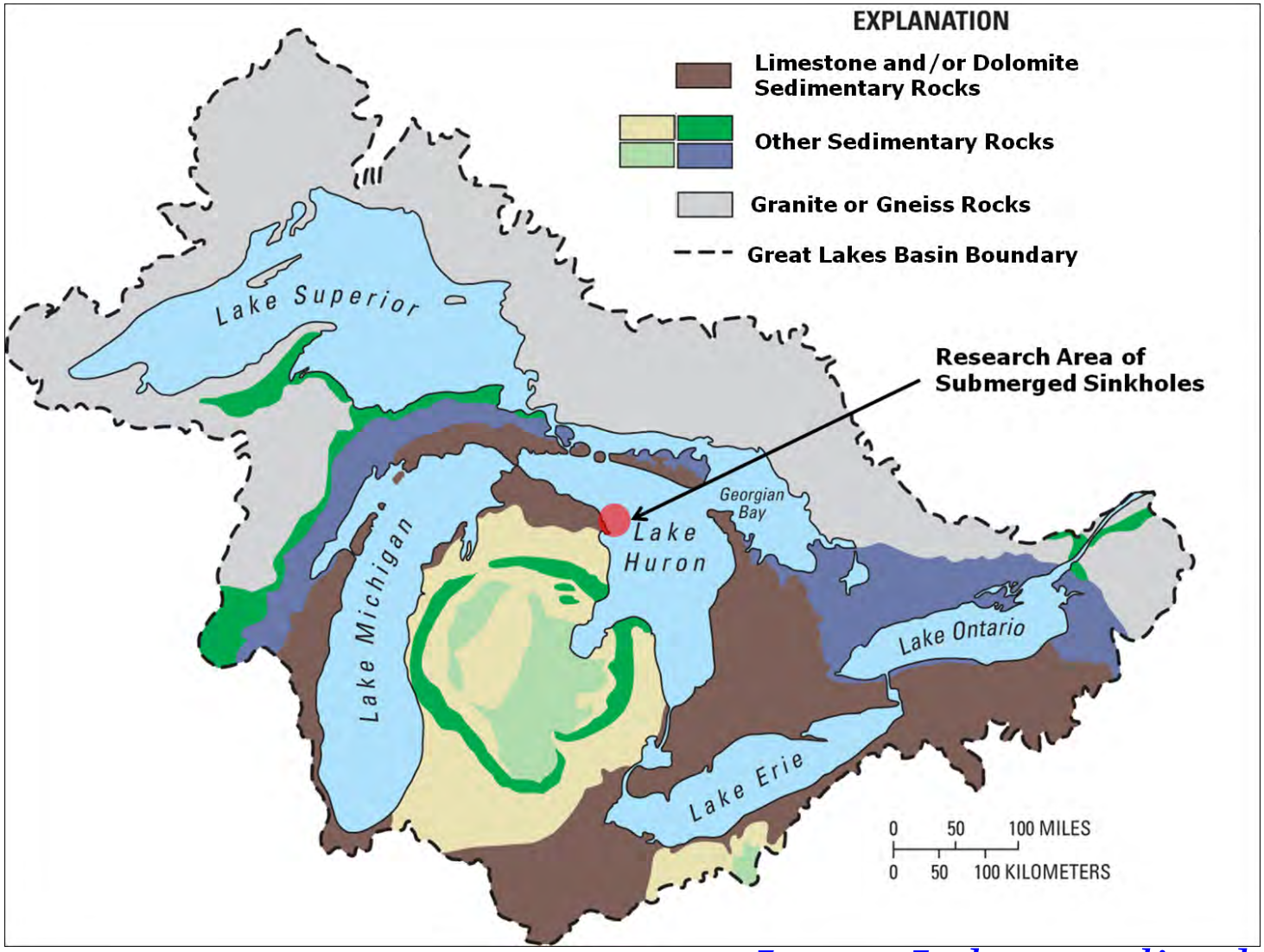
- Do the sinkhole microbial ecosystems resemble Life in the shallow anoxic and sulfurous seas of early Earth?
- Can the life in submerged sinkholes serve as models in our search for life in extraterrestrial waters?

Strategy:

- Search from shallow depths to deep sites….
- Go from near to far….

The Laurentian Great Lakes of North America

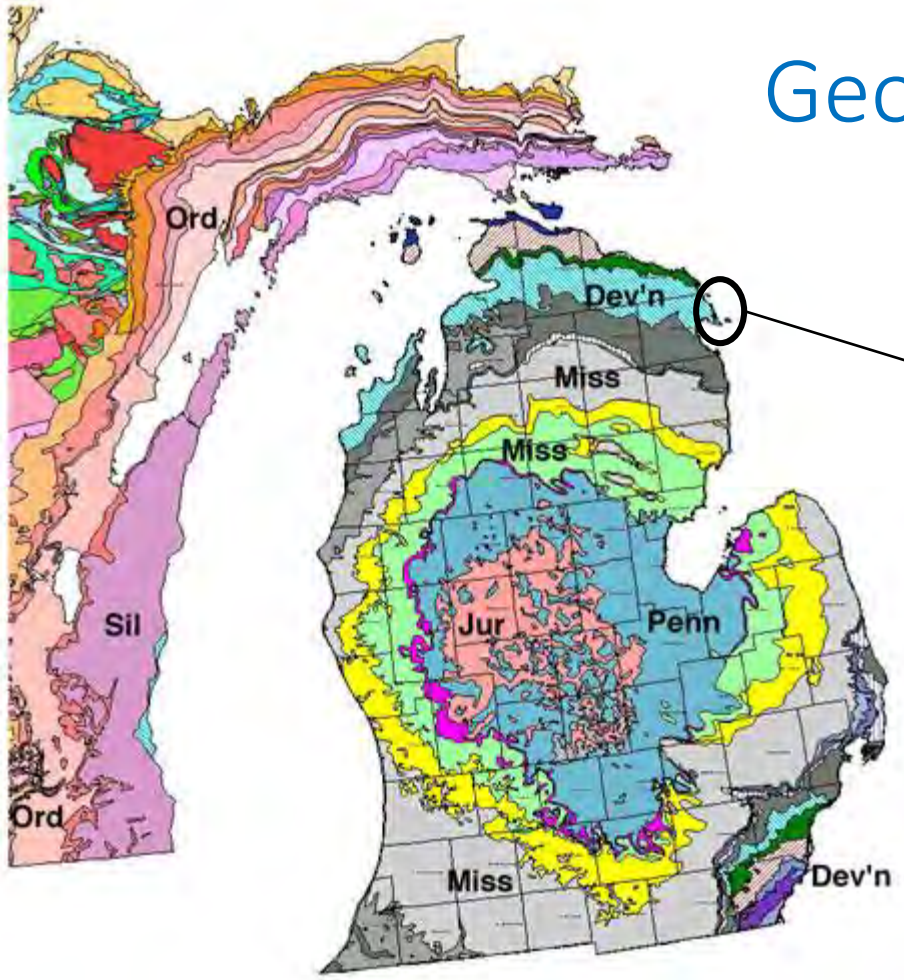
Bedrock Aquifers in the Great Lakes Basin



Lower Lakes are lined By Paleozoic Carbonate Aquifers

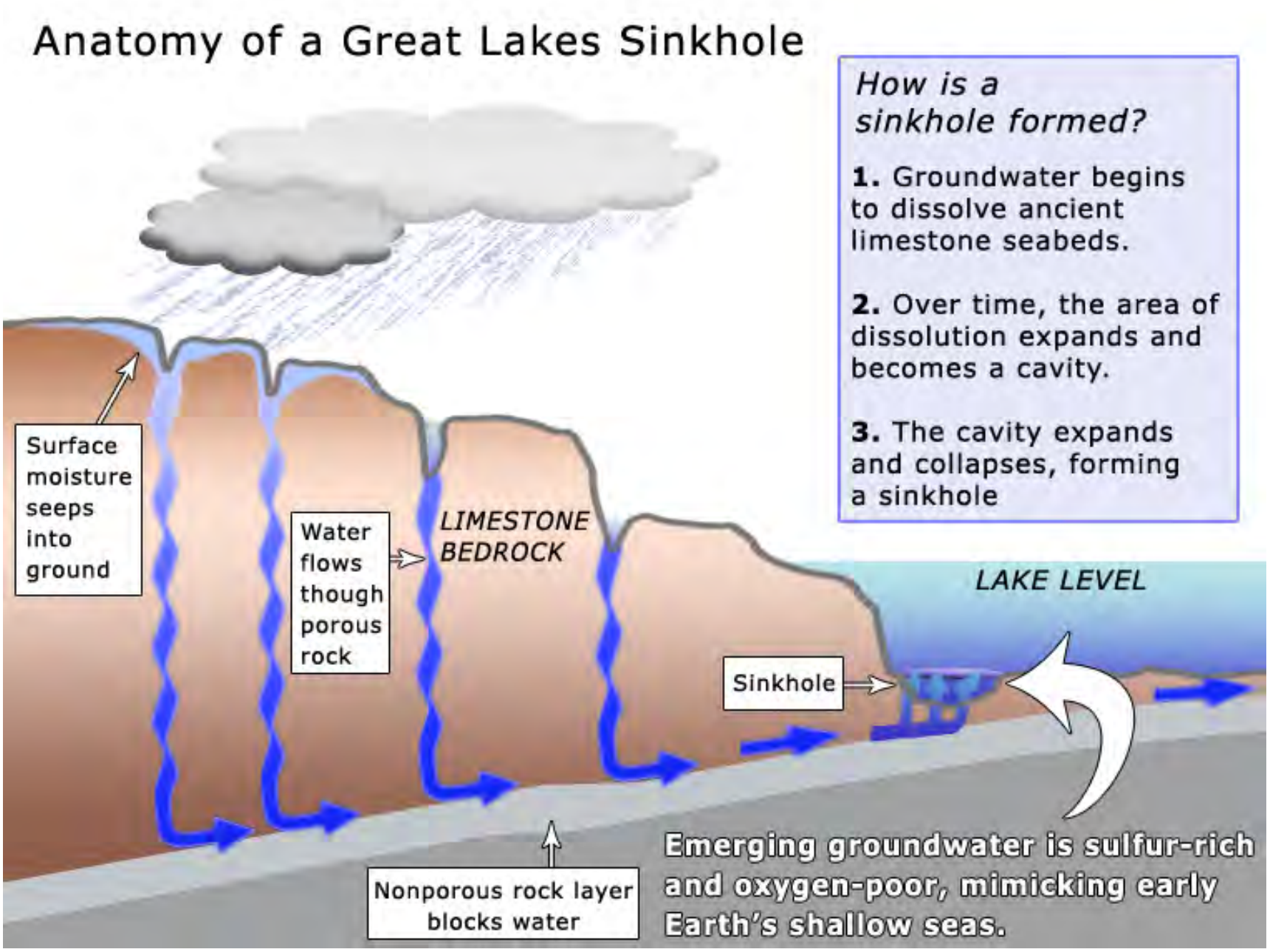
http://water.usgs.gov/ogw/pubs/WRI004008/WRIR_00-4008.pdf

Geology of Alpena, MI Area



http://www.geo.mtu.edu/svl/geoscience/figures/digital%20geologic%20map%20of%20michigan.jpg

- Sedimentary Rocks
  - Limestone ($CaCO_3$)
  - Dolomite ($MgCO_3$)
- Evaporites
  - Gypsum ($CaSO_4$)*

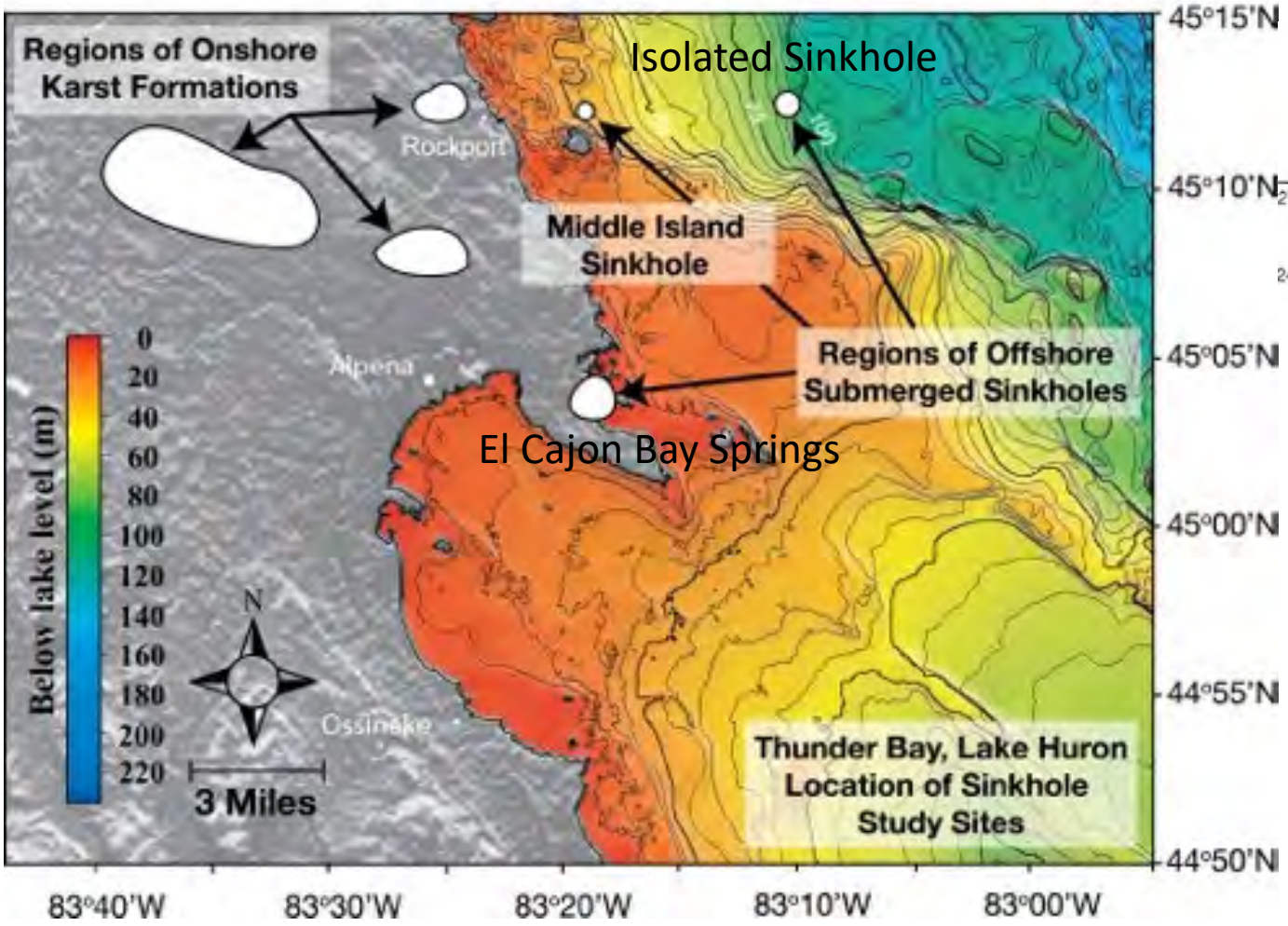


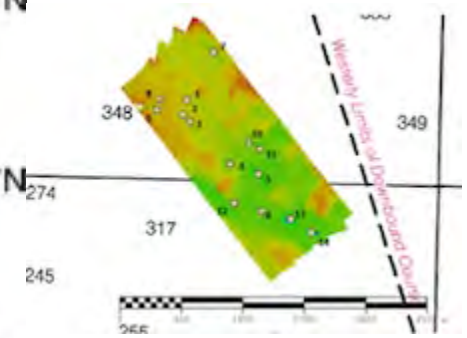
Biddanda et al. 2012 Nature Education Knowledge

Public Library Fountain, Alpena

Produced in collaboration with the Alpena Public Library, July 2018

Study Area: Submerged sinkholes along an increasing depth/decreasing sunlight gradient



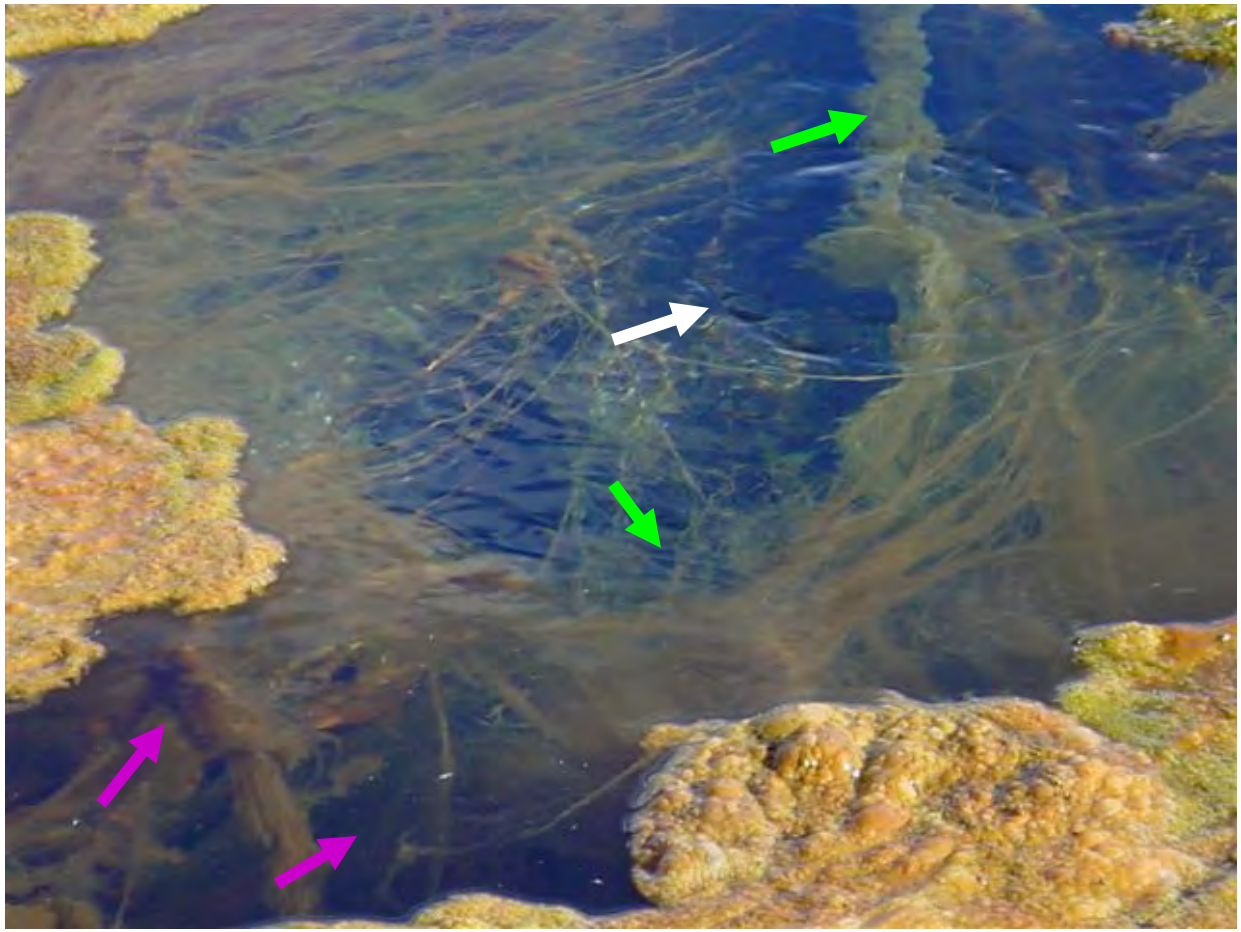


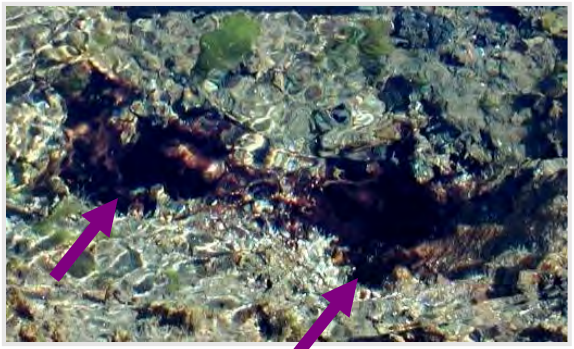
Deep water Offshore Areas of Karst 2016-2017

Many On-land Sinkholes NW of Rockport, MI

El Cajon Bay Springs (shallow)

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

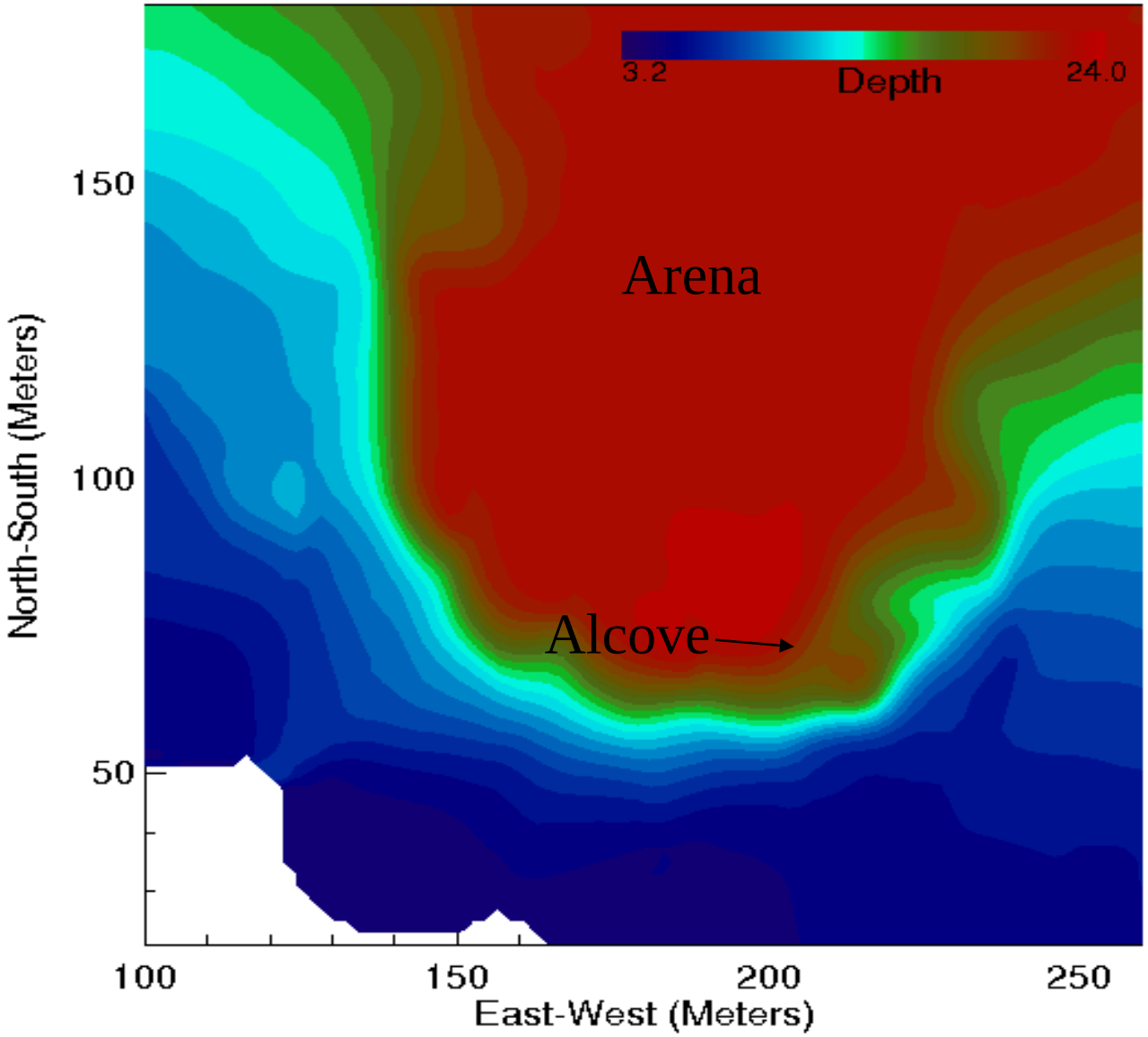




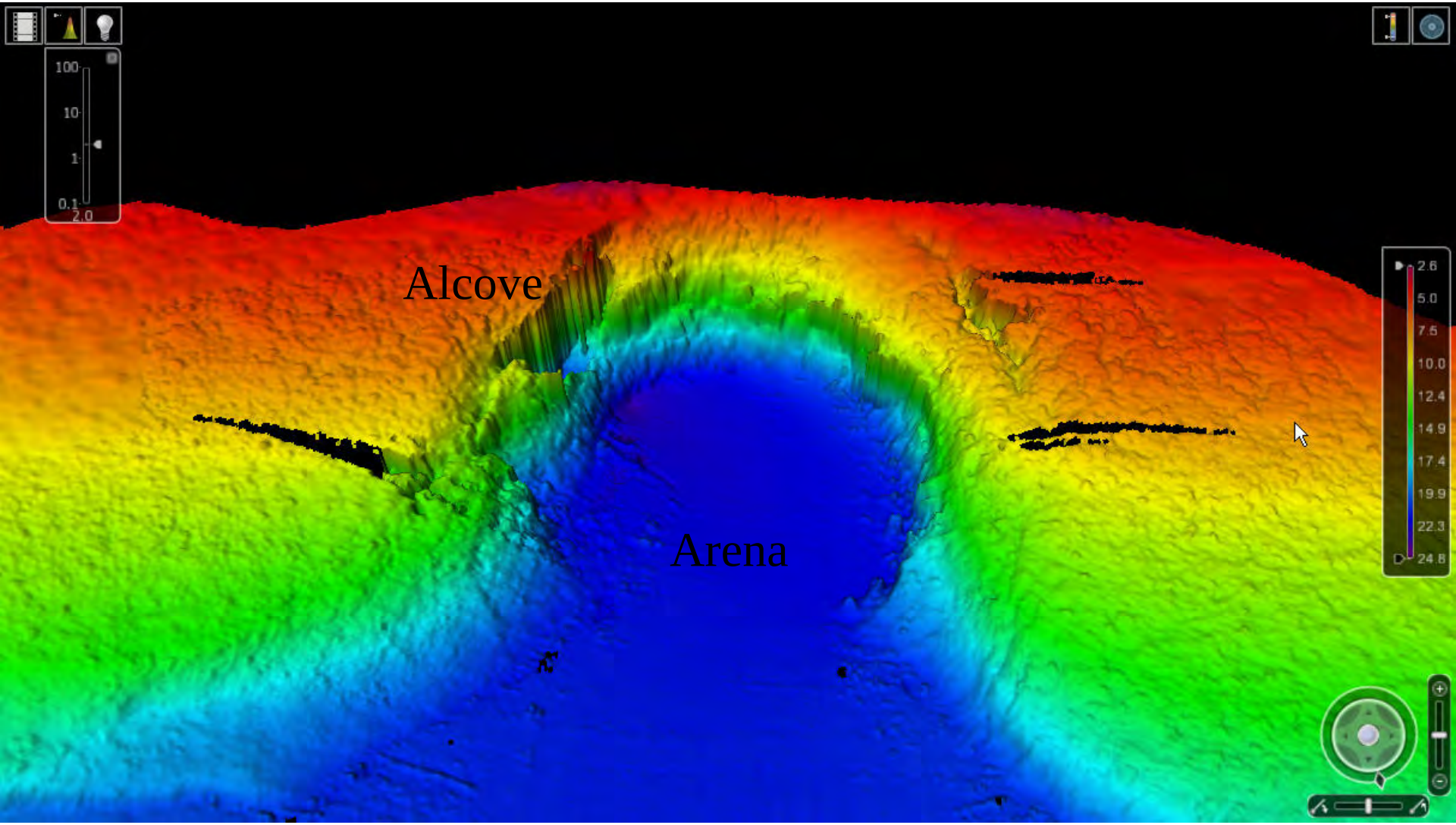
Purple Cyanobacteria

Middle Island Sinkhole (medium depth 23 m)

Bathymetric map of Middle Island Sinkhole From Side-Scan Sonar



High Resolution Multi-beam Bathymetric map of Middle Island Sinkhole



Visible Thermocline where Ground water meets Lake water

Common and distinct physical chemistry of Venting Sinkhole Water

Parameter	Lake Huron	Venting GW
Sp. Conductivity (*m*S/cm)	0.2	2.3
Chloride (mg/L)	6	25
Temperature (°C)	seasonal	≈9
pH	8.3	7.1
ORP (mV)	500	−134
Dissolved Oxygen (mg/L)	11	≈0
Sulfate (mg/L)	15	1250
DIC (mg/L)	19	48
DOC (mg/L)	1.7	<1

Table 1. Comparison of physicochemical properties of Lake Huron water and venting Groundwater at Middle Island Sinkhole, Lake Huron (ORP = oxidation–reduction potential; DIC = dissolved inorganic carbon; DOC = dissolved organic carbon).

← No Oxygen

← High Sulfate

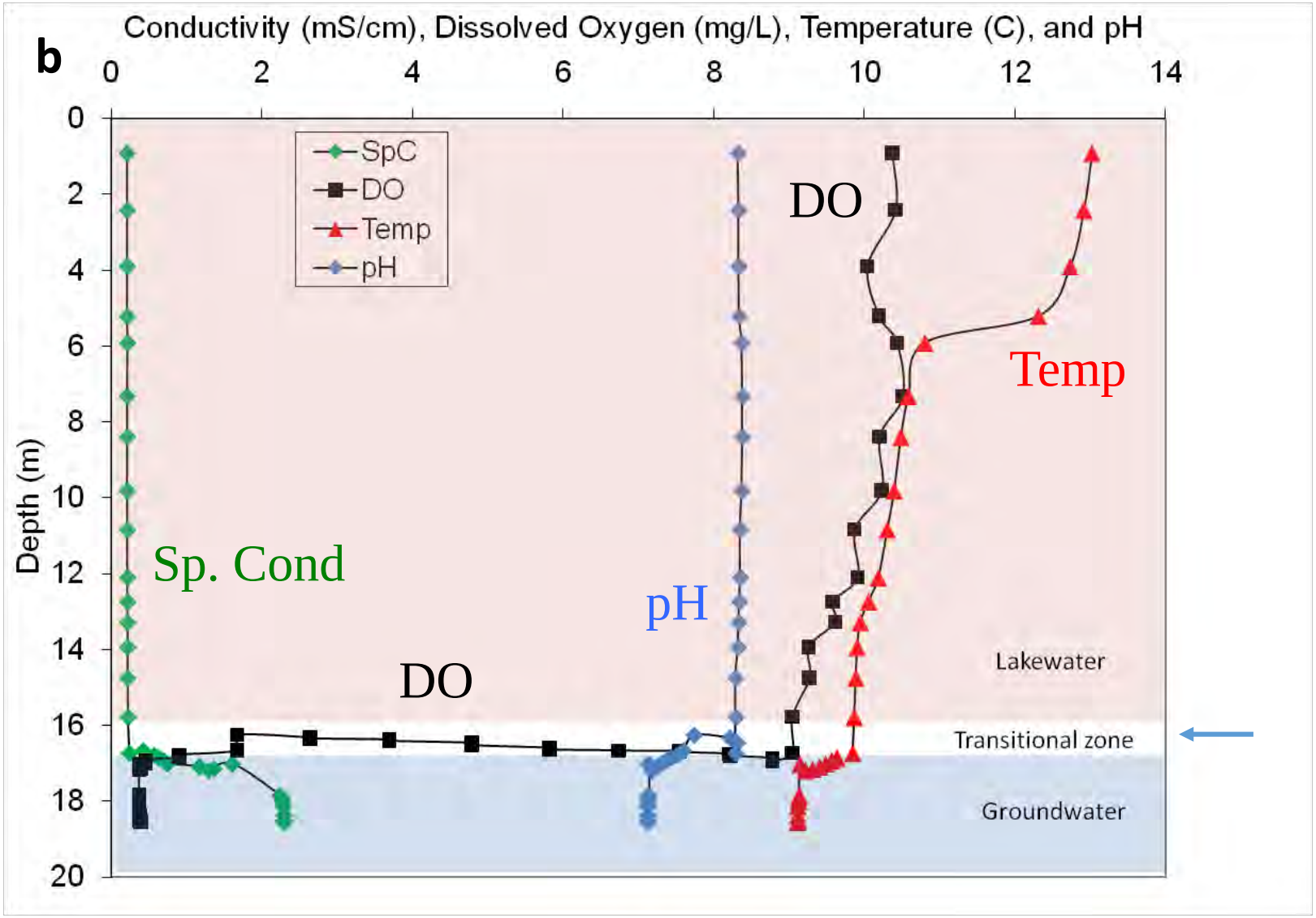
Ground water emerging at different sites has essentially the same chemical signature, suggesting a common aquifer source.

Early Earth's shallow seas had low Oxygen and high Sulfur!

Biddanda et al. Eos 2009

Standard Water-Column Features over a Lake Huron Sinkhole

Middle Island Sinkhole during summer



Biddanda et al. 2012. Nature Education Knowledge

Shallow Water

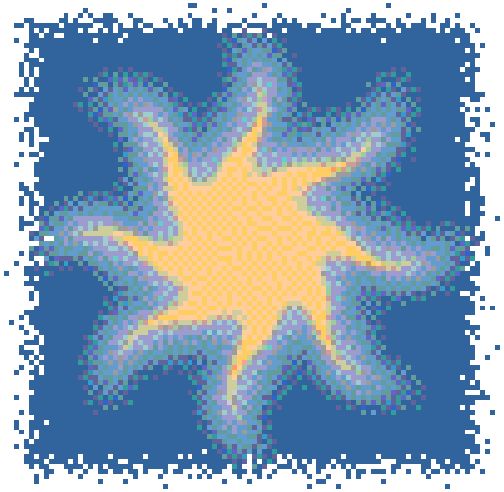
Sunlight

Photosynthesis

Chemosynthesis

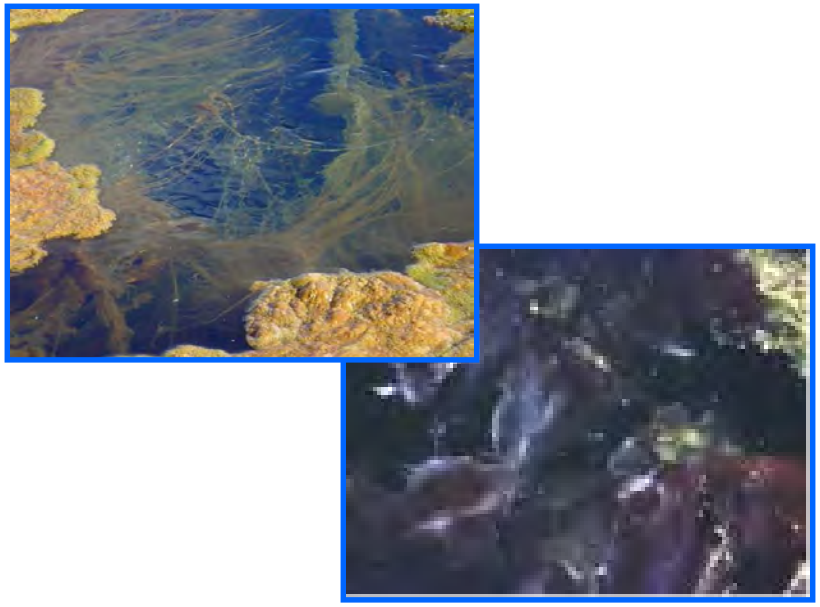
Deep Water

No Sunlight

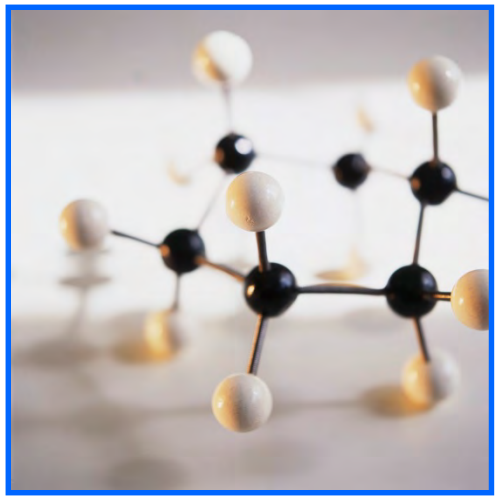


Sunlight

Energy

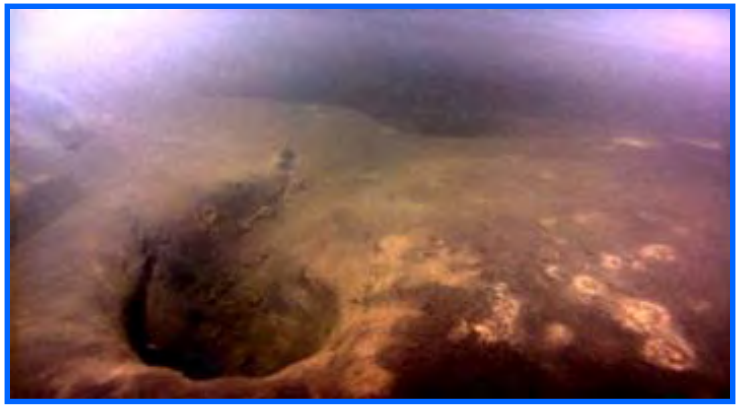


Photosynthesis



Energy in chemical bonds

Energy



Chemosynthesis

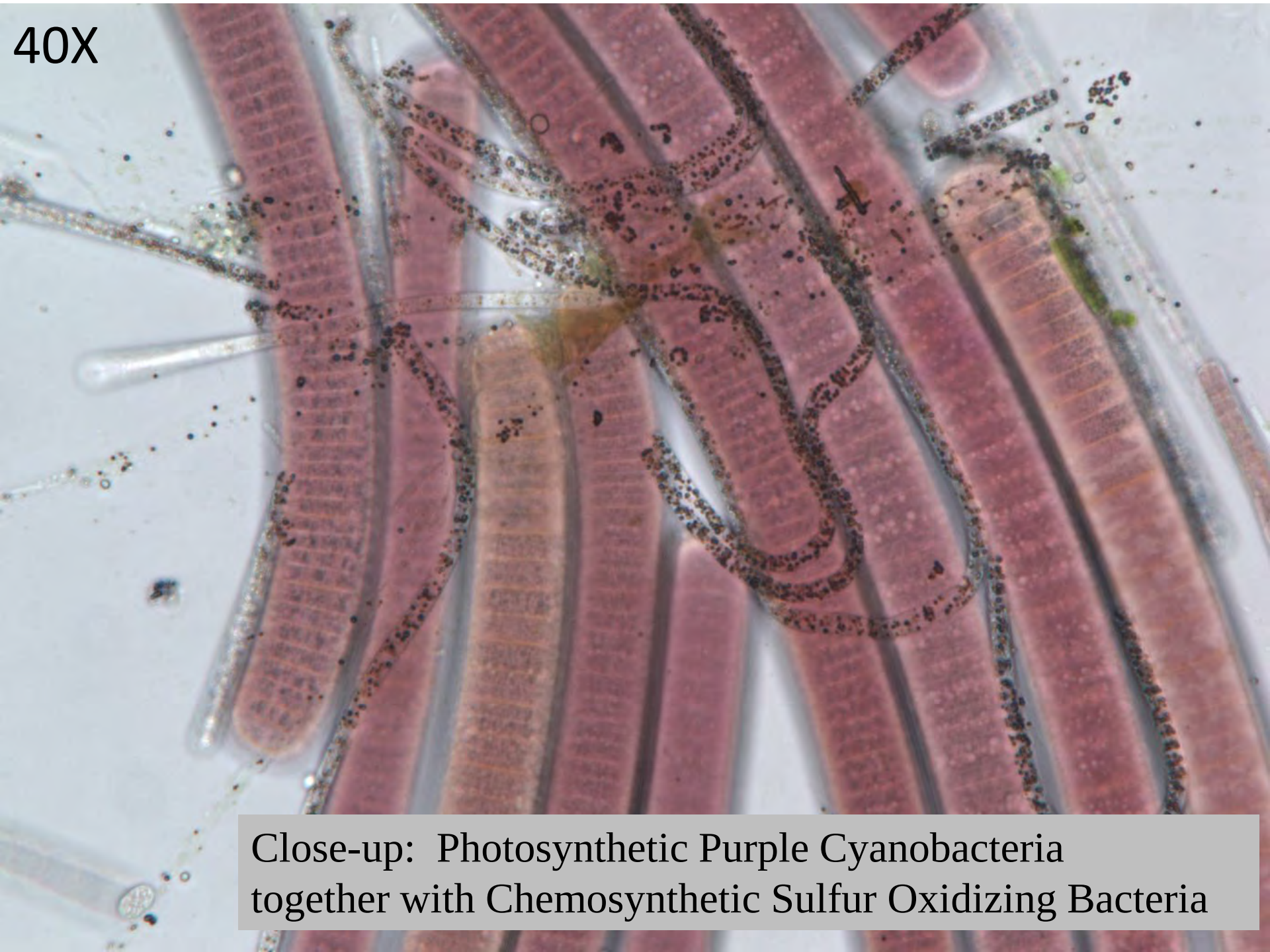
Sampling and Studying Microbial mats in the Sinkholes

Eos 2016

Geobiology 2013, 2017

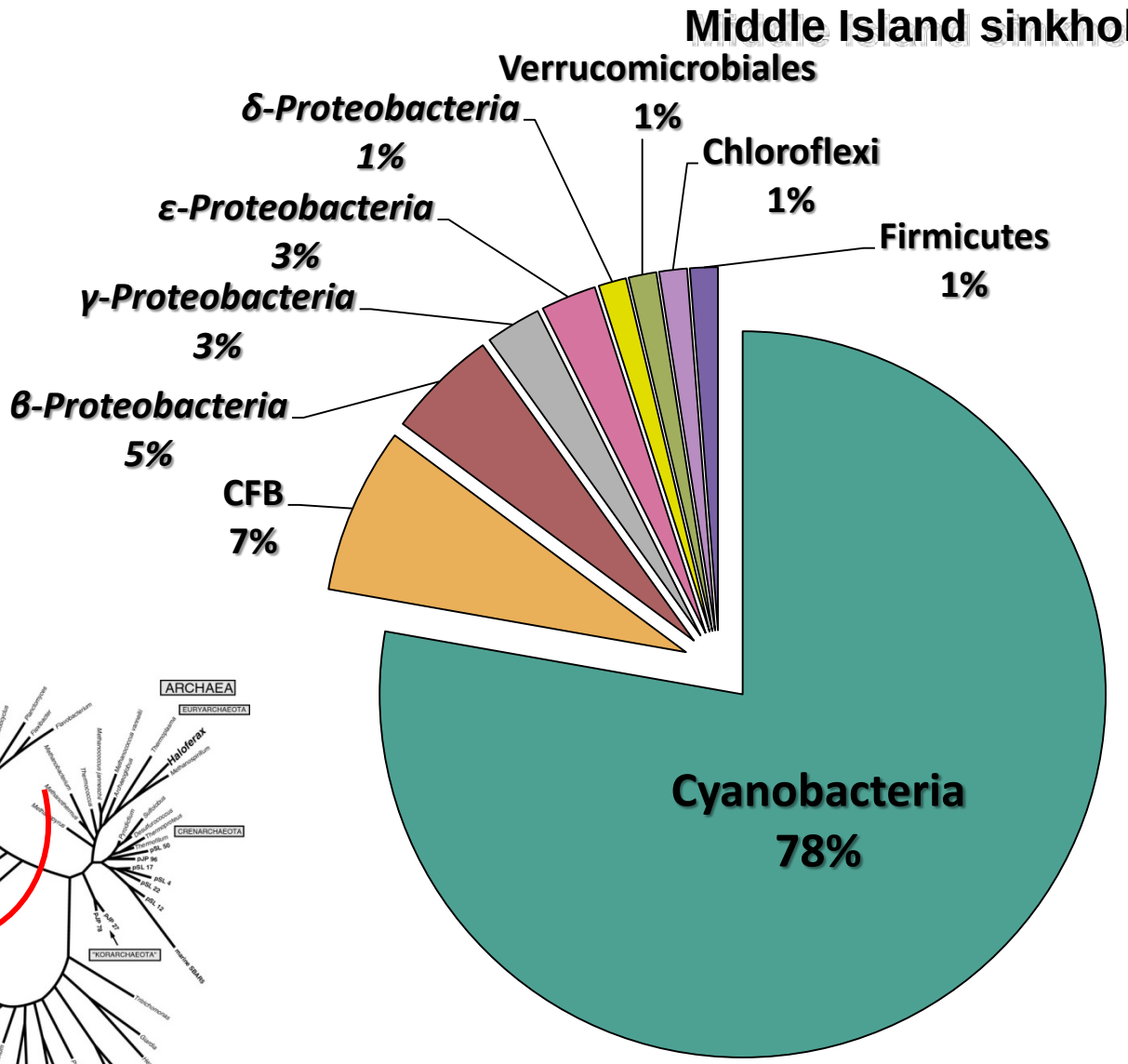
Could modern-day microbial mats like this have oxygenated our planet during life's turbulent childhood?

Mat microbes under the Microscope: Photosynthetic Cyanobacteria and Chemosynthetic Sulfur Oxidizing Bacterial filaments



Close-up: Photosynthetic Purple Cyanobacteria together with Chemosynthetic Sulfur Oxidizing Bacteria

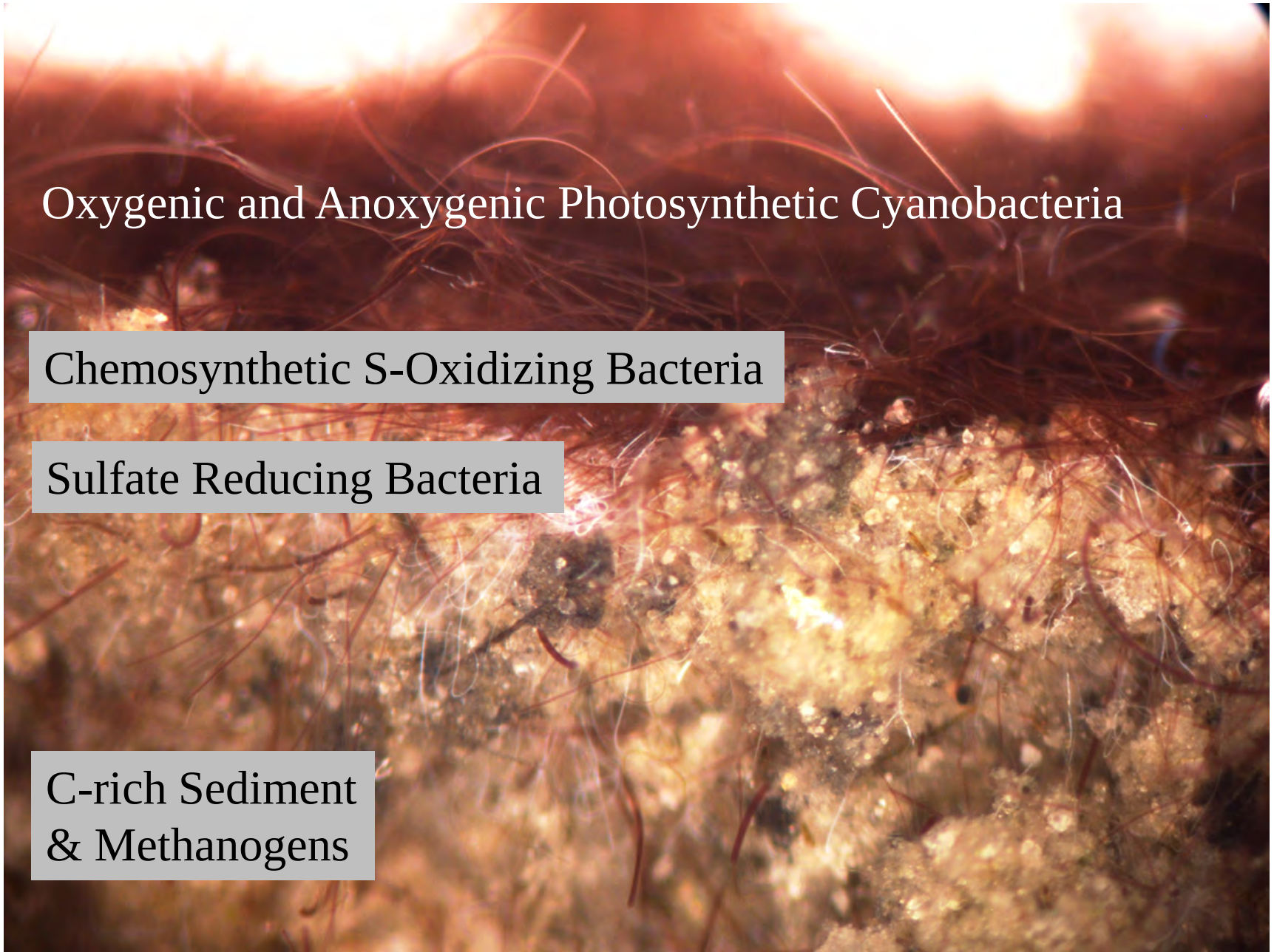
Bacteria: 16S rRNA Clone Library Composition



Cyanobacteria Dominate

Nold et al. 2010. App. Env. Micro.

Vertical Cross Section through Mat-Sediment Interface



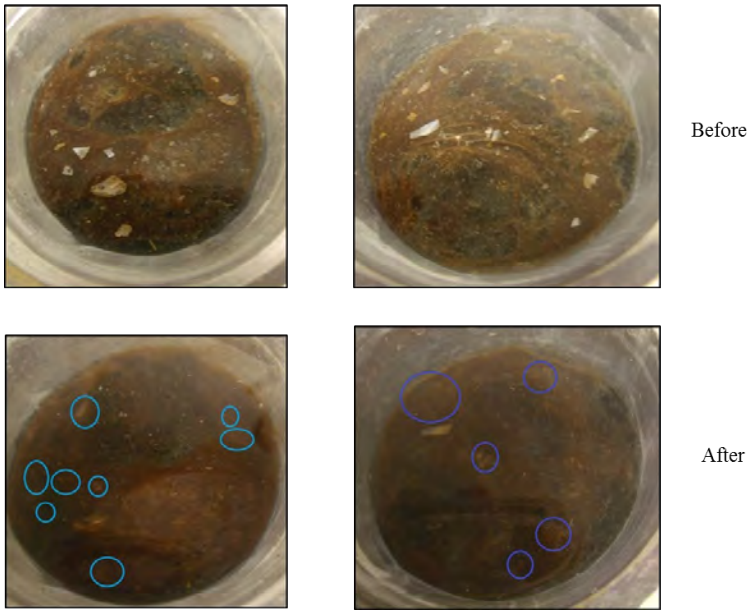
In Lab: Phototactic Filament Motility - Horizontal & Vertical

Rabbit, not Turtle: **Cyanos go mms in mins!**

Before Foil After

Trial 1 Trial 2

Horizontal Phototactic Motility



Before

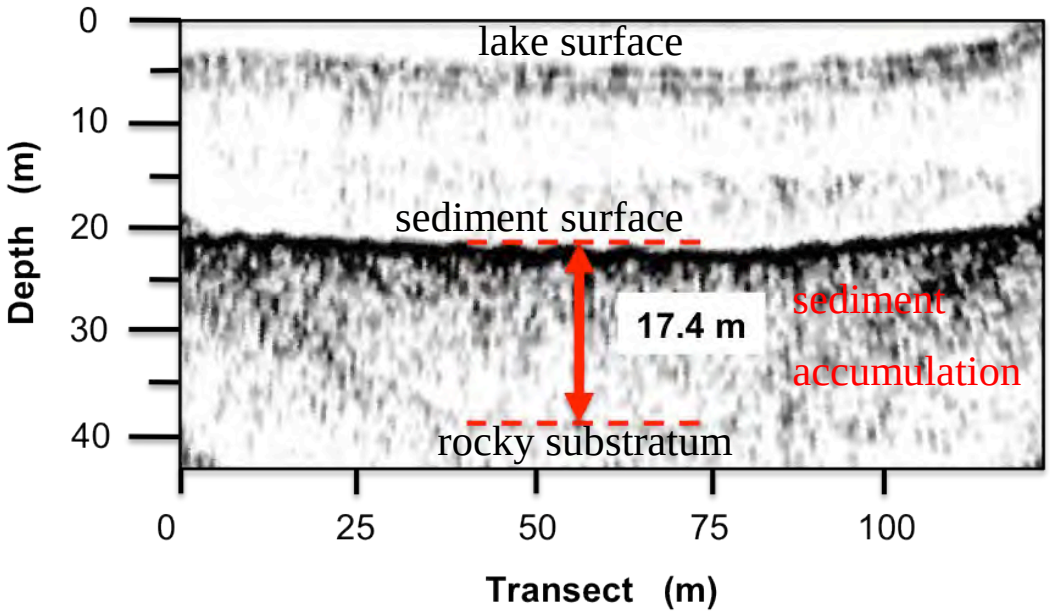
After

Vertical Phototactic/Chemotactic Motility

Biddanda et al. 2015 Frontiers

The Importance of Carbon Burial

Lots of Carbon-rich sediments beneath the Sinkhole.
Sinkholes are a Sink for Carbon



Acoustic sub-bottom profile of Middle Island sinkhole showing sediment surface (thick line at 22 m water depth), rocky substratum (fainter hemispherical line beneath sediment surface) and extent of sediment accumulation (ca. 17 m) within sinkhole

1-2m of sediment accumulation per 1000 yrs! Highest rate anywhere!!

Nold et al. 2013: Biogeochemistry

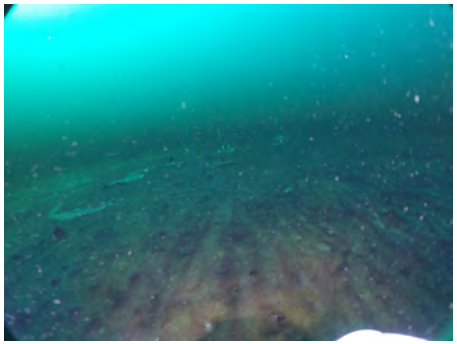
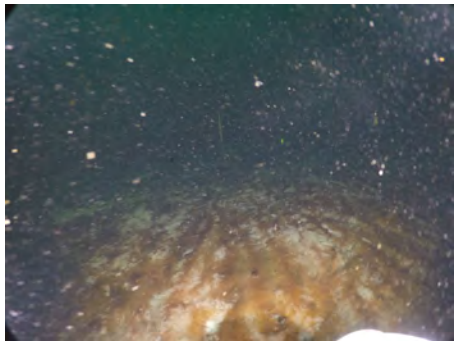
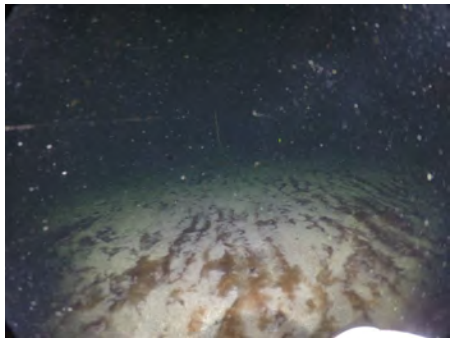
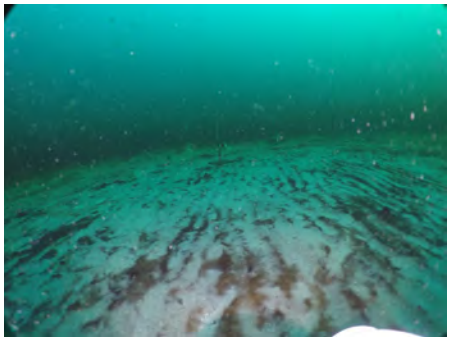
July 2018 Field Expedition to Track Diurnal Changes over 48 hrs

- **Marine Imaging Technologies® Blink Time-lapse photo system for the Go-Pro Hero 5**

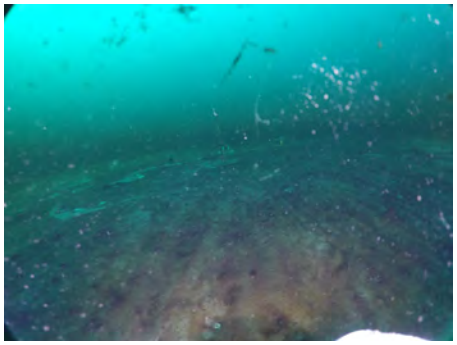
- **Half-hourly flash photography and video for around the clock documentation**

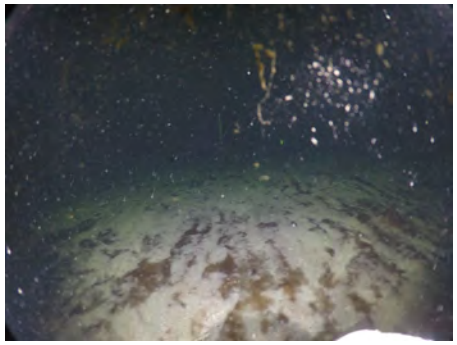
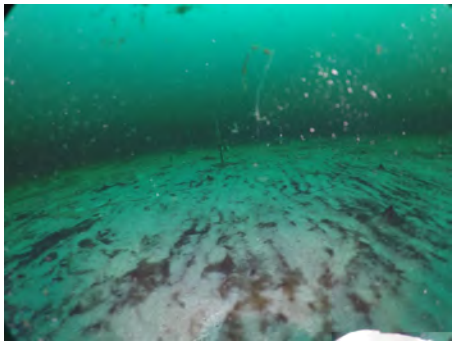
- **Additional mat-sediment cores collected for controlled lab studies**

In Field: Diurnal Changes Day 1

Sunset **Night** **Pre-Dawn** **Sunrise**

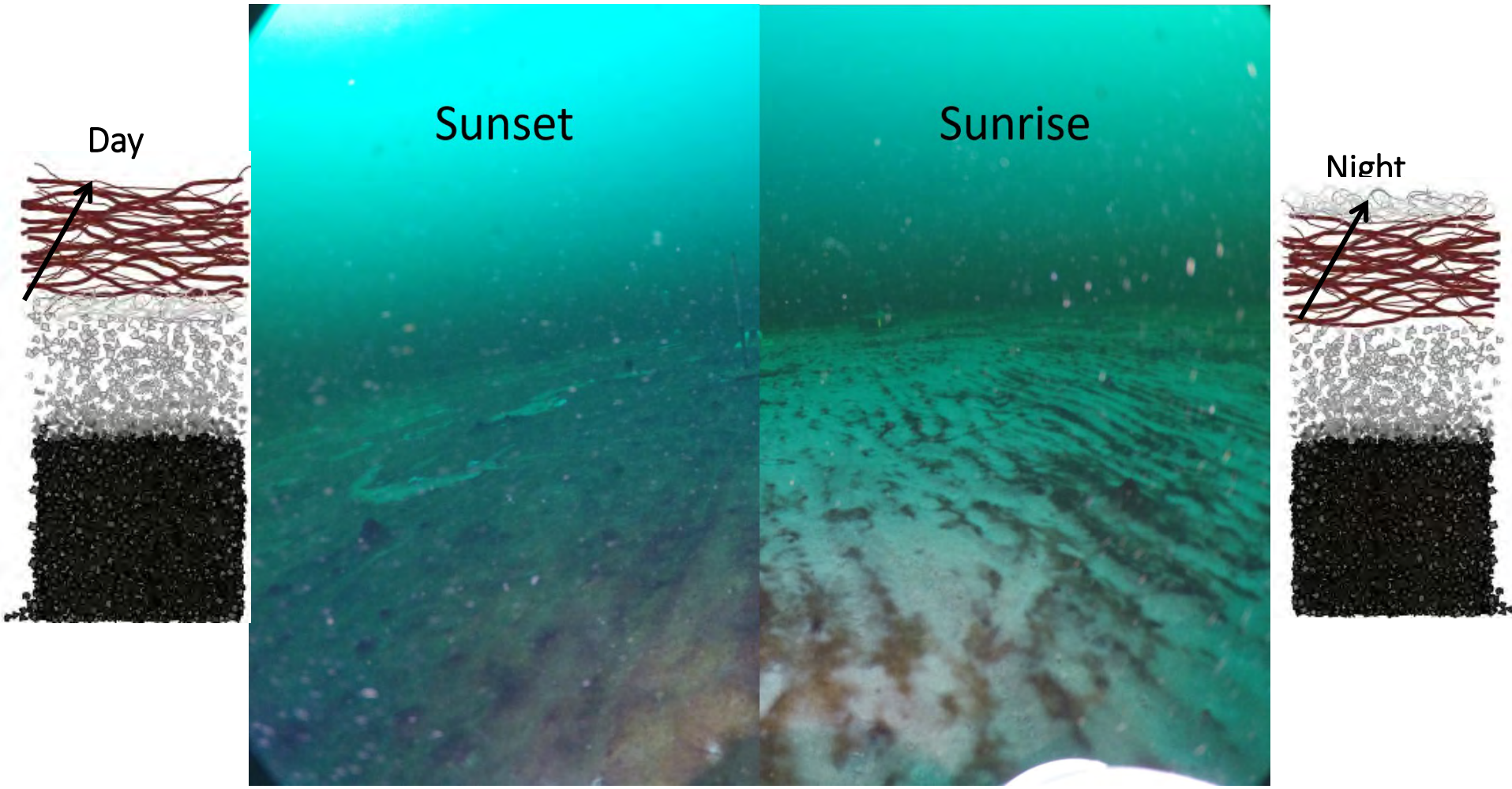


In Field: Diurnal Changes Day 2

Biddanda and Weinke, In Preparation

In Field: Diurnal Changes Summary



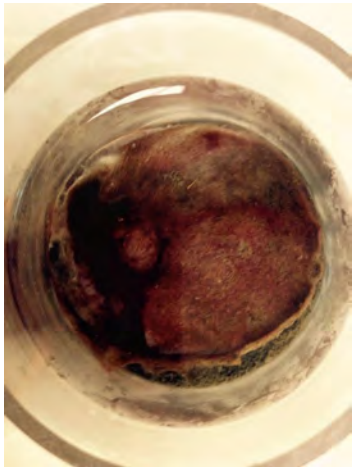
Life Optimizing the Use of Alternating Abundance of Sunlight and Chemicals

Biddanda and Weinke, In Preparation

In Lab: Diurnal Changes Summary

Core 1

Core 2

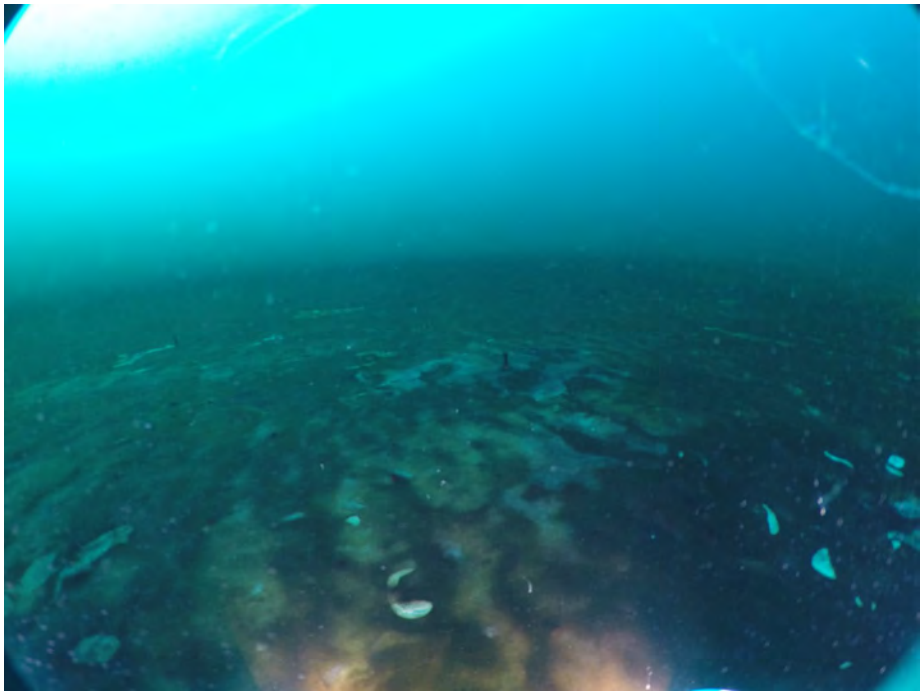


Sunset

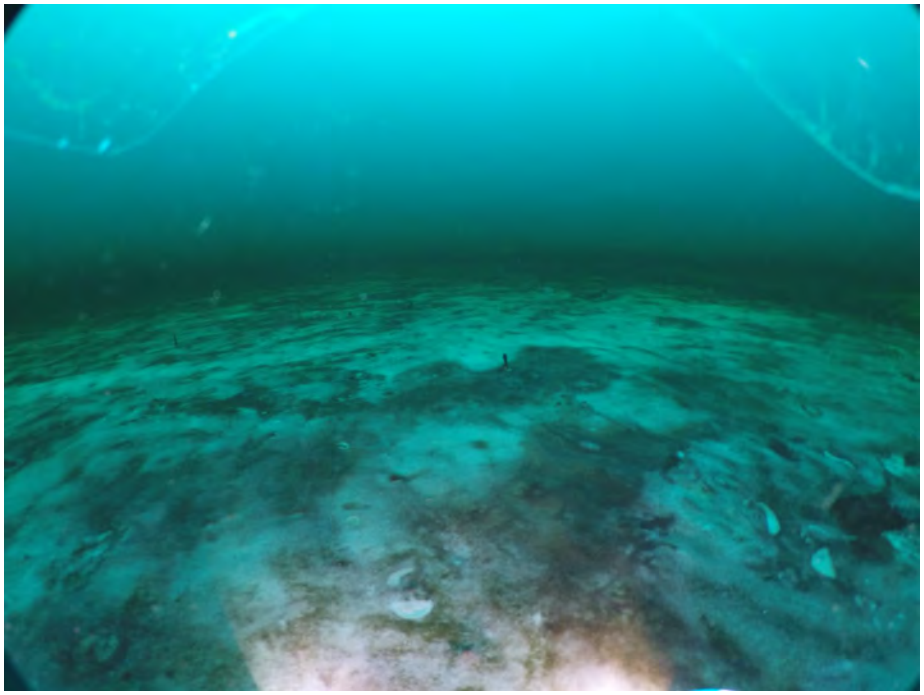
Sunrise

Biddanda and Weinke, In Preparation

June 2019 Confirmation of Day-Night Shifts



Sunrise



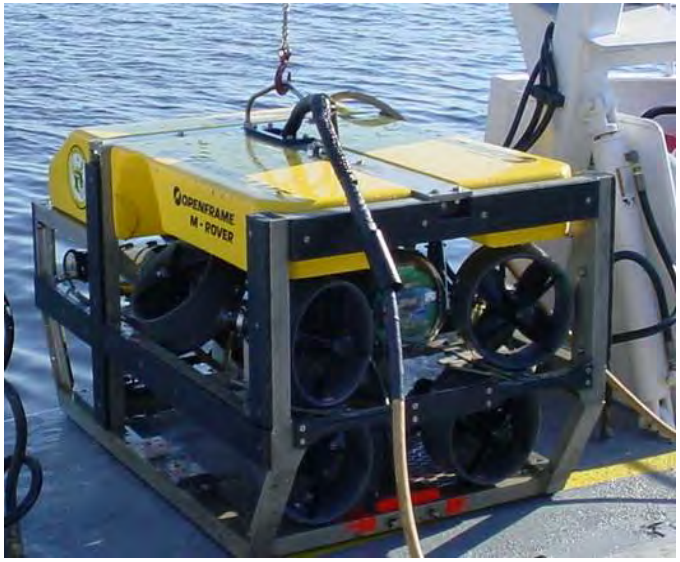
Sunset

First Tango?

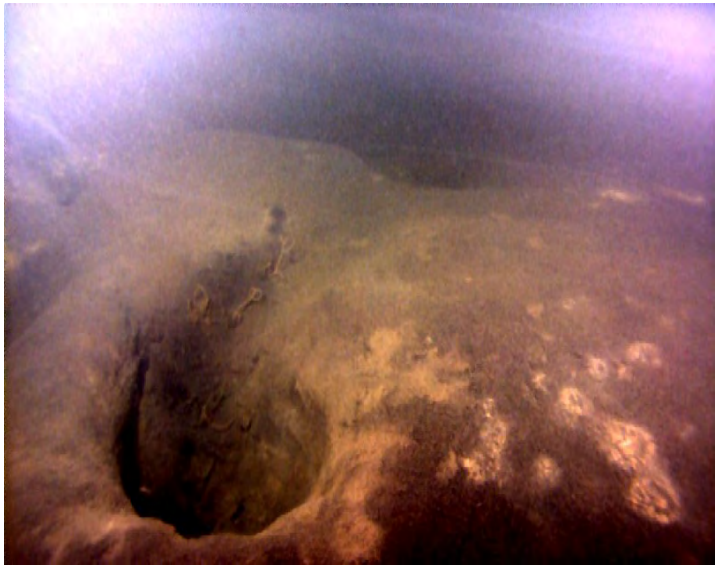
Could this have been the largest daily synchronized mass movement of life in early Earth?

Biddanda and Weinke, In Preparation

Deep Water Light-less Isolated Sinkhole (93 m): ROV and Benthic Mat Images

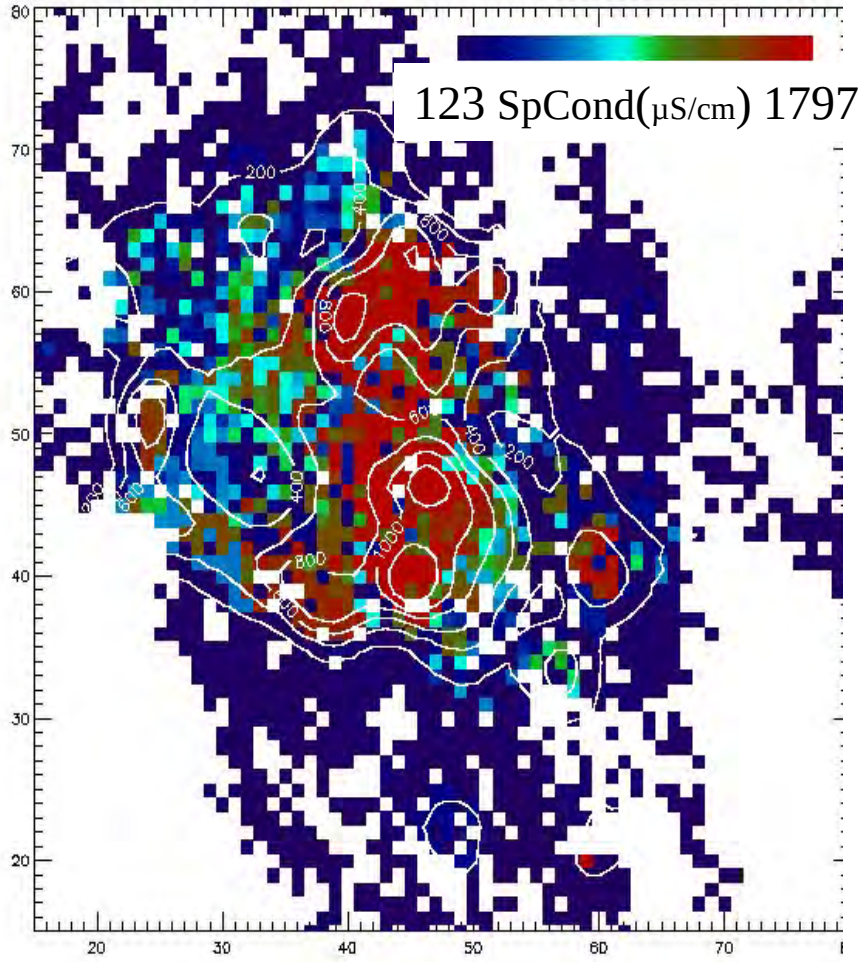


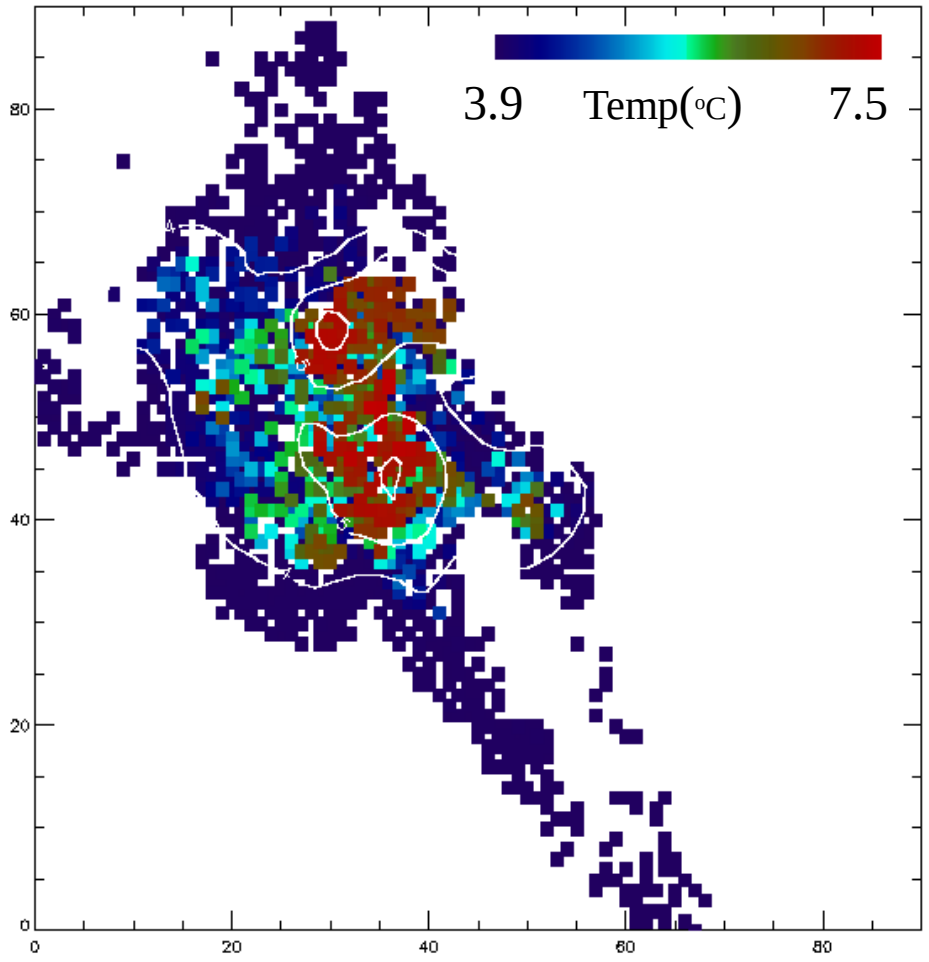
White chemosynthetic bacterial mats on Sinkhole floor



White Benthic Mats on lake floor
(Similar to Marine Vents and Seeps!)

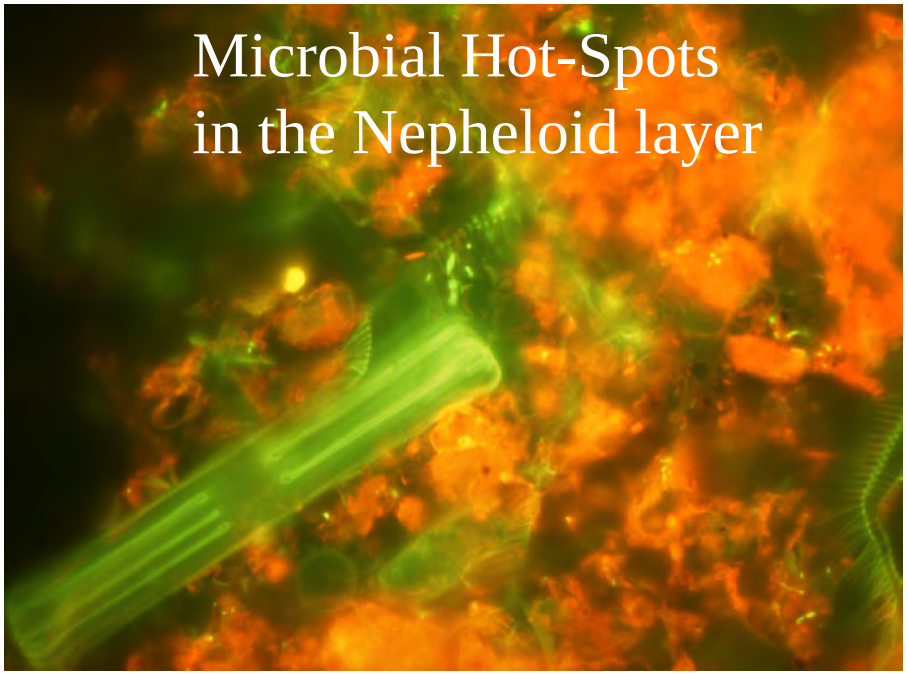
Conductivity and Temperature Maps Over Lake Floor of Isolated Sinkhole





Venting ground water is saltier and is warmer than lake water

Ruberg et al. 2005. Mar. Tech. J.



Sinkholes are Biogeochemical Hotspots

Biddanda et al. 2006. Ecosystems

Chemosynthetic mats of Aphotic Isolated Sinkhole: Analogs of Deep Sea Sulfur Seeps and Thermal Vents?

Fine scale networking of filaments
Of Bacteria and Archaea

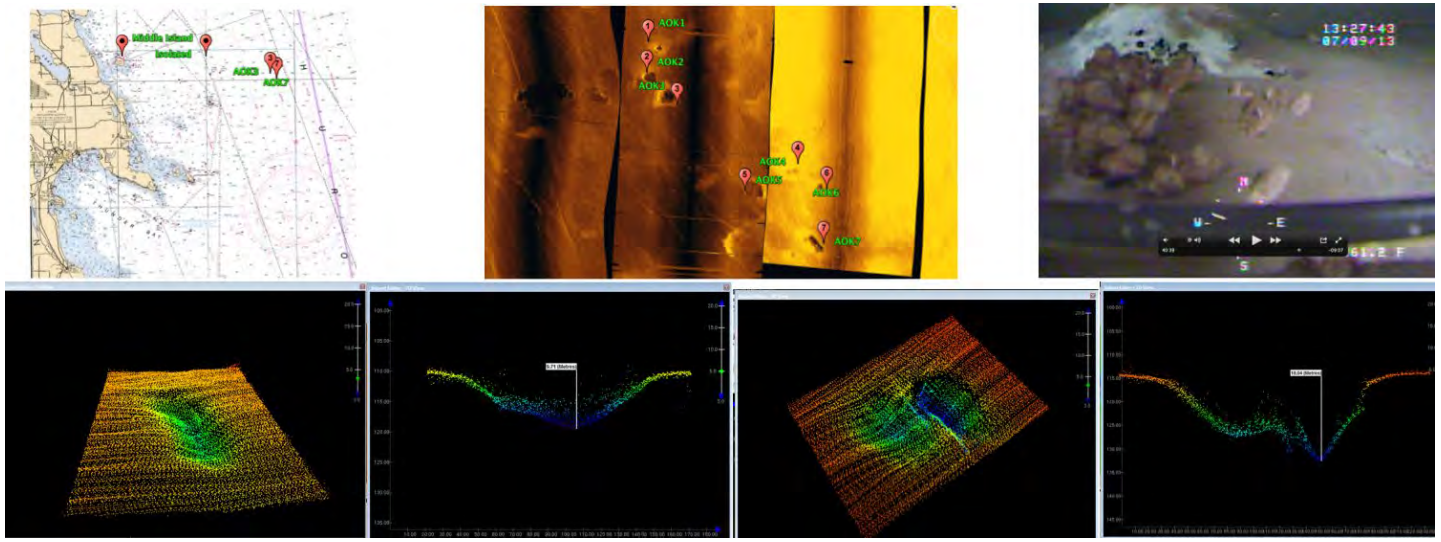
Beggiatoa and Thiomargarita sp.

Large Sulfur Bacteria (LSB)
Found here – similar to deep sea
Vent communities.

Biddanda et al. 2006. Ecosystems

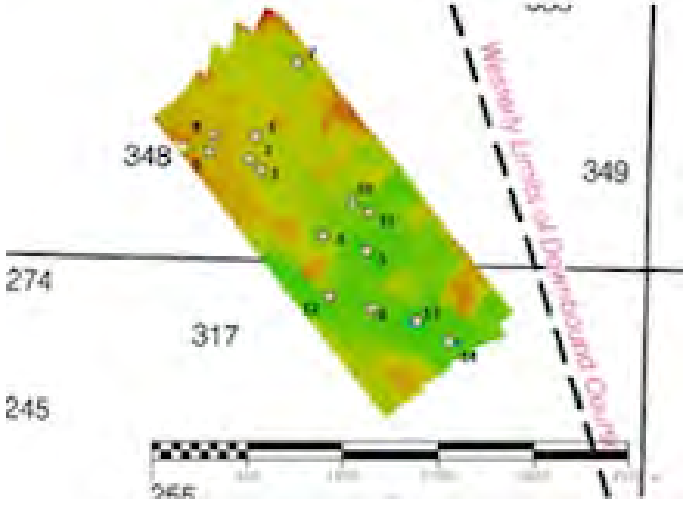
Sharrar et al. 2016 Frontiers

Discovery of New Sinkholes in Offshore Areas of Karst 2015-2017



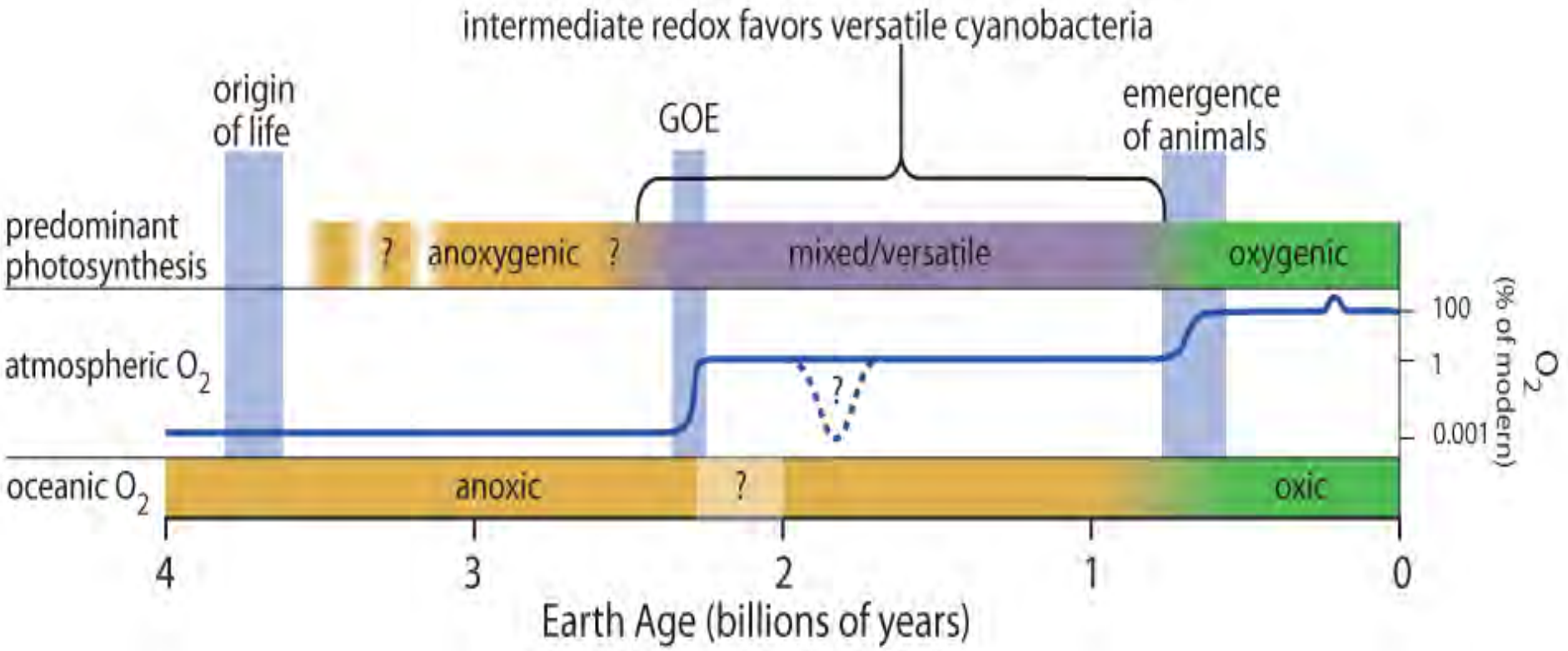
7 by Side-Scan in 2015

14 by Multi-Beam In 2016 and 2017



Ruberg et al. In Preparation

Great Lakes Sinkhole Ecosystems:
Analogs of Life in the Proterozoic 3.5-0.5 bya?



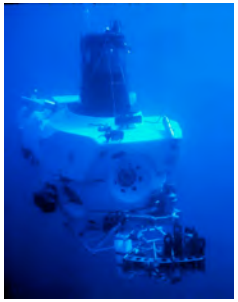
Schematic timeline of photosynthesis and the oxygenation of Earth's atmosphere and oceans. Oxygen concentrations are from (Lyons et al. 2009).

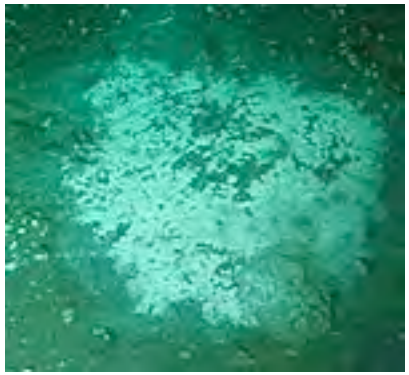
Biddanda et al. 2012 Nature Education Knowledge

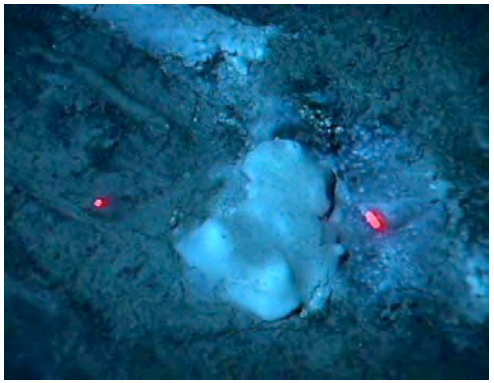
Where else "On Earth" are such microbial mat communities found?

Lake Untersee, Antarctica,
Andersen et al. 2011

Middle Island Sinkhole,
Lake Huron, Biddanda et al. 2012



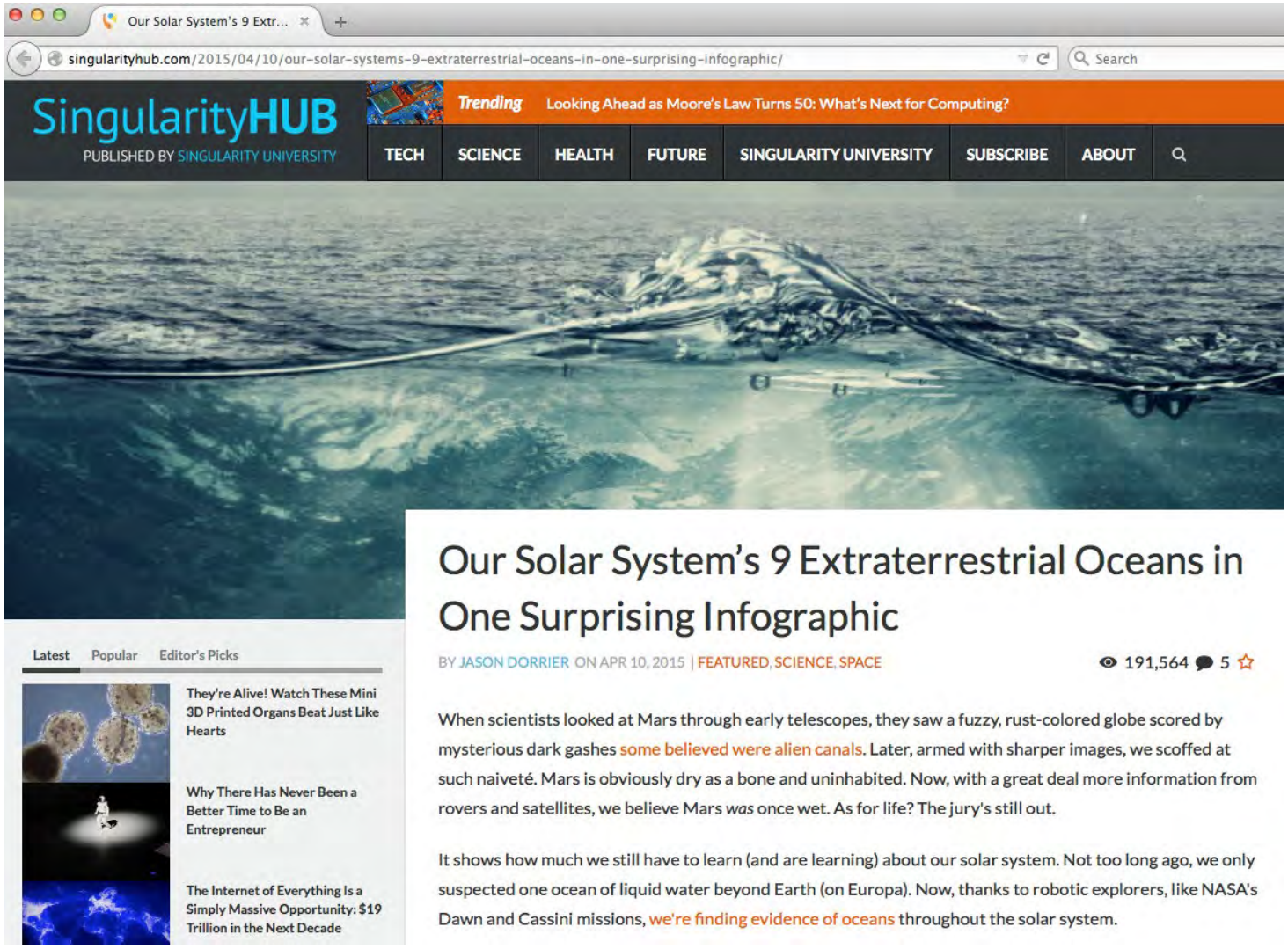




Deep Sea Sulfur Seeps and Thermal Vents

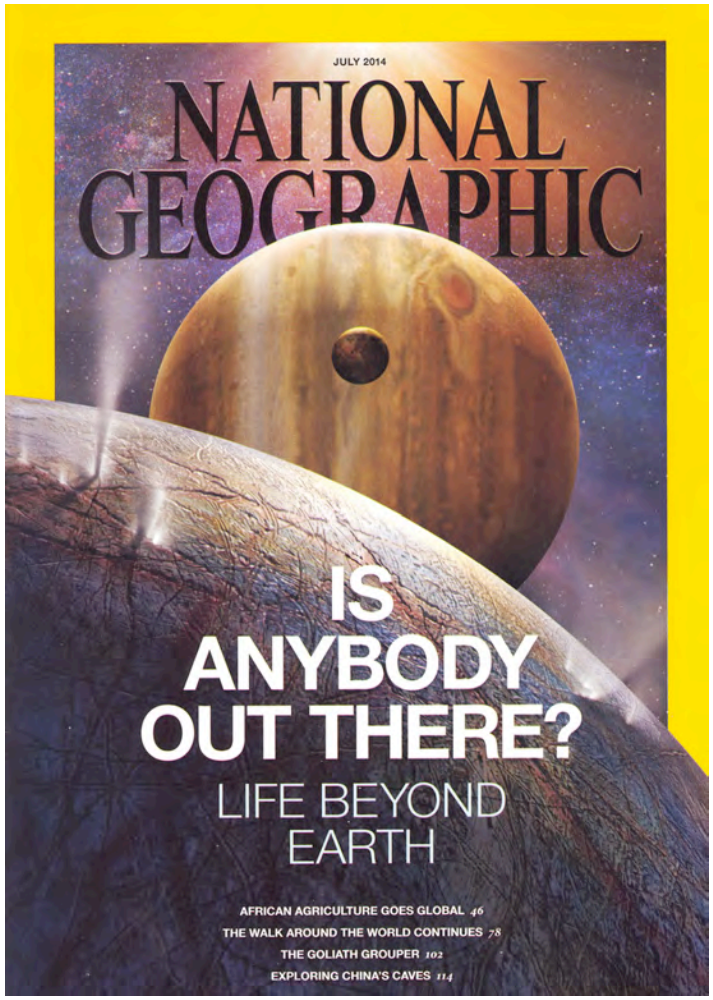
Are there other Shadow Biospheres in our midst? Elsewhere?

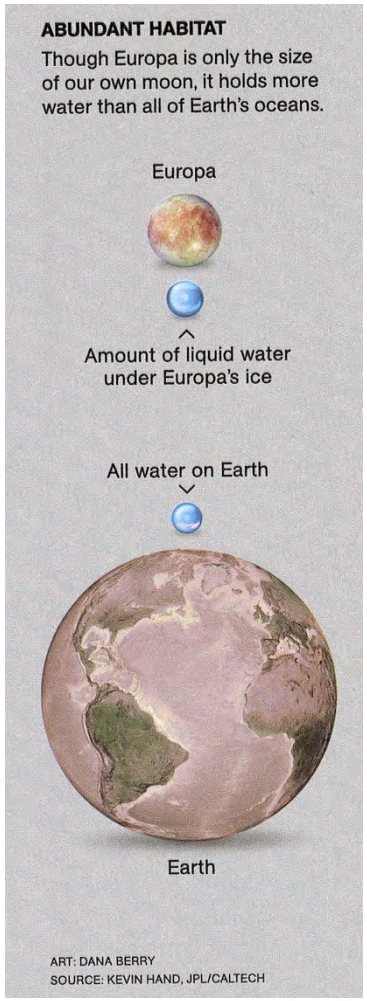
Where “Not on Earth” could such microbial mat communities be found?



There are Nine different Watery Bodies in the Solar System!

Europa's Massive Subsurface Ocean and Above-surface Watery Plumes





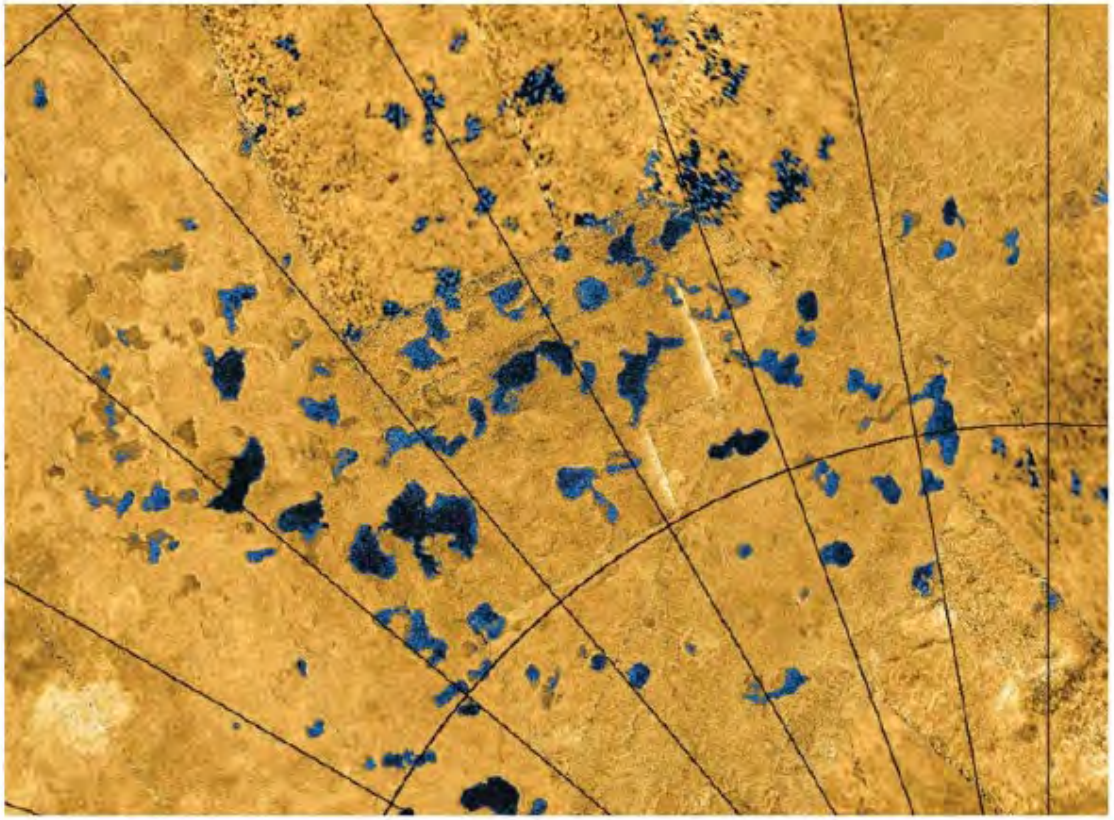
Nat. Geog. 2014

More water in Europas's Oceans than on all of Earth

Eos, June 2019
Lakes on Saturn's Moon - Titan

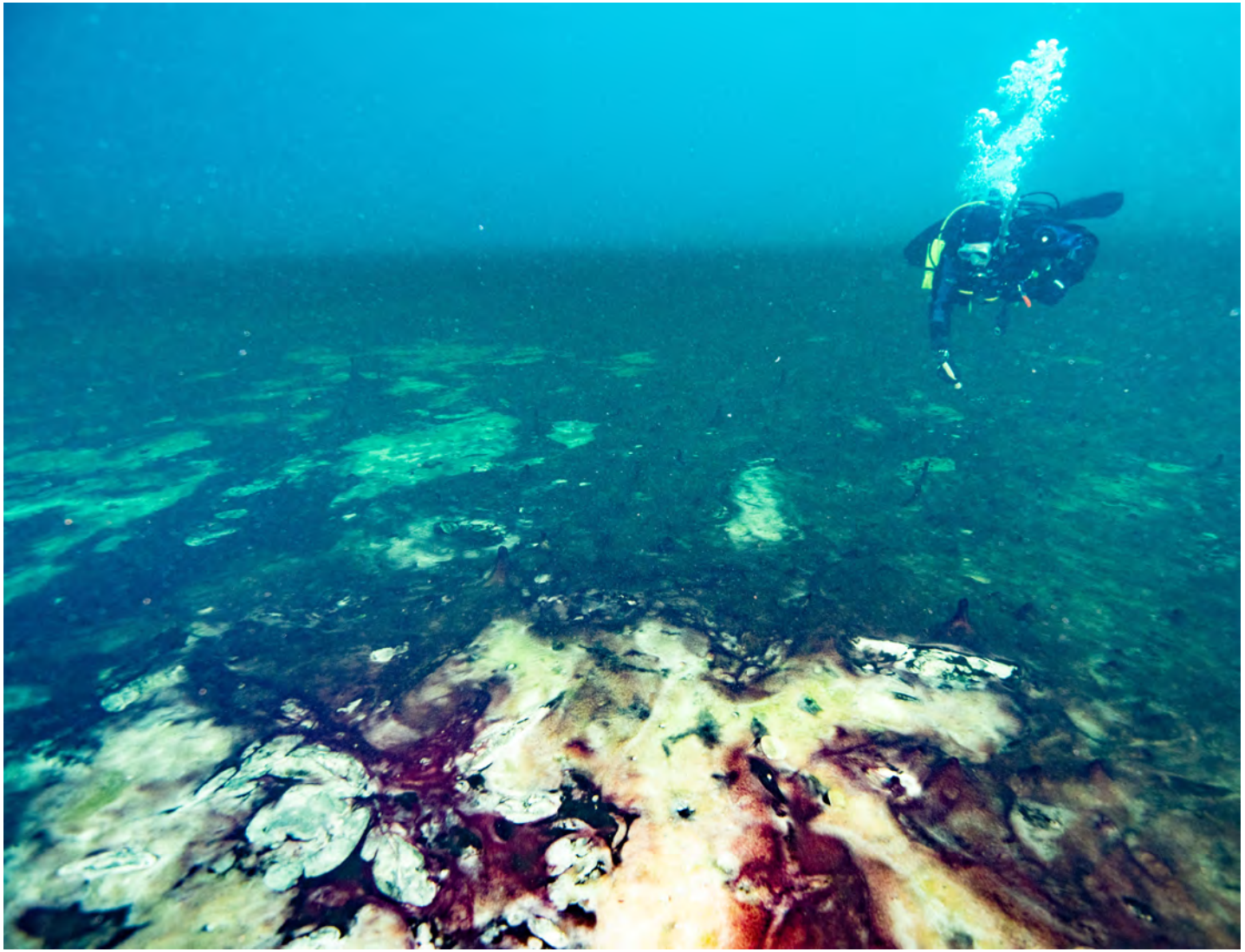
NEWS

Titan's Northern Lake District Has Hidden Depths



A radar map of the lake district near Titan's northern pole. These data from NASA's Cassini spacecraft are falsely colored to highlight areas with liquid hydrocarbons on the surface (blue-black) and areas that are dry (tan) and are overlaid with a geographic grid (black lines). Credit: NASA/JPL-Caltech/ASI/USGS

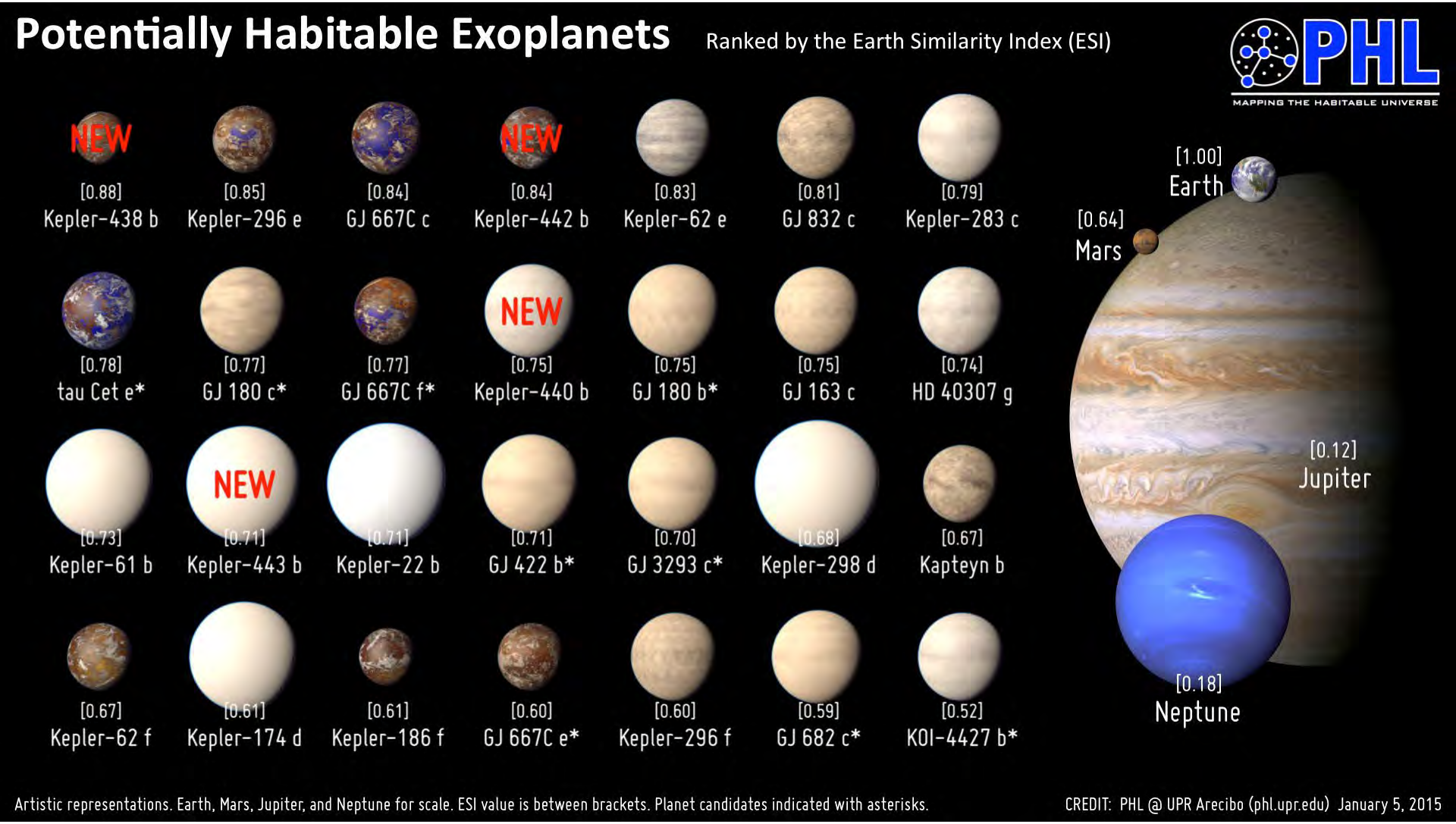
Earth Lakescape as a Model for Life in Extraterrestrial Waters



What might we find under the Lakes of Titan or the Oceans of Europa?

Eos, November 2019

Habitable Exoplanets (beyond the solar system) 2015



The TRAPPIST-1 System has 3 habitable Planets
Exoplanet K2-18B has water in its Atmosphere!

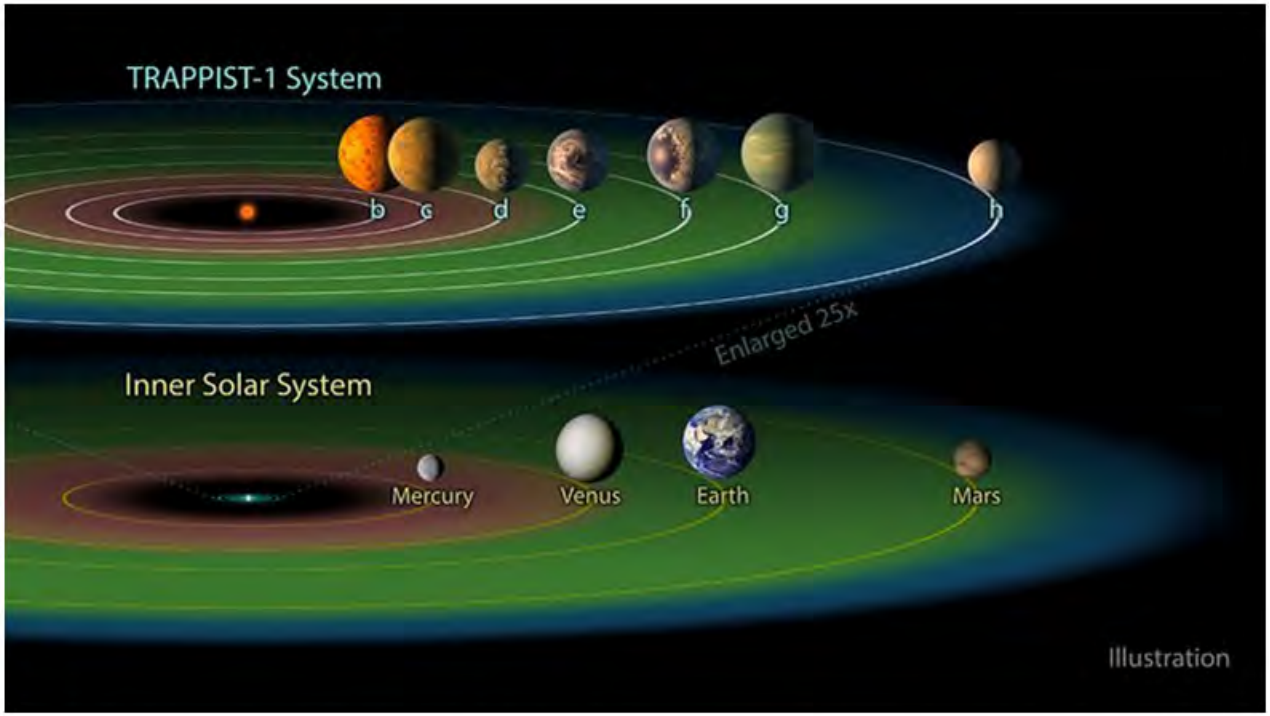


Fig. 3. The TRAPPIST-1 system includes seven known Earth-sized planets. Intense tidal heating of the innermost planets is likely. The projected habitable zone is shaded in green for the TRAPPIST-1 system, and the solar system is shown for comparison. Credit: NASA/JPL-Caltech

NEWS

Water Found in Atmosphere of Habitable Zone Planet

K2-18B Ideal Habitable Planet

This depiction illustrates K2-18b, foreground, and K2-18c (crescent) orbiting their red dwarf star. Credit: ESA/Hubble, M. Kornmesser

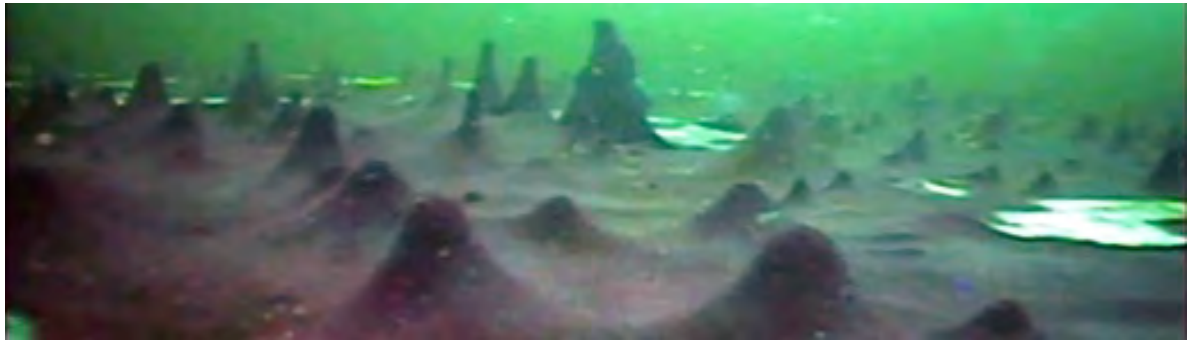
Eos, December 2019

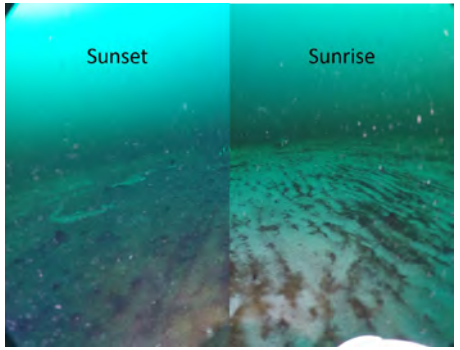
>1 Billion Stars in Our Galaxy – Twice as many!

Artist's impression of Gaia Satellite mapping the stars of the Milky Way.
Credit: ESA/ATG medialab; background: ESO/S. Brunier. Oct. 2016

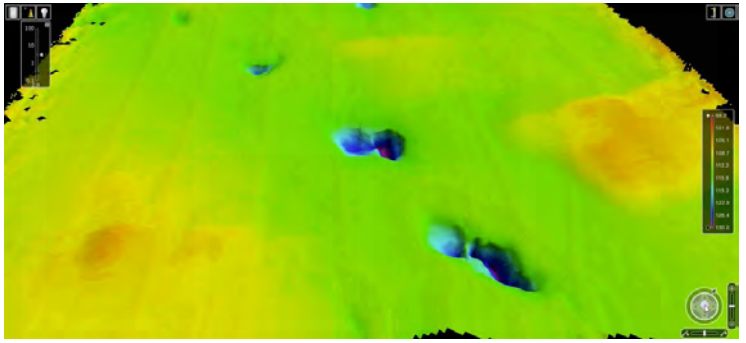
Now back on the home planet….

Time, water, and geologic forces have converged to create underwater sinkholes where oxygen-poor and sulfur-rich groundwater support prolific microbial mats **resembling life on early Earth.**





Whereas photosynthetic cyanobacteria in shallow sunlit sinkholes may be modern-day analogs of the Proterozoic, chemosynthetic mats in deepwater aphotic sinkholes may serve as ***analogs of modern-day deep sea vent and seep communities.***



Both of these types of Microbial Communities could be useful analogs in our search for life elsewhere…….

A Huge Thank You to the TBNMS Dive Team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John Bright


Phil Hartmeyer


Stephanie Gandulla


Joe Hoyt


Tane Casserley

Show Lake Huron Sinkhole - Microbial Systems - Overview – Audio-Video (5min)

Submerged Sinkhole Research