Life in marine extreme environments
examples from geological record

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Earth’s Oceans today
Earth’s Oceans

Diagram showing the layers of the ocean and their respective depths and characteristics. The diagram includes layers such as the Epipelagic, Mesopelagic, Bathypelagic, Abyssopelagic, and Hadopelagic. It also shows the plankton abundance, light distribution, and thermocline. The right side of the diagram includes graphs illustrating the growth rate, doublings per day, and pressure tolerance of different oceanic organisms. The graphs show categories such as Barophile, Barotolerant, and Extreme barophile, with examples like Psychrophile, Mesophile, Thermophile, and Hyperthermophile.
Alvin in 1978, a year after first exploring hydrothermal vents. The rack hanging at the bow holds sample containers.

1977: diffuse vents, Galapagos Spreading Center (Corliss et al. 1979)
1979: black smokers, East Pacific Rise (Spiess et al., 1980)
Earth’s Oceans
Hydrothermal vent

- Oceanic crust
- Earth’s mantle

- Magma 1,000°C
- Mineral-rich fluid

- Black smoker
- Seawater enters cracks

- Volcanic rock
- Diffuse venting
- Particle fallout

- Metal-rich sediments

- 2°C
- 2.05°C
Chemo-ecosystem
Hydrothermal system
Lost City

**Serpentinization**
Olivine $\rightarrow$ Serpentine (hydration)
Exothermic reaction $260^\circ C$
Basic fluids pH 9-10 (CaCO$_3$ precipitate)
Fluids contain high CH$_4$ and H$_2$

The Lost City Field include these white columns.
Hydrothermal systems have prevailed throughout geological history on Earth.
Earth’s Oceans
Early Oceans

4.4 Ga old zircon

Hadean Earth
Eons
Hadean: 4.56-4.0 Ga
Archean: 4.0-2.5 Ga

T (°C): ~ 23
pH: ~ 8
S (‰): 35
Early Oceans - T
Early Oceans – pH & S

T (°C): ~ 50-80 or 26-35
pH: ~ 5.5
S (‰): salty (Na, Cl, Br, Ca)

Arndt & Nisbet, 2012
Early Oceans: niches for life

Hydrothermal communities around andesite volcanoes
- Light
- Cu, Mo, Zn, S

Lake communities
- Light

Coastal sediment S-microbial mats
- Organic debris
- S cycle and methanogens

Mid-ocean ridge chemotrophic community
- Mg, SO₄
- Fe, Mn, S, CH₄, H₂

Hydrothermal systems around komatiite shields
- Light
- Ni, Co, Fe, S, Mg

Stromatolites
- Light

Open ocean
- More oxidized
- More reduced

Planktonic cyanobacteria

Hydrothermal supply of metals and reductant in deeper water

Lava
BIOALTERATION

preserved remains of microbial remineralization

Barberton Greenstone Belt Hooggenoeg Fm South Africa
Alvin

1984: cold seeps, base of the Florida escarpment in the Gulf of Mexico (Paull et al., 1984).

Alvin in 1978, a year after first exploring hydrothermal vents. The rack hanging at the bow holds sample containers.
GAS HYDRATE MOUND (~2m across) AT BUSH HILL (27°45.7’N, 91°30.5’W, Green Canyon, Gulf of Mexico)

Sassen et al., 2004)
SOBs BEGGIATOA MAT (~600m deep), active CH₄-seep, Black Ridge, S-Carolina
Middle Devonian (hydrocarbon) seep, Hollard Mound, eastern Anti-Atlas, Morocco
Authigenic carbonate crust with serpulids active hydrocarbon seep, North Adriatic Sea
VENT AND SEEP SEARCH-STRATEGY based on typical features recognized in (modern and fossil) ore deposit and vulcanogenic massive sulfide deposits, and carbonates:

- GEOLOGICAL SETTING
- SEDIMENT ACCUMULATIONS (ISOLATED) IN DEEP WATHER/SILICICLASTIC SEDIMENTS
- GEOMETRIES, MORPHOLOGIES AND STRUCTURES
- MONOSPECIFIC CHEMOSIMBIOTIC BENTONIC MEGAFANA ACCUMULATIONS (IN LIVE POSITIONS)
- GEOCHEMICAL SIGNATURES
- SEDIMENTARY FABRICS
- BIOCHEMICAL SIGNATURES/BIOMARKERS
- FLUID INCLUSIONS
bacterial mats, microbial fabrics and biomarkers

gas emissions

mound crest/hard ground

depleted $\delta^{13}$C carbonate

modified from Sassen et al., 2004
IKAITE: CaCO$_3$ 6H$_3$O

(Sedimentary) Ikaite forms in marine setting:
- near-freezing temperature (between -2 and 4°C)
- decompose as the water temperature rises (up to 5-6°C)
- ikaite loose 68.6% of its volume when convert to calcite and water
- grow displacively near the sediment-water interface
- geochemical and biogeochemical processes
- large blade-, stellate- or pine apple-shaped crystals are often encased in nodules/concretions

Single crystal of ikaite from Antarctic Peninsula.
Suess et al, 1992
IKAITE: $\text{CaCO}_3 \cdot 6\text{H}_2\text{O}$

Recent ikaite occurrences in the marine environment are typically linked to low temperatures below 6°C.

Ikaite has been a common mineral in cold-water environments throughout the geological record as glendonites are known from deposits of Carboniferous to Recent age from high latitudes of the northern and southern hemispheres.

Ikaite columns below the surface of Ikka Fjord, SW Greenland. Photo@ P. Martin.
Glendonite pseudomorphs after ikaite

... cold fluid venting of reduced geochemical species coupled with the AOM via SR could constitutes another mechanism that might be involved in the ikaite formation

Glendonites from northern Sakhalin Slope, Sea of Okhotsk, after Greinert and Derkachev, 2004
Dwyka Group/Ecca Group – GLENDONITES
Dwyka Group/Ecca Group – GLENDONITES
Grazie!