• Microorganisms that not only survive in high temperature, but that thrive there

• Temperature Range: 42°C to 121°C (well over the boiling point of water!)
Complex Chemistry around a Deep Sea Vent

Oxyanions, ($\text{HPO}_4^{2-}$, $\text{HVO}_4^{2-}$, $\text{CrO}_4^{2-}$, $\text{HAsO}_4^{2-}$), REE, Trace Metals

$^3\text{He}$, $\text{Mn}^{2+}$, $\text{H}_4\text{SiO}_4$, $\text{FeOOH}$, $\text{MnO}_2$, $\Delta T$, $\text{CH}_4$, $\text{Fe}^{2+}$, $\text{Fe}_x\text{S}_y$, $222^{\text{Rn}}$, $\text{H}_2$, $\text{H}_2\text{S}$

$2^\circ \text{C}$

$0.1 \text{ cm/s}$

HOT (focussed) flow $350^\circ \text{C}$

WARM (diffuse) flow $2 - 60^\circ \text{C}$

Precipitation Chimney (Black Smoker)

Spreading Axis

HT Reaction Zone $400^\circ \text{C}$

Evolved Seawater

Magma $1200^\circ \text{C}$

Metalliferous Sediments

Iron-Magnesium Crusts

H$^+$, Cl$^-$, Fe$^{2+}$, Mn$^{2+}$, $\text{H}_4\text{SiO}_4$, $^3\text{He}$, $\text{H}_2\text{S}$, $\text{CH}_4$, CO$_2$, H$_2$, Ca$^{2+}$, K$^+$, Li$^+$, Cu$^{2+}$, Zn$^{2+}$, Pb$^{2+}$

Sub Seafloor Microbial Biosphere

Basalt

Seawater

Flowing Seawater

Evolved Seawater

Seawater
Bacteria up to 177 F (80C)
Psychrophiles

“Cold-loving”

• Microbes that prefer to live in cold temperatures that linger around the freezing point of water and sometimes lower!

• Temperature Range: -3°C to 20°C
• Microorganisms that thrive in extremely acidic conditions. These microbes actually prefer liquids like boiling sulfuric acid.

• pH Range: less than pH 5 for optimum growth (down to level of battery acid!)
### Environmental Effects vs. pH Value

<table>
<thead>
<tr>
<th>pH Value</th>
<th>Examples</th>
</tr>
</thead>
<tbody>
<tr>
<td>pH = 0</td>
<td>Battery acid</td>
</tr>
<tr>
<td>pH = 1</td>
<td>Sulfuric acid</td>
</tr>
<tr>
<td>pH = 2</td>
<td>Lemon juice, Vinegar</td>
</tr>
<tr>
<td>pH = 3</td>
<td>Orange juice, Soda</td>
</tr>
<tr>
<td>pH = 4</td>
<td><strong>Acid rain</strong> (4.2-4.4)</td>
</tr>
<tr>
<td>pH = 5</td>
<td><strong>Acidic lake</strong> (4.5)</td>
</tr>
<tr>
<td>pH = 6</td>
<td>Bananas (5.0-5.3)</td>
</tr>
<tr>
<td>pH = 7</td>
<td><strong>Clean rain</strong> (5.6)</td>
</tr>
<tr>
<td>pH = 8</td>
<td><strong>Healthy lake</strong> (6.5)</td>
</tr>
<tr>
<td>pH = 9</td>
<td>Milk (6.5-6.8)</td>
</tr>
<tr>
<td>pH = 10</td>
<td>Pure water</td>
</tr>
<tr>
<td>pH = 11</td>
<td>Sea water, Eggs</td>
</tr>
<tr>
<td>pH = 12</td>
<td>Baking soda</td>
</tr>
<tr>
<td>pH = 13</td>
<td>Milk of Magnesia</td>
</tr>
<tr>
<td>pH = 14</td>
<td>Ammonia</td>
</tr>
<tr>
<td></td>
<td>Soapy water</td>
</tr>
<tr>
<td></td>
<td>bleach</td>
</tr>
<tr>
<td></td>
<td>Liquid drain cleaner</td>
</tr>
</tbody>
</table>

**ACIDIC**
- All fish die (4.2)
- Frog eggs, tadpoles, crayfish, and mayflies die (5.5)

**NEUTRAL**
- Rainbow trout begin to die (6.0)

**BASIC**
Pore water pH ~1

Slide courtesy of Norm Pace
This is a picture of *Cyanidium caldarium*, an organism that can live in a pH as low as ZERO!!!
Acidophiles

This warm, acid spring is a common habitat for acidophiles.
Rio Tinto, Southwestern Spain, pH 1.7-2.5

Mark A. Messerli, Linda Amaral Zettler, Peter J.S. Smith, Mitchell L. Sogin
Alkalophiles

"Basic-loving"

• These microorganisms like to live in areas of high alkalinity.

• **pH Range:** greater than pH 9 for optimum growth (like drain cleaner!)
Microbes that live in environments of extreme pressures such as miles under the ocean, in complete darkness.

**Pressure Range:** > 400 atmospheres for optimum growth.
This barophile was found in sediment deep on the ocean floor (no oxygen).
• Microorganisms that grow in extremely dry environments with only intermittent moisture.
Mixotrophs – Manganese oxidizing microbes
Halophiles

"Salty-loving"

• Microorganisms that like to live in salty environments. Think about rules governing osmosis to see why this could be a problem!

• **Salt Concentration:** >5% for optimum growth (sea water is about 3%)
• These are microbes that don’t like to function with oxygen in the environment.

• May use gases other than oxygen in order respire
Methane ice (crystallized structures of methane & water) that can form under conditions of low temperature and very high pressure. This methane hydrate mound in the Gulf of Mexico has thousands of polychaete worms on its exposed surface.
Deinococcus radiodurans is a microbe that can withstand 1000 times the radiation dose that would kill a human in minutes. It keeps 5 stacked copies of its DNA ready for very quick repairs.
The tardigrade or water bear is a fully functioning microscopic animal that can go into a freeze-dried wait state for centuries and reanimate in water. It is found in all Earth’s ecosystems.
Tardigrades have been revived after exposure to 10 days in space!
Atmospheres

Venus

Mars

Earth

Titan

CO₂

N₂

Thick atmo

Thin atmo
Water on Mars

i.e. Canyons - weathering
Mars in the past?
Europa

This Galilean moon of Jupiter is the closest thing in the solar system to another water world. An icy crust covers an ocean.
Europa
Subsurface Ocean – Europa
Lake Vostok - Antarctica
A potential mission to Europa would land on the ice pack, use heat from a nuclear reactor to melt through it, and release a hydrobot to explore the ocean.

There may be places where the crust is thin and water wells up and spreads over the surface.
Comets – Reservoirs of Icy Water

Takács - Kiss (Uni. Sydney) - Szabó (Uni. Szeged)
Comets – Reservoirs of Icy Water
Herschel Space Observatory
“Heavy” Water

“Normal” Water
Comets – Reservoirs of Icy Water
The orange track represents a typical KBO orbit. Pluto’s orbit is represented by the yellow ring.
Asteroids – How Much H$_2$O?

Vesta
Water in a Forming Solar System

Enough $\text{H}_2\text{O}$ to fill thousands of Earth’s oceans!
Water is COMMON in new Solar Systems!

Star Forming Regions in Orion