Juggling with tectonics, rocks, hot fluids and your neighbors: The secret lives of some terrestrial and deep-sea hot spring microbes

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• Overview similarities and differences
  • Chemical diversity
  • Microbial diversity
• Effect of perturbations? Or chemical/physical gradients/interactions
  • Who’s there?
  • What are they doing in response to ‘perturbations’
• Case studies:
  • Aquificales
  • Nanoarchaeota
Overview: continental and marine microbial systems
What do they share? How are they different from a microbial perspective?
How do they respond to perturbations? OR what affects their distribution?
Micro-niches for the occurrence of hyperthermophilic microbial processes at the top section of a smoker chimney wall based on gradients of nutrients of physico-chemical conditions.

From Janssen, 1985

Mesophilic
H₂S oxidizers, methanogens, Fe oxidizers, Mn oxidizers

Thermophilic methanogens
SO₄²⁻ reducers?

Chimney wall

Seawater

Vent fluid

'Koolgas' bacteria?
Bacteria in their natural environment, living happily together.
Back Arc Spreading Center (Eastern Lau Spreading Center)

Influence of subduction on melting, crustal composition/structure

Variable distance between spreading axis and arc volcanism

Effects of geographic isolation on biology

High CO₂, low H₂

ANDESITE

MOR-like chemistry

BASALT
Standardise Samples by Total
Transform: Square root
Resemblance: S17 Bray Curti's similarity

2D Stress: 0.19

Vent Field
- GB
- KM
- TC
- TAMO
- ABE
- TUMA
- MAR
- RB
- LS
- TAG

Flores et al., 2012
Geobiology
ELSC: bacterial and archaeal communities

Flores et al. 2012. Geobiol

<table>
<thead>
<tr>
<th></th>
<th>Kilo Moana</th>
<th>Tow Cam</th>
<th>ABE</th>
<th>Tui Malila</th>
<th>Mariner</th>
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<td>CO₂ mM/kg</td>
<td>7.5-8.5</td>
<td>10.5-11.5</td>
<td>5.1-6.9</td>
<td>11.7-13.8</td>
<td>32.3-71.4</td>
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</table>
The energy of reaction:

$$\text{HCOO}^- + \text{H}_2\text{O} \rightarrow \text{HCO}_3^- + \text{H}_2$$

$$\Delta G^0' = +1.3 \text{ kJ/mol}$$

was always considered to be insufficient to support microbial growth

But at 80°C, $$\Delta G^0'$$ varied from -8 to -20 kJ/mol

Thermotogales are not at continental hot springs (with an exception)

Like other groups.....
See their distribution at LAU trending with the sites.

Ferrera et al., 2014, Syst Appl Micro.

SE study: Aquiferales
Case Study: Aquificales in continental systems
Responding to perturbations: Metabolic flexibility..

Hamamura et al., Environ Micro
Takacs-Vesbach et al, Frontiers in Extreme micro

MICROPROFILES

Oxygen

Hydrogen
Figure x. A conceptual summary of the distribution of 16S rRNA genes indicated using genus names of closest cultivated relatives as a function of distance from geothermal source for representative geothermal sites included in this study (Table 1). The exact position of each microbial population with respect to temperature is not absolute, but the trends in phylogenetic change down-gradient of geothermal discharge are represented along an O₂ gradient ranging from below detection (green) to saturation (white). Members of the Aquificales are highlighted in brown font.

Hamamura et al, Inskeep et al,
The pattern of distribution suggests that major geological events in the past 2 million years explain more of the variation in sequence diversity in this system than do contemporary factors such as habitat or geographic distance.

with each of the volcanic eruptions in Yellowstone, ancestral thermophiles went extinct within the calderas and as new springs formed, they were subsequently colonized from peripheral sites that survived outside the calderas.

Takacs-Vesbach et al, 2008
Not only chemistry – interspecies interactions—snails and endosymbionts at LAU

Host I + γ 1

Host II + ε

Host III + γ Lau

Beinart et al, 2012 PNAS

Courtesy Pete Girguis
Not only chemistry – interspecies interactions—Case study: Nanoarchaeota and their hosts
Despite the increasing number of microbiologists, there will always be bacteria which will remain unknown.

These bacteria live in constant fear of being isolated.

The illusive Nanoarchaeota
A new phylum of Archaea represented by a nanosized hyperthermophilic symbiont

Harald Huber*, Michael J. Hohn†, Reinhard Rachel†, Tanja Fuchs*†, Verena G. Wimmer‡ & Karl O. Stetter*†

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‡ Max Planck Institute for Medical Research, Department of Cell Physiology, Johnstrasse 29, 69120 Heidelberg, Germany

According to small subunit ribosomal RNA (ss rRNA) sequence comparisons all known Archaea belong to the phyla Crenarchaeota, Euryarchaeota, and—indicated only by environmental DNA sequences—to the ‘Korarchaeota’1,2. Here we report the cultivation of a new nanosized hyperthermophilic archaean from

† Present address: AstraZeneca GmbH, Tinsdale Weg 183, D-22676 Wedel, Germany.

McClimment et al., first colonizer of deep-sea vent chimney
**Ignicoccus hospitalis**

- 90°C, marine, obligate chemolithoautotroph (CO₂, H₂/S⁰)


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**Nanoarchaeum equitans:**


- Little effect on *Ignicoccus* lab co-cultures (commensal/parasite?) Jahn et al (2008)


- Representative of a distinct archaeal phylum?
The split genes of *Nanoarchaeum equitans* are an ancestral character*☆

Massimo Di Giulio *

Laboratory for Molecular Evolution, Institute of Genetics and Biophysics ‘Adriano Buzzati Traverso’, CNR. Via P. Castellino, 111, 80131 Naples, Napoli, Italy

Research

**Nanoarchaea: representatives of a novel archaeal phylum or a fast-evolving euryarchaeal lineage related to Thermococcales?**

Celine Brochier*, Simonetta Gribaldo†, Yvan Zivanovic*, Fabrice Consalonieri* and Patrick Forterre††

Addresses: *EA EGEE (Evolution, Génomique, Environnement) Université Aix-Marseille I, Centre Saint-Charles, 3 Place Victor Hugo, 13331

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**Diagram:**

- **Euryarchaeota**
  - Crenarchaeota
  - Nanoarchaeota

- **Crenarchaeota**
  - vs.
  - Nanoarchaeota

- **Nanoarchaeota**
  - vs.
  - Crenarchaeota

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**Thermooccales...**

**Euryarchaeota**
Global distribution: >500 SSU rRNA sequences

- Caldera Uzon, Geyser Valley, Kamchatka (Russia)
- Furnas, Azores
- Yellowstone National Park (USA) (~20 sites)
- China, Chile
- South Africa (Casanueva et al, 2008)
- New Zealand, Mongolia (Casanueva et al, 2008)
- Mid Atlantic Ridge (Rainbow)
- 9N East Pacific Rise, Guaymas (Gulf of California), Eastern Lau (South Pacific)
- Mid Atlantic Ridge (Lucky Strike)

Terrestrial

Marine

- *Nanoarchaeum equitans* (Iceland)

**Euryarchaeota**
- *Thermococcus celer*

**Crenarchaeota**
- *Sulfolobus acidocaldarius*
- *Thermoplasma aggregans*
- *Crenarchaeum norribotus*
- *Thermofilum pendens*

**Nanoarchaeota**

- a few from non-thermal sites (saline) (Casanueva et al 2008)
- Including more data from 454 pyrosequencing characterizations
<5% sequence divergence
Yellowstone Nanoarchaeota diversity

>95% sequence identity

31 OTUs at 98%
Terrestrial Nanoarchaeota, who are their hosts, or do they have hosts?

Obsidian Pool, Yellowstone National Park

T ~ 80°C, pH ~ 5.5-6
Targeted single cell genomics and metagenomics

Hybridization of target organism(s) → Fluorescent cell sorting → Sequencing → Whole genome amplification (MDA)

- Single cells or populations
- Bacteria
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<th>Features</th>
<th>N. equitans</th>
<th>Nst1</th>
<th>Note</th>
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<td><strong>Split Proteins</strong></td>
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" Split in other archaea also"

Table 1. Notable genomic differences between *N. equitans* and *Nst1*.  

Podar et al 2013,
Global distribution: >500 SSU rRNA sequences

Terrestrial
- Caldera Uzon, Geyser Valley, Kamchatka (Russia)
- Iceland
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Marine
- 9N East Pacific Rise
- Guaymas (Gulf of California)
- Eastern Lau (South Pacific)
- Mid Atlantic Ridge (Lucky Strike)
- Mid Atlantic Ridge (Rainbow)

Free living?

Euryarchaeota
- Thermococcus celer

Crenarchaeota
- Thermoplasma acidocaldarius
- Sulfolobus acidocaldarius
- Sulfolobus solfataricus
- Ignicoccus hospitalis
- Bathyarchaeum oceanis
New Zealand Nanos
~74C, pH 6.45
Conclusions

- Some commonalities between continental and marine microbial systems
- You are what you eat
- What you eat depends on host rock, mineralogy, fluid flowpaths, water-rock reactions, time, interactions with your Nanoarchaeotes etc.
- Just scratching the surface re. what drives microbial diversity and colonization in hot springs but clearly the geology/geochemistry and biology are very deeply interconnected both in continental and marine systems
Thank-you

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