Astrobiology of Hot Springs on Early Earth and Mars

Kathleen A. Campbell, Frances Westall, Martin J. Van Kranendonk, Diego M. Guido
What is Astrobiology?

The science that seeks to understand the story of life in our universe ... holistically, beyond discovery, into fundamental questions.

- Conditions necessary for life to emerge and flourish
- The origin of life
- Life’s evolution and adaptation to range of environmental conditions
- The search for life beyond Earth
- Habitability of extraterrestrial environments
- Considering the future of life on Earth and elsewhere

Tools of physics, chemistry, biology, astronomy, geology, planetary science, microbiology, atmospheric science, oceanography, etc.
Asking Some Big Questions:
Are We Alone in the Universe?

>100 Billion Galaxies in the Universe. How many have Earth-like planets?
Asking Some Big Questions:
How did Life Originate?
What was Early Life on Earth Like?

Sources: Smithsonian Institution; mun.ca/biology/dmarshall
Asking Some Big Questions:
Was or is there life on other planets?
Where would you look for it?
What might it look like?
The face of an extraterrestrial?

- No signs so far of intelligent life from space

‘ET’ hasn’t called in yet for a visit …

Credit: National Geographic
The face of an extraterrestrial?

- What about microbial life?
- On Earth, it is everywhere, even in the most extreme environments – *cold, hot, acid, alkaline, salty, deep subsurface* – analogues for possible life elsewhere?

Purple sulphur bacteria eat carbon dioxide and hydrogen; give off methane gas bubbles in a super salty pond – *strange life!*

Credit: National Geographic
Some Present Day ‘Early Earth-Analogue’ Extreme Environments: Microbial Life

Where to look for life in our own Solar System?

Europa, a moon of Jupiter – ice tectonics, subsurface ocean with methane – microbes living in it?

Credits: jpl.nasa.gov, planetary.org
Where to look for life in our own Solar System?

Antarctic subglacial lakes: Extreme environment analogues for icy worlds

Credits: oneworldoneocean, livescience
ET life on Mars? Evidence for ancient volcanism and running water

Hosts the Solar System’s largest volcano, largest canyon carved by water ... active around same time as life originated on Earth.... Mars too?
How did life take hold on Earth, > 3 Ga?

- The role of early bombardment, + or – for life?


Earth finally cooled enough for volcanic vapours to condense & form oceans
How did life take hold on Earth, > 3 Ga?

- Terrestrial organic soup model
- Terrestrial hydrothermal vent model
- Extraterrestrial seeding by meteorites, comets

Credits: daviddarling.info, Wicander & Monroe 2004
Deep roots (most primitive living organisms) of Tree of Life are heat-loving microbes – remnant of early bombardment?

Aquifex pyrophilus in Yellowstone hot spring
Why Study Terrestrial Hot Spring Deposits? – Mars Analogue, Early Life on Earth

- Coeval past volcanic activity + surface water on Mars – on Earth habitable extreme environments
- Rapid mineralization by silica, carbonate or iron – potential to preserve microbial fossils in situ
- Textural-mineral biosignatures distributed along environmental gradients – parallels to some Early Archean (3.3-3.5 Ga) hydrothermal settings on Earth ... and Mars?
Oldest Microfossils?
3.5 Ga Apex Chert, Pilbara, Western Australia

Schopf, 1993; Brasier et al. 2002
Filamentous microfossils -- 3.25 billion year old hydrothermal vent deposit, Pilbara, Western Australia

Some early life habitats were HYDROTHERMAL

Biofilms -- hydrothermal shallow marine sediments, Barberton, South Africa (3.4-3.2 Ga)

Rasmussen 2000; Westall et al. 2001
A, E, F – mat fragments, 3.3 Ga, South African hydrothermal chert

G, H – mat fragment, 150 Ma, Argentine siliceous hot spring deposit (sinter)

LASER µ-RAMAN COLOUR KEY:
- green, carbon
- red to yellow, quartz
- magenta, muscovite
- blue, anatase, TiO₂

Westall et al., 2015
Early life and Hot Water on Land: 3.48 Ga, W Australia

9kyrs, Mangatete sinter, New Zealand

Djovic et al., in review; Drake et al., 2014

Hot Water Creek, Waimangu, NZ
Early life and Hot Water on Land: 3.48 Ga, W Australia

Drilling beneath weathering – biogeochemical cycles of early microbes
Characteristics, distribution, origin, and significance of opaline silica observed by the Spirit rover in Gusev crater, Mars

Steven W. Ruff,1 Jack D. Farmer,1 Wendy M. Calvin,2 Kenneth E. Herkenhoff,3 Jeffrey R. Johnson,3 Richard V. Morris,3 Melissa S. Rice,5 Raymond E. Arvidson,6 James F. Bell III,5 Philip R. Christensen,1 and Steven W. Squyres5


Home Plate,
Columbia Hills
opaline silica deposit
An origin for the silica-rich nodular outcrops by precipitation from near-neutral pH thermal springs or geysers cannot be ruled out based on available observations.

Parariki Stream acidic sinter, Rotokawa

Mars Si deposits

Credits: Schinteie et al. 2007; Ruff et al. 2011
Alkali-chloride siliceous hot spring (sinter) facies model

Hamilton et al. 2016
<table>
<thead>
<tr>
<th>Facies Assemblage</th>
<th>Facies</th>
<th>Geometry &amp; Textures</th>
<th>Microbial Fossil Association</th>
</tr>
</thead>
<tbody>
<tr>
<td>PROXIMAL</td>
<td>Vent Mound or Spring Vent Pool</td>
<td>Conduit/Throat</td>
<td>Biofilm</td>
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<tr>
<td></td>
<td>geyserite</td>
<td>Breccia/Panal</td>
<td>Tubular biormorphs/filaments in morphologically varied geyserite (i.e., very thin, commonly dense, finely laminated sinter)</td>
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<td></td>
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<td>Channel</td>
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<td>Spicular/Nodular/Botryoidal/Columnar/Pseudocolumnar/Cumulate</td>
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<td></td>
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<td>Beads</td>
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<td></td>
<td>Radiating macrobotryoids</td>
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<tr>
<td></td>
<td>Proximal Slope</td>
<td>Fine lamination</td>
<td></td>
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<tr>
<td>MIDDLE</td>
<td>Channel</td>
<td>Wavy laminated ‘bubble mats’</td>
<td>Lenticular voids interfacered with wavy mat laminae</td>
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<td>Packed fragmental</td>
<td>Hot-water creek point bars of silicified, imbricated mat fragments</td>
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<td>Streamer fabric</td>
<td>Densely aligned on bedding planes, associated with wavy laminated fabric</td>
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<td>Digitate / knobby / spicular</td>
<td>Microstromatolitic growth due to evaporative wicking in shallowly channelized sheet flow</td>
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<tr>
<td></td>
<td>Pool</td>
<td>Network/Conical tufted/Ropy folded</td>
<td>Tufts vs. ropy fabric represent undisturbed vs. disturbed growth in pools; networks around drying pool margins</td>
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<tr>
<td></td>
<td></td>
<td>Low amplitude wavy siliceous sheets</td>
<td>Pool mats with large gas bubbles trapped underneath</td>
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<tr>
<td>DISTAL</td>
<td>Distal Apron</td>
<td>Domal laminated</td>
<td>Pool floor and wall growth of domal stromatolites</td>
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<tr>
<td></td>
<td></td>
<td>Terracettes/Thick palisade lamination</td>
<td>Coarse filaments in densely packed vertical pillar structures</td>
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<td></td>
<td>Mottled/Clotted/Peloidal</td>
<td>Clotted, fine-grained siliceous matrix</td>
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<tr>
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<td>Plants and/or animals</td>
<td>Encrusted with biolaminites</td>
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<tr>
<td></td>
<td></td>
<td>Paleosol</td>
<td>Weathered sinter fragments, some microbial</td>
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<tr>
<td>LACUSTRINE</td>
<td>Lakeshore Margin</td>
<td>HCS sandstone/Vaned mudstone</td>
<td>Encrusting wavy crenulated fabric</td>
</tr>
<tr>
<td>FLUVIAL</td>
<td></td>
<td>Plastically deformed siliceous pebbles (gel?)</td>
<td>Encrusting irregularly laminated fabric</td>
</tr>
</tbody>
</table>

Alkali chloride sinter textures – across sinter apron dominantly microbial, diverse fabrics, spatially variable, preservation potential variable

modified from Guido & Campbell 2011
Columbia Hills, Mars. Photo: S. Ruff (Ruff et al., 2015)

“Digitate protrusions”
Ruff et al. (2011)
Columbia Hills, Mars. Photo: S. Ruff (Ruff 2015)

“Digitate protrusions”
Ruff et al. (2011)
Digitate / knobby / spicular protrusions – New Zealand

Atiamuri – alkali chloride

Lake Rotokawa – acid

Waimangu – alkali chloride

Parariki Stream – acid-sulfate-chloride

Tiketere – alkali chloride

Columbia Hills, Mars. Photo: S. Ruff
Favored Mars 2020 rover landing sites

Scientists have nominated the most desirable sites for NASA’s next Mars rover, to be launched in 2020. Many of the favored sites lie in hydrothermal terrains near the edge of Isidis Basin.

Home Plate, Columbia Hills, Mars. Credit: S. Ruff

Lake Rotokawa

Parariki Stream spicules - microbial

Schinteie et al., 2007

Credit: AmericaSpace
Sample return mission to Mars - next decade(s)?

Human mission to Mars

Credit: Lunar & Planetary Sci Inst
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