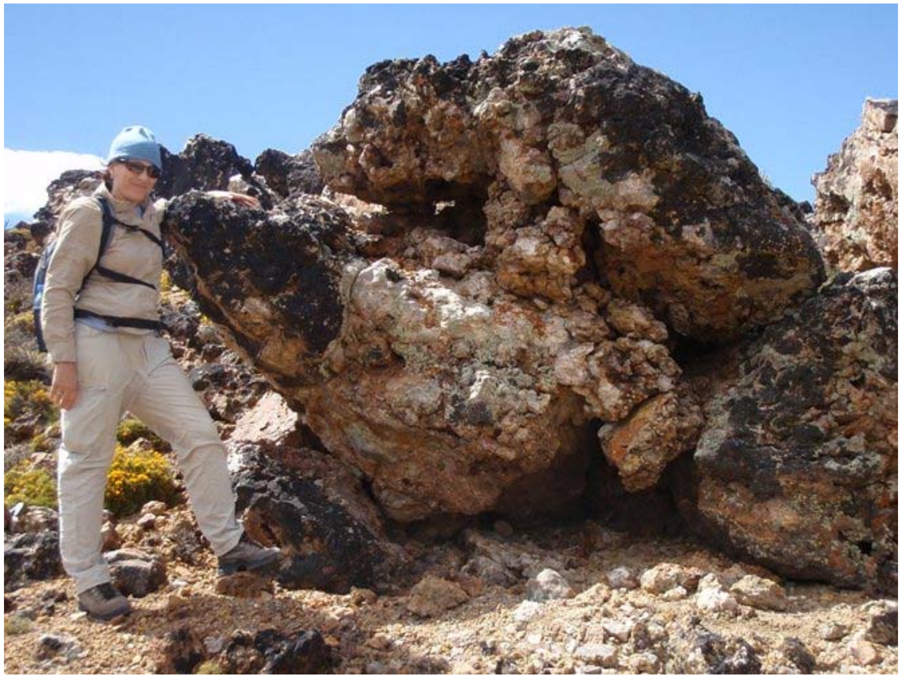
Astrobiology of Hot Springs on Early Earth and Mars



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THE UNIVERSITY OF AUCKLAND
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NEW ZEALAND

cnrs

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CONICET

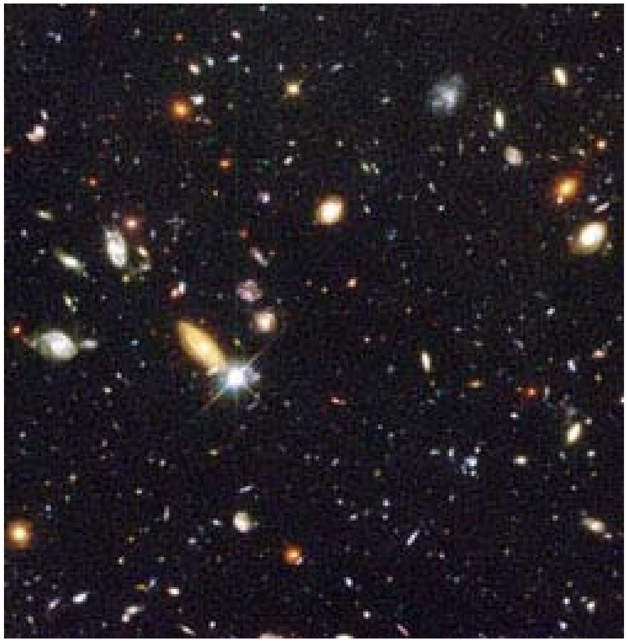
What is Astrobiology?

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

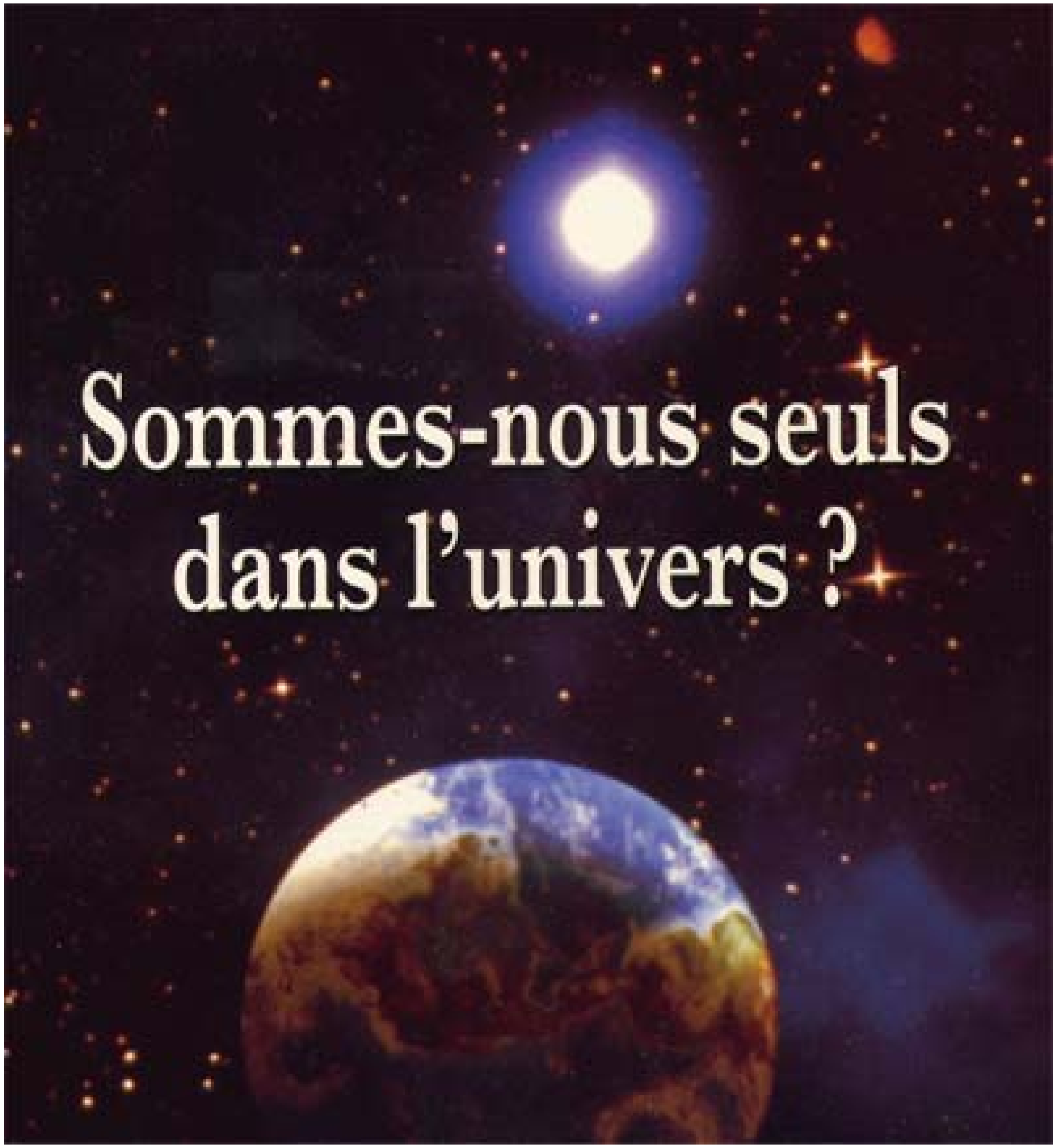
¤ Conditions necessary for life to emerge and flourish
¤ The origin of life
¤ Life's evolution and adaptation to range of environmental conditions
¤ The search for life beyond Earth
¤ Habitability of extraterrestrial environments
¤ Considering the future of life on Earth and elsewhere

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?

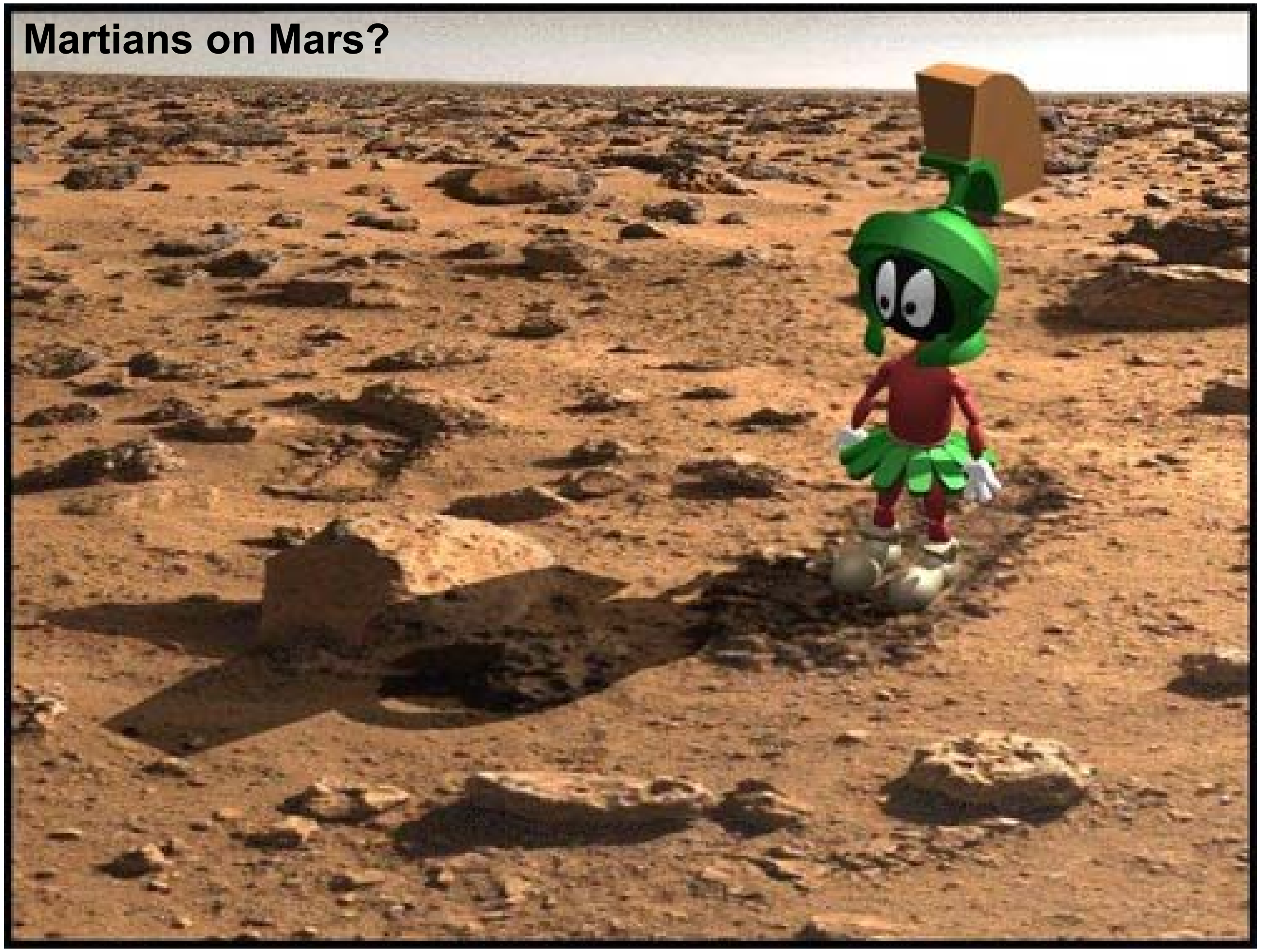


Asking Some Big Questions:
How did Life Originate?
What was Early Life on Earth Like?

Microbial - Bitter Springs site, Australia, 900 million years old

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?

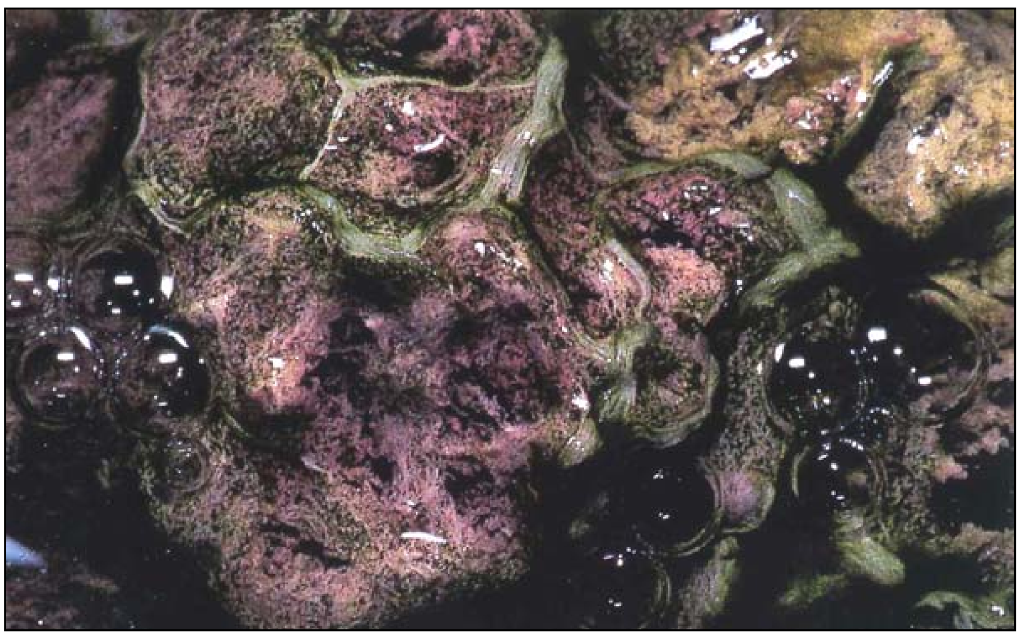
- No signs so far of intelligent life from space

Credit: National Geographic

'ET' hasn't called in yet for a visit …

The face of an extraterrestrial?

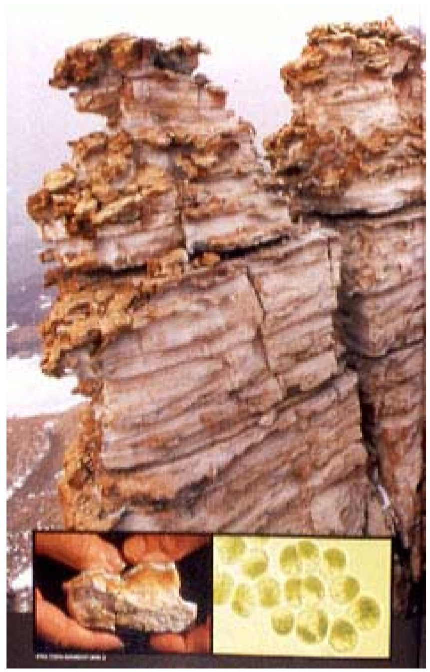
- **What about microbial life?**
- **On Earth, it is everywhere, even in the most extreme environments – *cold, hot, acid, alkaline, salty, deep subsurface* – analogues for possible life elsewhere?**



Credit: National Geographic

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

Some Present Day 'Early Earth-Analogue' Extreme Environments: Microbial Life

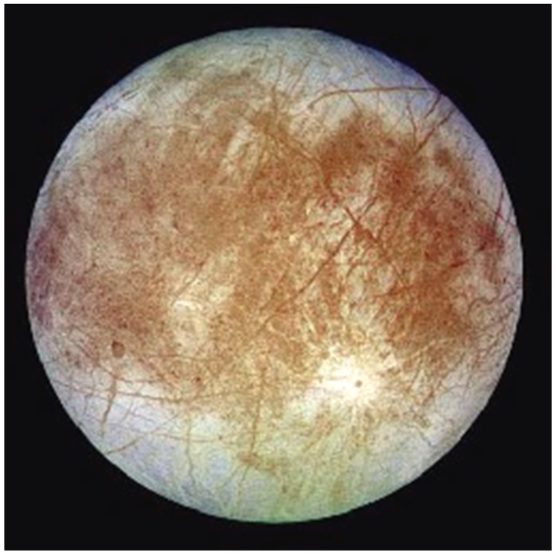


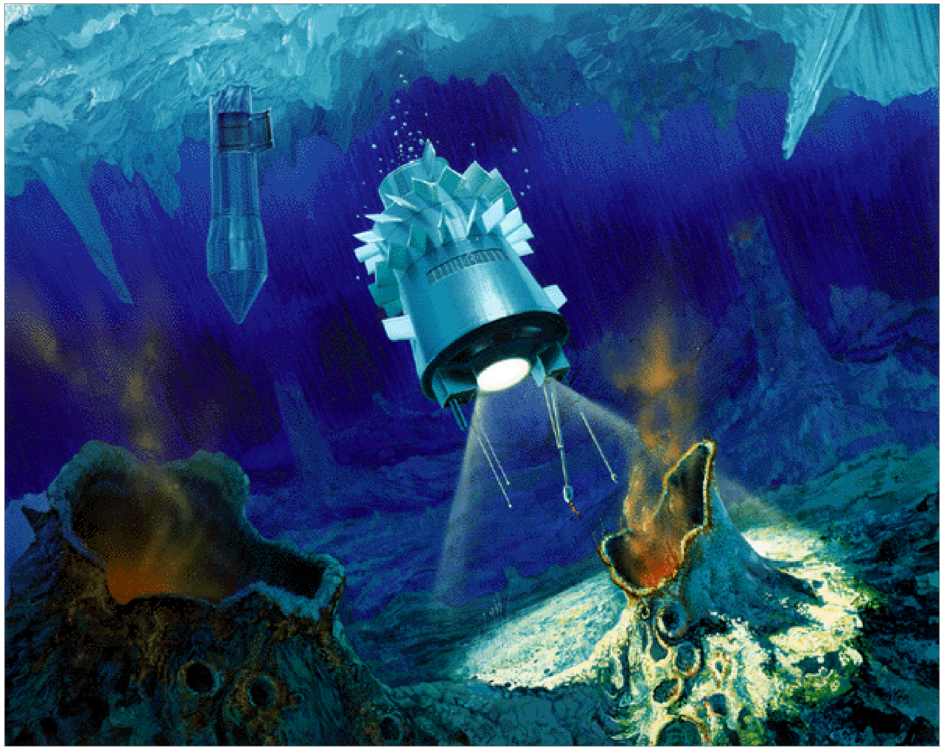
Credit: National Geographic

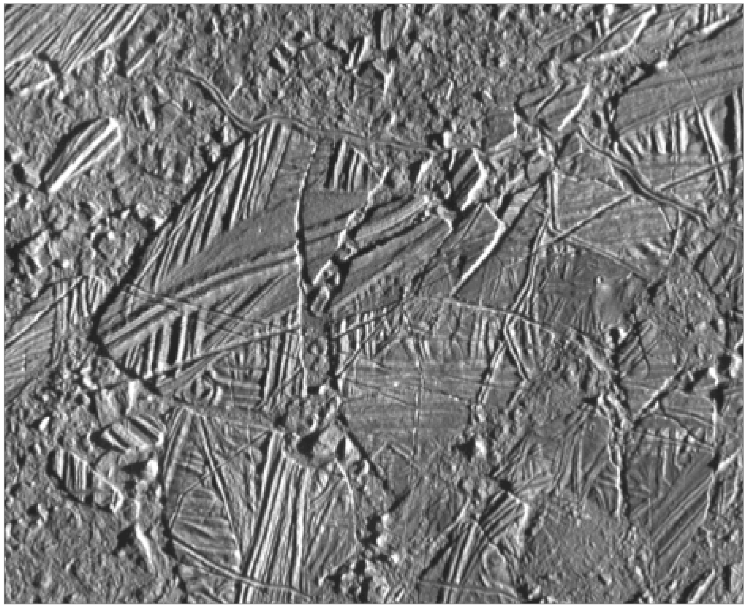
Hydrothermal Vents, Antarctic Dry Valleys, Very Salty Lagoons, Deep-Rock Subsurface, Hydrocarbon Seeps, High Dry Deserts, Sub-Glacial Lakes and Oceans, Terrestrial Hot Springs

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?

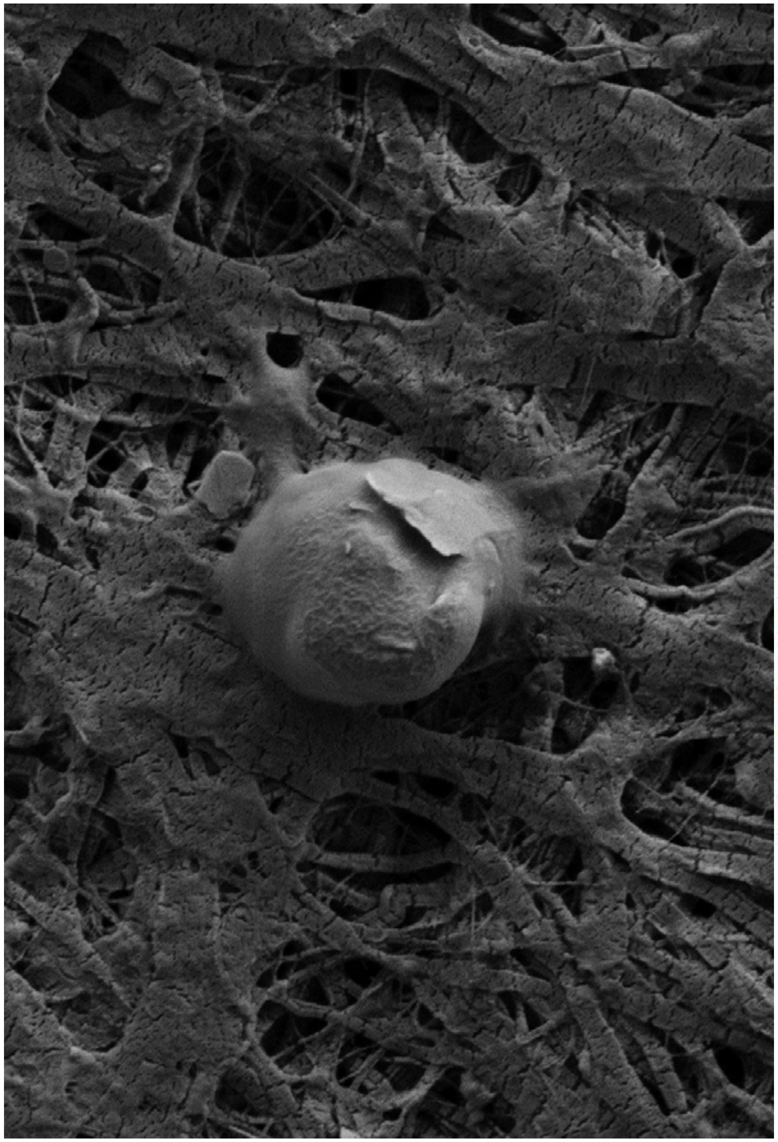


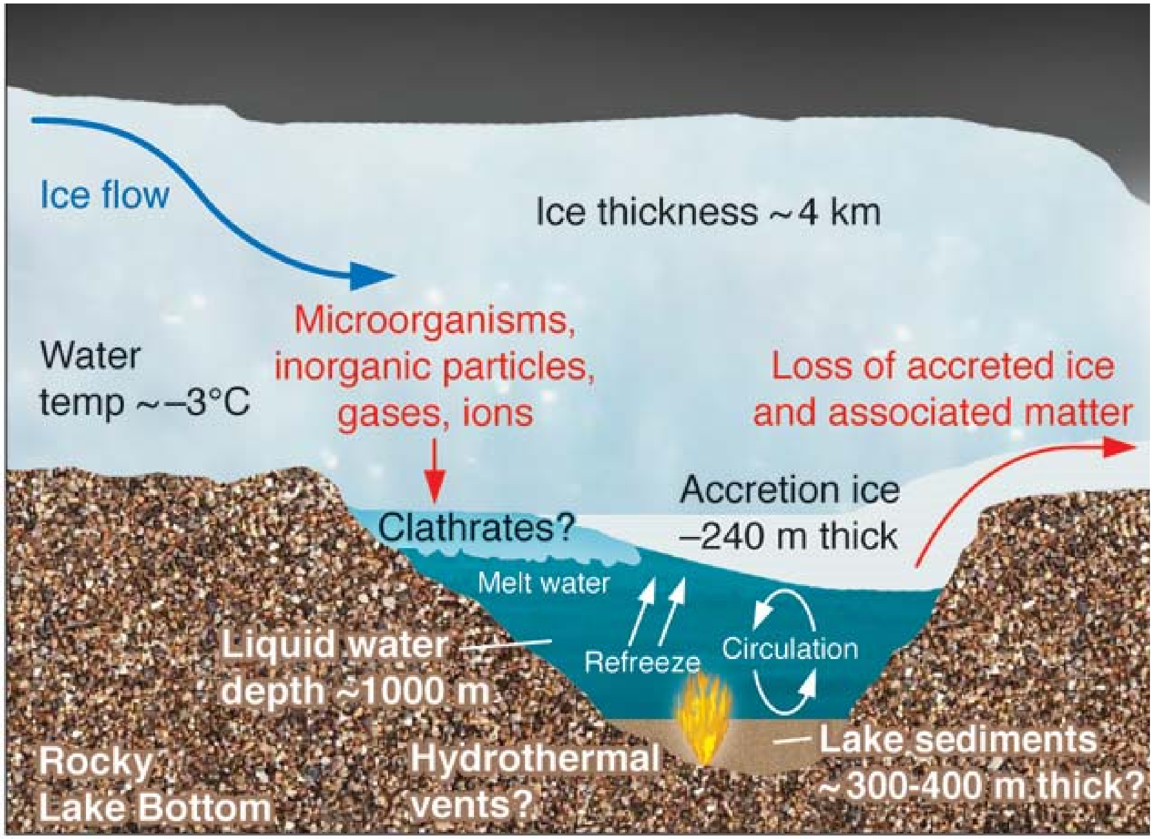




Credits: jpl.nasa.gov, planetary.org

Where to look for life in our own Solar System?

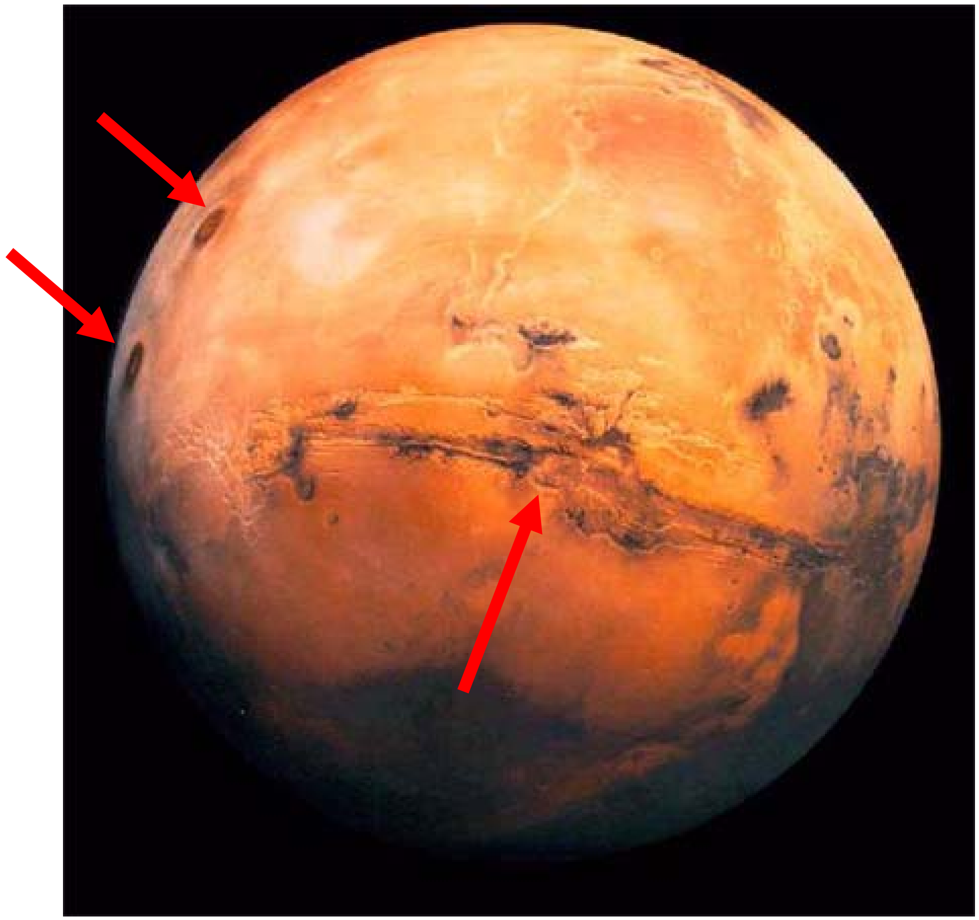




Antarctic subglacial lakes: Extreme environment analogues for icy worlds

Credits: oneworldoneocean, livescience

ET life on Mars? Evidence for ancient volcanism and running water



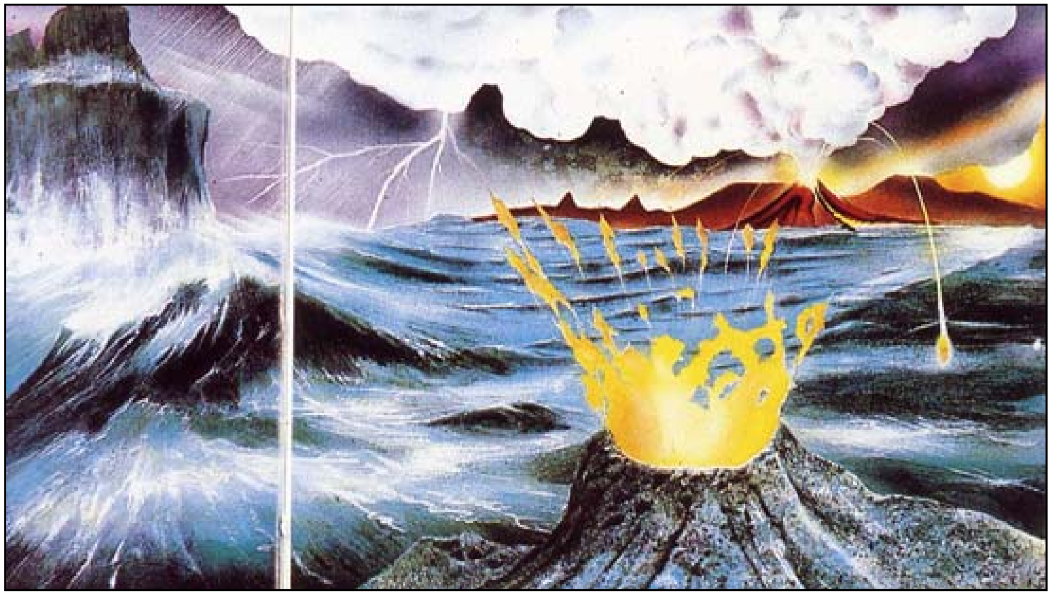
Credit: Lunar Planetary Institute

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?**

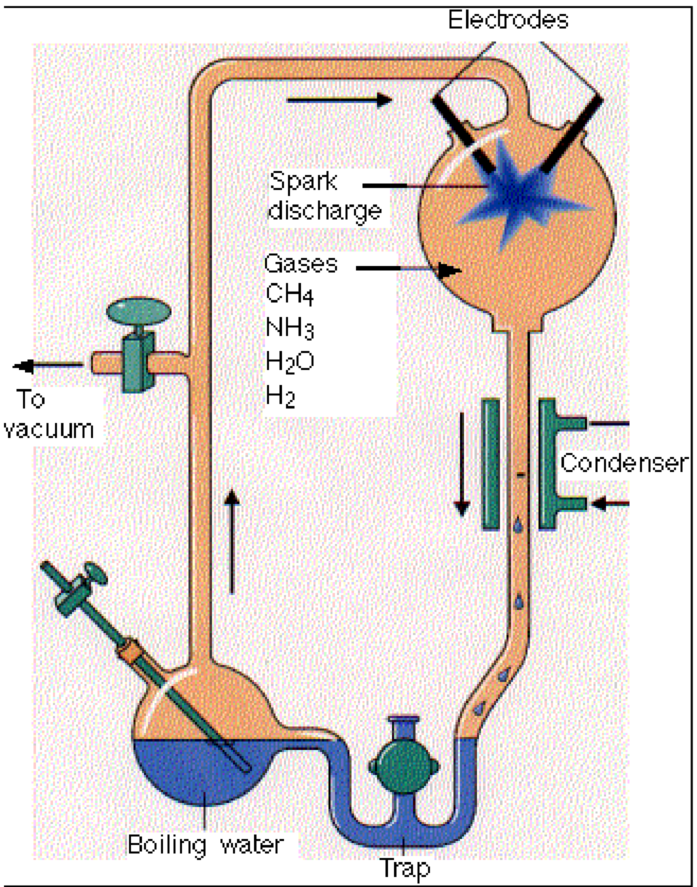
More debris in Solar System early in its history. More meteorite impacts – hot – on early Earth until ~3.8 Ga.

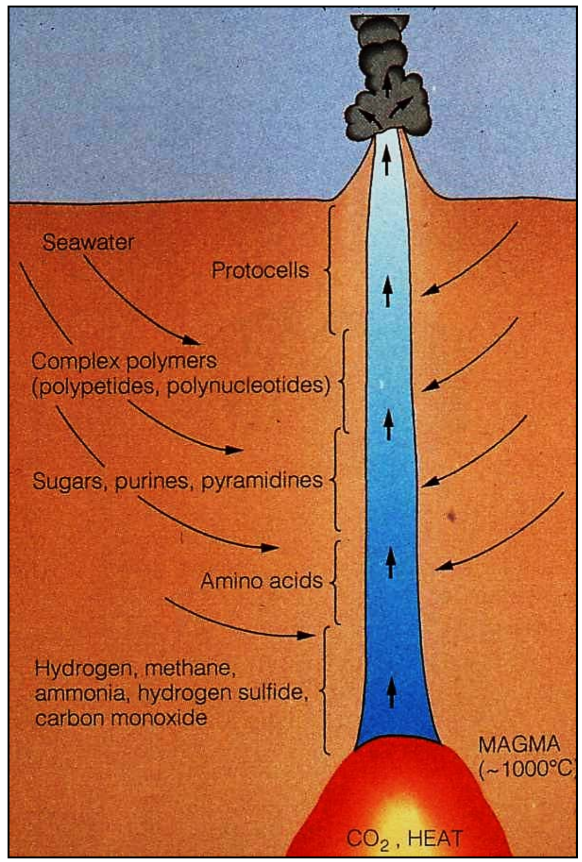


Earth finally cooled enough for volcanic vapours to condense & form oceans

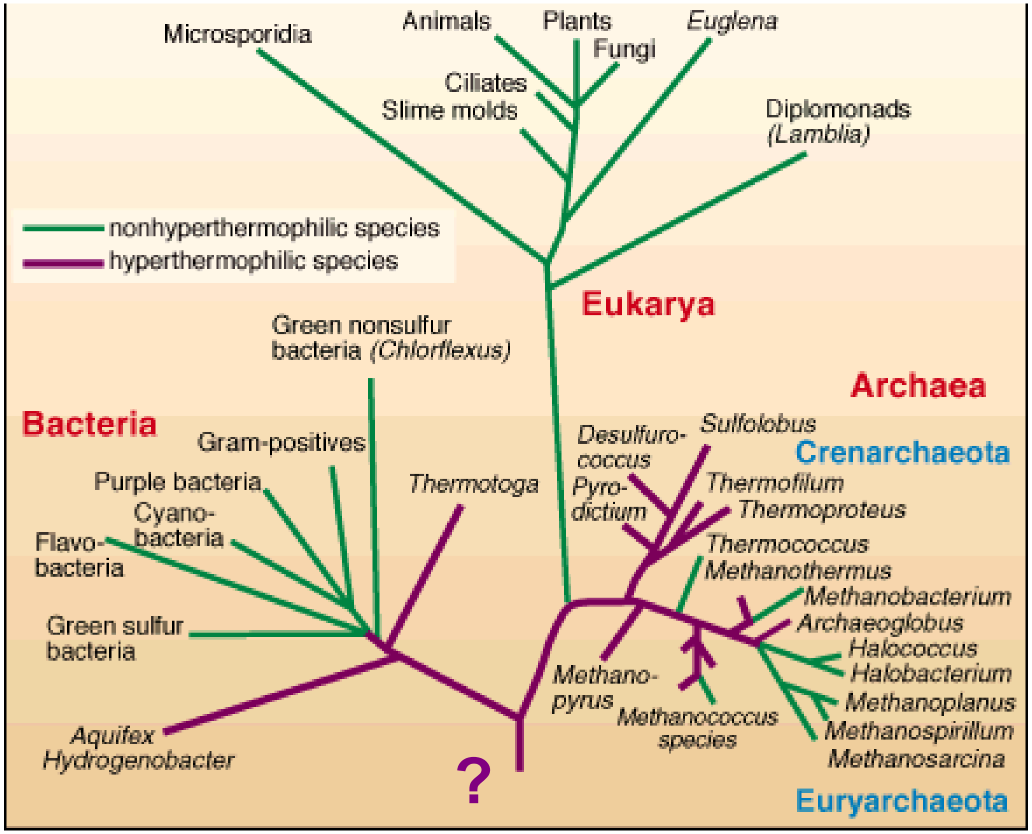
How did life take hold on Earth, > 3 Ga?

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





Credits: daviddarling.info, Wicander & Monroe 2004

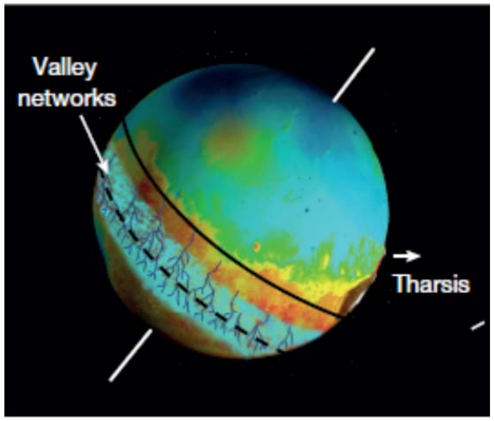


Credits: Science, MicrobeWiki

Aquifex pyrophilus in Yellowstone hot spring

Deep roots (most primitive living organisms) of Tree of Life are heat-loving microbes – remnant of early bombardment?

Late Noachian/Early Hesperian



Tharsis dome formation,
tropical precipitation with valley
networks formation

Bouley et al. 2016 (March)

Why Study Terrestrial Hot Spring Deposits? – Mars Analogue, Early Life on Earth

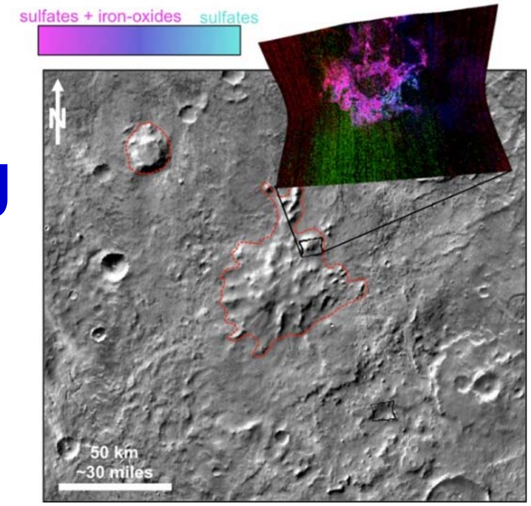
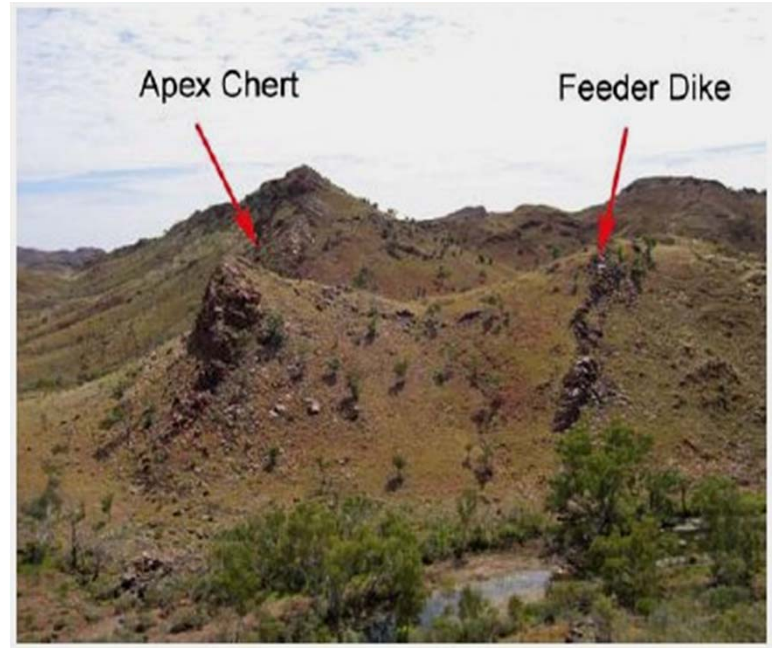


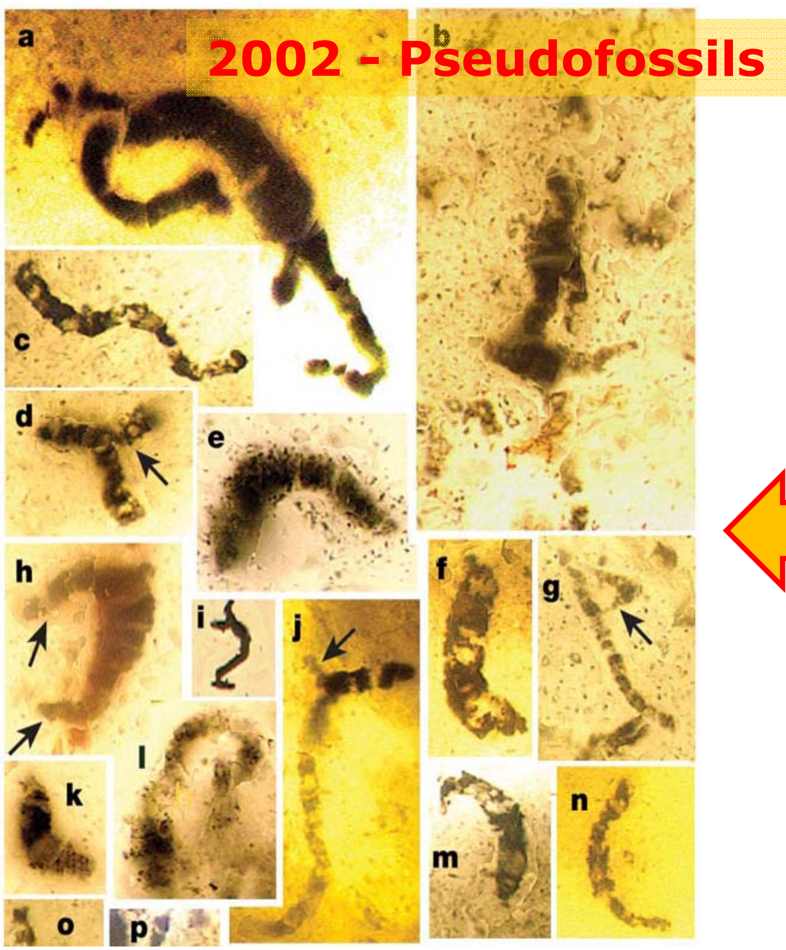
photo: NASA/JPL-Caltech/JHUAPL/ASU

Sisyphi Montes – Ackiss et al. 2016 (May)

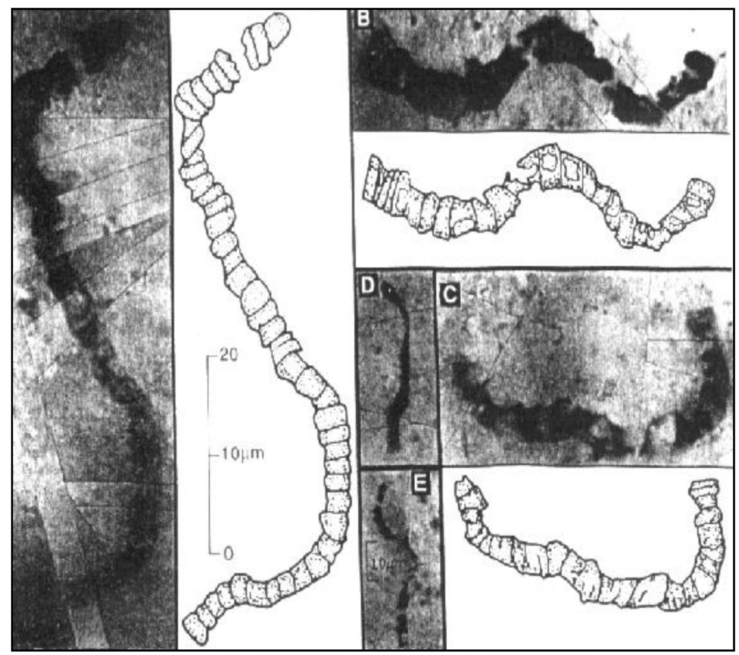
- **Coeval past volcanic activity + surface water on Mars – on Earth habitable extreme environments**
- **Rapid mineralization by <u>silica</u>, carbonate or iron – potential to preserve microbial fossils *in situ***
- **Textural-mineral biosignatures distributed along environmental gradients – parallels 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



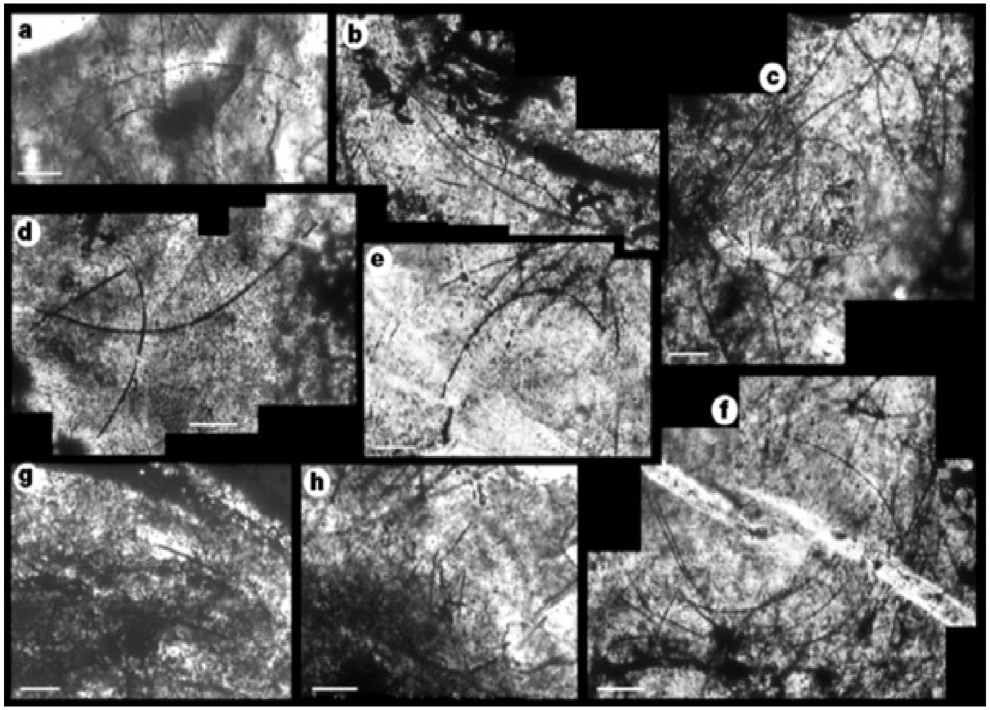


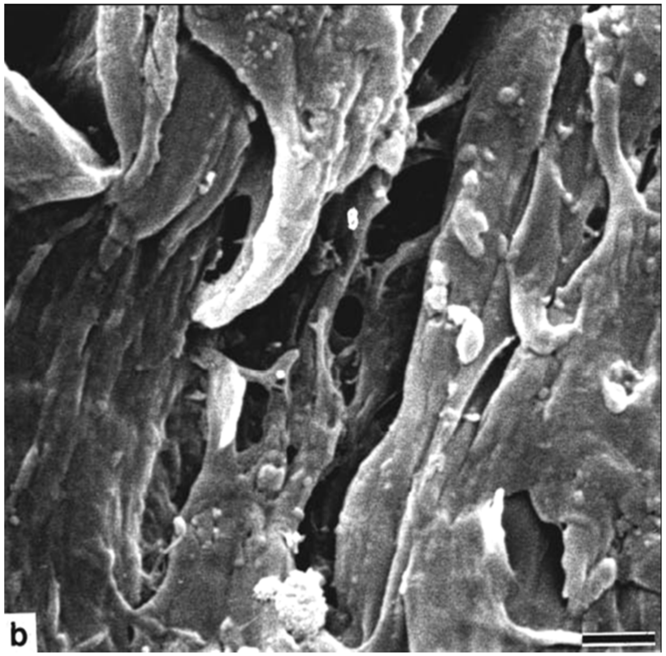
1993 - 11 spp. Cyanobacteria?



Schopf, 1993; Brasier et al. 2002

Filamentous microfossils -- 3.25 billion year old hydrothermal vent deposit, Pilbara, Western Australia

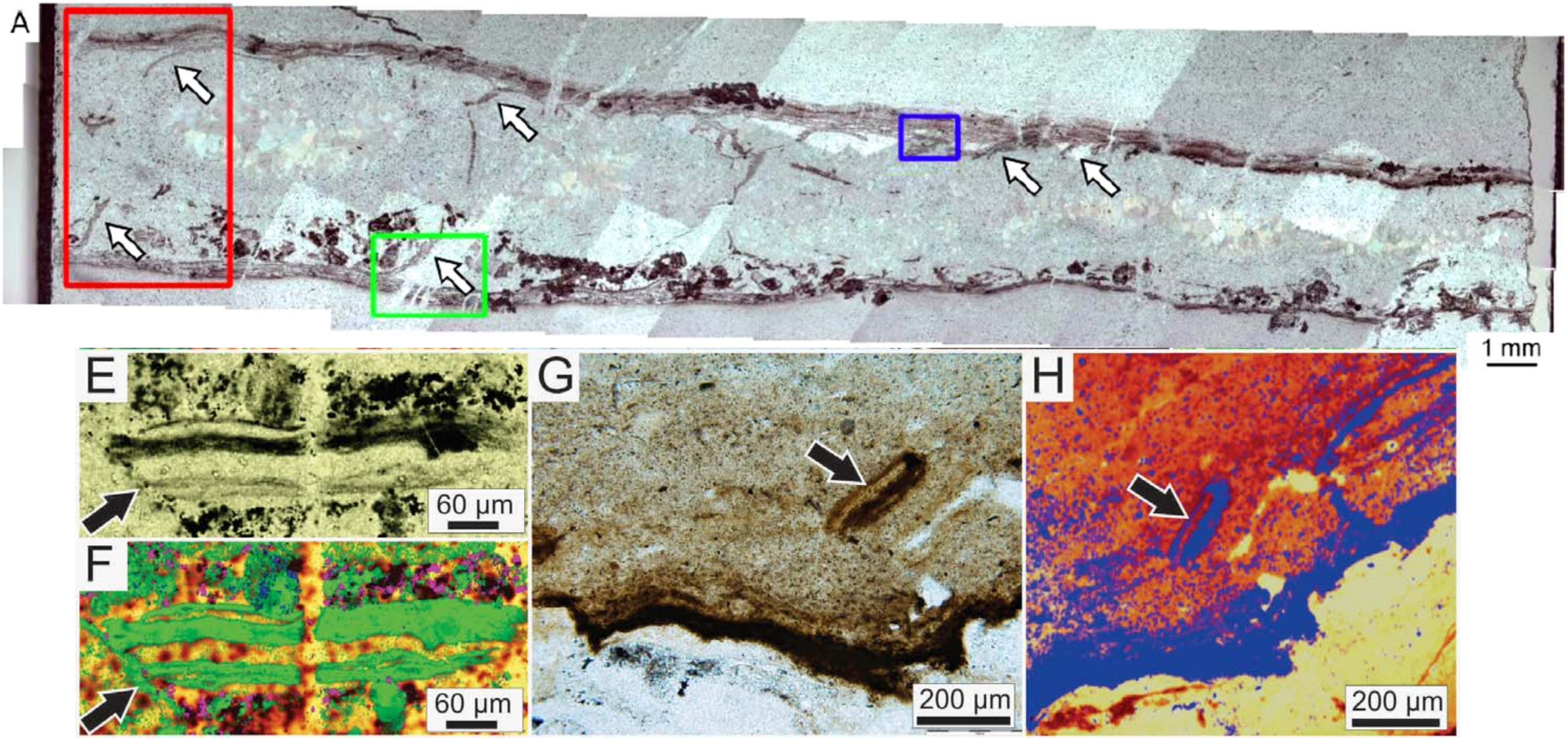




Biofilms – hydrothermal shallow marine sediments, Barberton, South Africa (3.4-3.2 Ga)

Some early life habitats were HYDROTHERMAL

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)

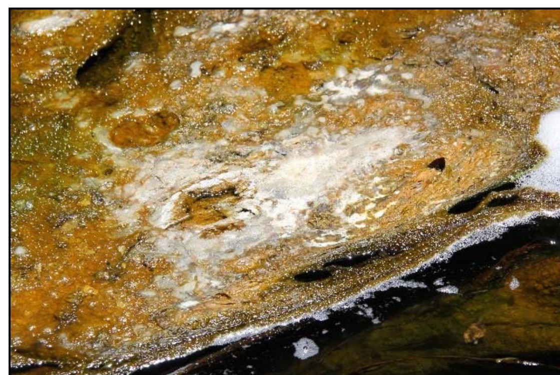
LASER µ-RAMAN COLOUR KEY:

- green, carbon
- red to yellow, quartz
- magenta, muscovite
- blue, anatase, TiO_2

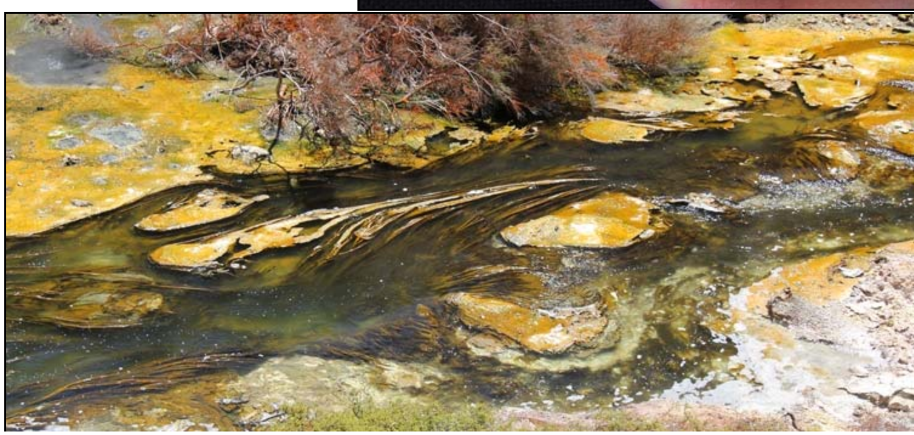
Westall et al., 2015

Early life and Hot Water *on Land*: 3.48 Ga, W Australia

9kyrs, Mangatete sinter, New Zealand

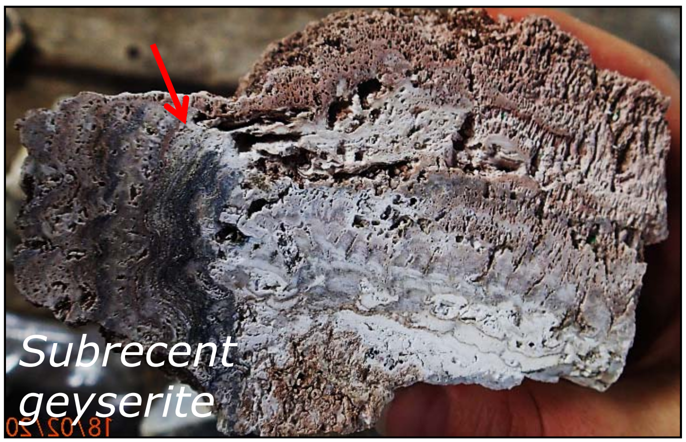


Djovic et al., in review; Drake et al., 2014



Hot Water Creek, Waimangu, NZ

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

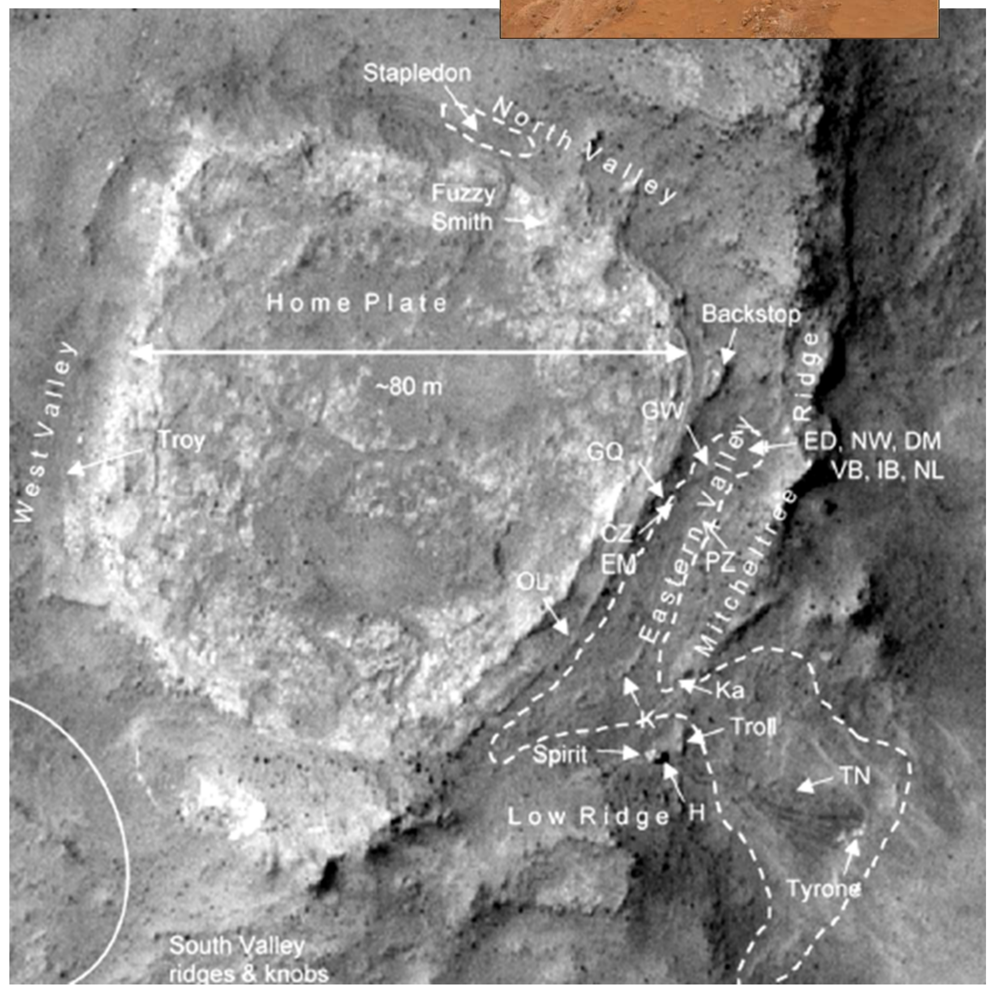


Drilling beneath weathering – biogeochemical cycles of early microbes

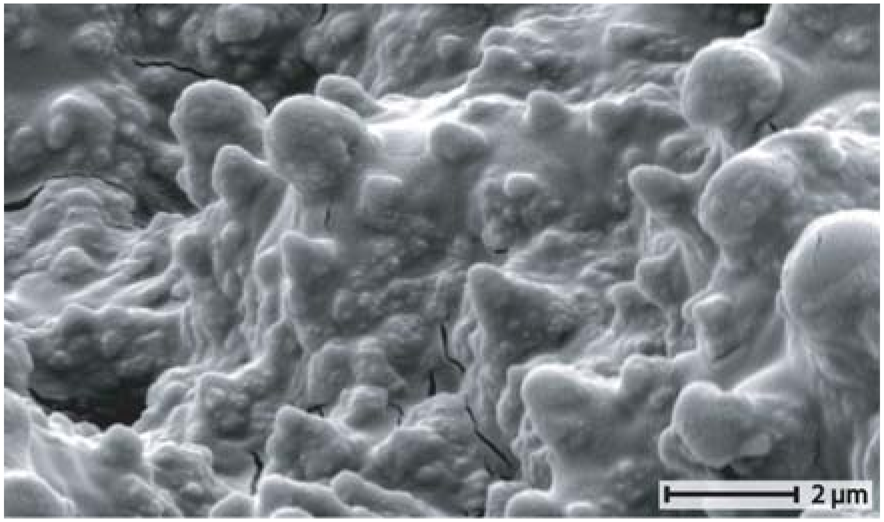
Characteristics, distribution, origin, and significance of opaline silica observed by the Spirit rover in Gusev crater, Mars

Steven W. Ruff,[1] Jack D. Farmer,[1] Wendy M. Calvin,[2] Kenneth E. Herkenhoff,[3] Jeffrey R. Johnson,[3] Richard V. Morris,[4] Melissa S. Rice,[5] Raymond E. Arvidson,[6] James F. Bell III,[5] Philip R. Christensen,[1] and Steven W. Squyres[5]

JOURNAL OF GEOPHYSICAL RESEARCH, VOL. 116, E00F23, doi:10.1029/2010JE003767, 2011



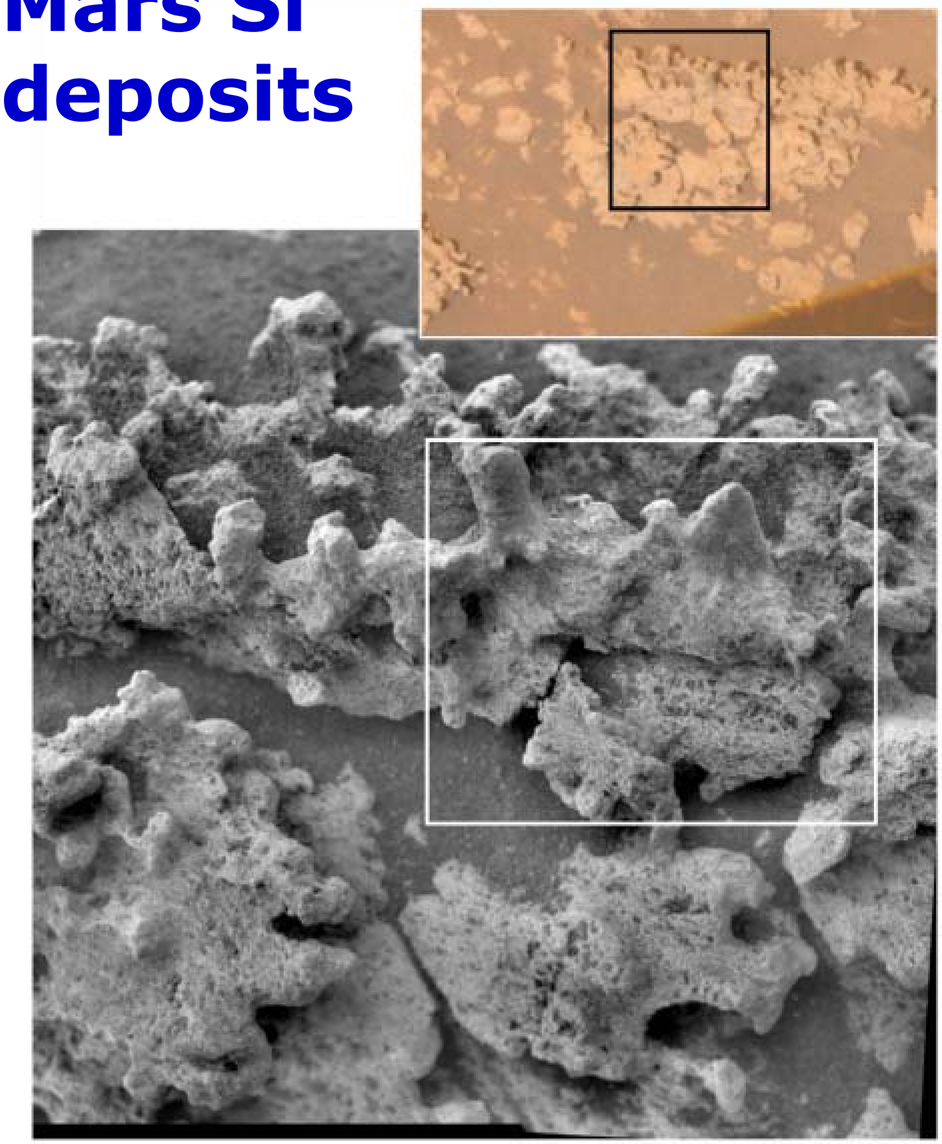
Home Plate, Columbia Hills opaline silica deposit

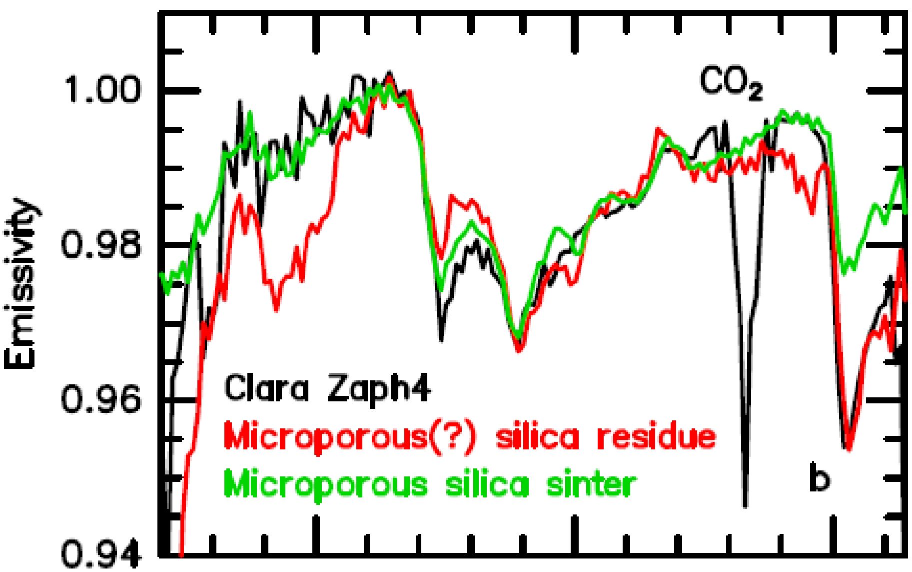


Parariki Stream acidic sinter, Rotokawa

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.

Mars Si deposits

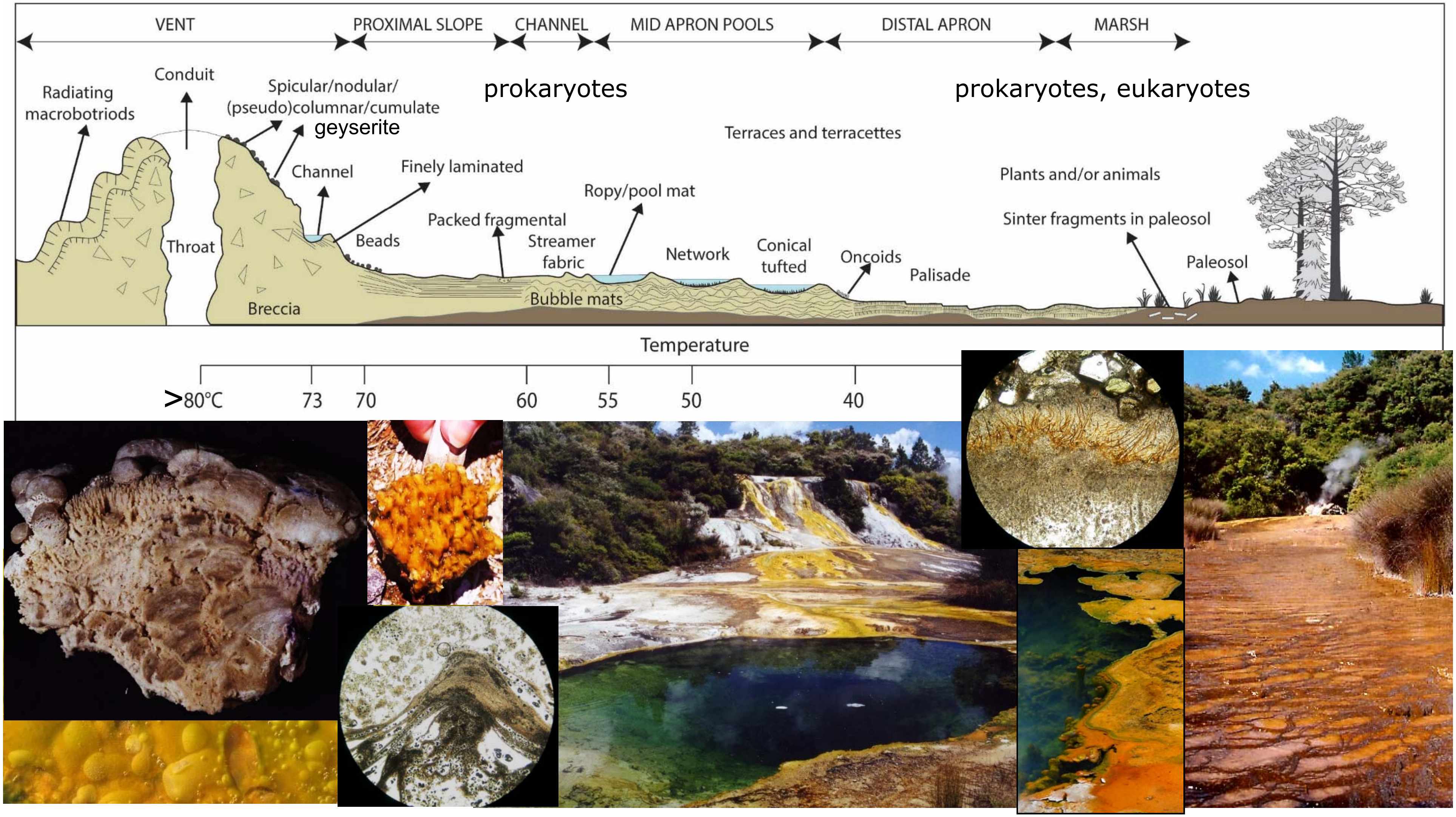




Credits: Schinteie et al. 2007; Ruff et al. 2011

Alkali-chloride siliceous hot spring (sinter) facies model

Hamilton et al. 2016

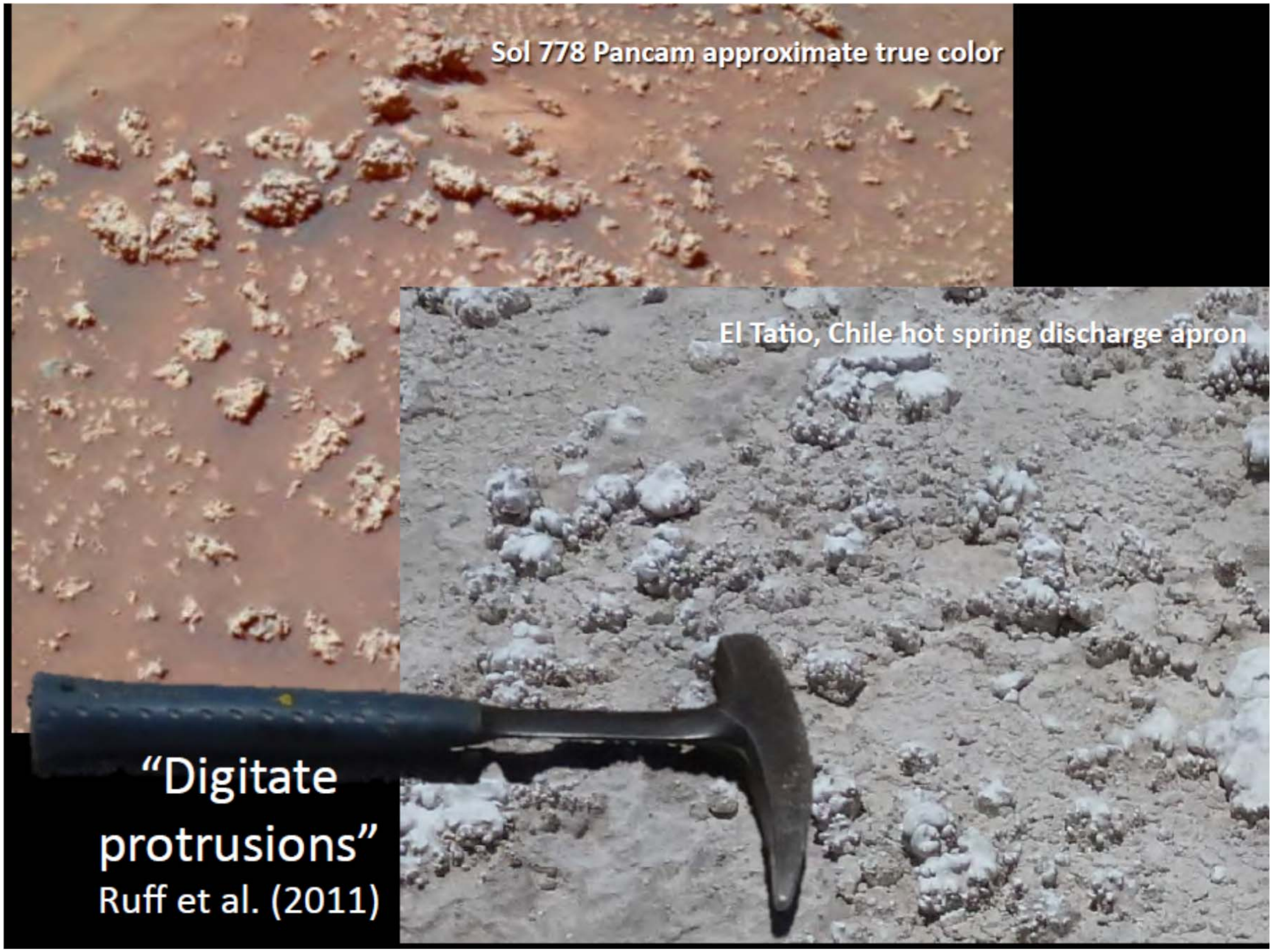


Facies Assemblage	Facies	Geometry & Textures	Microbial Fossil Association
PROXIMAL	Vent Mound or Spring Vent Pool	Conduit/Throat	
		Breccia/Panal	
		Channel	Biofilm
	geyserite	Spicular/Nodular/Botryoidal/Columnar/ Pseudocolumnar/Cumulate	Tubular biomorphs/filaments in morphologically varied geyserite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

modified from Guido & Campbell 2011

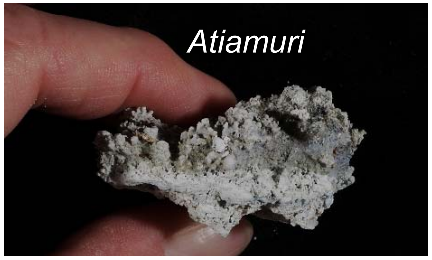
Alkali chloride sinter textures – across sinter apron dominantly microbial, diverse fabrics, spatially variable, preservation potential variable

Columbia Hills, Mars. Photo: S. Ruff (Ruff et al., 2015)



Columbia Hills, Mars. Photo: S. Ruff (Ruff 2015)

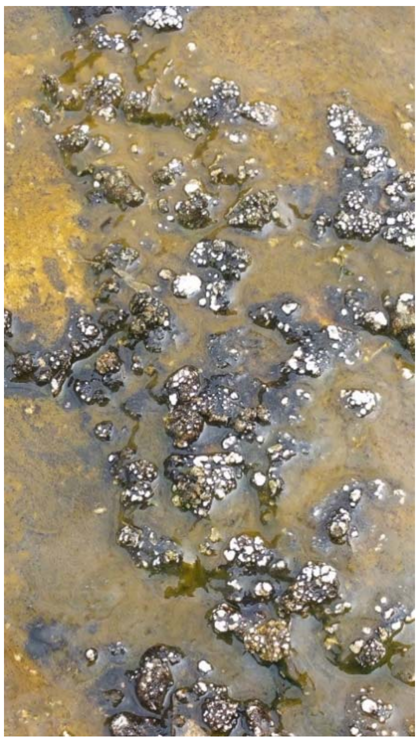
Digitate / knobby / spicular protrusions – New Zealand



Atiamuri

Waimangu – alkali chloride

Parariki Stream – acid-sulfate-chloride

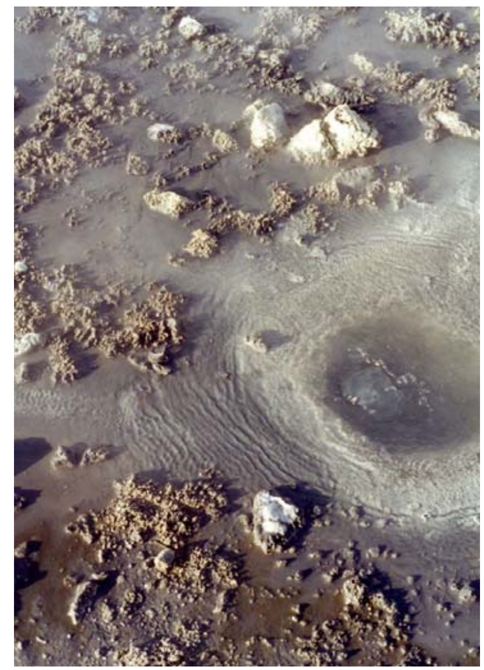


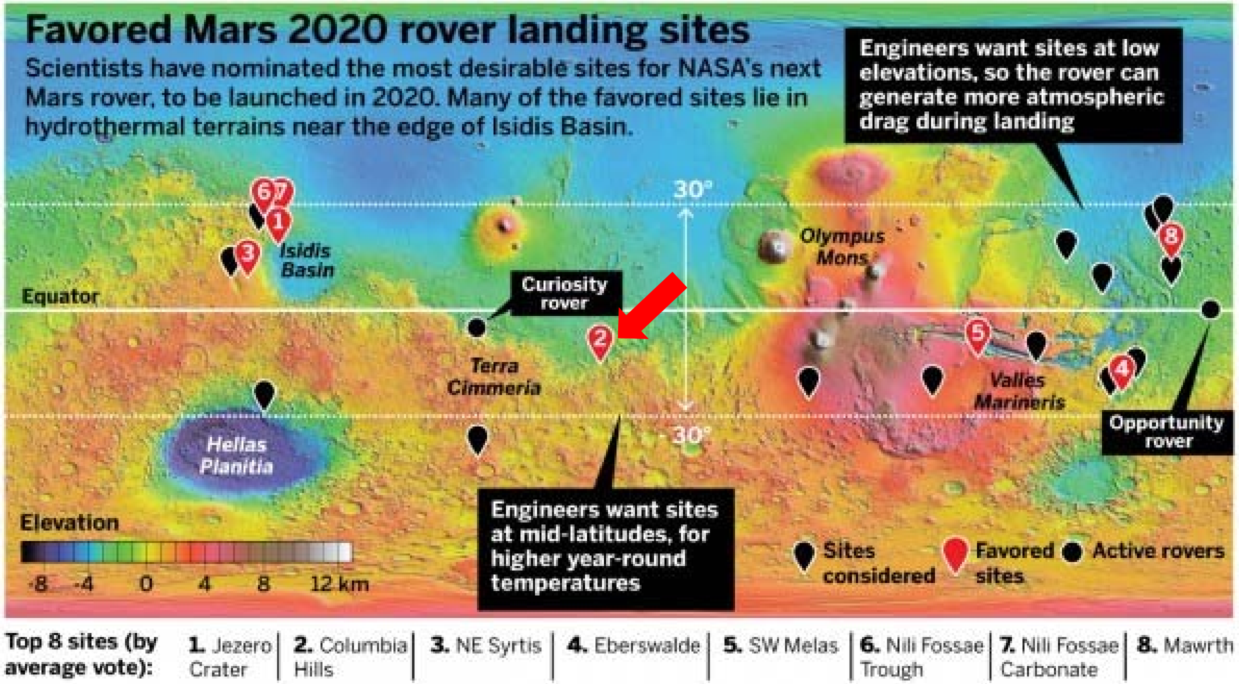
Atiamuri – alkali chloride

Tiketere – alkali chloride

Columbia Hills, Mars. Photo: S. Ruff

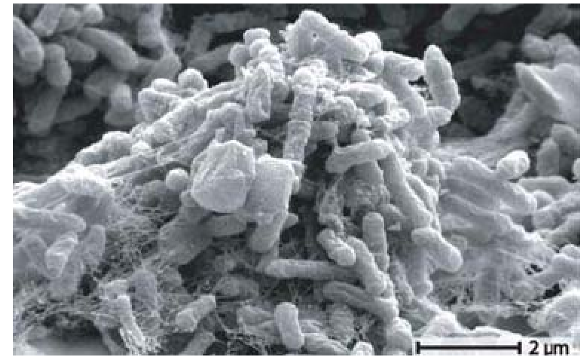
Lake Rotokawa – acid





Credit: AmericaSpace

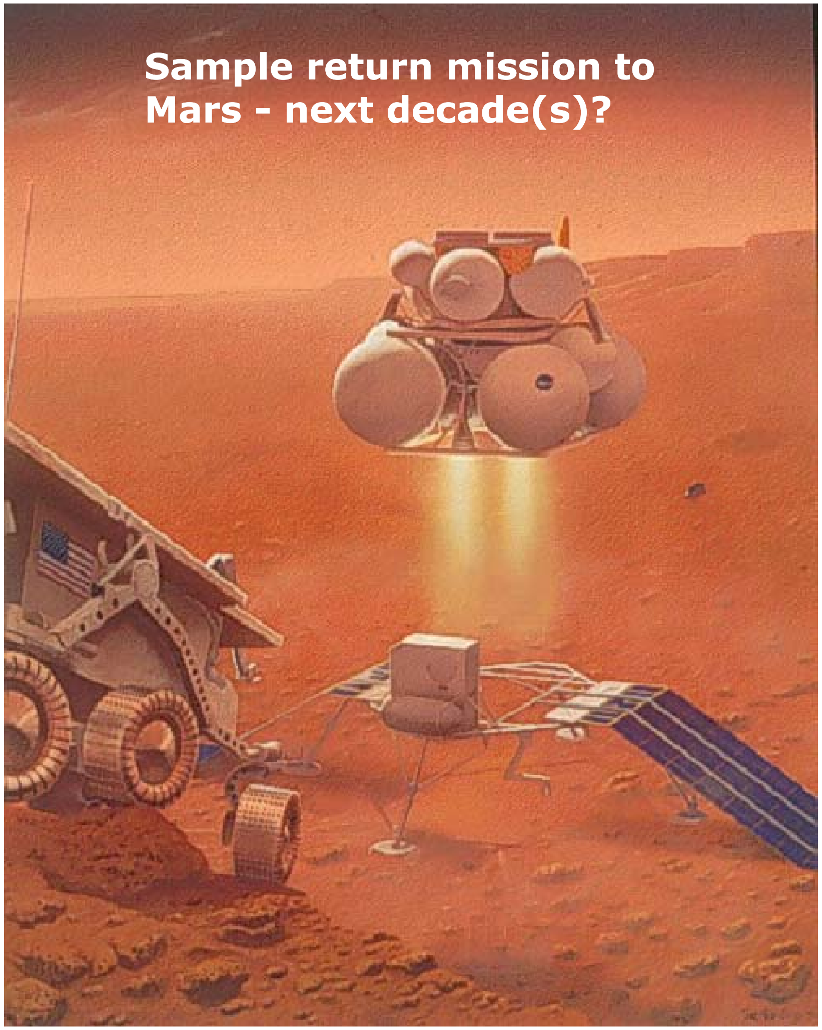
Parariki Stream spicules - microbial



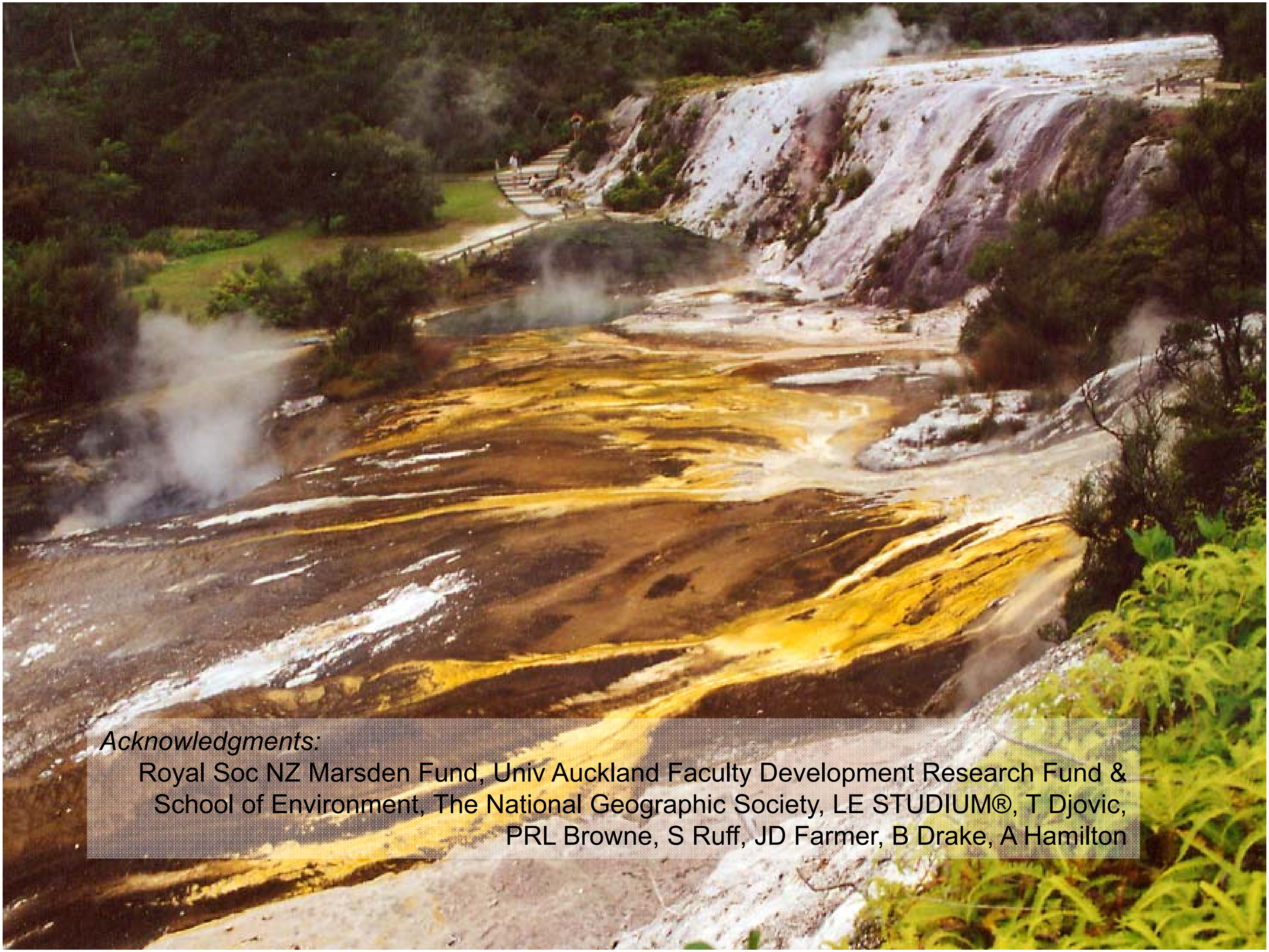
Schinteie et al., 2007

Lake Rotokawa

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



Credit: Lunar & Planetary Sci Inst



Acknowledgments:

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