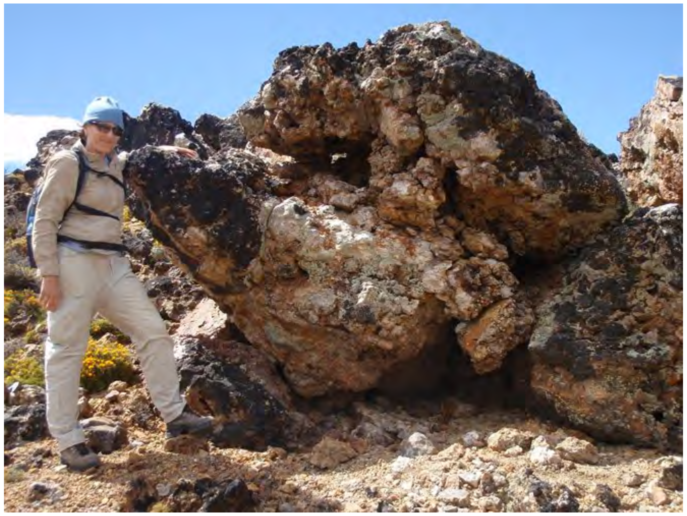
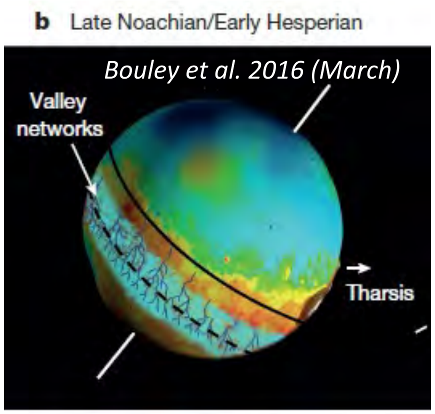
Tracing hot-spring facies and their geothermally silicified microbial textures into the terrestrial geologic record: Relevance for Mars biosignature recognition



K.A. Campbell, D.M. Guido, J.D. Farmer, M.J. Van Kranendonk, S.W. Ruff, F. Westall



Tharsis dome formation, tropical precipitation with valley networks formation

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

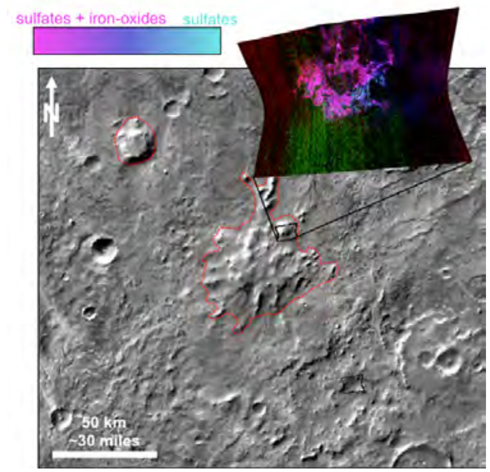


photo: NASA/JPL-Caltech/JHUAPL/ASU
Sisyphi Montes – Ackiss et al. 2016 (May)

- Coeval past volcanic activity + surface water on Mars – on Earth habitable extreme environments
- Rapid mineralization by silica, carbonate or iron – potential to preserve microbial fossils *in situ*; tracking post-depositional biosignature quality
- Textural-mineral biosignatures distributed along environmental gradients – parallels to some Early Archean (3.3-3.5 Ga) hydrothermal settings on Earth (... Mars?)

Bicarbonate springs

Acid sulfate springs

Acid sulfate-chloride springs

Alkali chloride, near neutral pH

opal-A

Hydrothermal Environments, Terrestrial, Table 1 Selected chemical analyses of hot spring and geyser waters

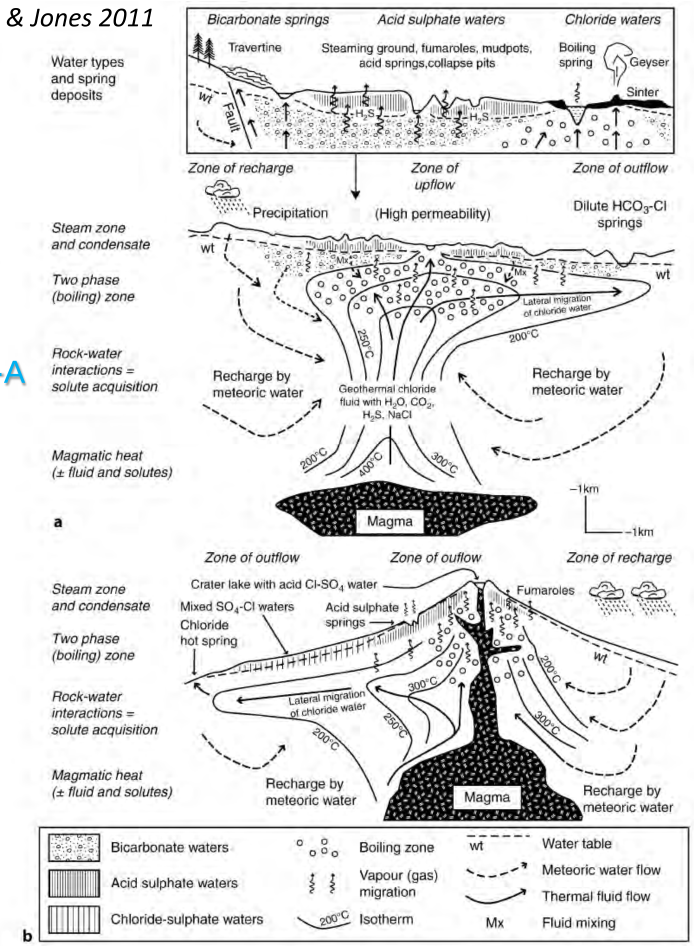
Water type	Source	pH	T°C	Na	K	Ca	Mg	B	Cl	SO_4	HCO_3	SiO_2
Chloride waters												
Ohaaki Pool, NZ	A	7.1	95	860	82	2.5	0.1	32	1,060	100	679	338
El Tatio, Chile	B	7.4	85	4,600	520	280	0.3	187	8,220	38	39	256
Sulfate waters												
Waiotapu, NZ	A	2.2	99	32	6.6	4.0	0.8	2	6	338	<1	308
Roaring Mt., Yellowstone	C	2.4	92	48	42	3.8	0	–	43	435	–	335
Bicarbonate waters												
L. Bogoria, Kenya	D	9.02	99	1,710	38	0.2	0.05	–	340	65	3,750	135
Mammoth, Yellowstone	E	7.2	69	130	54	323	67	4.1	163	563	755	54
Mixed anion waters												
Rotokawa, NZ	A	6.6	90	380	32	30	0.8	16.3	477	103	173	182
North Waiotapu, NZ	F	3.1	99	153	28	12.9	2.1	–	182	338	0	363

Sources of data: *A* Nicholson (1993, Table 2.1), expressed in mg kg^{-1}. *B* Cusicanqui et al. (1986), expressed in mg kg^{-1}. *C* Brock (1978, Table 2.3), expressed in mg l^{-1}. *D* Renaut and Jones (1997), expressed in mg l^{-1}. *E* Bargar (1978), average of 15 analyses, expressed in ppm. *F* Jones et al. (2000), expressed in ppm

Character of resulting siliceous hot-spring deposits:

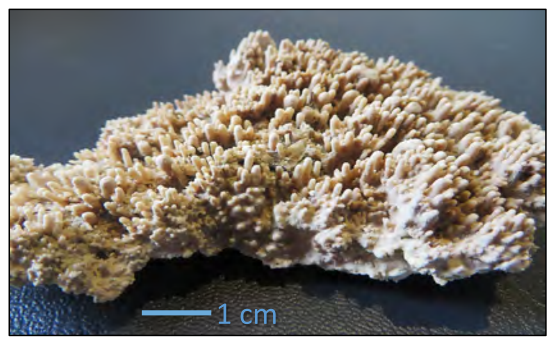
- fluid composition, temp., duration & volume
- topographic relief, aridity, water table
- geological setting & history

Renaut & Jones 2011

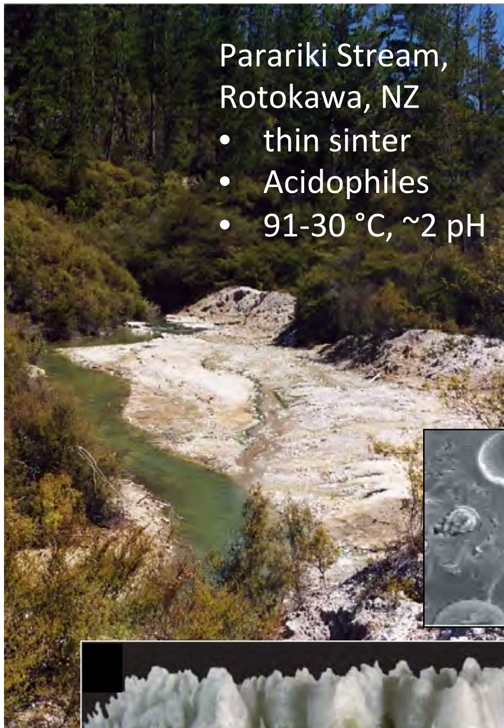


Hydrothermal Environments, Terrestrial, Figure 3 General models of liquid-dominated magmatic geothermal systems showing relationships between subsurface fluid evolution and associated surface environments. (a) Liquid-dominated system in a low-relief setting. Inset expands the upper left half of the figure to show how surface environments and deposits vary spatially according to the type of fluid being discharged. (b) Liquid-dominated system in a high-relief (stratovolcano) setting. Adapted from figures by Henley and Ellis (1983) and Nicholson (1993).

Acid sulfate systems - destructional



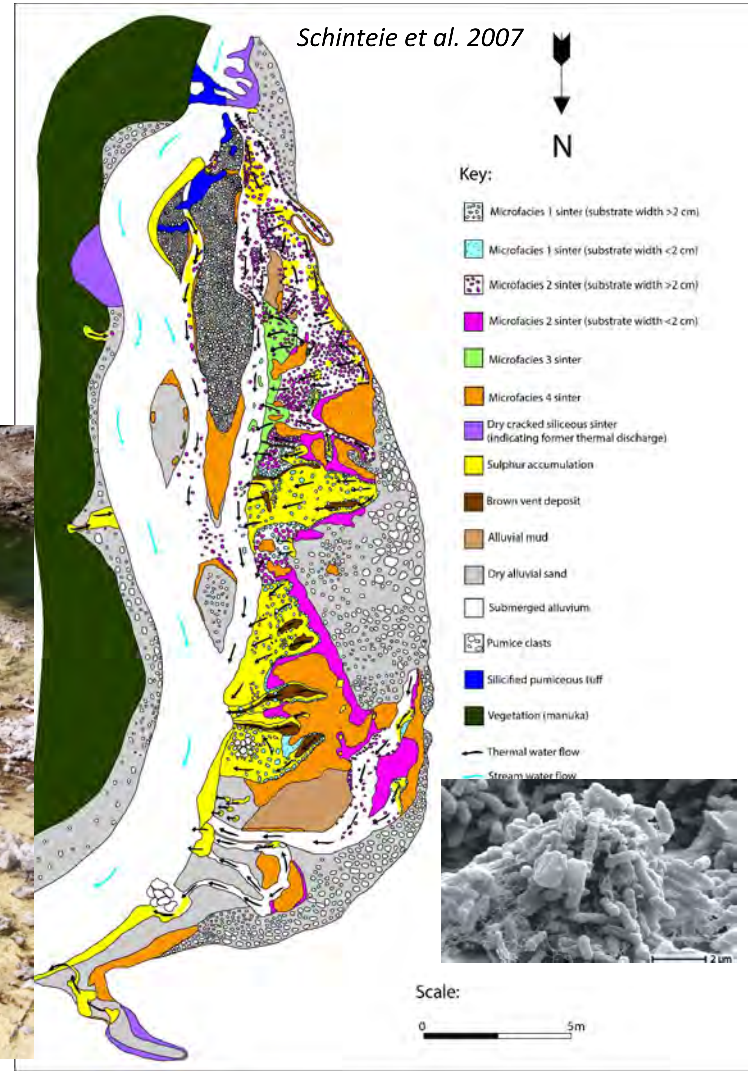
Acid sulfate-chloride springs – mixed

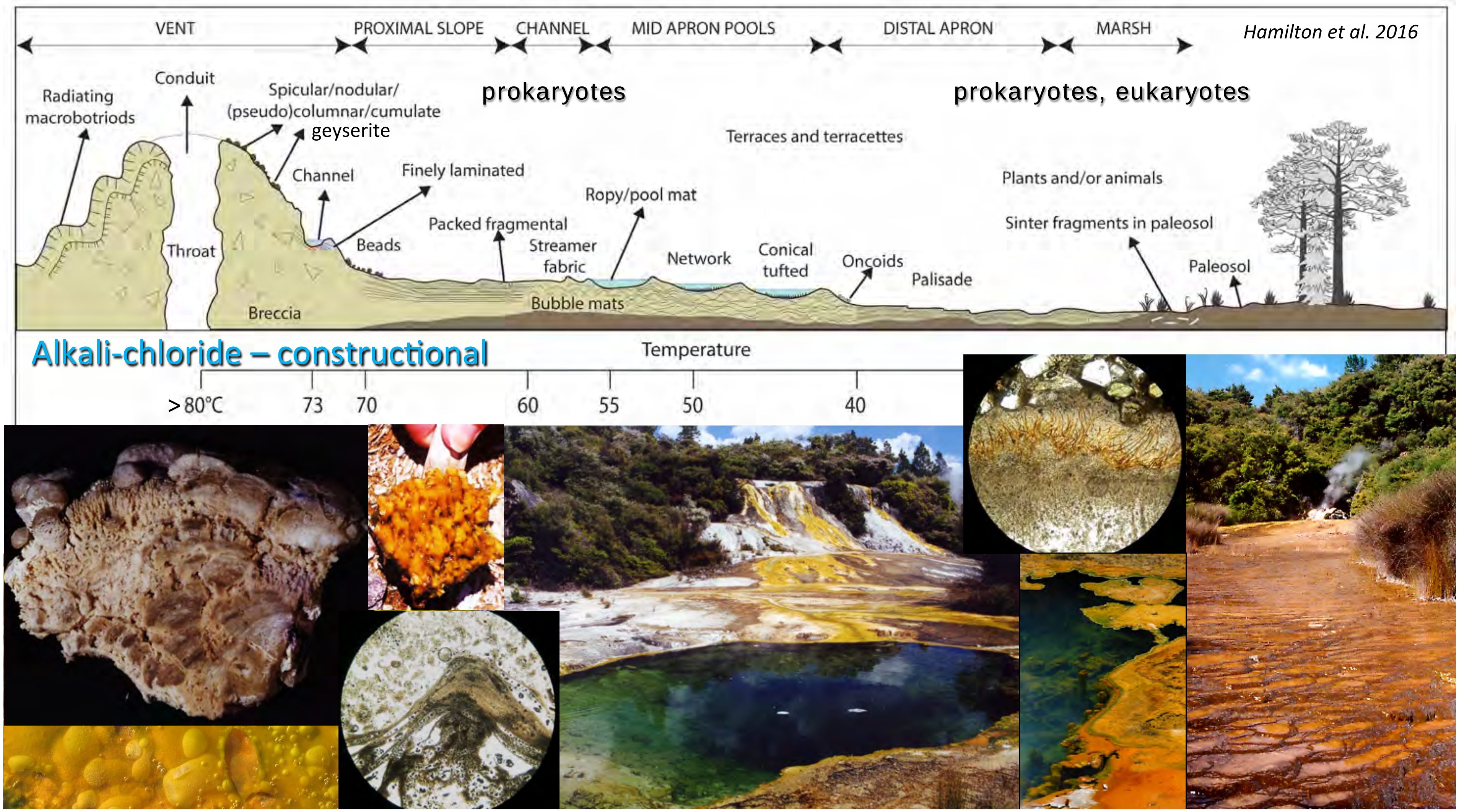


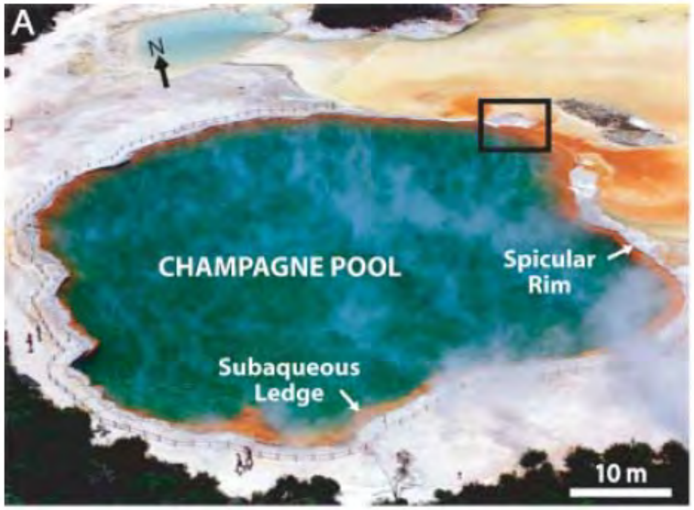
- thin sinter
- Acidophiles
- 91-30 °C, ~2 pH

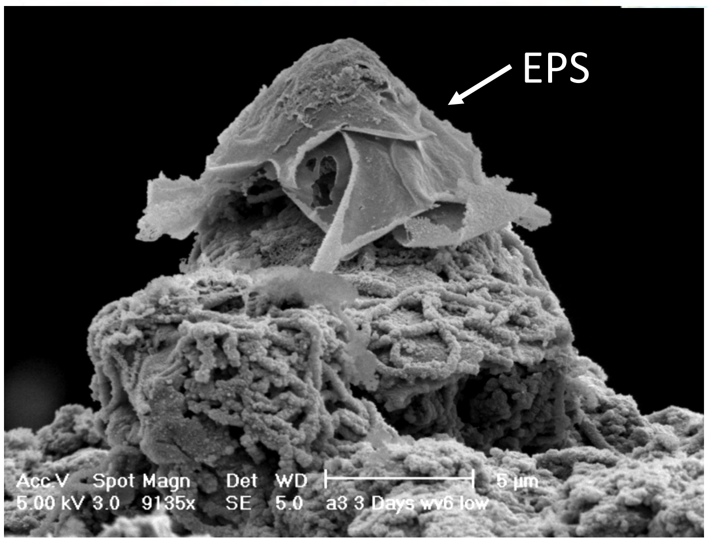
Cyanidiophyceae

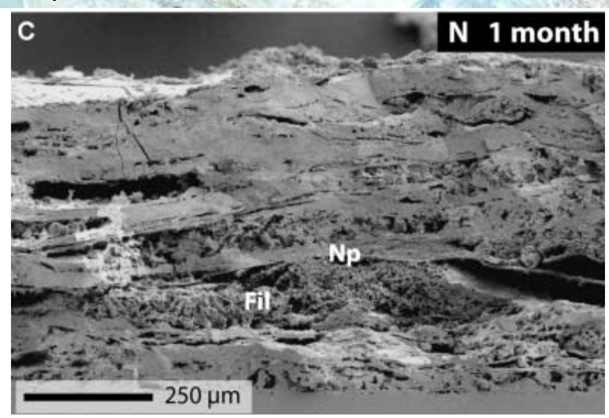
Schinteie et al. 2007




VENT
PROXIMAL SLOPE
CHANNEL
MID APRON POOLS
DISTAL APRON
MARSH
Hamilton et al. 2016
prokaryotes
prokaryotes, eukaryotes
Radiating macrobotriods
Conduit
Spicular/nodular/ (pseudo)columnar/cumulate geyserite
Channel
Finely laminated
Terraces and terracettes
Plants and/or animals
Ropy/pool mat
Packed fragmental
Sinter fragments in paleosol
Throat
Beads
Streamer fabric
Network
Conical tufted
Oncoids
Palisade
Paleosol
Breccia
Bubble mats
Alkali-chloride – constructional
Temperature
>80°C
73
70
60
55
50
40



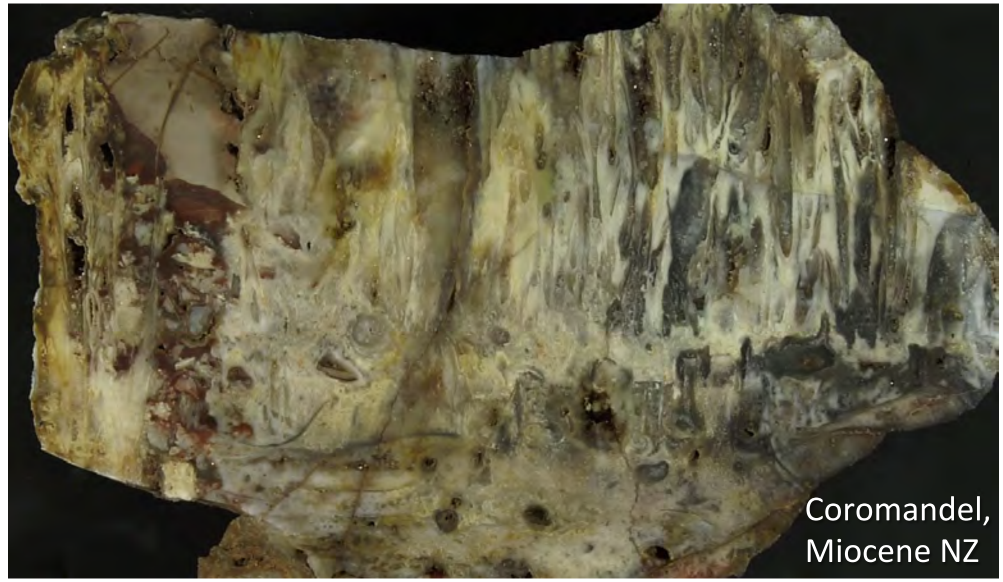




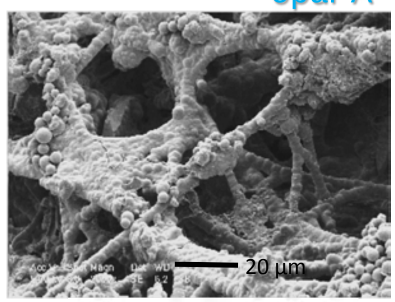
Porous sinter: filamentous

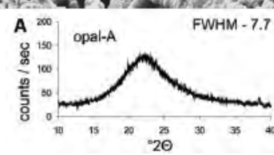
Non-porous (solid) sinter: silicified EPS

Tracking Diagenetic Changes

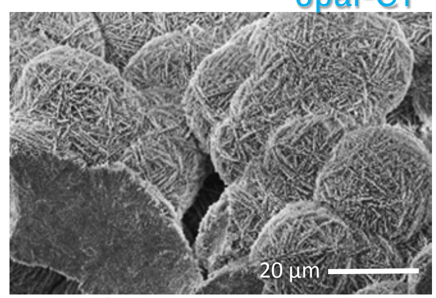


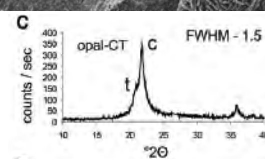
opal-A



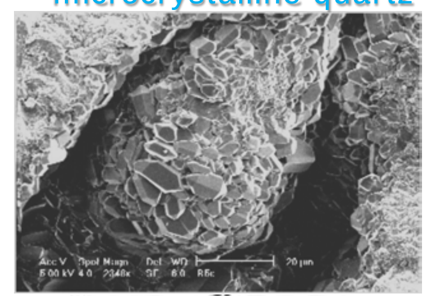


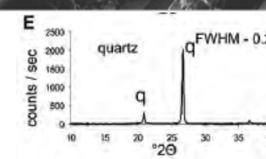
opal-CT



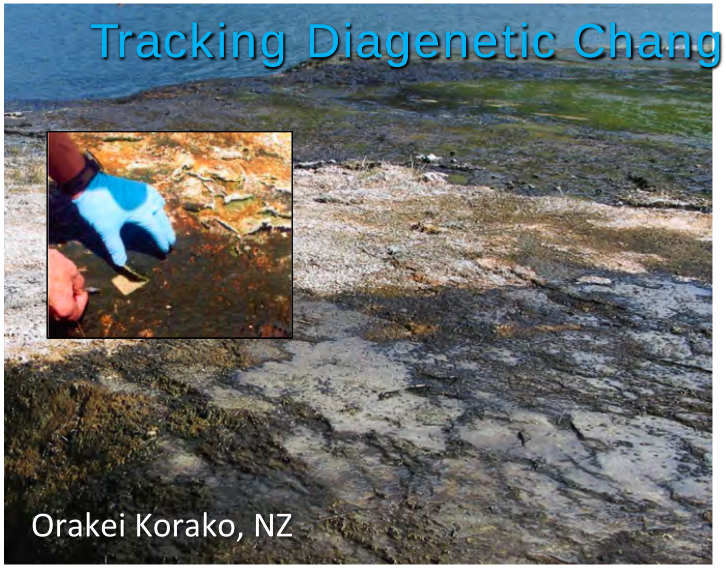


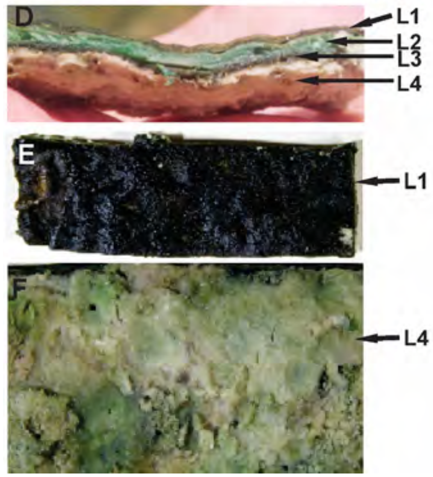
microcrystalline quartz

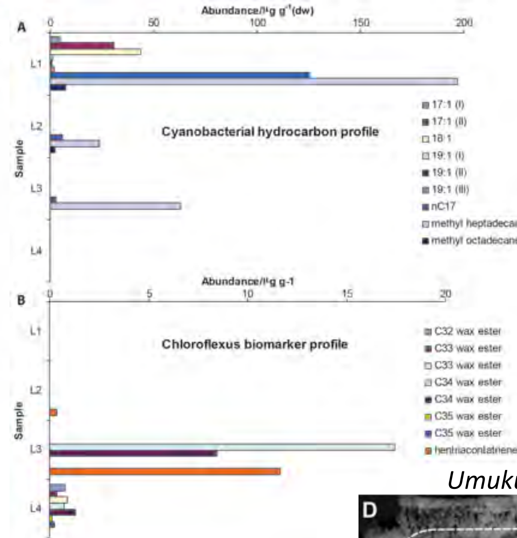




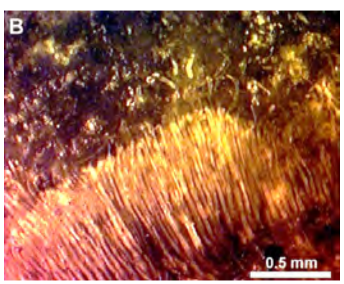
Tracking Diagenetic Changes – palisade fabric – distal apron (~35-40 °C)

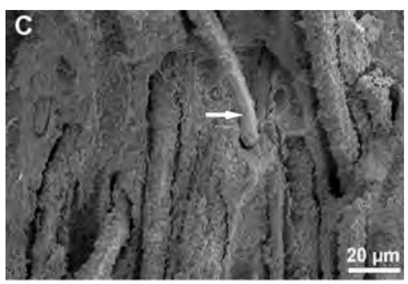


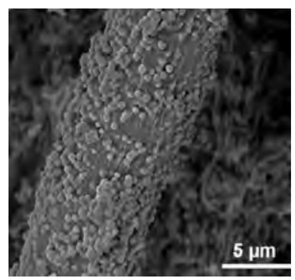




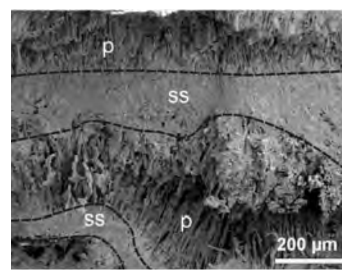
Greenish brown mat - bacterial 16S rRNA molecular analysis = *Calothrix* cyanobacterium



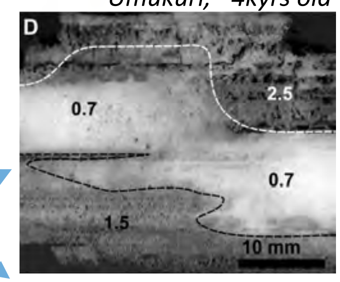




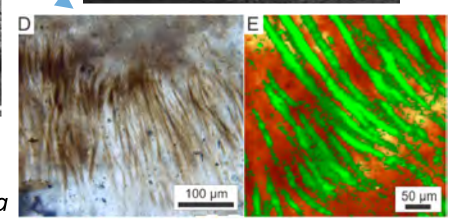
Campbell et al. 2015



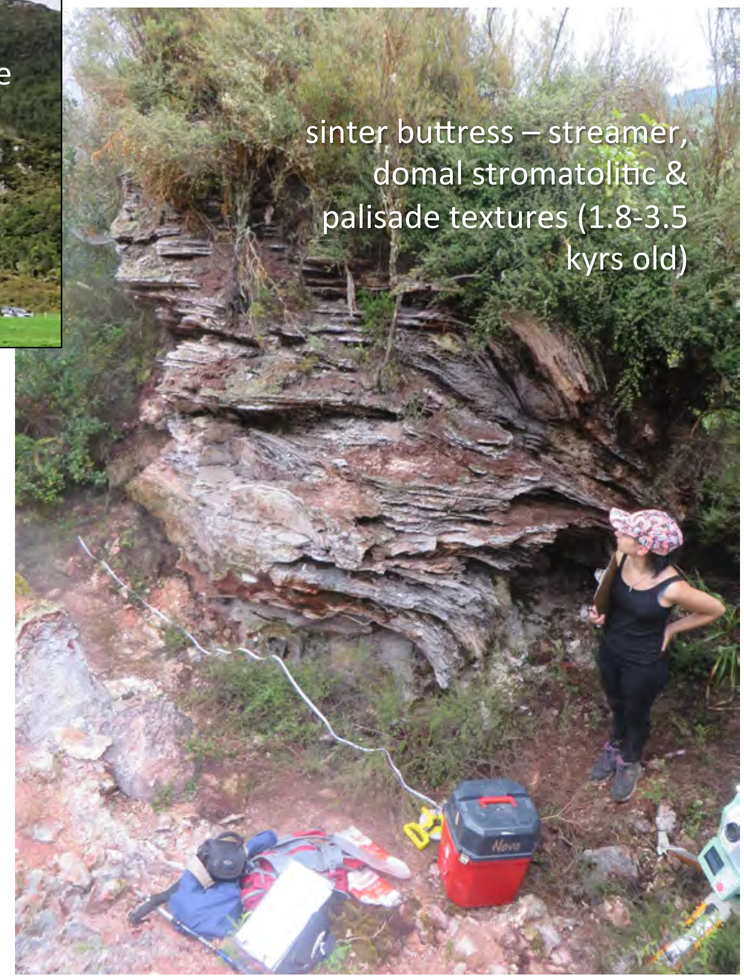
Umukuri, ~4kyrs old



?



Patagonia, 150 Ma



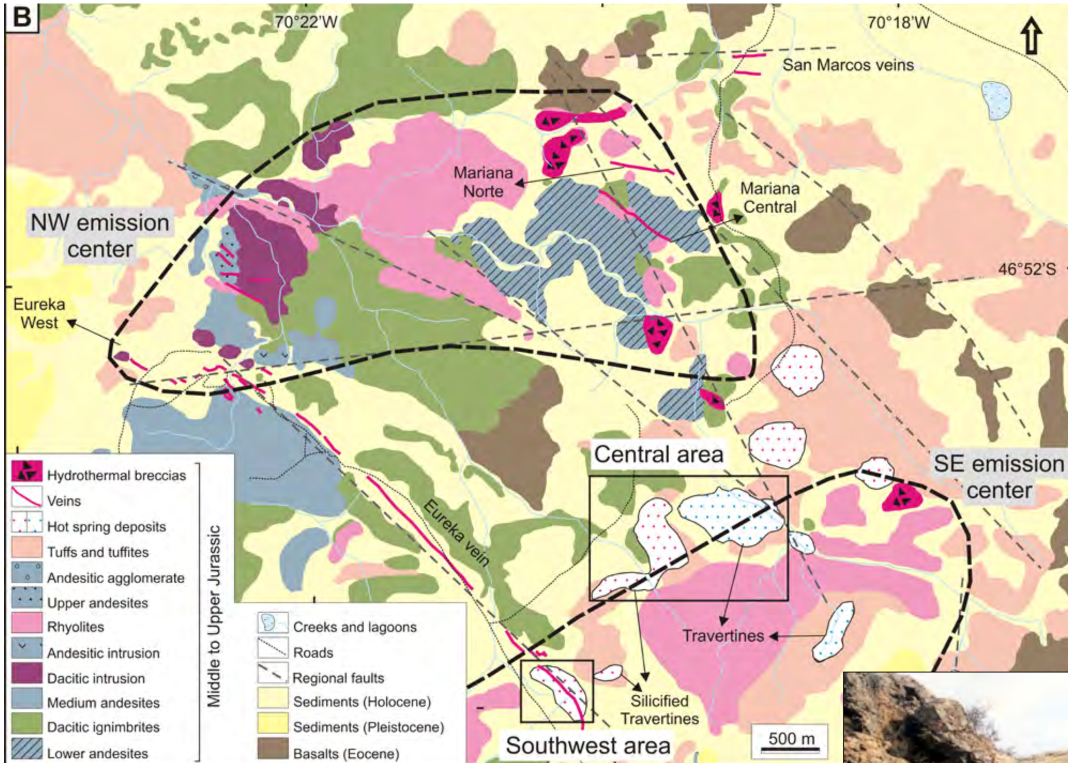
Overprinting – steam-heated acid sulfate alteration

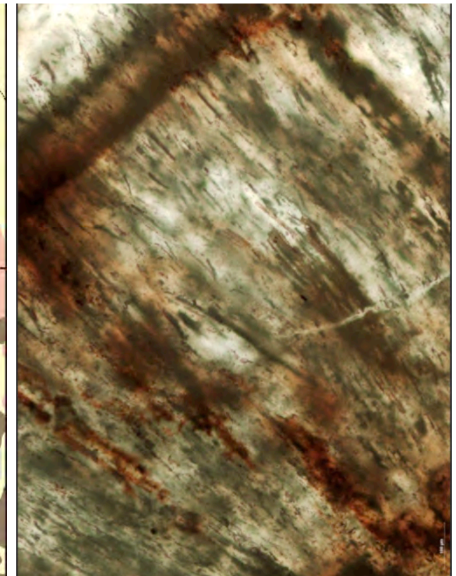
Local and regional geological controls on preservation

"8th Wonder of the World" – White Terraces, Rotomahana.
Charles Blomfield (1897), Auckland Art Gallery

World-Famous Pink and White Terraces destroyed by 1886 Tarawera volcanic eruption – an ultimate control on sinter preservation

Alexander Turnbull Library archive, Wellington, NZ, ca. 1880's

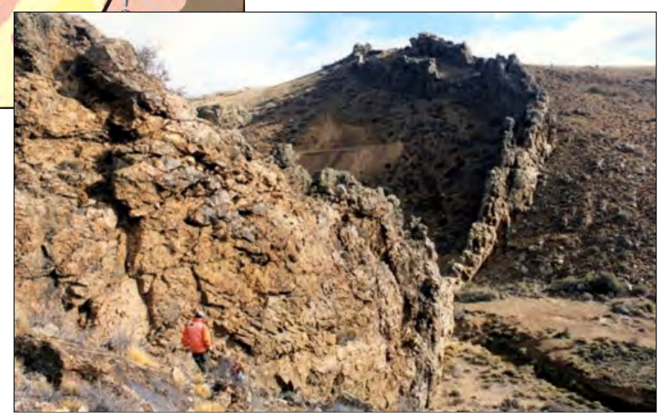




Guido & Campbell 2011, 2012

Best fossil preservation (Late Jurassic, 150 Ma, Argentina):

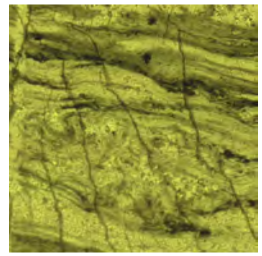
- Local = early silicification, biggest Au vein 'feeder', more fluids and/or longer
- Regional = waning volcanism

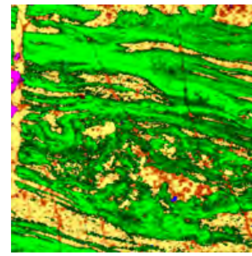


Early Life and Hot Water: 3.33 Ga, South Africa

Josefsdal Chert – Archean shallow marine, hydrothermal influence, microbial biofilms (no stromatolites): phototrophic, heterotrophic

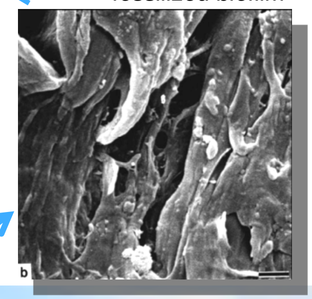
Westall et al. 2015





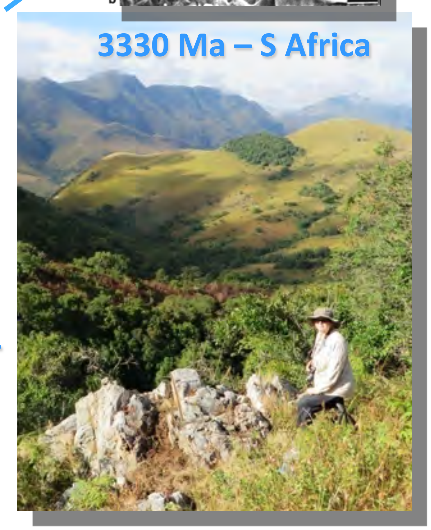
Raman – green, carbon

fossilized biofilm



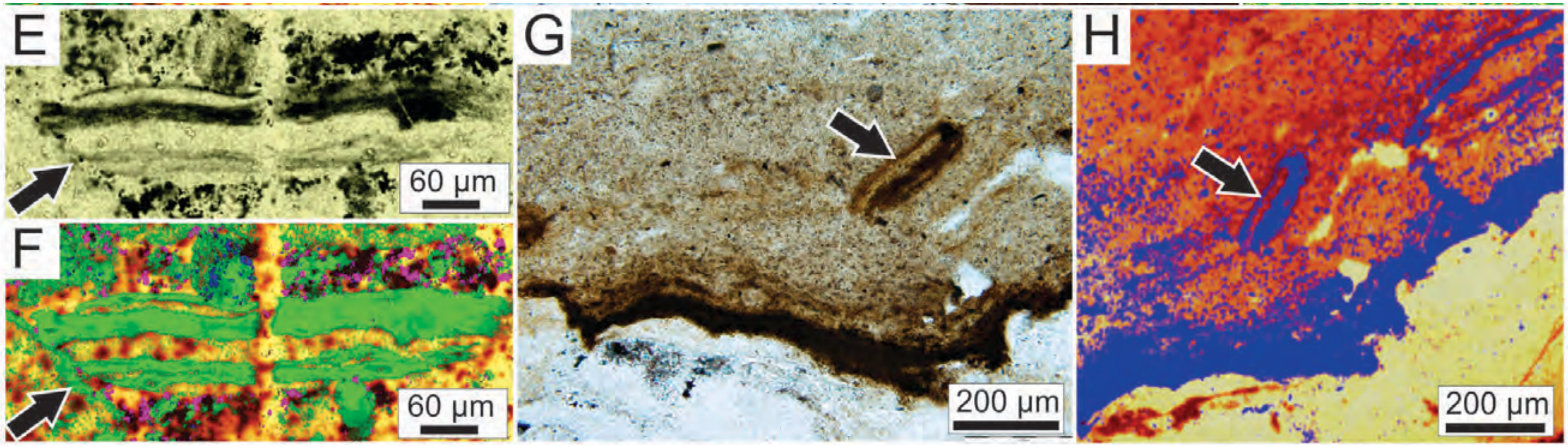
Network microbial fabric

150 Ma – Argentine sinter



0 Ma – NZ silicifying mat

Westall et al. 2015



E, F – mat fragment, 3.3 Ga, South African chert

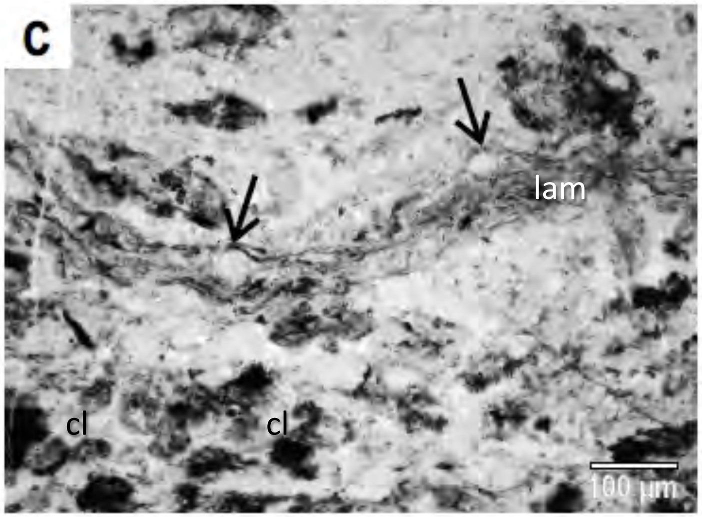
G, H – mat fragment, 150 Ma, Argentine sinter

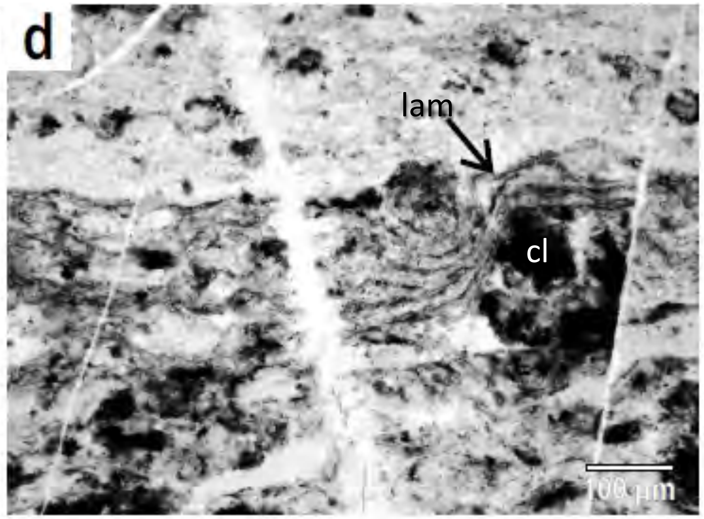
µ-RAMAN COLOR KEY:

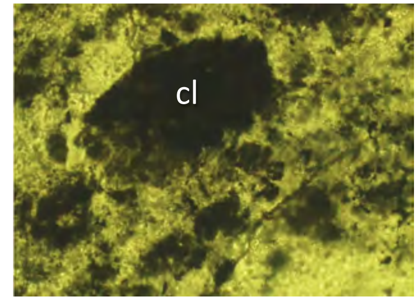
- green, carbon
- red to yellow, quartz
- magenta, muscovite
- blue, anatase

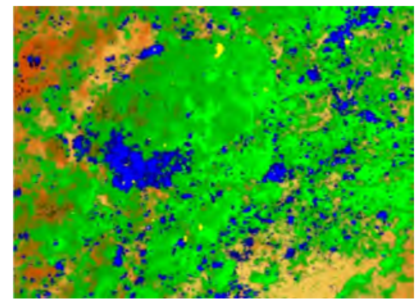
Westall et al., 2015

$\delta^{13}C$ as low as –45‰ PDB, low $\delta^{34}S$

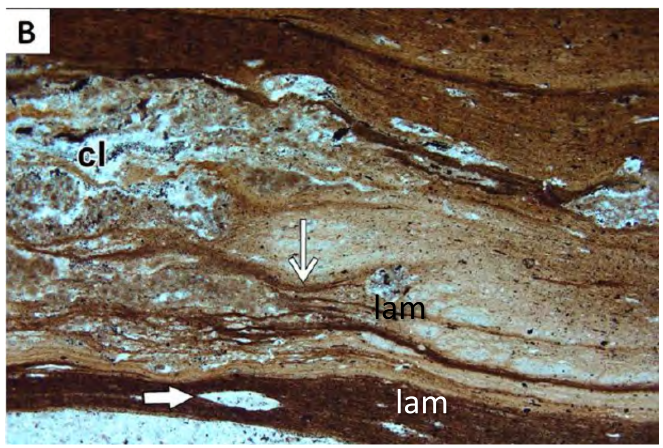








Josefsdal chert (3.33 Ga) – clots, laminae



Argentine sinter (150 Ma) – clots, laminae

Wavy carbonaceous laminae (inferred phototrophs)

Clots (inferred chemotrophs)

Laser micro-Raman maps confirm distribution of carbon, anatase

Facies Assemblage	Facies	Geometry & Textures	Microbial Fossil Association
PROXIMAL	Vent Mound or Spring Vent Pool geyserite	Conduit/Throat	
		Breccia/Panal	
		Channel and rim	Biofilm
		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
DISTAL	Distal Apron	Domal laminated	Pool floor and wall growth of domal stromatolites
		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

Digitate / knobby / spicular protrusions


Atiamuri


Waimangu – alkali chloride



Parariki Stream – acid-sulfate-chloride

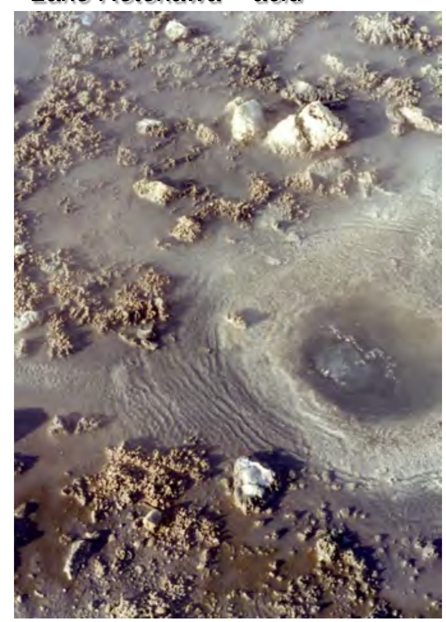

Atiamuri – alkali chloride



Tiketere – alkali chloride

Columbia Hills, Mars. Photo: S. Ruff

Lake Rotokawa – acid



Textures (macro & micro) are powerful biosignature indicators in terrestrial hydrothermal systems

Acknowledgments:

Biosignatures organizers, Royal Soc NZ Marsden Fund, Univ Auckland Faculty Development Research Fund & School of Environment, The National Geographic Society, LE STUDIUM®, PRL Browne, B Lynne, K Rodgers, J Rowland, L Cotterall