

Preservation of Biosignatures in Icelandic Hot Spring Deposits Spanning Acidic to Circumneutral Conditions

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1 | INTRODUCTION

Detecting organic biosignatures is key to the search for extraterrestrial life. **Mars is a strong astrobiological target** because it once had liquid water, warmer conditions, organic molecules, and minerals that could support microbial life. While no direct evidence of life has been found, signs of ancient life may still be preserved in Martian rocks.



Silica rich dunes, Nili Patera, Mars (NASA/JPL/JHUAPL/USGS)



Silica sinter deposit, Iceland (Borgi et al., 2023)

Hydrothermal silica deposits identified on Mars at Nili Patera and Gusev crater may preserve biosignatures, similar to those in siliceous hot spring deposits on Earth. **Iceland serves as an important analog for studying biosignature preservation and detection** because it has basaltic geology and hydrothermal systems comparable to ancient Mars.



Silica Rich Rocks, Gusev crater (Ruff et al., 2021)



Microbial-silica interactions in Icelandic hot spring sinter (Konhauser et al., 2001)

3 | KEY RESULTS

Mineralogy & TOC

Kerlingarfjöll (Acidic)

Helgrindur (Circumneutral)

	A1	A2	A3	A4	A5	A6	A7	N1	N2	N3
TOC (%)	0.18	0.09	0.24	0.1	0.3	0.12	0.14	0.41	0.58	0.58
Mineralogy	Poorly crystalline iron oxide	Poorly crystalline iron oxide	Hydrated iron sulfate Quartz	Goethite Quartz	Goethite	Goethite Quartz	Goethite Quartz	Calcite	Opal-A	Amorphous

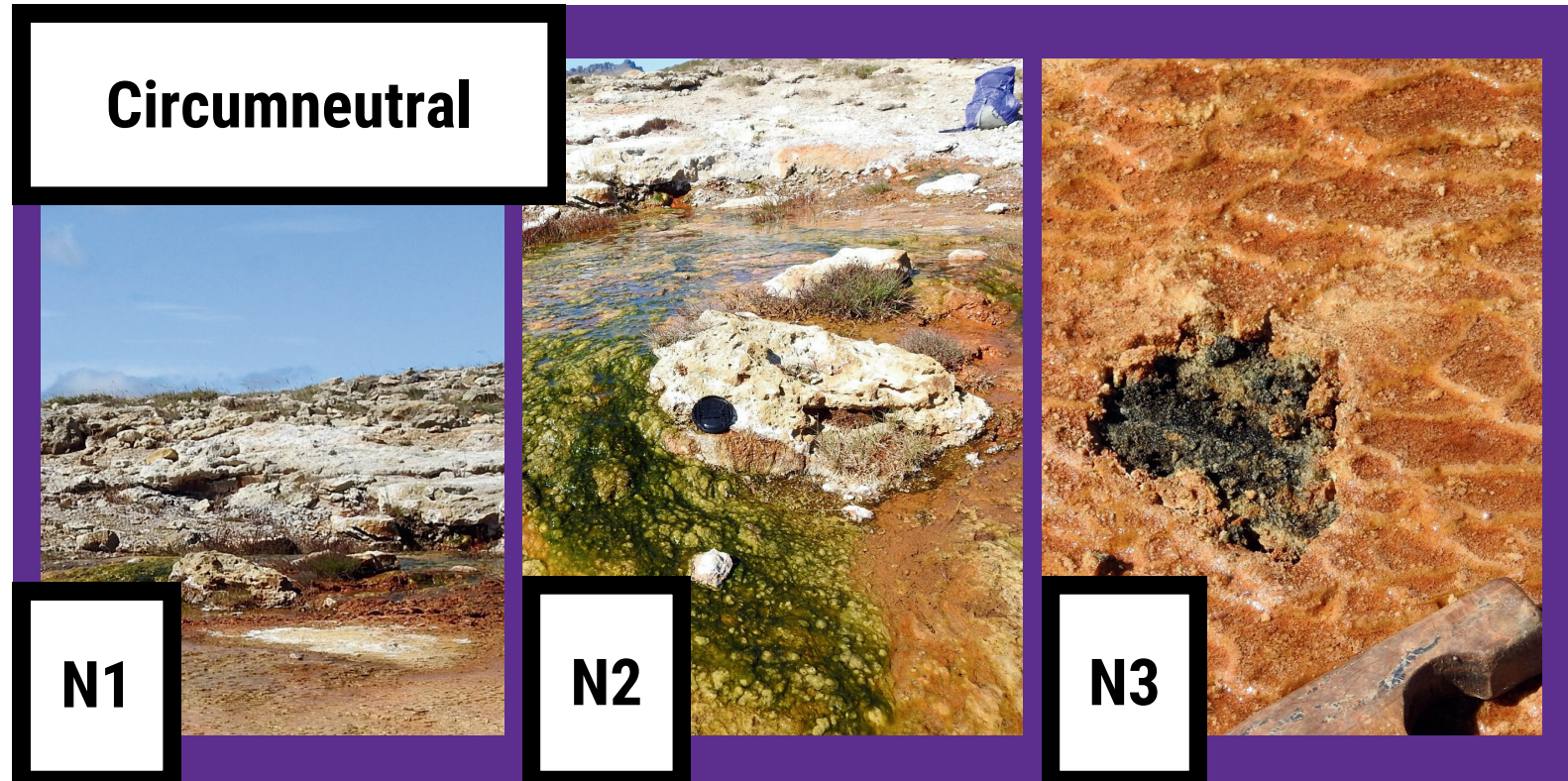
Thermochemolysis & Pyrolysis

Method	Acidic	Circumneutral
Bligh and Dyer Lipid Extraction	FAMES: C4:0 to C24:0 Hydrocarbons: C7 to C29	FAMES: C4:0 to C26:0 Hydrocarbons: C10 to C33
Neat Flash Pyrolysis 600°C	No compounds detected	Hydrocarbons: C9-C16
Neat Flash Pyrolysis 850°C	No compounds detected	Hydrocarbons: C11 - C23
TMSH Thermochemolysis 400°C	No compounds detected	FAMES: C14 - C18
TMAH Thermochemolysis 500°C	FAMES: C8:0-C18:0	FAMES: C8 - C26
SAM-like Ramp (35°C) with TMAH	No compounds detected	FAMES: C14:0 to C24:0

2 | OBJECTIVES, SAMPLE LOCATION, & METHODOLOGY

This study assesses **(1)** the biosignature preservation potential of acidic versus circumneutral pH siliceous sinter hydrothermal environments in Iceland, and **(2)** the analytical conditions that optimize biosignature detection.

We hypothesize that **(1)** neutral pH siliceous sinter hydrothermal systems will preserve greater biosignature diversity and abundance than acidic systems, driven by reduced iron-mediated oxidative degradation and more favorable conditions for silica encapsulation of organic matter; and **(2)** derivatization-based thermochemolysis techniques (TMAH and TMSH) will outperform neat flash pyrolysis in detecting biosignatures across both mineralogical contexts, with performance varying systematically with pH-dependent mineral composition.



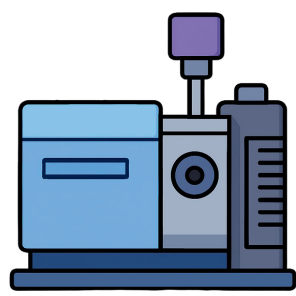
Study Site

- Kerlingarfjöll (acidic: n=7; pH 3.43 - 4.05; Ca/Mg -sulfate waters)
- Helgrindur (circumneutral: n=3; pH 6.85 - 7.01; Na/K - bicarbonate waters)



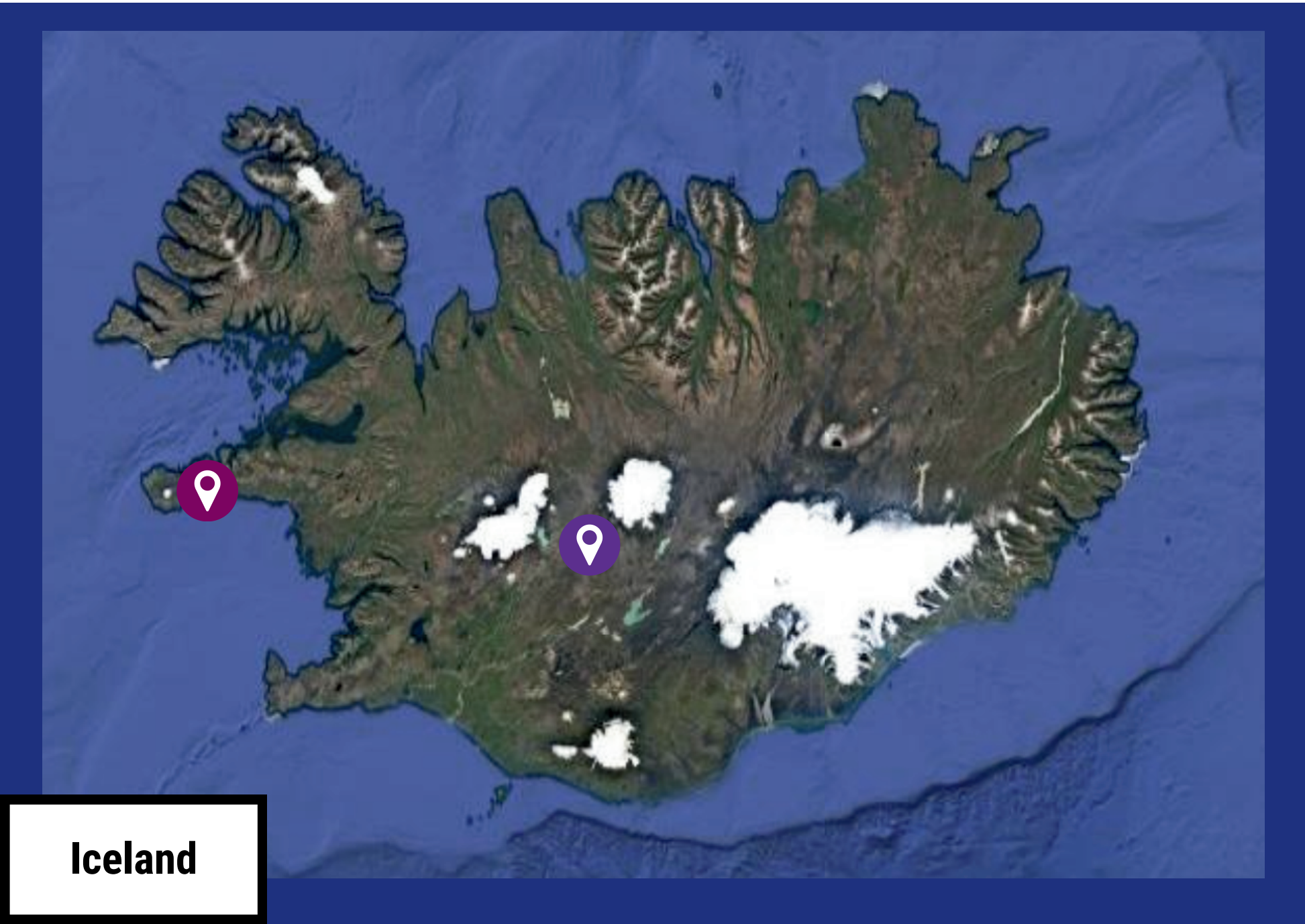
Geochemical Characterization

XRD, ICP-MS, TOC



Thermochemolysis GC-MS

5 approaches compared utilizing off-line lipid extraction or on-line thermochemolysis similar to space flight-like technology



4 | DISCUSSION

Mineralogy Matters

Acidic samples are dominated by iron oxides, which likely consume derivatization reagents and suppress on-line detection

Method Performance

Bligh and Dyer extraction yields the greatest lipid diversity. TMAH thermochemolysis is the most effective on-line approach

Acidic Challenges

TMSH and pyrolysis fail in acidic, iron-oxide-rich matrices, highlighting mineral controls on analytical success

Implications for Mars

Circumneutral siliceous sinter deposits may better preserve biosignatures and are promising targets for Mars missions

5 | CONCLUSIONS & IMPACTS



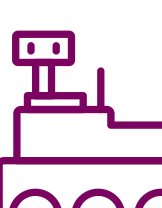
Neutral pH siliceous sinter environments preserve greater organic biosignature diversity and abundance than acidic counterparts, supporting the study hypothesis



The Bligh and Dyer method remains the most sensitive technique for comprehensive lipid profiling, while TMAH thermochemolysis is the most effective on-line derivatization approach compatible with Mars instrument suites



The failure of TMSH and pyrolysis in acidic, iron-oxide-rich matrices highlights the importance of sample mineralogy in reagent selection



Hydrothermal pH controls biosignature preservation and detectability – circumneutral siliceous sinter environments are priority targets for Mars exploration, and TMAH-based thermochemolysis is the detection method of choice