Microbial lipids & isotopic biosignatures from terrestrial hot springs can inform life detection missions

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Life Detection in Hot Springs

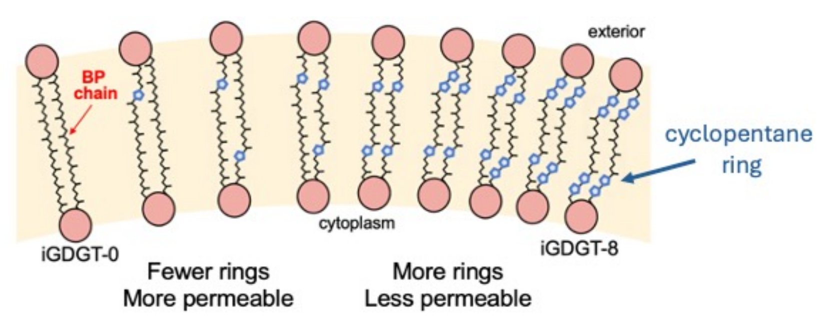
Hydrothermal activity is common in our solar system. These systems provide rich geochemical gradients that are prime targets for astrobiological study. Terrestrial hot springs are accessible analogs to hydrothermal systems on Mars and other rocky bodies. The study of microbial life, lipid biomarkers, and associated stable isotope compositions in hot springs is particularly relevant to the search for life beyond Earth.

Here, I synthesize complementary lab and field investigations that explore the production and preservation of lipid biosignatures & their hydrogen isotope compositions from extremophilic microbes.

Lipid & isotope Biosignatures

Lipids are universal biosignatures for life

- Synthesized by all known forms of life
- Complex, non-random branching



Archaea produce distinctive membrane lipid structures – glycerol dialkyl glycerol tetraethers (iGDGTs) – which can contain between 0 and 8 rings. More rings represent an adaptation to extreme conditions, like heat and acidity.

Stable isotope analysis can determine biogenicity

- Metabolic processes tend to concentrate the lighter isotope (e.g., ^{1}H, ^{13}C) in biomass
- Analysis of specific compounds, such as lipids, is better for constraining biogenicity
- Lipid-bound H is stable over astrobiologically relevant time scales (e.g., billions of years)

Relevance to Astrobiology

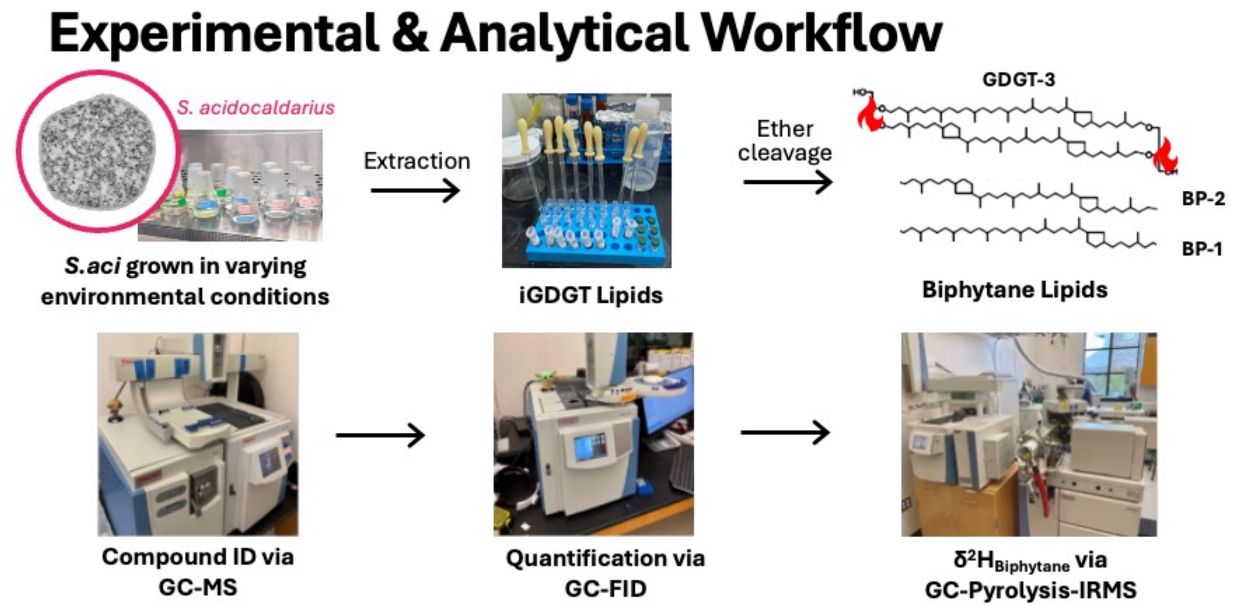
This study advances life detection science by:

1) Characterizing microbial adaptations (e.g., alterations to lipid structures) to the "extreme" conditions in hydrothermal systems, which are common beyond Earth.
2) Determining patterns in lipid & isotope biomarker production and preservation in relation to geochemical conditions.

Ultimately, this study will help develop a framework to guide site selection for astrobiology targets where hydrothermal activity is suspected.

Lab Experiments on a Thermoacidophilic Archaeon

Experimental & Analytical Workflow



To determine the impact of environmental conditions on iGDGT lipid profiles & their stable H-isotope compositions, we cultured the model hyperthermophilic and acidophilic archaeon *Sulfolobus acidocaldarius* under a range of temperature, pH, dissolved oxygen, and e- donor fluxes.

S. acidocaldarius is an aerobic heterotroph that was isolated from a Yellowstone hot spring and thrives in high heat and acidity.

Fig. 1. Doubling Time

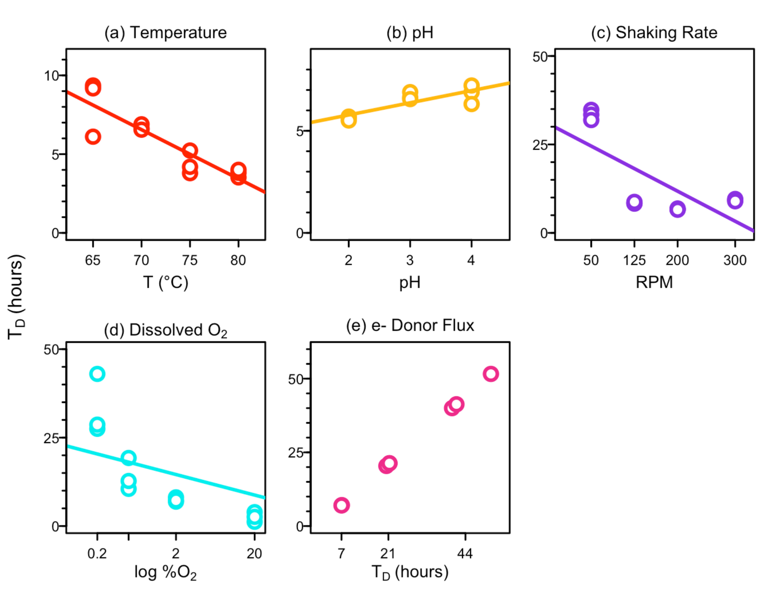


Figure 1. Doubling time for each environmental condition. All conditions impacted growth rate, resulting in a 25-fold change in doubling time.

Fig. 2. Biphytane lipid profiles

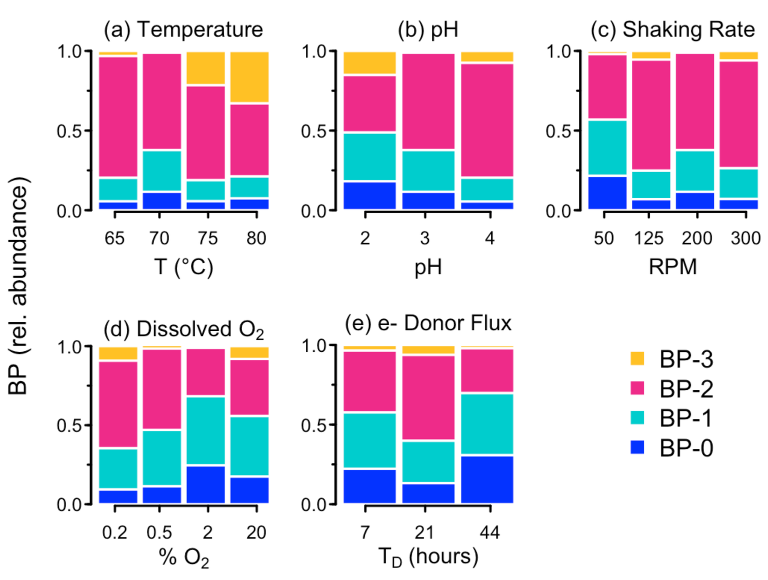


Figure 2. Relative abundance of biphytane lipids with 0 to 3 rings. Only T and pH impacted profiles, with more BP-3 in high heat & low pH treatments.

Fig. 3. Lipid/water ^{2}H fractionation

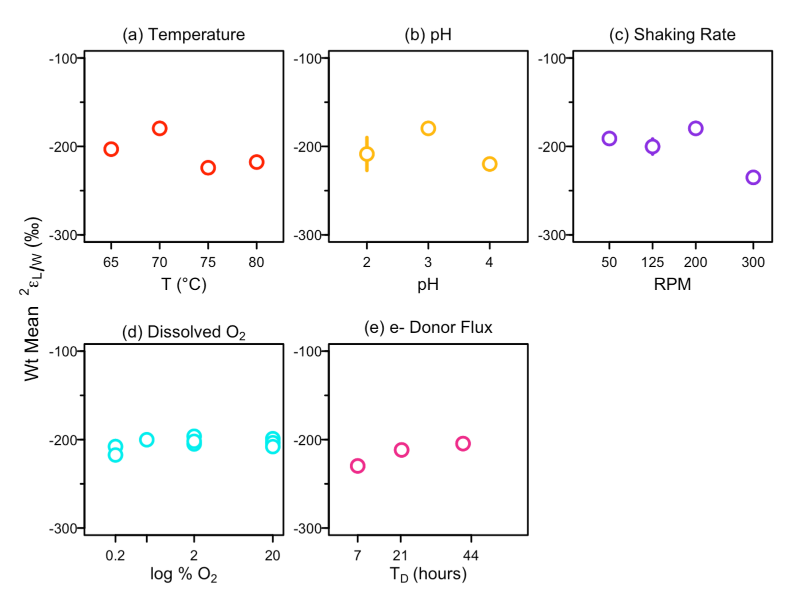


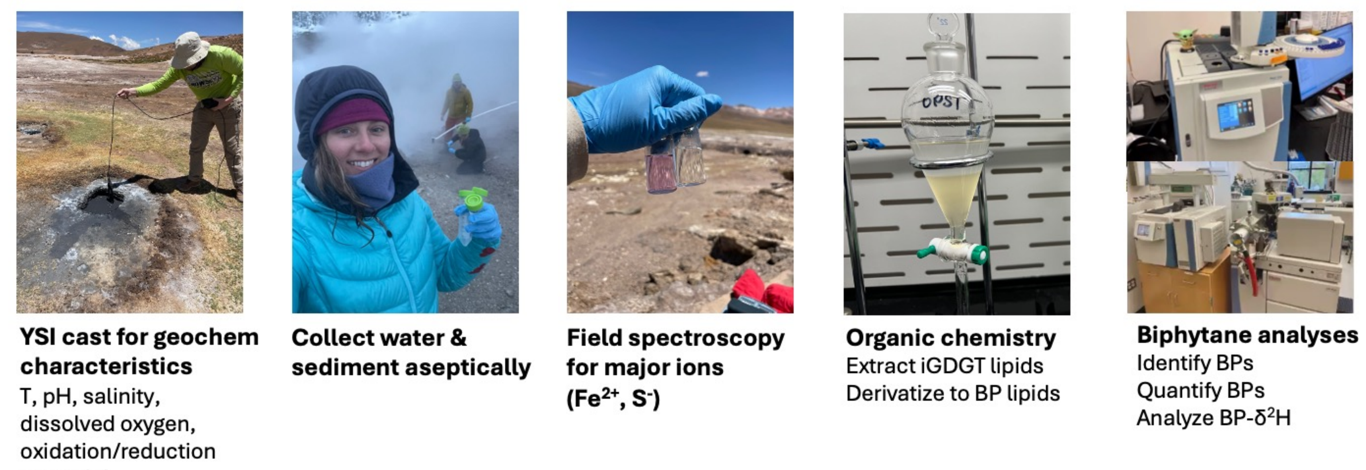
Figure 3. Lipid/water ^{2}H fractionation for each condition. Fractionation was largely invariant, despite significant impacts to growth and lipid cyclization.

These experiments suggest (1) lipids are a key adaptation allowing archaea to thrive in multiple extreme conditions, and (2) a negative lipid/water ^{2}H fractionation indicates biotic origin. This framework can be used to interpret lipid biomarkers in modern and ancient environments on Earth and potentially for isoprenoid-type hydrocarbon on other worlds. However, these patterns should be validated in natural systems...

Field Studies at Yellowstone & El Tatío Geyser Fields

Field & Analytical Methods

Research conducted under Yellowstone Research Permit YELL-2022-SCI-5544



To investigate the impact of geochemical condition on lipid & isotope biosignature production, we sampled 44 active hot springs from **Yellowstone National Park** (USA) and 7 hot springs in **El Tatío Geyser Field** (Chile).

Fig. 4. Aqueous Geochemistry

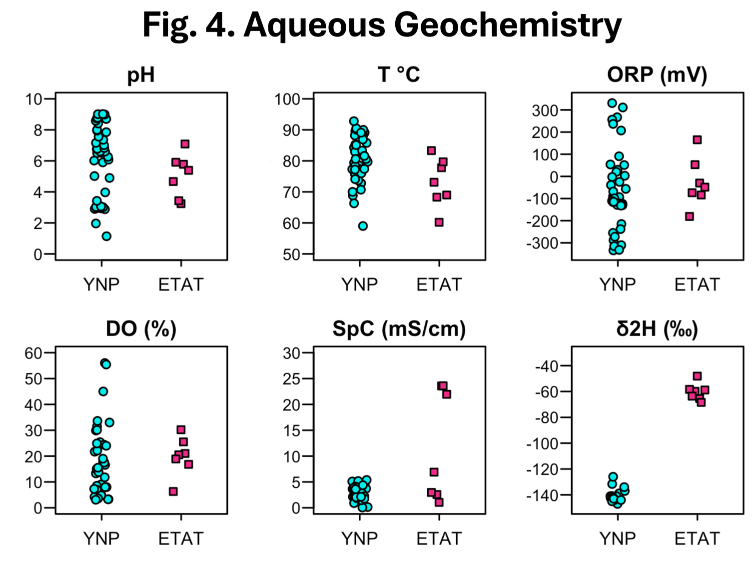


Figure 4. Hot springs waters spanned a wide range of T, pH, redox, and dissolved oxygen conditions. El Tatío hot springs were saltier than YNP springs and water ^{2}H composition varies between the sites.

Fig. 5. Lipid (iGDGT) Concentration

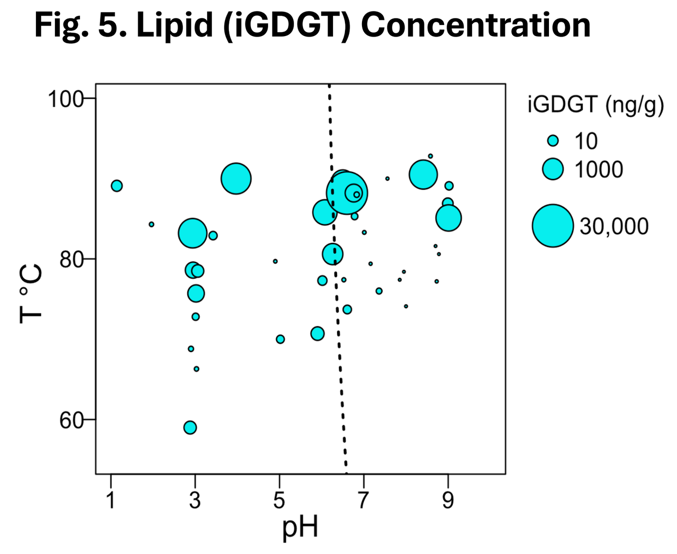


Figure 5. Lipids associated with extremophilic archaea were recovered from all YNP springs. Spring temperature is the dominant control on iGDGT concentration, with no impact of pH.

Fig. 6. iGDGT Profiles

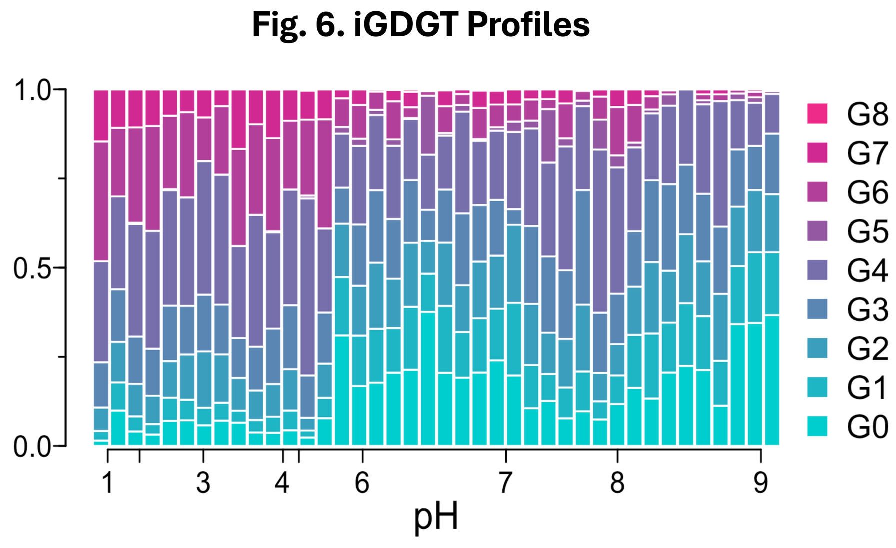


Figure 6. Relative abundance of iGDGT lipids with 0 to 8 cyclopentane rings for all 44 YNP springs. Spring pH is the dominant control on iGDGT cyclization, with little impact of temperature.

I am currently extracting lipids from El Tatío spring sediments. Next, I will determine the H-isotope composition of lipids (biphytanes) from YNP and El Tatío. I hypothesize that lipids will be consistently ^{2}H- depleted relative to source waters (indicating biogenic origins) and that this signal will not be impacted by any major geochemical parameters.

QUESTIONS, COMMENTS? Contact Carrie @ carolynn.m.harris.GR@dartmouth.edu • CarolynnHarris.com

REFERENCES

Calhoun (2023) Undergraduate Thesis. Dartmouth College.
Finkel et al., (2023). Astrobiology
Harris et al., (2022) Front. Astron. Space Sci.
Hays et al., (2017) Astrobiology
Leavitt et al., (2023) Geochim. Cosmochim. Acta
Rhim et al., (2023) bioRxiv

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