Elemental Relics: Biosignatures for Microbial Life in Terrestrial Hot Springs on Ancient Earth and Mars

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Abstract

Terrestrial hot springs have existed throughout Earth's history and house some of the most ancient evidence of life on our planet. These settings are known for their high habitability and preservation potential, and are extensively studied as analog environments since hot spring deposits are thought to exist on the surface of Mars. Hot spring water commonly precipitates silica that coats microbial life dwelling in the hot spring outflow streams. This process can entomb microorganisms and preserve microbial remains over long timescales and with high morphological fidelity. Here we present research carried out on modern and sub-recent remains of microbial filaments from amorphous (unaltered) silica deposits in Yellowstone National Park. This work suggests that various elements sequestered by hot spring-dwelling organisms during life are preserved in microbial remains and persist over $>$ 10,000 years. We also present findings from microfossils preserved in mid-Paleozoic terrestrial hot spring deposits which also show sequestrations of select elements in microfossil remains, suggesting that certain elements may persist even after several hundred million years and substantial host rock alteration. These elemental concentrations may be indicative of metabolic functioning during life and have application as biosignatures. Recent developments in analytical instrumentation now allow for even extremely low trace elemental abundances to be detected and mapped, regardless of sample complexity. This work is especially relevant to the search for life on Mars, as evidence of impact-induced hydrothermal activity may exist near the rim of Jezero Crater and may be sampled by the Perseverance rover. As a primary objective of the Mars 2020 mission is to search for evidence of past life on Mars, we suggest the application of this analytical technique to be valuable for potential samples returned to Earth by future Mars Sample Return missions. Distribution Statement A. Approved for public release: distribution unlimited.

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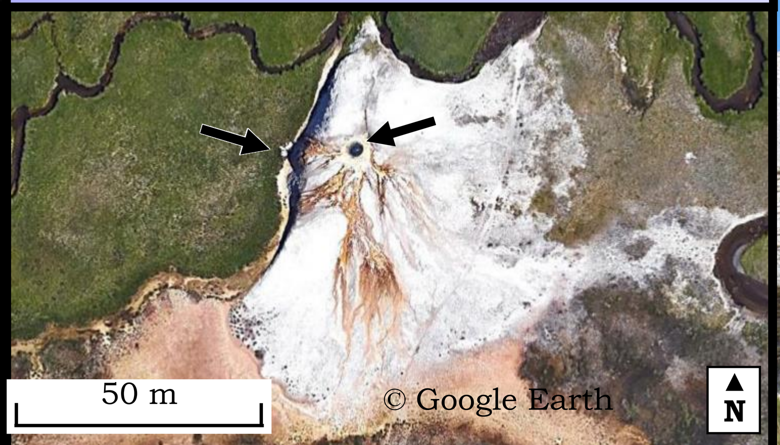
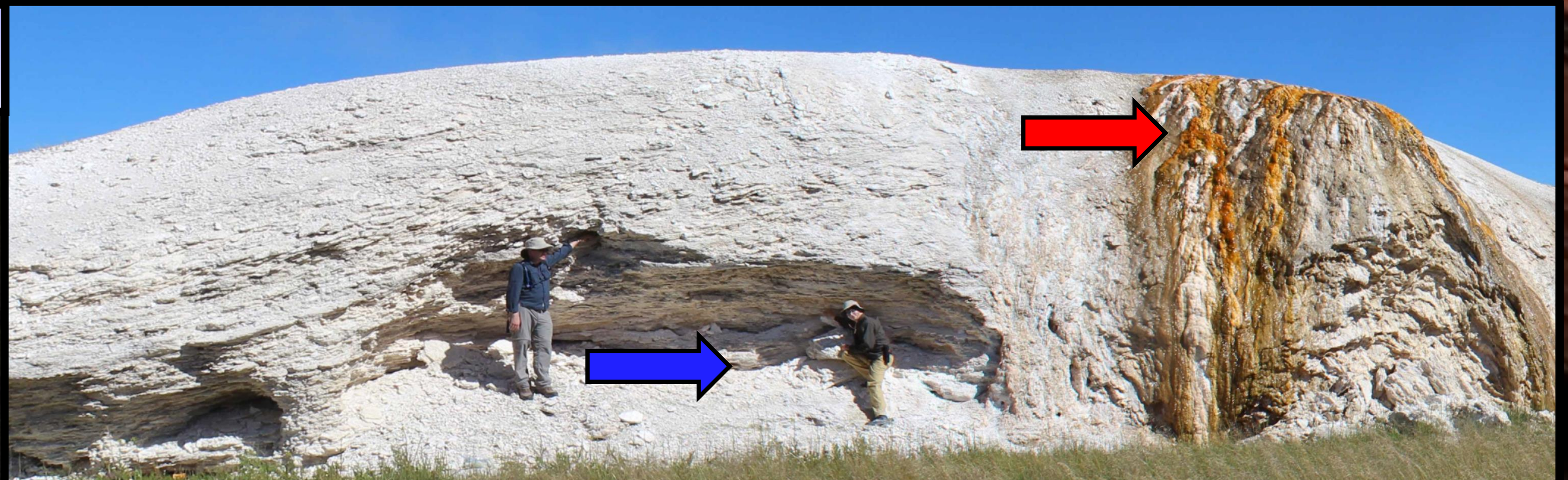
Summary

Terrestrial hot springs are teeming with microbial life. This life is commonly preserved due to silica precipitating from the spring water and entombing the microorganisms. Comparisons from modern and ancient spring deposits suggest that several elements associated with preserved microbial remains can be utilized as robust biosignatures to aid in the search for life on Mars.

Steep Cone, Yellowstone





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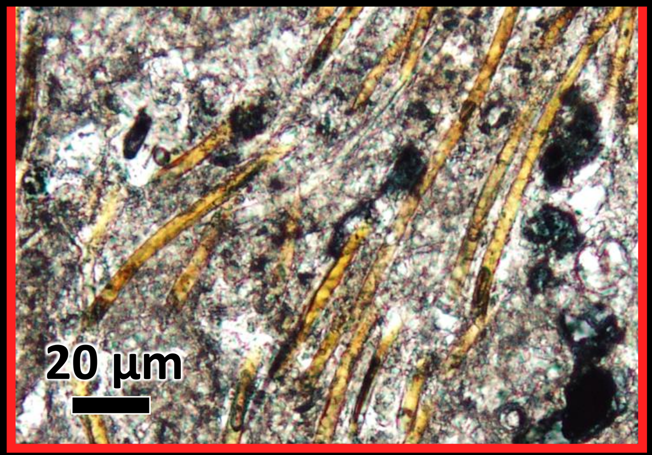
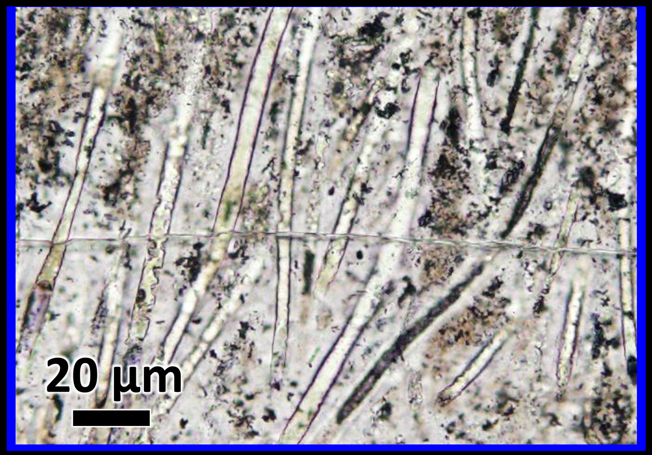
Recent Silicified Filaments



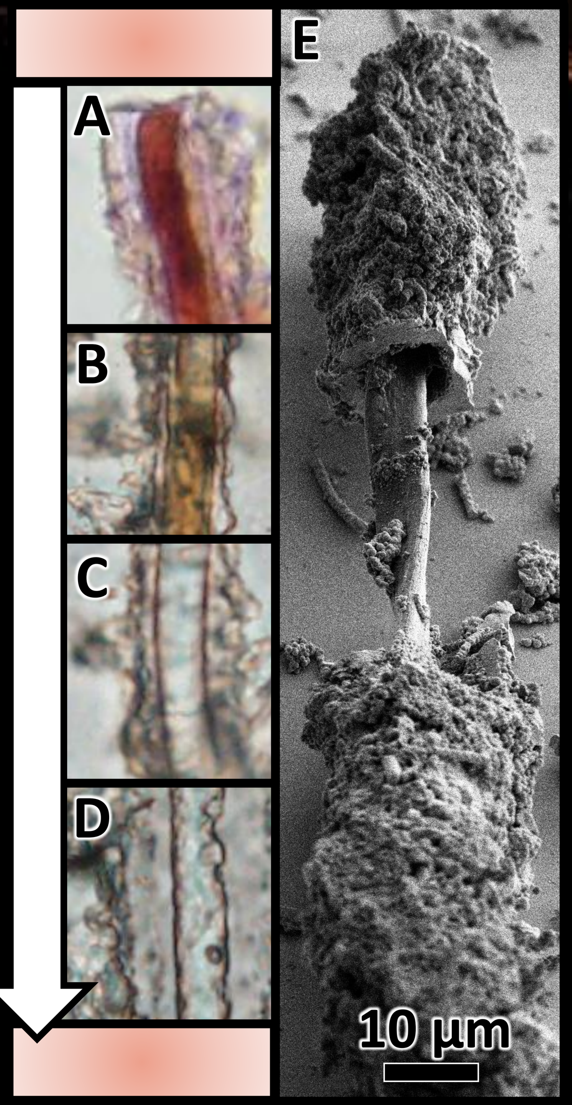
Older Silicified Filaments



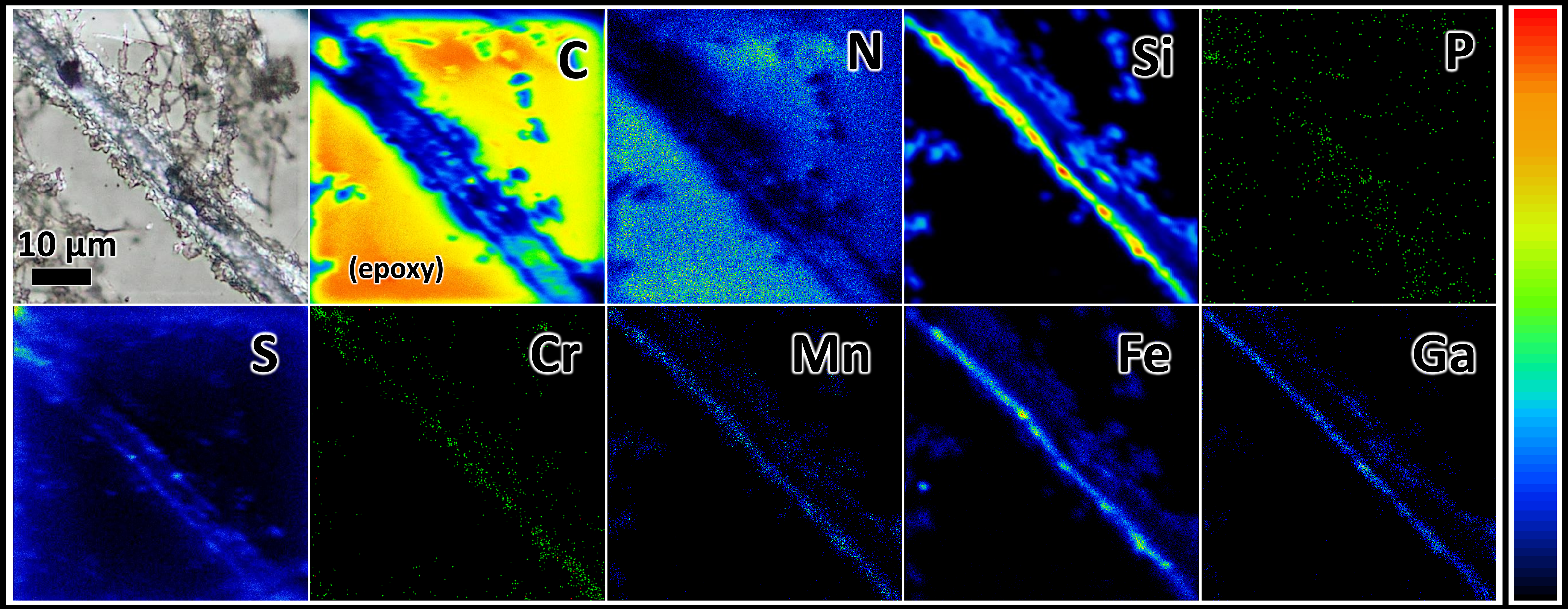
Left:
The Red Panel shows recently silicified microbial filaments from the top strata of Steep Cone, displaying an orange pigment. The Blue Panel shows older silicified microbial filaments from the base strata of Steep Cone, displaying the same size and morphology as the recently silicified filaments from the top strata of Steep Cone, but no pigment.

Right:
A succession of microbial samples obtained from Steep Cone, starting with a live filament obtained from an active discharge channel (A), followed by a recently silicified filament (B), a silicified filament from the mid-strata of Steep Cone (C), and finally a silicified filament from the base strata of Steep Cone (D). (E) shows an SEM image of the live filament from (A).

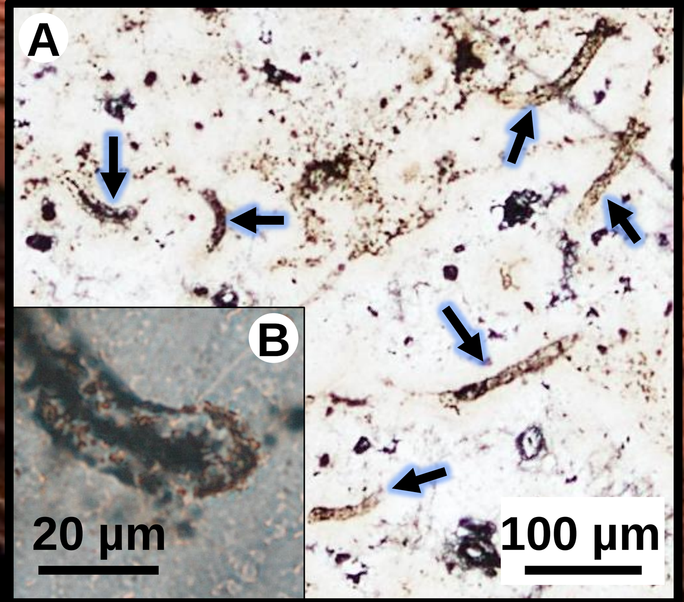
Below:
Silica sinter samples from Steep Cone were analyzed using a Secondary Ion Mass Spectrometer (SIMS) to map various elemental distributions. Silicified microbial filaments were consistently shown to sequester several elements (both primary and trace elements).

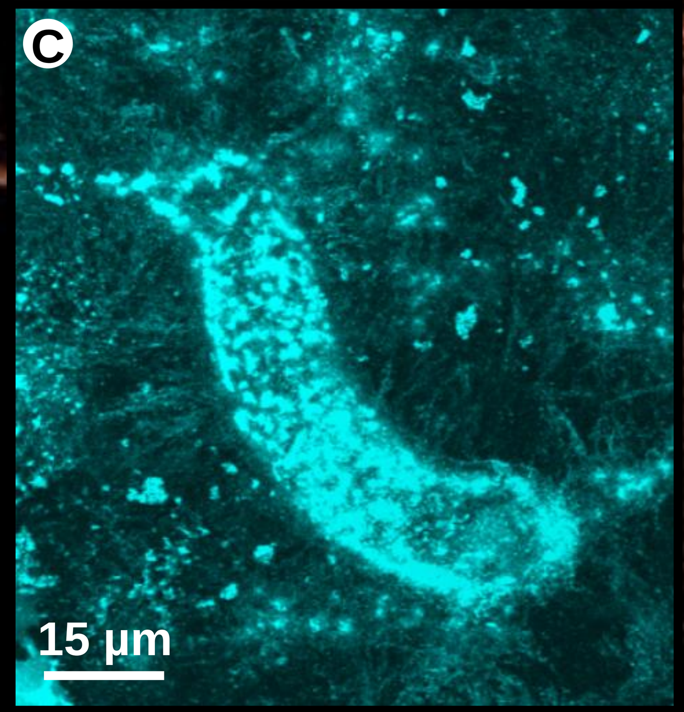


SIMS Elemental Mapping of a Silicified Microbial Filament (CAMECA IMS-7f-GEO)



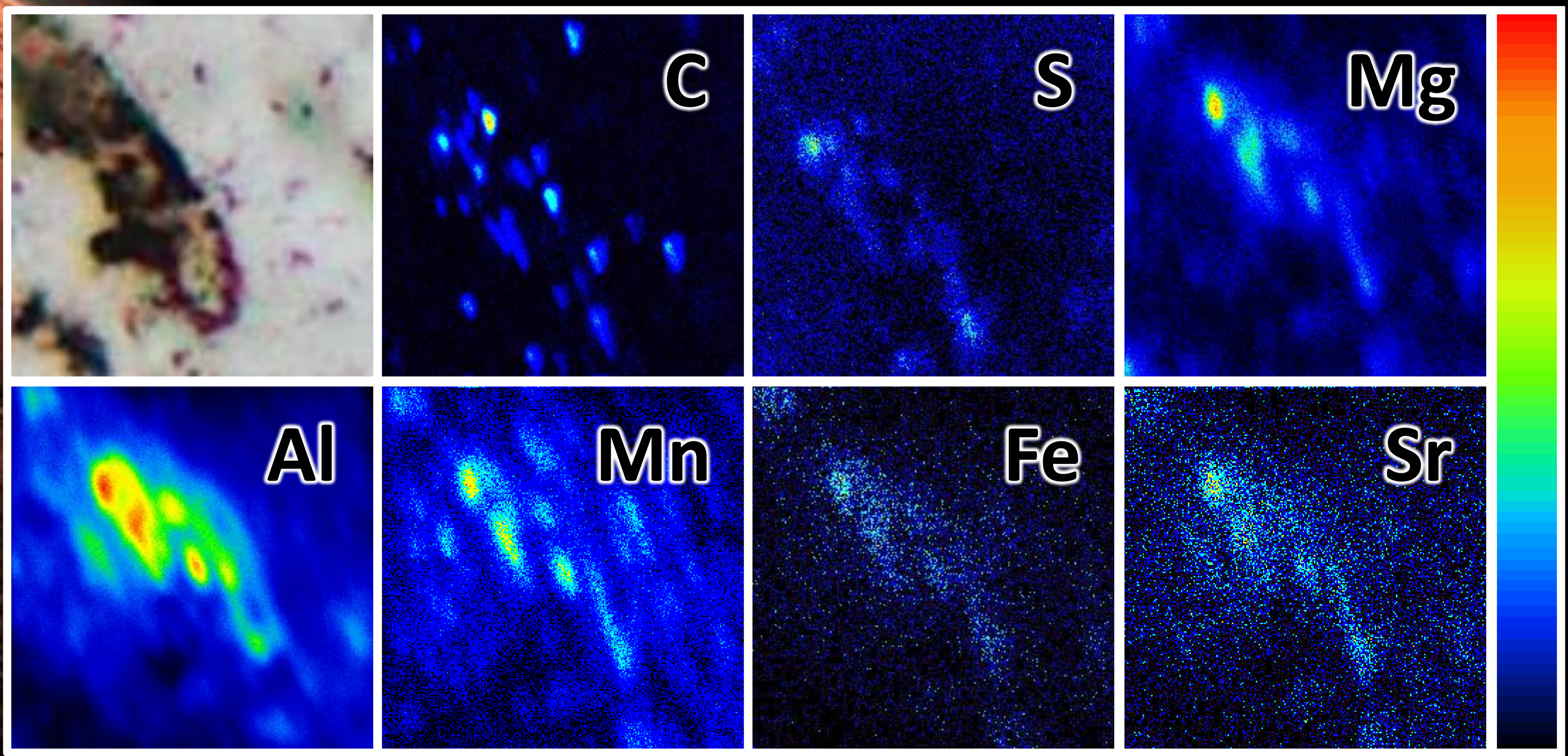
Comparison with Drummond Basin – An Extinct Terrestrial Hot Spring from the Mid-Paleozoic



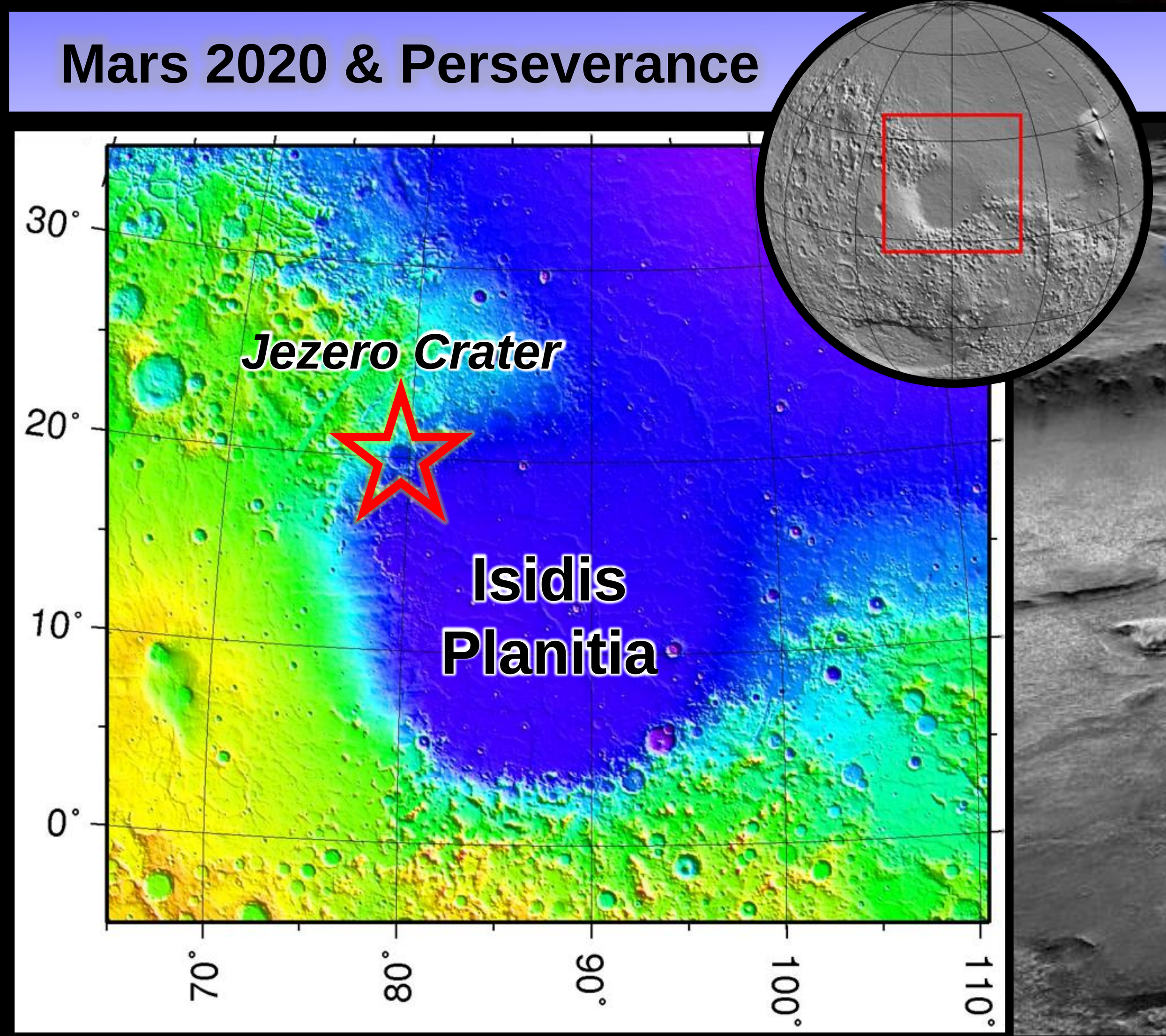


Left:
Filamentous microfossils from the mid-Paleozoic Drummond Basin, an extinct terrestrial hot spring deposit in Queensland, Australia. These microbial fossils share the same size, shape, geologic setting, and potentially metabolism as microbial remains from Steep Cone. (A) Plane-polarized light photomicrograph of several well-preserved microfossils, indicated by arrows. (B) Detailed view of a microfossil from panel A (indicated by the left-most arrow in panel A). (C) Confocal laser scanning microscope image of the microfossil from panel B, highlighting the organic cell walls via fluorescence.

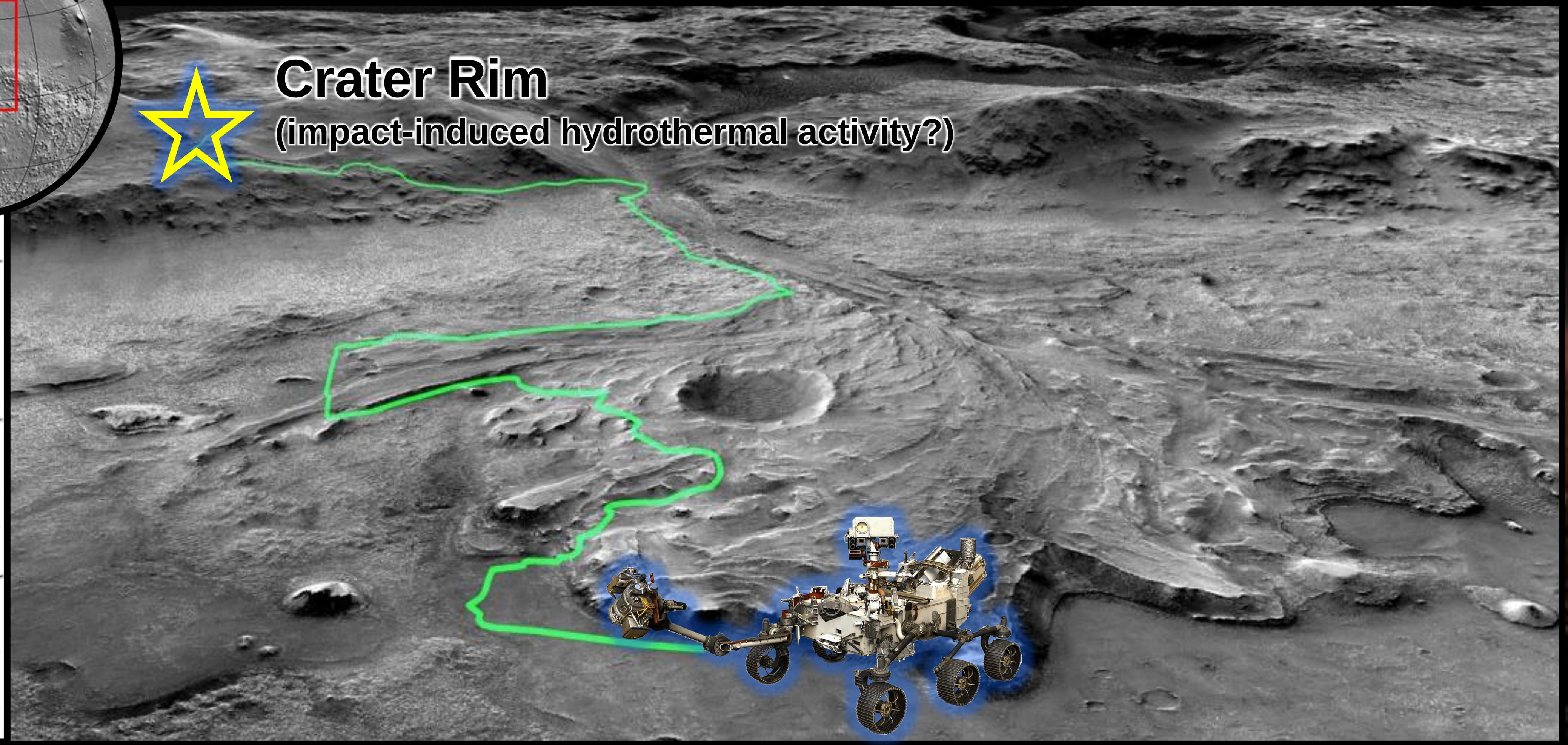
Right:
SIMS elemental mapping of a Drummond Basin microfossil. Several elements are found in association with the microfossil body similarly to what was observed in microbial remains from Steep Cone hot spring. These elemental signatures are thus apparently preserved despite substantial host-rock alteration and the passage of hundreds of millions of years.



Mars 2020 & Perseverance



Relevance to the Search for Signs of Past Life on Mars



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