SIMS Applications to Biogeochemistry

Analysis of Sequestered Trace Elements

Developing an elemental biosignature for microbial fossils

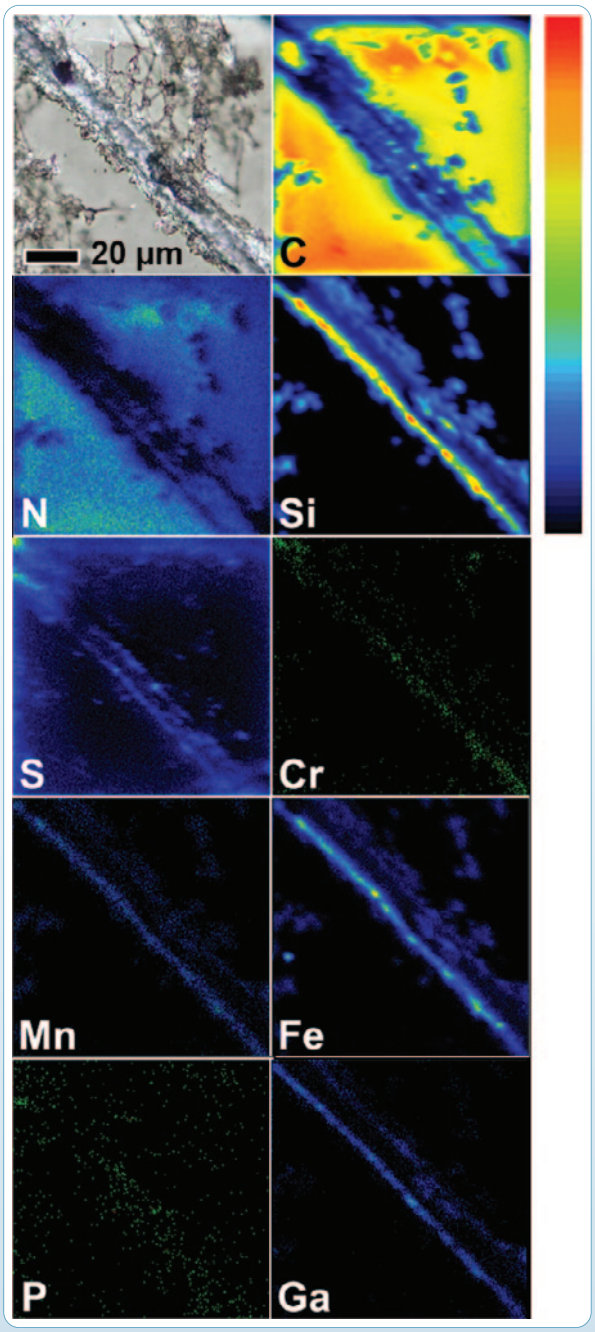
Impending missions focusing on the search for life outside of our planet require the development of robust and conclusive biosignatures. Hydrothermal silica deposits preserve some of the most ancient evidence of life on Earth, and such deposits are also suggested to exist on the surface of Mars. In this study, micron-scale elemental mapping by secondary ion mass spectrometry (SIMS) was used to investigate the distribution of trace elements that are preferentially sequestered by microbial life and subsequently preserved in hydrothermal deposits.

Elemental mapping by SIMS was obtained with the IMS 7f-GEO on samples from different locations within the Steep Cone hot spring deposit (Yellowstone Caldera), spanning from modern microbial mats to the most ancient layers accessible. Within each sample, one or more 100 by 100 µm areas of interest were targeted for major (C, N, Si, P, and S) and trace (Al, Cr, Mn, Fe, and Ga) element analyses to quantify the concentrations and spatial distributions of these elements relative to modern and silicified microbial mats or filaments from Steep Cone.

The IMS 7f-GEO delivers optimum sensitivity analyses by measuring the elements of interest either as negative ions (produced by Cs^+ primary ion bombardment) or positive ions (produced by O^- primary ion bombardment). In order to enhance the ionization yield of nitrogen, N was monitored as CN^-, which provided an ion map of nitrogen in carbon-rich locations.

The IMS 7f-GEO also ensures optimum lateral resolution by easy adjustment of beam diameter down to sub-µm scale, while main mass interferences can be resolved using high mass resolving power. In this study, a 1–2 µm beam diameter was used for both Cs^+ and O^- conditions; primary beam current was 25 pA (Cs^+, 20 keV impact energy) and 140 pA (O^-, 23 keV impact energy); mass resolving power was ~4500 and ~6000 for negative and positive secondary ion images, respectively.

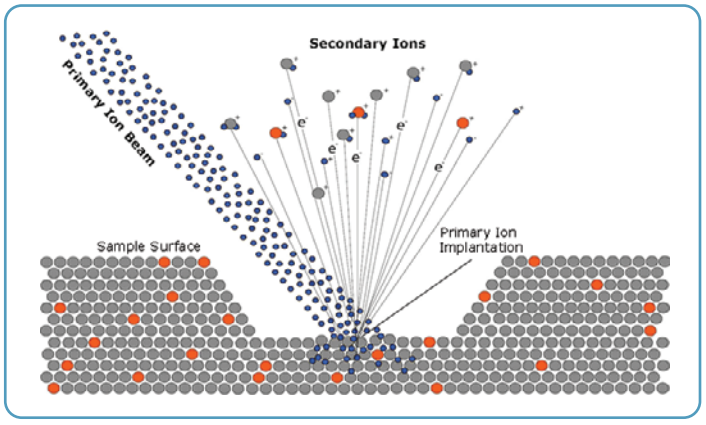
Results show that elements such as C, N, P, S, Cr, Mn, Fe, and Ga are often co-localized in or around preserved organics, indicating that these elemental distributions could have an application as a biosignature. This biosignature could provide an additional tool to enhance current methods for determining biogenicity in conjunction with providing information on paleoenvironmental conditions.



SIMS accumulated ion images showing elemental distribution in a single silicified microbial filament from the base strata of Steep Cone, together with a plain-light photomicrograph (top left). The scale bar applies to all images. The color scale bar is relative intensity from low (black) to high (red).

Data collected on IMS 7f-Geo WUSTL (US). From A. Gangidine et al., "Trace Element Concentrations in Hydrothermal Silica Deposits as a Potential Biosignature" Astrobiology 20, 3, 2020.

The technology behind



Dynamic SIMS

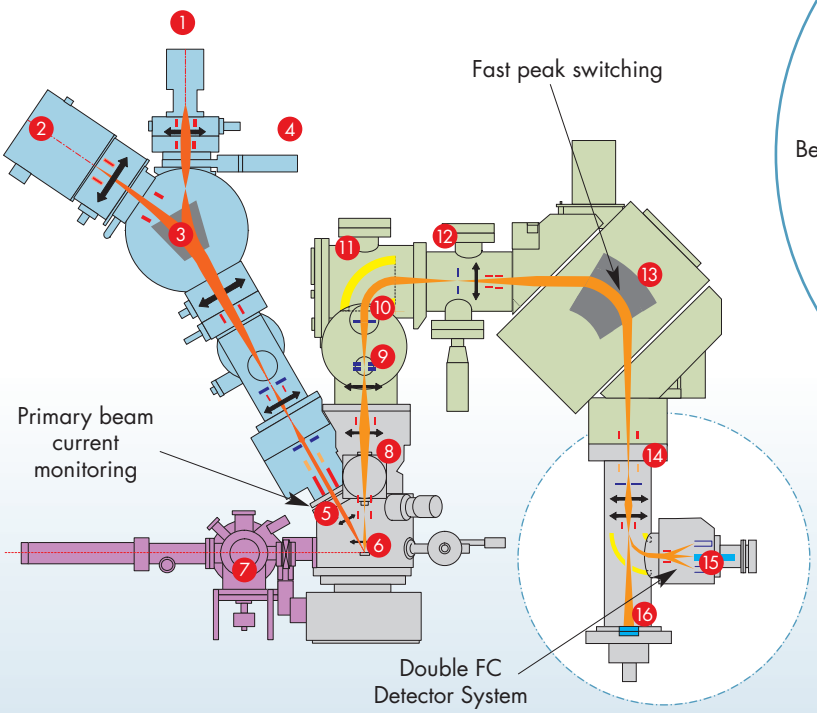
When a solid sample is sputtered by primary ions of few keV energy, a fraction of the particles emitted from the target is ionized. Secondary Ion Mass Spectrometry consists of analyzing these secondary ions with a mass spectrometer.

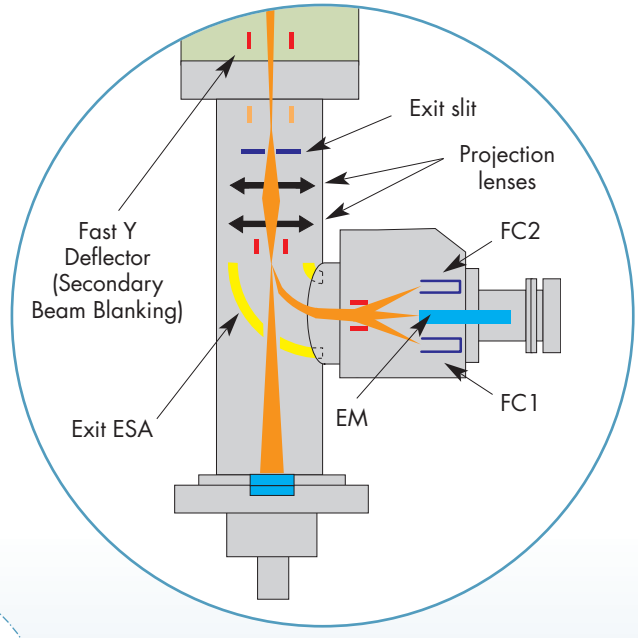
The SIMS technique is "destructive" by its nature (sputtering of material). It can be applied to any type of flat, solid material that can be kept under vacuum.

In dynamic SIMS, bulk composition and in-depth distribution of trace elements are investigated with a depth resolution ranging from sub-nm to tens of nm. SIMS is recognized as the most sensitive elemental and isotopic surface analysis technique.

CAMECA IMS 7f-GEO

The IMS 7f-GEO is a mono-collection SIMS model that combines the well-proven features of the IMS 7f with a specific detection system including two Faraday cups and one Electron Multiplier.





1 Microbeam Cesium ion source
2 Duoplasmatron ion source
3 Primary Beam Mass Filter (PBMF)
4 Cesium source isolation option
5 Primary Faraday cup
Motor driven primary column aperture
6 Sample (-10kV to +10kV) (Z axis in option)
7 UHV airlock system (Sample storage chamber in option)
8 Normal incidence Electron Gun (NEG)
9 Motor driven contrast aperture and entrance slit
10 Motor driven field aperture
11 Electrostatic Analyzer (ESA)
12 Motor driven energy slit
13 Fast laminated magnet
14 Motor driven exit slit
15 Electron Multiplier and double FC detectors
16 Ion image detector

For more information please visit www.cameca.com/products/sims/ims7f-geo

Ref. AP 7f-geo-bio-signature upd 2023