Scoping out soils with CAMECA NanoSIMS

Nanoscale imaging and analysis for:

- Microbial activity & processes
- Soil organic matter allocation & sequestration
- Plant–microorganism soil interactions in the rhizosphere
- Mineral particles & aggregates
- Element distribution in soil micro-structures
- Interfaces of soil minerals & biota
- Environmental carbon capture & storage

CAMECA NanoSIMS 50L advantages:

- Unique high-performance ion micro-probe / secondary ion mass spec-trometer (SIMS)
- Utmost-precision isotopic & trace element analysis
- High spatial resolution (down to 50 nanometers)
- Parallel acquisition of seven masses
- High mass resolution (M/dM)
- Ability to complement other imaging techniques

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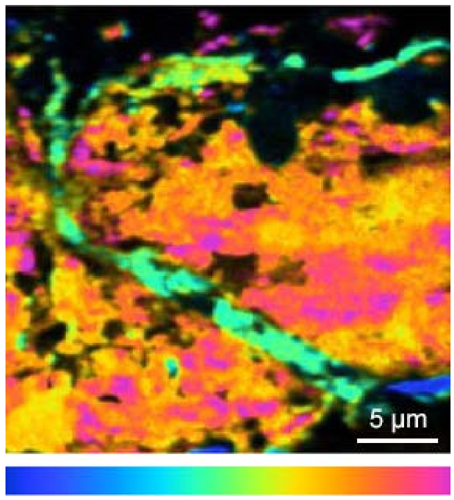
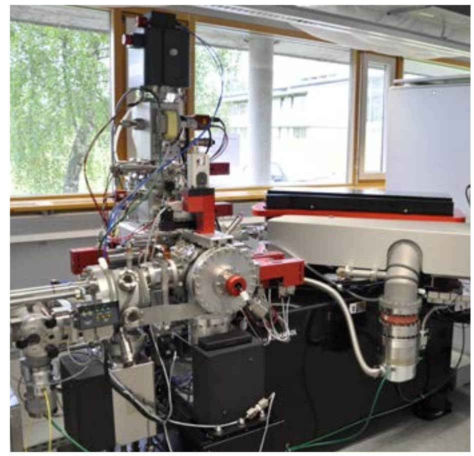
A SUCCESS STORY



A key to carbon capture: Examining soil minerals, plant litter, fungal hyphae, and extracellular polymeric substances. Unique nanoscale imaging reveals interfaces where persistent organic carbon is formed. Purple shows spots with high enrichment in carbon-13.



NanoSIMS 50L ion microprobe at the Chair of Soil Science, Technical University of Munich (TUM).

The Challenge

The soil beneath our feet not only grows most of our food. It also impacts the sky above our heads. For example, as long as they persist below ground, huge reservoirs of a substance vital to soil functioning — carbon (C) — are prevented from helping accelerate atmospheric climate change. So topics such as carbon capture and storage have become important parts of the larger picture in soil science.

One key contributor to developing that picture: Carsten W. Müller, a German soil scientist. He's currently associate professor in the Department of Geosciences and Natural Resources Management at Denmark's University of Copenhagen. There, and during his earlier education at and assistant professorship in the Technical University of Munich (TUM), Dr. Müller has helped pioneer the use of advanced nanoscale imaging to study complex soil component interactions.

A recent study that Dr. Müller designed and supervised was carried out with Kristina Witzgall, a graduate student at TUM, and their team. The scientists were interested in the fate of plant litter — leaves, bark, needles, twigs, and other bits of dead plant residue, categorized as *particulate organic matter (POM)*. POM is known to provide nutrients for soil microorganisms, the key players in transforming plant-derived carbon into soil-locked organic carbon.

Among the study's objectives: to quantitatively assess interactions between microbial decay of plant residues and soil structure formation. And to determine how the formation of POM — including persistent carbon stores — is fostered by the biogeochemical interaction of POM, microorganisms, and minerals at their interfaces.

The Instrument

Dr. Müller has continued to collaborate with his former lab at TUM plus several other facilities that house some critical tools: including an advanced CAMECA NanoSIMS 50L ion microprobe.

This unique instrument optimizes secondary ion mass spectrometry (SIMS) performance at ultra-high lateral resolution and sensitivity. So it furnishes superior isotopic and trace element analysis in small regions of interest.

Dr. Müller reports that the NanoSIMS 50L provides some important benefits:

- High spatial resolution, to examine small spatial distributions throughout soil at ultra-fine scales
- Parallel acquisition of seven masses, to simultaneously view and measure elements such as carbon and nitrogen (N), plus isotope systems like ^{13}C and ^{15}N, plus metals in soil minerals
- Added value when used with complementary imaging techniques

All these capabilities enable investigators, for the first time, to resolve processes at very fine soil structures down to microscale-size aggregates, single minerals, and microbial cells.

"NanoSIMS has revolutionized soil science," Dr. Müller declares. "You might have a concept, you might think of spatial distribution of carbon on a mineral surface — but then you *see* it. Now we can directly witness the arrangement of soil constituents and gain insight into their interactions at the sub-micrometer scale: something hitherto impossible."

The Work

For the POM study, the researchers incubated samples of isotopically labelled litter (containing ^{13}C), to study how soil structures, namely soil aggregates, affected the POM's fate. They directly measured samples of intact plant–soil interfaces. They also investigated the spatial distribution and isotopic enrichment of fungal hyphae (filaments), microorganisms, and minerals assembled at POM surfaces.

These microscale structures were first analyzed using a scanning electron microscope (SEM). Spots that best exemplified the microbial transformation on the POM surface were then imaged using a CAMECA NanoSIMS 50L.

The Results

Among the team's findings: not only are those POM surfaces hotspots for microbial activity. Confirming earlier theories, they're also critical nuclei for the formation of mineral-associated organic matter, regardless of soil texture. Fungi play a surprisingly large role here. And ultimately, the activity at the POM surface is a key to regulating carbon persistence in the soil.

"So for the first time," says Dr. Müller, "we were able to directly image it! To see how these phenomena work. Those hotspots — those interfaces between plant residues, microorganisms, and soil particles — are where persistent organic carbon is formed."

The Future

One practical outcome might be intensified use of compost, plant residues, or other organic amendments on cropland, for sustaining yields and increasing carbon capture in a changing climate.

From a research point of view, Dr. Müller says, "It's up to the soil science community to integrate a tool like NanoSIMS wisely into their experiments, with the right sample prep, in conjunction with other instruments in the analytical tool box — to unravel soil processes at the microscale.

"I think there's much, much more to come. With this imaging and other tools, we can really get down to the microbial ecology in conjunction with soil minerals in intact soil structures — in the roots or rhizosphere plant–soil interactions, plant–mycorrhizal interactions, mycorrhizal–soil interactions.

"Natural processes in the environment, biodiversity, water availability, pollution control — that's all soil science," he concludes. "If we want to tackle the most urgent questions that humanity has, we need to understand soils."

About the Scientist

Dr. Carsten W. Müller has helped pioneer applying nanoscale imaging techniques to soil science investigations. He pursued this work from 2005 to 2019 in undergraduate through doctoral studies, then as assistant professor — all at the Technical University of Munich. Since 2020, he's been associate professor in the Department of Geosciences and Natural Resource Management at the University of Copenhagen. His research combines physical, biological, and chemical analyses to discern energy and matter fluxes in the complex 3-D structures that sustain soil functionality.

About CAMECA

CAMECA is a world-leading supplier of microanalytical and metrology instrumentation for research and process control. Our instruments measure elemental and isotopic composition in materials down to atomic resolution. Advanced CAMECA technologies include secondary ion mass spectrometry (SIMS), atom probe tomography (APT), and electron probe microanalysis (EPMA). We address challenging characterization needs in diverse markets, from soil science, materials sciences, life sciences, geology, and cosmochemistry to environmental, nuclear, and semiconductor research.

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