New developments in hard x-ray fluorescence microscopy to visualize trace element distributions in aqueous systems of soil colloids

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Trace elements, in particular metals, play a significant role in most known life forms. It is estimated that one-third of all known proteins contain metal cofactors, and the majority of these function as essential metalloenzymes catalyzing biochemical reactions. It is getting more and more recognized that trace elements have a critical impact on human health both in their natural occurrence and via therapeutic drugs. Because of metals’ significant impact on the life sciences, there is also tremendous interest in detailed understanding of metal transport phenomena. Here, one of the critical components are colloids. The huge specific surface area of soil colloids is a major feature and determines properties such as adsorption or transport processes. The colloidal interactions differ significantly from the behavior of the same materials in a bulk system. There is still a need for better suited analytical resources when studying interactions in the colloidal regime, as these are crucial e.g. for the transport and release of nutrients and toxicants in soils, which then influences directly the growth of plants for example.

Hard x-ray fluorescence microscopy is a powerful technique to map and quantify element distribution. It provides attogram sensitivity for transition metals like Cu, Zn, and other geochemically relevant trace elements, at submicrometer spatial resolution (currently down to 150 nm), combined with the capability to penetrate water layer of several tens of micrometer. Elemental content is measured directly by using the characteristic fluorescence of the interesting element atoms excited by the microfocused X-ray beam. Typically, up to 15 elements are mapped simultaneously, leading to precise elemental colocalization maps. In addition, the possibility of selecting the incident X-ray energy enables microspectroscopy and chemical state mapping to determine the speciation of elements of interest. These unique capabilities of x-ray fluorescence microscopy have been employed in diverse environmental applications, and complement other modern microscopy techniques. We will demonstrate their application in several ongoing studies, ranging from the dynamical behavior of these colloidal suspensions at changing pH, to 3 dimensional visualization of trace elemental content in environmental structures.

Figure 1: In-situ experiment represented by colocalization of three elements obtained from X-ray fluorescence image taken at 10 keV. Elements shown are Si (red), K (green), and Fe (blue). Left: Colloids, in aqueous dispersion, taken from a Pseudogley aqueous sandwiched between two silicone nitride membranes. Fast fly scan of 185x115 µm² area, 500 nm² pixel size, 20 ms dwell per pixel. Right: Same sample as on the right, but after in-situ injection of urea. Detail shown from 200x150 µm² scan area.