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Applications of Micron Resolution Chemical Imaging using Fast, Efficient X-ray Fluorescence Microscopy

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X-ray fluorescence microscopy (XFM) can be used for elemental and chemical microanalysis across length scales ranging from millimeter to nanometer. XFM is ideally suited to quantitatively map trace elements within whole and sectioned plant, biological specimens such as tissue sections, environmental and soil samples. The high elemental sensitivity of X-ray fluorescence microprobes coupled with deep penetration of hard X-rays enables measurement of an incredibly diverse range of samples in situ and under environmental conditions with a minimum of preparation.

Event mode X-ray fluorescence detection methods pioneered by the Maia detector system [1,2,3] at the Australian Synchrotron XFM beamline [4] enable high definition imaging which can approach megapixel per minute rates. The ability to rapidly acquire 2D images enables higher-dimensional studies such as fluorescence tomography [5,6], X-ray absorption near edge structure (XANES) imaging, and XANES tomography in realistic times.

Full spectral XANES imaging takes advantage of fast XFM and results in X-ray absorption near edge structure spectra from X-ray fluorescence at each pixel in the image. The speed and efficiency is gained by employing on-the-fly raster scanning and large solid angle, often multi-element, detectors with high count rate capabilities. The efficiency and speed ensures the lowest possible dose alongside high throughput.

XANES imaging is now a mature technique. This paper briefly describes the range applications of chemical imaging using fast XFM with micron resolution predominantly at the Australian Synchrotron, and focussing on studies under environmental conditions.

The technique was first demonstrated in a geochemical context studying inhomogeneous oxidized pisolitic regolith [7]. XANES imaging has been employed with micron resolution and moderate definition (10K pixels and 100–300 incident energies) across a diverse range of sciences and applications from environmental chemistry [8], to arsenic toxicity in crop production [9,10]. Recently XANES imaging was used to map manganese distribution and speciation to explain the effects of silicate and phosphate on manganese toxicity in four crop species [10].

Environmental pollution studies using XANES imaging have included, for example, how ferric minerals and organic matter change arsenic speciation in copper mine tailings [11].

Full spectral XANES imaging has been applied in cultural heritage studies including research into the alteration process of chrome yellow pigments in Vincent van Gogh paintings [12].

The technique has also been described as fluorescence imaging XANES (ϕXANES) and used to visualize in vivo coordination environments of metals in biological specimens [13]. More recently tomography and XANES imaging have been coupled in fluorescence XANES tomography in a study to visualise coordination chemistry by mapping the distribution of cuperous and cupric complexes within *Drosophila melanogaster* [14]

The speed and efficiency of the technique ensures the lowest possible dose and can avoid radiation damage. XANES imaging has been applied to fresh and hydrated plant samples in a number of studies including the speciation imaging of selenium in fresh roots and leaves of wheat and rice [15].

In recent efforts XANES imaging has been used in research around bio-fortification of staple cereal crops to understand, for example, the correlated element distribution and iron speciation in mature wheat grains (*Triticum aestivum L.*) [16].

The breadth of applications demonstrates the power and versatility of XANES imaging to determine the spatial distribution of chemical speciation in situ and under environmental conditions.

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