Looking into Art and Cultural Heritage with Synchrotron X-Rays

E. Dooryhee[1,2*], M. Anne[1], J-L. Hodeau[1], P. Martinetto[1], P. Walter[3], M. Menu[3]

[1] *Neel Institute, CNRS-UPR2940, Joseph Fourier University, 25 av. des Martyrs, BP 166, 38042 Grenoble Cedex 9, France*
[2] *Brookhaven National Laboratory, National Synchrotron Light Source 2 (NSLS II), Upton, NY 11973 USA*
[3] *Centre de Recherche et de Restauration des Musées de France, CNRS-UMR 171, Palais du Louvre, 14, quai François Mitterrand 75001 Paris, France*

**dooryhee@bnl.gov*

Cultural heritage objects inspire through their artistic merit and through their encapsulation of the art, science and technology of past and present cultures. The microstructure and composition of many archaeological objects are a direct or indirect record of ancient ways of life, know-how and trade routes. As a consequence, there is an increased demand for the scientific characterization of objects that are part of our cultural heritage, such as paintings, ceramics, books, sculptures and utensils to name but a few. One looks forward to unveiling the secrets that lie within these artifacts such as their origin, history, manufacturing processes and about the specific societies from which they emerged. One also often questions the authenticity of these objects.

Moreover it is essential to preserve this cultural heritage for future generations. The diagnosis of degradation/aging mechanisms of artifacts and the development of repair or stabilization strategies are areas of central importance. This can only be accomplished by means of multidisciplinary analysis of complex systems and innovative problem solving, and also leads to the development of new noninvasive or microsampling examination technologies.

It is thus desirable to implement non-destructive experimental techniques that preserve the "real character" of the objects, without contaminating or damaging them. Synchrotron radiation (SR) covers a very wide range of wavelengths, from infrared up to x-rays. It offers many well-established experimental techniques capable of providing elemental analysis, internal structural analysis and even in some cases atomic structure analysis. It can allow non-destructive imaging of the surfaces and also 3D structural information of the artifacts, since x-rays can penetrate through the materials without leaving a trace of the investigation process.

Applications of physics and chemistry in archaeology thus emerge as a part of materials science and the needs for SR-based techniques are ever increasing, including x-ray imaging, x-ray diffraction, x-ray fluorescence and FTIR spectroscopy. This is also an opportunity to exploit the appeal of this cross-disciplinary field to engage the public and train students in science.

As an example among many, Fig. 1 shows the combined fluorescence-diffraction work carried out over several paint samples of Matthias Grünewald, a major painter at the beginning of the German Renaissance. Chemical and phase mappings of the cross-sections, keeping the stratigraphy intact, are an essential step towards the description of the artist's paint palette and know how [1].

Ancient materials often are complex, heterogeneous samples with a hierarchical arrangement which is related with the artifact manufacturing. Different structural probes covering different scale lengths are required. X-ray diffraction is one of the prime structural methods but suffers from a relatively poor detection limit, whereas transmission electron analysis involves destructive sample preparation. In a second example (Fig. 2), we show the potential of coupling pencil-beam tomography with x-ray diffraction to examine unidentified phases in ill-ordered and poly-phased materials [2].

I shall present a brief overview of the different aspects of SR "archaeometry", in terms of diversity and complexity of historically and/or artistically interesting samples, as well as SR technical and instrumental requirements. The present contribution outlines the new but still fragile interface between art, archaeology and synchrotron science.

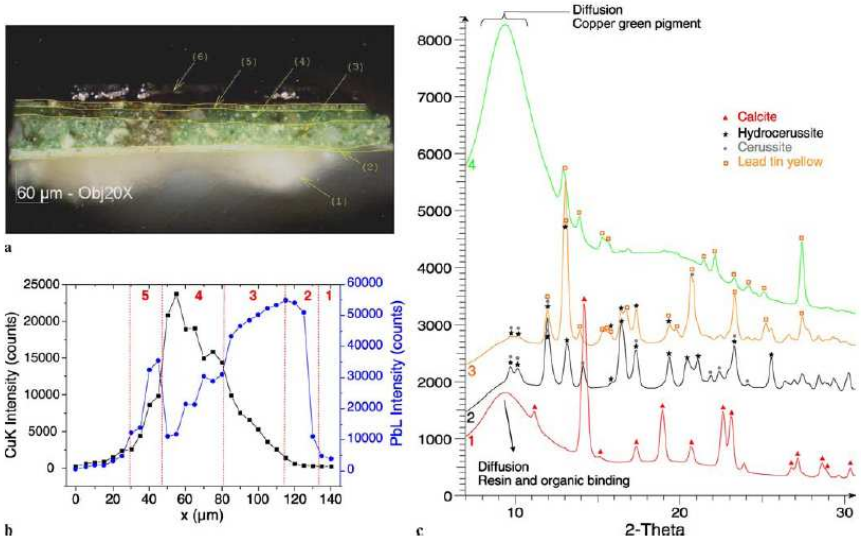

Figure 1 from ref. [1]: SR micro-beam diffraction (XRD) and fluorescence (XRF). (**a**) Optical microscope observation of a cross section embedded in resin, magnification: ×20. (**b**) XRF transverse line-scan across the stratigraphy of the cross section, from the outer to the inner layer. The intensities of the Cu *K* and the Pb *L* emission rays are plotted as a function of depth. (**c**) SR x-ray micro-XRD patterns from the four distinct layers 1,2,3 and 4. Layer 1: calcium carbonate preparation layer; layer 2: priming layer made of lead carbonates (hydrocerussite and cerussite); layers 3,4,5: green copper pigments composed of lead tin yellow and lead carbonates; layer 6: organic layer, varnish.

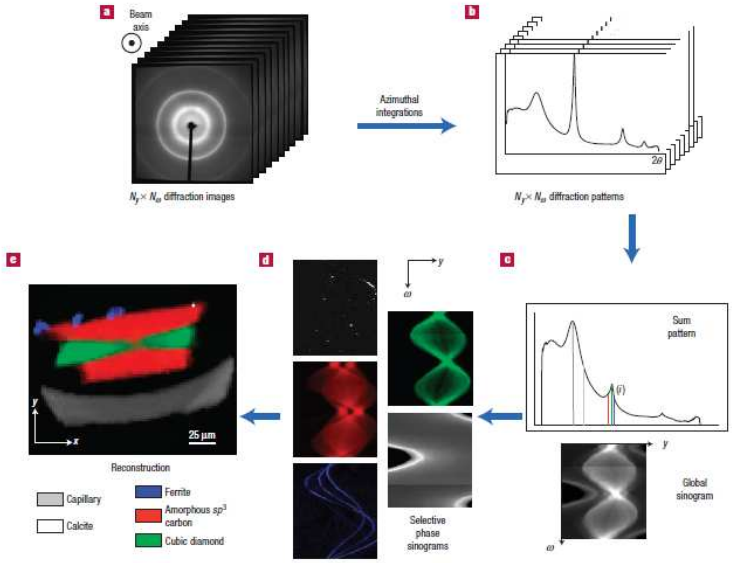

Figure 2 from ref. [2]: The successive steps and principles of the reconstruction scheme of the Diffraction–Tomography direct analysis are illustrated here. **a**,**b**, For every position (y, ω), the 2D scattering pattern is integrated over the azimuthal angle and produces the respective 1D scattering pattern f(2θ). **b**,**c**, On the one hand, all the 1D patterns are summed up over y and ω, to construct the scattering sum pattern of the entire sample. On the other hand, each 1D f(2θ) pattern is integrated over the diffraction angle 2θ, and the resulting total scattering intensity is plotted as a function of (y, ω) to build up the global sinogram. **d**, a ROI over a selected 2θ angle range, corresponding to a given scattering contribution or a diffraction peak, can be defined to extract the relevant sinogram of the corresponding individual phase. **e**, Finally, a reconstruction from these sinograms provides axial slices of the corresponding phases. This cross-section image reveals the spatial distribution of the different phases inside the sample and the surrounding glass capillary holder.

[1] E. Welcome, P. Walter, P. Bleuet, J.-L. Hodeau, E. Dooryhee, P. Martinetto, M. Menu Appl. Phys. A 89, 825 (2007)
[2] P. Bleuet, E. Welcomme, E. Dooryhee, J. Susini, J.-L. Hodeau, P. Walter Nature Materials 7, 468 (2008).