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Total X-ray Intensity Images of Mouse's Femoral Epiphysis and Incisor Tooth from SEM-EDS

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Energy-dispersive spectroscopy of X-ray (EDS) is a widely used analytical technique attached to a scanning electron microscope (SEM) for the elemental or chemical characterization of a sample, which, when combined with the morphological information from secondary electron (SE) and/or backscattered electron (BSE) images (Figures 1a & 2a), is an effective approach to characterize materials in terms of chemistry and morphology. The SEM-EDS analysis is commonly presented as qualitative or quantitative elemental results in a spectrum, a table of element wt% or at%, or an X-ray linescan or map of a specific element. An X-ray map or image of an individual element elucidates the two-dimensional distributions of the specific element mapped across a well-polished sample surface (Figures 1b to 1c & 2b to 2c). We here introduce a new type of EDS image based on the total intensity of all X-rays (Figures 1d & 2d) and its applications in imaging mouse's femoral epiphysis and incisor tooth samples.

A total X-ray intensity image, or total X-ray counts per second (CPS) image, is obtained by combining all X-ray signals from all elements in a sample. In digital EDS X-ray mapping, the electron beam is scanned across the sample surface pixel by pixel (x, y) and the intensities (I) of all X-ray signals from all elements are collected for each pixel. Then a two-dimensional X-ray map or image is constructed using the intensity and location information from these three parameters (I, x, y). During the mapping, the electrons signals (SE, BSE or both) can be collected simultaneously. Figures 1 & 2 are BSE, P Kα, Ca Kα, and total CPS image for mouse's femoral epiphysis and incisor tooth, respectively, which were obtained using an EDAX Octane Elect Elite Plus EDS system attached to a Philips XL30 FEG-ESEM at the University of Missouri-Kansas City. The total CPS images were generated using EDAX APEX Advanced software, which include X-rays from all elements identified (P Kα, Ca Kα, C Kα, O Kα, Na Kα, Cl Kα and Mg Kα). The SEM and EDS experimental conditions were accelerating energy 15 kV, spot size 5, work distance 10 mm, dwell time 50 or 100 µS, and frames 256 or 512. Our measurements indicate that a good digital EDS X-ray map typically requires a total collecting time of one hour or longer.

The total CPS images (Figures 1d & 2d) are very much similar to the BSE images (Figures 1a & 2a) of the same area. In fact, both BSE and X-ray signals are proportional to atomic number Z through Z contrast and Moseley's Law, respectively [1, 2, 3]. The bright areas correspond to high average atomic numbers. However, BSE and X-ray signals are generated through different mechanisms or scattering processes. BSE is due to the elastic scattering of the incident beam electrons with the atoms in the sample without energy loss of the incident electrons. On the other hand, X-rays signals are generated from the inelastic scattering of the incident beam electrons with the atoms, which involves the energy loss of the incident beam electrons. Geometrically, the BSE image (Fig. 1a) is acquired in the compositional mode from the detector right above the sample surface, while the total CPS image is from the EDS detector on the side from the electron column with a take-off angle of approximately 45°. There is no 3D effect in the BSE images (Figures 1a & 2a). However, the corresponding total CPS images shows strong 3D shadow effect as shown by the fracture in the upper central position in Figure 1d and the shadow rims around the lower left sides of the dark areas in Figure 2d. In addition, the total CPS images are smoother than the corresponding BSE image and reveal additional information about the sample surface roughness. The

conventional element X-ray images are provided to illustrate that such images only display the distribution of the element of interest without any surface features.

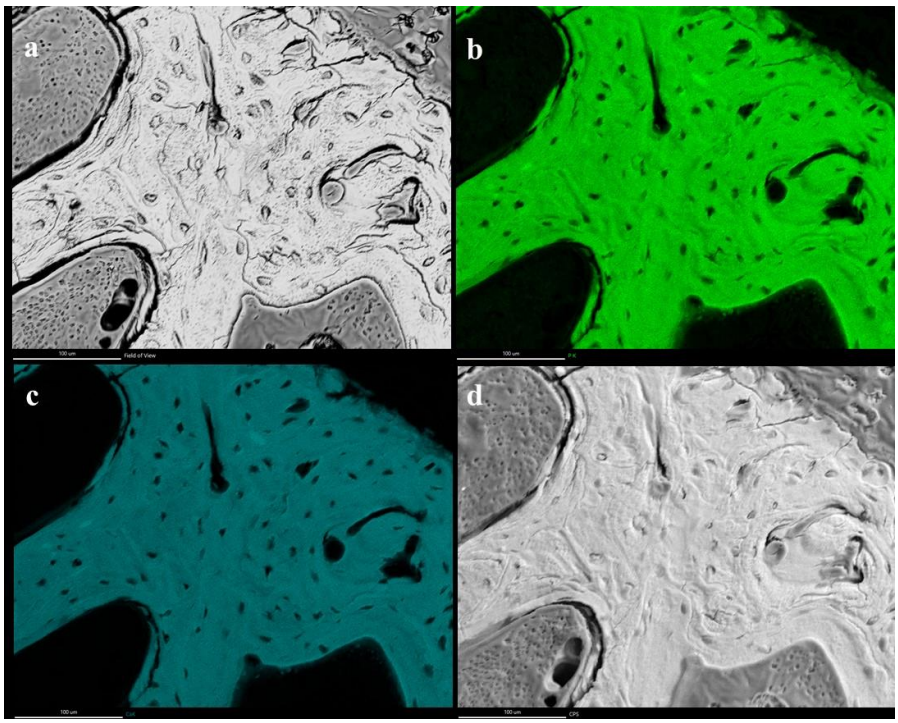

Figure 1. Figure 1. BSE and X-ray images of a mouse's femoral epiphysis. a) BSE, b) P Kα, c) Ca Kα, and d) total CPS image. The width of the individual images is the same, approximately 400 µm.

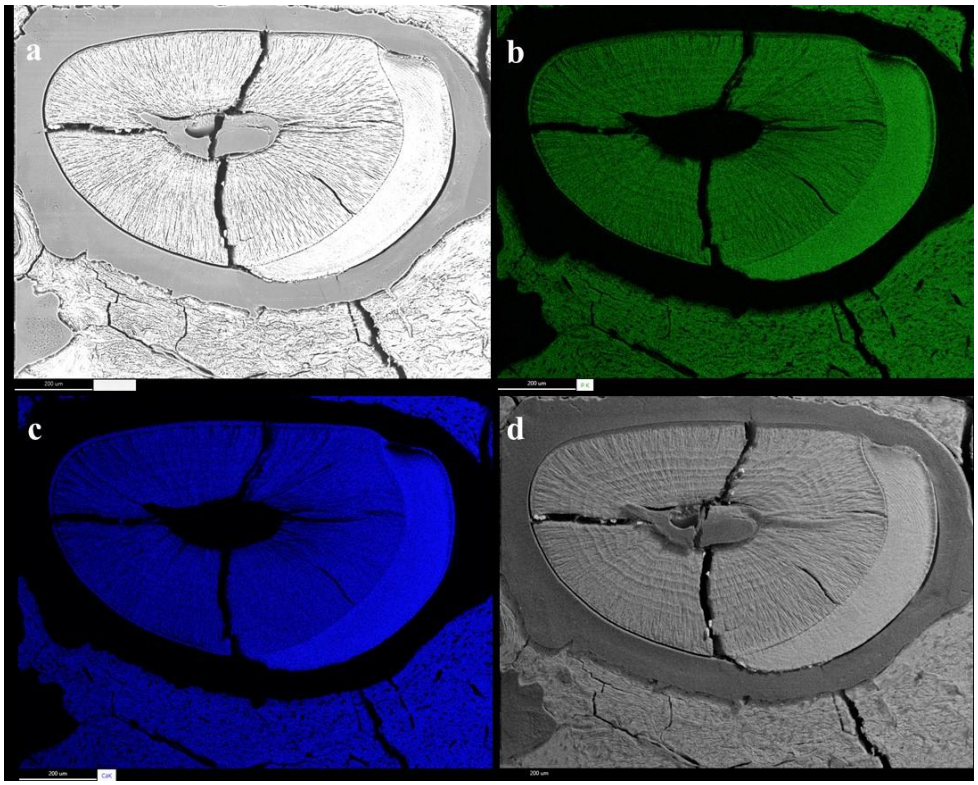

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Figure 2. Figure 2. BSE and X-ray images of a mouse's incisor tooth. a) BSE, b) P Kα, c) Ca Kα, and d) total CPS image. The width of the individual images is the same, approximately 1100 µm.

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