

Mapping α -particle X-ray Fluorescence Spectrometer (Map-X). D.F. Blake¹, P. Sarrazin² and T. Bristow¹,
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Introduction: Many planetary surface processes (like physical and chemical weathering, water activity, diagenesis, low-temperature or impact metamorphism, and biogenic activity) leave traces of their actions as features in the size range 10s to 100s of μm . The Mapping α -particle X-ray Spectrometer (“Map-X”) is intended to provide chemical imaging at 2 orders of magnitude higher spatial resolution than previously flown instruments, yielding elemental chemistry at or below the scale length where many relict physical, chemical, and biological features can be imaged and interpreted in ancient rocks.

Map-X: Map-X is an arm-based instrument placed directly on the surface of an object to be analyzed (e.g., pristine or abraded rock, soil, drill core on an observation tray) and held in registry with it through the use of touch sensors that physically contact the surface. During an analysis, a radioisotope source bombards the sample surface with α -particles and γ -rays, resulting in x-ray fluorescence from the sample. X-rays emitted in the direction of an X-ray sensitive CCD imager pass through an x-ray 1:1 focusing lens (called an X-ray μ -Pore Optic, MPO) that projects a spatially resolved image of the x-rays generated from the sample surface onto the CCD. The frame-transfer CCD is read at the rate of 1 frame per second. The images are stored in memory and processed in real time using algorithms parameterized from the ground. The source flux is designed and scaled such that during a single exposure, in the large majority of cases, no more than a single photon strikes each pixel between frame transfers. In this way, the energy of each x-ray photon can be measured and its source element in the sample identified. In a 2-3 hour experiment, several thousand frames

are both stored and processed in real-time.

Primary data products include single-element maps for elements of interest with a lateral spatial resolution of $\leq 100 \mu\text{m}$ and an XRF spectrum from the area imaged. Additional data products include XRF spectra from ground-in-the-loop defined Regions of Interest (ROIs). XRF spectra from ROIs are processed on the ground to determine quantitative elemental compositions. Quantitative compositions from ROIs are compared with known rock and mineral compositions to extrapolate the data to rock types and putative mineralogies. A single Map-X experiment provides elemental and compositional maps and quantitative XRF spectra having a spatial resolution of $\leq 100 \mu\text{m}$, commensurate with other imaging instruments.

Proof-of-Concept Instrument: Figure 1 shows hardware used to validate the Map-X proof-of-concept instrument. The instrument has only limited functionality relative to the proposed Map-X instrument since the proof-of-concept COTS CCD camera has a $250 \mu\text{m}$ Be window (limiting sensitivity to elements Ca and above) and the excitation source is a Mo x-ray tube (having limited fluorescence efficiency below Ca). The x-ray MPO lens in the proof-of-concept has not been optimized for this application. Figure 1a-b show different views of the hardware, and Fig. 1c shows the instrument in position to analyze a sample of an ancient methane seep deposit [1-3]. The curvilinear laminae visible in the optical image (Fig. 1d) and clearly defined in the Ca map (Fig. 1e) are dolomicrite remnants of microbial mats that have been deformed and fragmented by fluid flow.

XRF Spectroscopy with Radioisotope Sources: α -particles, γ -ray and x-ray photons suffer inelastic

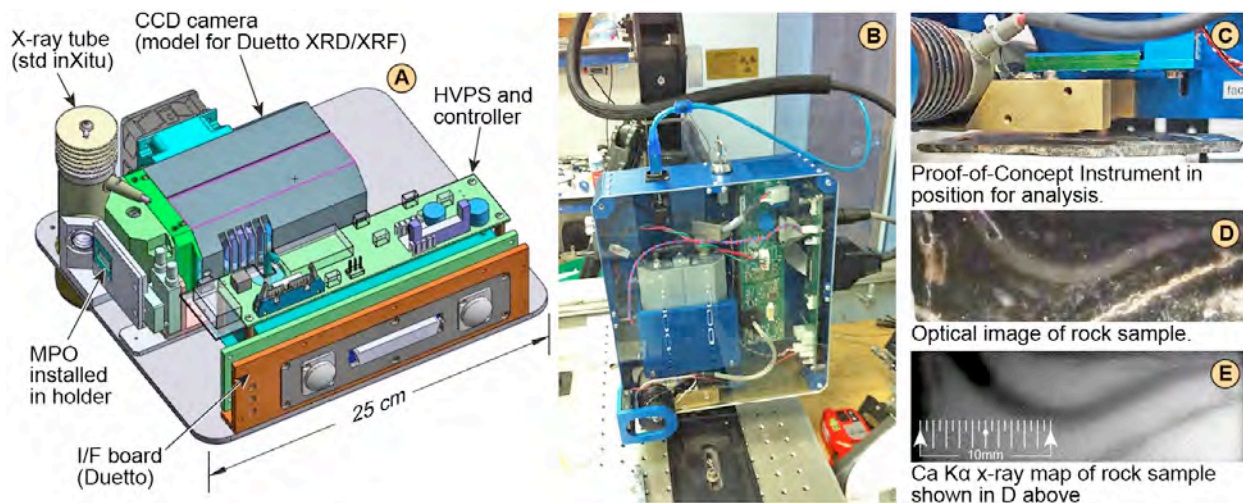


Figure 1. Proof-of-concept Map-X instrument and example data from a polished rock section (see text).

interactions with sample atoms, resulting in the secondary fluorescence of x-rays from the sample. The APXS instruments use ^{244}Cm (a radioisotope that yields α -particles and γ -rays) as an x-ray excitation source [4,5]. The fluorescing ^{244}Cm γ -ray emission lines of principal interest lie in the range 10-20 KeV, and are most efficient at fluorescing x-rays from higher atomic number (Z) elements $\sim 20 < Z < 30$ (Ca $K\alpha$ to Ni $K\alpha$) in the target material. α -particles emitted by ^{244}Cm are most efficient at exciting x-ray fluorescence from lower atomic number elements $\sim 10 < Z < 19$ (Na $K\alpha$ - K $K\alpha$). Thus, a radioisotope source that yields both γ -rays and α -particles is desirable for applications like Map-X because it efficiently excites x-rays from both high- Z and low- Z elements. By comparison, x-ray tube sources are typically very efficient at exciting higher Z elements (with energies just below the characteristic x-ray energy of the source anode typically Co, Cu, Mo), but inefficient for lower Z elements. For spaceflight XRF applications, the use of a radioisotope source eliminates the high cost, complexity, risk, power requirement, thermal and vibration sensitivity and mass of an x-ray tube and high-voltage power supply. We are developing an XRF test fixture to determine the optimum radioisotope type and quantity for Map-X

(radioisotopes to be tested include ^{241}Am (α, γ emitter), ^{55}Fe (γ -emitter), ^{252}Cf (α -emitter) and ^{244}Cm (α, γ emitter)).

Instrument geometry and MPO optimization:

The geometry of the Map-X instrument is being refined by experimental measurements and ray-tracing simulations. Experimental measurements will be made using our proof-of-concept instrument fitted with a Mo x-ray tube. Ray-tracing simulations will be used to determine the resolution obtained with varied MPO characteristics, x-ray energy and CCD characteristics (x,y dimensions and pixel size).

Fig. 2 shows an example dataset from the Map-X prototype instrument, obtained from a polished section of carbonate-cemented basalt breccia (Svalbard, Norway).

References: [1] Jiang G.Q et al. (2003) *Nature* 426, 822-826. [2] Bristow T.F. et al (2011) *Nature* 474, 68-71. [3] Bristow T.F. and Grotzinger, J.P. (2013) *Geology* 41, 811-814. [4] Rieder et al. (2003) *JGR* 108 No. E12, 8066. [5] Gellert et al. (2006) *JGR* 111 E02S05.

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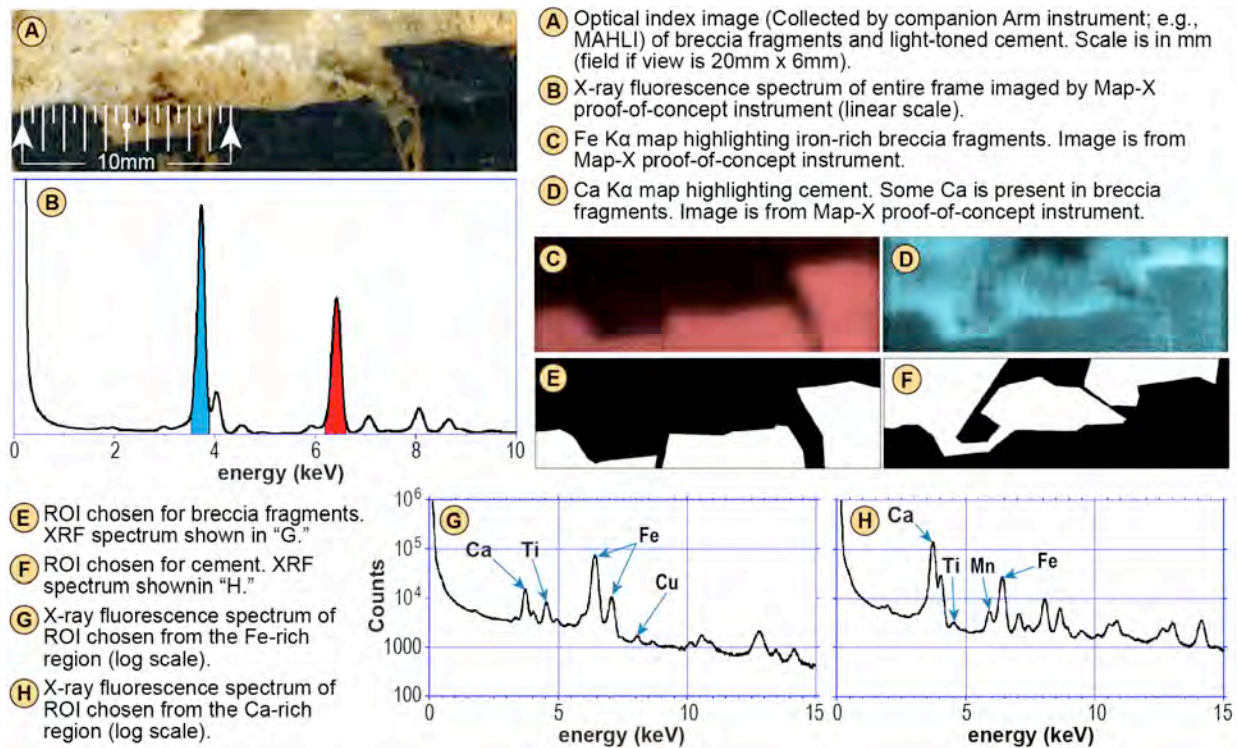


Fig. 2. Data products from the Map-X instrument