MapX: An In-situ X-ray μ -Mapper for Habitability and Biosignature Studies.

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Introduction: The search for evidence of life or its processes on Mars takes on two major themes: 1), the identification of environments that have or once had the potential to harbor life (habitability); and 2), the detection of morphological or chemical features suggestive of extinct or extant life (biosignatures). Compositional heterogeneity at the mm-to-100 μ m scale can reveal geological processes indicative of past or present habitability, and morphological and compositional heterogeneity on a similar length scale can provide evidence of life's processes. The Mapping X-ray Fluorescence Spectrometer (MapX) is an arm-based *in-situ* instrument designed to identify these features on planetary surfaces [1].

Instrument Description: MapX is a full-frame elemental imager capable of analyzing samples *in situ* without sample preparation. The instrument has no moving parts and is designed to utilize ^{244}Cm radioisotope sources, eliminating the need for a High Voltage Power Supply or X-ray tube. Figure 1 shows a), a schematic of the instrument, which consists of X-ray / γ -ray / α -particle sources, a Micro-Pore Optic (MPO) focusing lens and CCD imager; and b), a 3-D model of the arm-mounted imaging unit. The MPO X-ray focusing lens (PHOTONIS) is placed equidistant between the sample and the CCD. The lens derives from “lobster-eye” multichannel optics used for X-ray astronomy [2]. It is implemented here in a flat geometry for 1:1 focusing. This lens provides a much improved aperture when compared to pin-hole camera optics having similar spatial resolution, and true focusing when compared to polycapillary collimating optics also used for X-ray mapping. The camera is driven at up to 3 frames per second. The MPO has a large depth of field, ($\sim 1\text{cm}$) allowing rough unprepared surfaces to be imaged with minimal loss of resolution. The CCD is exposed and read rapidly (several frames per second) such that each pixel records

Figure 1: a). Schematic representation of MapX. MapX is a full-frame X-ray spectroscopic imager designed to work with either radioisotope (^{244}Cm) or electrical (X-ray tube) fluorescent sources. b). 3-D model of MapX flight instrument (arm unit shown with X-ray tube source). A RAMP unit inside the body of the rover controls the instrument, processes the data and communicates with the rover computer.

either a single photon from the sample or background. The number of electron hole pairs generated in a single pixel is directly proportional to the energy of the X-ray photon, and after summing a large number of individual frames, an XRF spectrum is generated for each pixel of the CCD. Each individual 0.3 sec. frame is a complete image; however, many frames must be summed to produce low-noise elemental images and quantifiable XRF spectra. Longer collection times allow for improved signal to noise; however in the event an image collection is interrupted, the partial data will still yield a complete image.

Instrument control, image collection, data processing and communication with the rover are accomplished in a second unit located in the instrument bay of the rover (“RAMP unit”). Downlinked data products include: Elemental maps $11 < Z < 40$, instrument-selected [3] Regions of Interest (ROI) having common compositions, and quantifiable XRF spectra from ROI.

Example MapX datasets: rough surfaces, polished stubs, or petrographic thin-sections were imaged first on an EDAX commercial laboratory instrument ($\sim 50 \mu\text{m}$ resolution), then on MapX-III, a third-generation prototype of MapX ($\sim 150 \mu\text{m}$ resolution). MapX-III data are collected in vacuum; on Mars, images will be collected at ambient pressure.

Figure 2 shows a partial MapX dataset collected from a quartz sandstone decorated with hematite crystals (similar to magnetite crystals observed on the surface of mudstones by the MSL *Curiosity* rover). The instrument nominally collects $\sim 10,000$ 0.3 second images into an HDF5 data cube. These data cubes can be as large as a Gigabyte, so they must be processed on-board. An unsupervised machine learning algorithm resident on the instrument computer produces ROI comprised of common elemental compositions.

Figure 2. Hematite crystals on quartz sandstone. a). image of sandstone fragment, scale bar = 1 cm; b). RGB elemental image from EDAX commercial instrument, Fe=Red, Si=Green, K=Blue; c). RGB elemental image from MapX-III prototype, same color scheme as b); d). instrument selected ROI, H = hematite, QS = quartz sandstone; e). XRF spectra from yellow ROI (hematite) and purple ROI (quartz sandstone).

Figure 3. Basalt breccia cemented by carbonate. a). image of basalt breccia, scale bar = 1 cm (note: the image shown is the obverse of the side used for elemental imaging); b). RGB elemental image from EDAX commercial instrument, Fe=Red, Ca=Green, Mg=Blue; c). RGB elemental image from MapX-III prototype, same color scheme as b); d). instrument selected ROI, B = basalt breccia, C = Carbonate, MC = magnesian carbonate; e). XRF spectra from ROI.

Quantifiable XRF spectra are generated from each ROI, which are analyzed off-line using a fundamental parameters technique. ROI compositions are used in conjunction with the RRUFF database [4] to determine putative mineralogy.

Figure 3 shows a partial MapX-III dataset collected from a brecciated basalt infilled with hydrothermal carbonate cements from Spitsbergen, Norway (analogous to Comanche Carbonate reported from MER [5,6]).

Figure 4 shows a partial MapX-III dataset collected from a polished stub of 1.9 Gyr old Gunflint Chert Stromatolite (Schrieber Beach locality). While the compositional features in the rock are $<50\mu\text{m}$, the elemental images, ROI and XRF spectra returned by MapX-III are sufficient to identify this rock as a chert with preserved carbonates displaying stromatolitic features, deserving of further *in-situ* analysis or return to Earth.

Figure 4. *Precambrian Gunflint Stromatolitic Chert. a). image of Gunflint Chert, scale bar = 1 cm; b). RGB elemental image from EDAX commercial instrument, Fe=Red, Ca=Green, Si=Blue; c). RGB elemental image from MapX-III prototype, same color scheme as b); d). instrument selected ROI, C = Chert, FC = Ferroan Carbonate; e). XRF spectra from ROI.*

MapX Flight Instrument. Figure 5 shows cut-away and solid 3D views of the MapX camera head, containing the sources, imaging optics, CCD and camera electronics (“Arm Unit”). A second processing unit (“RAMP Unit”) is located in the body of the rover and contains the computer processor, communications and instrument control software. Table 1 shows the proposed mass, volume and power requirements of the instrument as well as survival and operating temperatures.

Figure 5. *3D models of the MapX flight instrument. MapX. Right: Rendering of the arm mounted instrument in a flight like configuration.*

Table 1: MapX Environmental Conditions and Operating Parameters (^{244}Cm sources)

	Mass	Vol.	Pwr.	Survival Temp.	Operating Temp.*	Analysis time
Arm Unit	1.7 kg.	1.5 L	19 W	-70° C to 55° C	-40° C to 40° C	10 ksec.
Ramp Unit	2.2 kg.	1.5 L	25 W	-50° C to 50° C	-40° C to 40° C	10 ksec.
Total	3.9 Kg	3.0 L	44	*Heat to use		

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