A GEOCHEMICAL AND MINERALOGICAL INSTRUMENT TO ENABLE SCIENCE AND EXPLORATION WITH THE ARTEMIS PRESSURIZED ROVER. E. B. Rampe[1], P. Sarrazin[2], P. G. Lucey[3], P. Walter[4,5], C. Alkire[1], P. D. Archer, Jr.[6], J. A. Berger[6], D. F. Blake[7], L. Breitenfeld[8], A. Bumbalough[9], J. Chen[10], R. T. Downs[11], B. Lafuente[2], A. Madera[1], P. J. McNally[12], K. Prissel[13], T. Prissel[13], K. Thompson[14], S. VanBommel[15], M. Zanetti[8], [1]NASA Johnson Space Center (elizabeth.b.rampe@nasa.gov), [2]eXaminart, [3]HIGP, [4]CNRS, France, [5]LUMETIS, France, [6]Amentum at JSC, [7]NASA Ames, [8]PSI, [9]MSFC, [10]Baja Technology, [11]Univ. Arizona, [12]Univ. Michigan, [13]Purdue Univ., [14]SETI, [15]WUStL.

Introduction: Geochemical and mineralogical measurements are essential for interpreting the formation and evolution of a celestial body. Mapping the physical relationships between minerals at the outcrop to regional scale provides petrological information relevant to key science objectives and identify sites for exploration and sampling with robotic and crewed missions to the surfaces of rocky bodies. Mobility assets in the Artemis architecture, including the Pressurized Rover (PR) and Lunar Terrain Vehicle (LTV), offer unique opportunities to address many decadal-level lunar science objectives by facilitating access to a broad area and varied terrains in the lunar South Circumpolar Region (SCPR). Both the PR and LTV are anticipated to carry multiple science instruments and will operate during crewed and uncrewed periods. Here, we describe a chassis-mounted science payload called “Mineralogy and Petrology of the Lunar Environment (MAPLE).” MAPLE utilizes X-ray fluorescence (XRF) spectroscopy and UV to thermal-infrared spectroscopy to quantify the geochemistry and mineralogy of the lunar surface and map the distribution of minerals in rock/outcrop. These measurements will help address major open questions in lunar science by evaluating: (1) whether lithologies rich in KREEP (i.e., potassium, rare earth elements, phosphorus) are globally distributed, (2) how the lunar crust formed, (3) if the South-Pole Aitken (SPA) impact excavated mantle material, (4) the provenance of hematite at the lunar poles, and (5) the nature and distribution of volatiles near the lunar south pole.

Instrument Description: MAPLE is an instrument suite that includes an XRF spectrometer, a hyperspectral thermal-infrared imager (IRS), and a multispectral visible/near-infrared imager (MVIM). MAPLE is designed to be externally mounted on the PR or LTV chassis, allowing the XRF to measure rock and regolith below the instrument and the IRS and MVIM to image rock and outcrop near the rover. The XRF, IRS, and MVIM are mechanically independent but share a central control unit that includes FPGA and data storage, a low-voltage power supply, and motor boards to scan the IRS and MVIM.

MAPLE XRF. Unlike other XRF instruments proposed or flown to date, the MAPLE XRF does not require an arm or other deployment mechanism. The X-ray tube has flight heritage from the Planetary Instrument for X-ray Lithochemistry (PIXL) on the Mars 2020 *Perseverance* rover [1], and the overall instrument was prototyped with NASA SBIR funding [2]. The XRF operates from a distance commensurate with the ground clearance of the PR or LTV. The X-ray tube points downward, illuminating the lunar surface over one of two specified fields of view (FOV): 50-cm and 5-cm-diameter, assuming a 50-cm rover clearance. A collimated silicon drift detector (SDD) collects the spectrum of emitted and scattered X-rays from the chosen field of view.

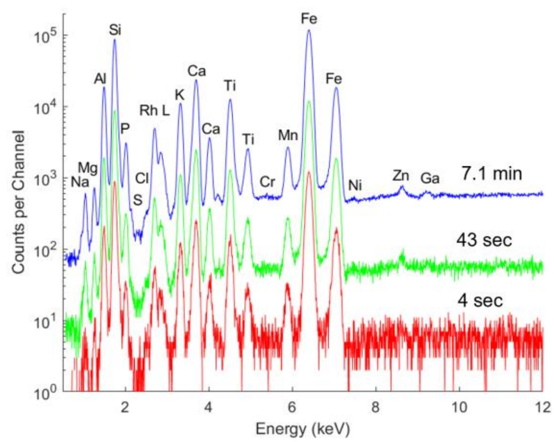

Fig. 1. MAPLE XRF prototype data (50 cm FOV) of a Hawaiian basalt acquired over three durations.

Quantifiable major and minor elements critical for interpreting lunar materials include Na, Mg, Al, Si, P, K, Ca, Ti, Cr, Mn, and Fe. Quantifiable trace elements useful for fingerprinting lunar materials and tracking volatiles include S, Cl, and elements with Z>26. MAPLE XRF exhibits improved spectral resolution relative to PIXL and the Alpha Particle X-ray Spectrometers (APXS) on the Mars Exploration Rovers *Spirit* and *Opportunity* and the Mars Science Laboratory *Curiosity* rover [e.g., 3,4]. With a 50 cm-diameter FOV, MAPLE XRF has an improved Figure Of Merit (FOM) relative to PIXL and APXS due to higher X-ray flux and larger collection solid angle. Preliminary modeling, experience with similar instruments, and analogous laboratory measurements indicate that we can determine major element concentrations after measuring for only 5 seconds and minor/trace element measurements after ~30 seconds. MAPLE XRF can provide high-precision abundances of major, minor, and some trace elements in 7 minutes (Fig. 1).

MAPLE IRS. The IRS is a 550 g infrared Fourier Transform hyperspectral imager operating from 7.5 to 14 µm at 10.8 cm^{-1} spectral resolution. MAPLE IRS will detect and map silicates, some Fe-oxides, elemental S, and phosphates on rock surfaces, and will characterize the position of the silicate Christiansen Feature (CF) in lunar regolith. The instrument operates as a pushbroom spectrometer with a horizontal field of view (FOV) of 6˚, and a maximum vertical field of regard of 90˚. With a 12-µm pixel size and a 50-mm focal length f/1.1 lens, the diffraction-dominated IFOV of each pixel is 0.3 mrad with a spatial resolution of 1.5 mm at a 5-meter distance. MAPLE IRS is a modification of the Hyperspectral Thermal Imager (HyTI), an instrument on a NASA ESTO InVEST program 6U CubeSat mission [5]. MAPLE IRS replaces the HyTI cooled infrared detector with a TRL 7 Teledyne FLIR Boson+ uncooled microbolometer space hardened by Marshall Space Flight Center.

The high resolution of MAPLE IRS enables it to directly characterize the mineral composition of rock surfaces with coarse-grained fabrics. Through linear unmixing [e.g., 6], the IRS will determine mineral abundances quantitatively at the 10 vol% level, and with detection at the 3 vol% level. For example, trace abundances (<0.1 vol%) of phosphates can be found in most lunar rocks, but in a 1.5-mm pixel, of which there are hundreds of thousands in a single scan, a single 80 µm grain or tens of 10 µm grains will be detected.

MAPLE MVIM. MVIM combines UV/visible/near-IR cameras evaluated by the CNES detector service (CASPEX: *CAmera for SPace EXploration*) and pulsed and synchronized LEDs at UV through near-IR wavelengths developed by LUMETIS (France, www.lumetis.fr). MVIM has up to 20 channels from 400 to 1700 nm. This wavelength range is ideal for identifying phases with transition metals (e.g., Fe^{2+} in pyroxenes or olivine) and/or OH (e.g., water ice, hydroxyapatite) in their structures [e.g., 7,8]. Most of the main technological components of this system is in the process of being adapted for human spaceflight, and safety studies are currently ongoing. A study led by Lumetis in partnership with Comat (France) and CNES, in the framework of the SpaceshipFR project, will be launched early 2025 to adapt, test, and validate the technological readiness for lunar missions.

Concept of Operations: During uncrewed surface operations, MAPLE would be primarily operated when the PR or LTV is stopped. To take full advantage of our payload's capabilities, the rover would park near targets of interest such as a cobble or outcrop within ~5 m of the vehicle. The IRS and MVIM would collect images of science targets over the course of several minutes. In parallel with imaging activities, the XRF would fluoresce a specified area with X-rays, and the SDD would collect an XRF spectrum from that area. The XRF analysis duration will depend on the amount of time available, the field of view mode selected (i.e., 50 cm vs. 5 cm), and the sensitivity of measurement sought. We anticipate a typical bulk (i.e., 50 cm FOV) XRF analysis will last 2-10 minutes (including tube warmup), and restricted XRF analyses (i.e., 5 cm FOV) will last between 7 min (for major element chemistry) to 1 hour (for major and minor element geochemistry). MAPLE XRF can detect total volatiles at or above the 5 wt.% level with only 10 minutes of integration time, so at potential volatile-bearing locations, we would request at least 10 minutes for XRF integration. MAPLE XRF can be operated while the PR is in motion to evaluate changes in major element composition over a traverse.

MAPLE will have an important role in operations conducted both before crew arrival and during crewed operations. Prior to crew arrival, MAPLE can be used to identify and characterize sites for crewed exploration. During a pre-crew reconnaissance phase, the IRS and MVIM could identify outcrops and cobbles of mineralogical interest, and the XRF and MVIM could identify locations where ices may be present for volatile sampling in Artemis VII and beyond. Crew could also use MAPLE to triage cobbles/hand samples by placing collected samples on the ground and remotely commanding the PR to analyze the samples. IRS and MVIM scans would provide mineral maps, and XRF analyses would measure geochemistry, helping to identify the samples of highest scientific value for return to Earth.

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