XTRA: AN EXTRATERRESTRIAL REGOLITH ANALYZER FOR LUNAR SOIL D.F. Blake,[1] T.F. Bristow,[1] J. Chen,[2] P. Dera,[3] R. Downs,[4] M. Gailhanou,[5] P. Lucey,[3] W. McKenzie,[3] L. Martel,[3] R. Quinn,[1] P. Sarrazin,[6] G. Taylor,[3] K Thompson,[6] R. Walroth[3] and K. Zacny[7] [1]Exobiology Branch, MS 239-4, NASA Ames Research Center, Moffett Field, CA 94035 (david.blake@nasa.gov), [2]Baja Technology LLC, Tempe, AZ, [3]Univ. of Hawai'i Honolulu, HI, [4]Univ. of Arizona, Tucson, AZ, [5]IM2NP-Aix Marseille Universite'-CNRS, [6]SETI Institute, Mountain View, CA, [7]Honeybee Robotics, Pasadena, CA.

The importance of mineralogy to lunar science and exploration: The mineralogical composition of lunar soil can be used to elucidate its petrogenesis and that of its parental lithologies (e.g., igneous rocks, impact breccias), as well as subsequent diagenetic or metamorphic events. In addition to its value to landed lunar science and as ground truth for orbital missions, in-situ mineralogical analysis can be used to evaluate potential In Situ Resource Utilization (ISRU) processes such as the production of water or oxygen, metallic Fe or Al, or of ceramic building materials. Mineralogical analysis can be used to discover ore deposits useful for Rare Earth Element extraction.

Mineralogical analysis using X-ray Diffraction and X-ray Fluorescence (XRD/XRF): XRD is the only in-situ technique able to definitively identify, quantify and determine the elemental composition of minerals present in lunar regolith. XRD can also determine the quantity of X-ray amorphous material present in a regolith sample, and when combined with XRF, the elemental composition of the amorphous component(s). Taken together, these techniques provide a comprehensive analysis of lunar regolith mineralogy that can only be improved upon by sample return. Taylor et al. [1] report the mineralogy of 118 returned Apollo regolith samples in the <150 μm grain-size range analyzed by Terra, a commercialized version of the CheMin instrument (e.g., Fig. 1). Sun et al. [2] report XRD-based ground-truth mineralogy of the Apollo 17 landing site. Fig. 2 shows example results from an ISRU test during the 2007 Scarab-RESOLVE field demonstration [3]. XRD patterns and mineral abundances from [1] are available on the Open Data Repository https://odr.io/lunar-regolith-xrd.

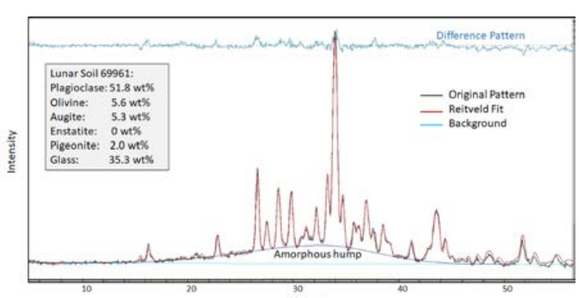

Fig. 1: X-ray Diffraction pattern of Lunar soil from the Apollo 16 site (analyzed in the Terra XRD).

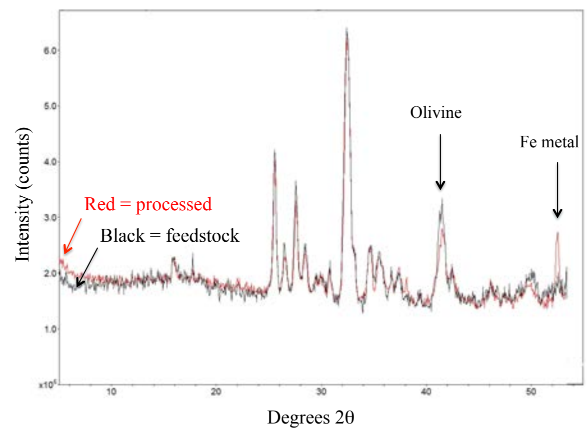

Fig. 2: Mauna Kea volcanic soil before processing (black) and after processing at high temperature in the presence of H_2 (red). Fe-containing phases are reduced to Fe metal, yielding H_20.

The eXtraTerrestrial Regolith Analyzer (XTRA): XTRA is an X-ray Diffraction / X-ray Fluorescence (XRD/XRF) instrument capable of quantitative analysis of as-received lunar regolith when deployed from a small lander or rover. XTRA is a CheMin inspired XRD/XRF instrument with enhanced XRF capabilities (11<Z<30) due the incorporation of a Silicon Drift Diode (SDD) detector in reflection geometry, as well as its operation in vacuum at the lunar surface. As-received regolith samples are delivered to the XTRA instrument and placed in a vibrated, reflection geometry cell. Collimated X-rays from a Co anode X-ray tube intersect the sample surface at an acute angle. Diffracted CoKα photons between 15–60° 2θ are detected by an energy-discriminating, single photon counting CCD. These photons are identified by their energy and summed into a 2D array that constitutes the diffraction pattern of the sample. A histogram of the energies of all photons detected by the SDD detector constitutes an X-ray fluorescence spectrum of the sample. Fig. 3 shows the geometry of the XTRA XRD/XRF experiment and its expected products.

Rietveld refinement and full pattern fitting are used to determine the abundance and elemental chemistry of the crystalline material and the relative amount of amorphous material. Fundamental parameter calculations are used to determine the quantitative elemental composition of the sample from its XRF spectrum.

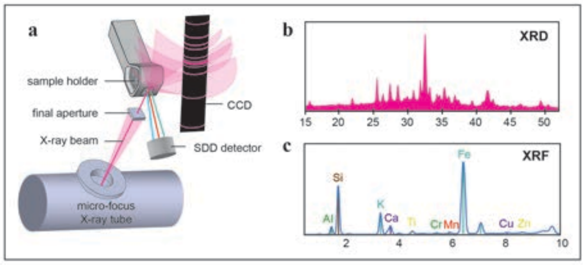

Fig. 3: a), schematic diagram of XTRA diffraction and fluorescence geometry. CoKα X-rays (magenta) are identified by their energy. An image of these constitutes the 2-D diffraction pattern. b), The 2-D pattern is summed radially about the central beam to yield a 1-D diffractogram. c), fluorescence X-rays from the sample are detected by an SDD detector and summed into a histogram of photon energy vs. number of counts.

Data from XTRA directly address lunar concepts outlined in the 2007 NRC study "The Scientific Context for the Exploration of the Moon" as updated by the LEAG Specific Action Team in 2018, "Advancing Science of the Moon," including Concept 2 (structure and composition of the lunar interior), Concept 3 (planetary processes recorded in the diversity of lunar crustal rocks), Concept 4 (lunar poles as special environments), Concept 5 (lunar volcanism as a window into the thermal and compositional evolution of the Moon), and Concept 7 (the moon as a natural laboratory for understanding regolith processes).

Flight-qualifiable components: XTRA benefits from previous NASA technology programs and shares high-maturity components with MapX, funded under MatISSE. Common components include a flight-qualifiable X-ray tube from RTW, Ltd. and High Voltage Power Supply (HVPS) from Battel Engineering (Fig. 4). The XTRA geometry has been validated by commercial portable reflection XRD/XRF instruments developed for non-destructive identification of pigments in works of art and archeological materials.

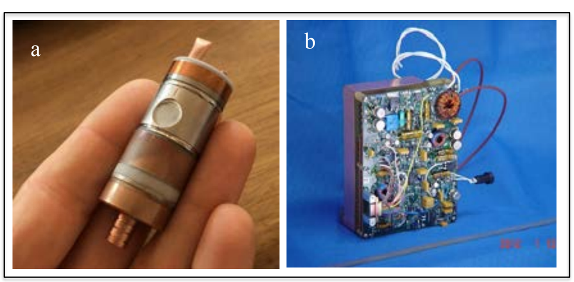

Fig. 4: a), flight qualifiable X-ray tube developed by RTW, Ltd. and b), flight qualifiable Battel engineering HVPS. Both will be used in XTRA, MapX and future X-ray instruments.

Sample acquisition and delivery to XTRA: XTRA will be integrated with a sample collection/delivery system developed by Honeybee Robotics. The sample delivery system is based on HBR's PlanetVac system in which sample acquisition is achieved through a pneumatic system attached to the footpad of the lander. The system has been tested at lunar gravity in vacuum on the Zero-G airplane [4].

XTRA's initial deployment will be as a proof of concept instrument on early commercially-launched landers (Fig. 5). Instruments having carousels and multiple sample analysis capability are being designed for follow-on rover missions.

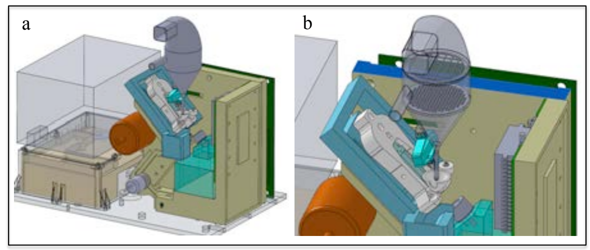

Fig. 5: Notional design of the XTRA instrument. a), overall view, 240 X 150 X 130 mm (excluding cyclone funnel). b), detail of the sample delivery system. Calibration cell is in position for analysis, lunar soil cell is in position for sample delivery. A 1-time actuator will move the 2nd cell into the analysis position once it is filled.

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References: [1] Taylor, G.J., et al. (2012), LPSC 43 #2313; Taylor et al., (2019), Am. Min., in prep. [2] Sun, et al. (2018), LPSC 49, #1693; *AbSciCon 2017*, #3074. [3] Blake et al., 9th ILWEG (ICEUM9/ILC2007) abstract #225. [4] Zacny et al. (2010), AIAA Space 2010 Conference and Exposition.