XTRA: AN EXTRATERRESTRIAL REGOLITH ANALYZER FOR RESOURCE EXPLORATION.
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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 rock types, as well as subsequent 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 extraction of water or oxygen, metals (e.g., Fe, Ti, or Al), or of ceramic (sintered) building materials. Mineralogical analysis can be used to discover ore deposits useful for extraction, such as rare earth elements, U, and Th (e.g., phosphate minerals, zircon).

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 on the Curiosity rover on Mars. Fig. 1 shows example results from an ISRU test during the 2007 Scarab-RESOLVE field demonstration [2]. XRD patterns and mineral abundances from [1] are available on the Open Data Repository https://odr.io/lunar-regolith-xrd.

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. 2 shows the geometry of the XTRA XRD/XRF experiment and its expected products.

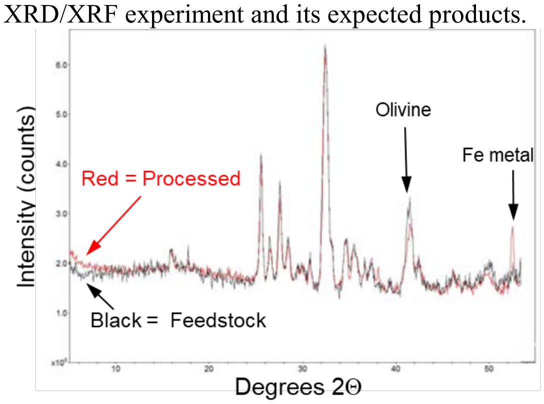

Fig. 1: Mauna Kea volcanic soil before processing (black) and after processing at high temperature in the presence of H2 (red). Fe-containing phases are reduced to Fe metal, yielding H20.

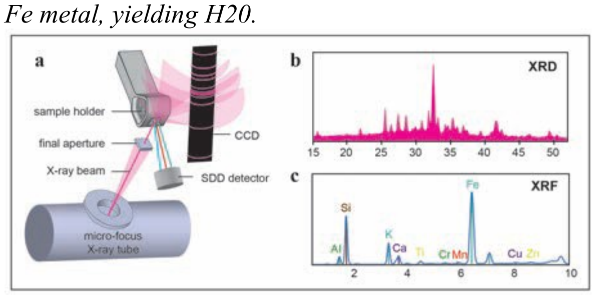

Fig. 2: a), schematic diagram of XTRA diffraction and fluorescence geometry. CoKα X-rays (magen ta) are identified by their energy. An image of these constitutes the 2-D diffraction pattern. b) The 2-D pattern is summed radially about the central beam to yield a 1-D diffractogram. c), fluorescence X-rays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

References: [1] Taylor et al., (2019), *GCA*., submitted. [2] Blake et al., 9th ILWEG (ICEUM9/ILC2007) abstract #225.