MIA: Miniature In-Situ Analyzer for Mars, the Moon or Asteroids. P.E. Clark[1], W. Farrand[2], D. Scheld[3], J. Martin[3], C. Dreyer[4]; [1]IACS (Catholic University of America), NASA/GSFC, Code 695, Greenbelt, MD 20771, clarkp@cua.edu), [2]Space Science Institute, farrand@spacescience.org, [3]n-Science Corporation, dscheld@nscicorp.org, joemartin@forethought.net, [4]Colorado School of Mines, cdreyer@mines.edu.

Problem and Solution: Planetary surface exploration involving lander, rover or sample return missions to Mars, the Moon, and/or asteroids or comets [1,2] requires: 1) rapid, quantitative in situ analysis of unexplored surfaces and/or of potential samples prior to their collection; 2) minimized instrument mass, volume, and power usage; and 3) the ability to address high priority science objectives for determining the nature and origin of the materials being sampled as a means of understanding and mapping the planetary body. Chemical and mineralogical analyses are essential components of this task; additionally a further capability of providing a petrological framework, that maps the form, size, and relationships between crystalline minerals, and that can be carried out on unprepared samples, would be a major breakthrough not only in understanding sample formation history, but in sampling and in situ analysis technology. To meet these challenging science requirements, we are developing a next-generation in-situ geochemical, mineralogical, and petrological analysis tool requiring no sample preparation, the Miniature In-situ Analyzer (MIA), a combination X-ray diffraction (XRD) and X-ray fluorescence (XRF) instrument with a state-of-the-art compact X-ray source, and dual CCD detectors. MIA combines this dual X-ray analyzer with two other optical components, an optical micro-imager and a compact Raman spectrometer, to provide a broader context and constraints to the geochemical interpretation of the X-ray analyses. MIA performs mineral identification, major element chemistry determination and also assessments of crystal 'texture' (in terms of intra– and inter–grain composition, size, and orientation) on unprepared samples. Because MIA performs XRD without the need to grind up samples, MIA can literally 'map' a rock, preserving primary information on the relationship between minerals.
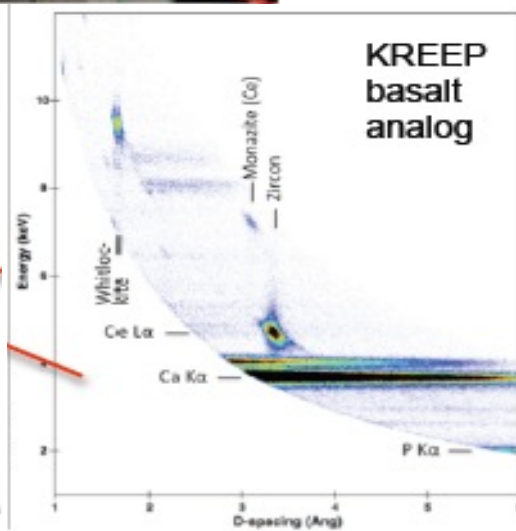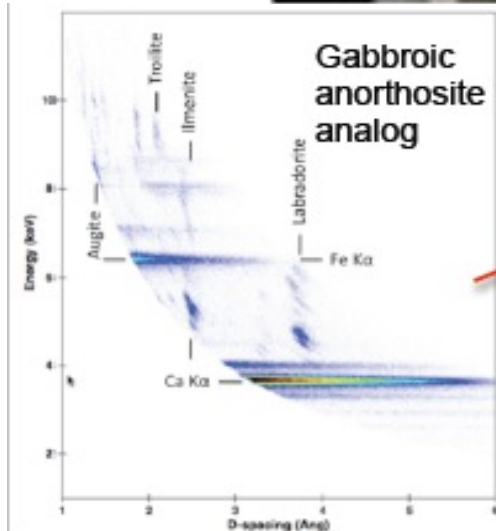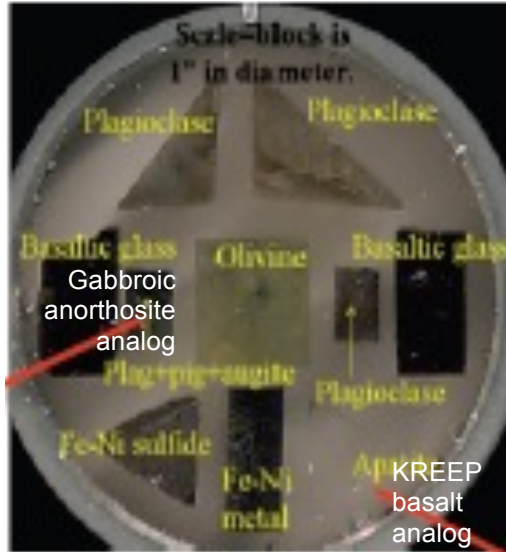
Approach and Methodology: XRD and XRF have been essential analysis techniques in terrestrial geologic studies for many years. Remote XRF instruments provided the first orbital compositional analysis (e.g., [3]) of a solar system object. XRF also was used for the first in situ compositional analysis on Mars (e.g., [4]). However, the need for extensive sample preparation requiring many moving parts and increased operational complexity, mass, cost, power, and volume have proven daunting for landed XRD devices. An XRD/XRF instrument (CheMin) was selected for MSL [5,6] and initial surface operations have detected crys-

talline feldspar, pyroxenes olivine amd smectite clays along with amorphous substances, validating the scientific value of XRD for planetary exploration, although the XRF was de-scoped from the flight instrument. Our previous experience with MICA [7] and CMIST [8] have demonstrated clearly that the very expensive, risky, and heavy sample processing equipment required by CheMin on Curiosity is not necessary for meaningful diffraction information on geologic samples, especially when the diffraction information is augmented by the XRF and contextual imaging. This complementarity will be even more complete with Raman spectroscopy included as an additional component.

Technological innovations offer significant new capability. MIA exploits state-of-the-art compact X-ray tubes and photon-counting, spectroscopic, and imaging capabilities of X-ray charge-coupled devices (CCDs) to enable simultaneous energy-dispersive XRF and angle-dispersive XRD. Additionally, we will explore the value of incorporating Raman spectroscopy into MIA. Raman spectroscopy will serve as a check on XRD mineral identifications and will be capable of identifying additional mineral, and organic, phases. An additional capability of MIA is the inclusion of an optical micro-imager.

Demonstrated Capability: The capability to distinguish composition and identify minerals of crystals in the field of view has already been demonstrated by an earlier laboratory prototype. Figure 1 demonstrates CMIST's ability to distinguish lunar minerals of typical (solution series) composition in a standard calibration source documented by both electron and ion microprobe [8,9]. Polished fragments of analogues of lunar mineral assemblages, including Mg-suite dunite (forsterite), anorthosite (anorthite, labradorite), gabbroic anorthosite (anorthite, labradorite, augite, ilmenite), and KREEP (apatite, whitlockite, monazite), were embedded in a 1-inch diameter disk. In ongoing work, we have established the "typical" composition of each by taking measurements at several locations on a sample, and found consistency with the known bulk composition. As a next step, we would develop a sample interface to allow systematic mapping of each sample as a function of position.

Current Status: Our goal at present is to create a laboratory validated breadboard of MIA, which will be a low mass (< 5 kg), compact (coffee-can size) multifunctional in-situ analysis tool, all within a portable

Scale-block is 1" in diameter.

Plagioclase   Plagioclase

Basaltic glass   Olivine   Basaltic glass

Gabbroic anorthosite analog

Plag+pig+augite   Plagioclase

Fe-Ni sulfide   Fe-Ni metal

KREEP basalt analog

Gabbroic anorthosite analog

Troilite
Ilmenite
Augite
Labradorite
Fe Kα
Ca Kα
Energy (keV)
D-spacing (Ang)

KREEP basalt analog

Monazite (Ce)
Zircon
Whitlockite
Ce Lα
Ca Kα
P Kα
Energy (keV)
D-spacing (Ang)

package and requiring no sample preparation. Its major components are an X-ray diffractometer, fluorescence spectrometer (with <150 eV FWHM enabling characterization of K, L, and M lines for major and minor elements from C to Ni with high sensitivity), and an optical micro-imager and Raman spectrometer. This combination will measure element abundances, distinguish mineral phases, and determine the unaltered sizes and orientations of crystals. In addition, it will enable identification of rock type via identified mineral assemblages and their relationships, all within a few millimeter field of view. To date, earlier partial versions of this instrument concept were supported through NASA funds: MICA, through MIDP and CMIST through PIDDP. MIA leverages developments that have led to more compact components, including miniature X-ray sources (~0.3 mm spot size), deep depletion back illuminated high quantum efficiency CCDs, and a compact Raman spectrometer to further constrain mineral identification. In our validation of

MIA, we will utilize new approaches for calibration with target analogue rock and mineral assemblage standards. We will also use unprepared mineral samples of known composition and rock samples of known petrogenesis analogous to major rock suites of the Moon, Mars, and asteroids.

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