QUANTITATIVE MINERALOGY, SAMPLE ACQUISITION & ANALYSIS ON SMALLER AND MORE CAPABLE ROVERS AND LANDERS IN THE POST-MSL ERA

D. F. Blake,[1] P. Sarrazin[2] and and K. Zacny.[3]
[1]MS 239-4, Exobiology Branch, NASA Ames Research Center, Moffett Field, CA 94035 (david.blake@nasa.gov),
[2]The SETI Institute, Carl Sagan Center, 189 Bernardo Avenue Mountain View, CA 94043 (psarrazin@inxitu.com),
[3]Honeybee Robotics Spacecraft Mechanisms Corporation, 398 W. Washington Blvd., Suite 200, Pasadena, CA 91103 (zacny@honeybeerobotics.com).

Introduction: A smaller and more cost-effective landed Mars exploration program will require smaller spacecraft (MER-, mid-rover or discovery-class), but should not require a reduction in science capabilities. The reduction in size and complexity and standardization of spacecraft architecture (propulsion, EDL systems and rover concepts), and further reduction of the size and complexity of science instruments and sample acquisition systems is quite possible. To reduce mission cost, instrument refinement and space-qualification of components should be accomplished prior to payload selection.

In this presentation, quantitative mineralogical and elemental analysis instruments and sample acquisition systems will be described that are already under development and that will be available for future MER- and mid-rover class missions to Mars.

Quantitative Mineralogy: A fundamental characteristic of any planetary surface is its mineralogy. Specific minerals form and persist through limited ranges of temperature, pressure and ambient chemical conditions (i.e., water activity, Eh, pH, chemical potential). A knowledge of the minerals present in a sample of regolith provides insight into the physical / chemical conditions of formation, and provides a context for other measurements (stratigraphic, morphological, isotopic, organic). The CheMin[1] instrument on Mars Science Laboratory is the first definitive and quantitative mineralogical instrument to be sent into space. CheMin's size, complexity and sample preparation requirements limit its deployment to flagship missions such as MSL. However, next-generation mineralogical instruments are presently under development that will be suitable for smaller and less complex spacecraft.

XTRA: The Extraterrestrial Regolith Analyzer (XTRA)[2] is a reflection geometry powder X-ray Diffraction (pXRD) instrument with X-ray Fluoresecence (XRF) capabilitiy that requires only a "scoop and dump" sample acquisition system. The instrument consists of an electrical X-ray source, a sample holder, and an X-ray imaging CCD. Figure 1 shows the first prototype instrument built. An as-received lunar regolith sample was placed in a reservoir between the X-ray source and CCD detector, and levelled with a razor blade to make a uniformly flat surface. Figure 2 shows the resulting XRD pattern, relative to a pattern collected using a commercial pXRD instrument. Differences in relative peak intensities are due to the sensitivity to grain size of the XTRA breadboard. This issue has been addressed by a vibration sample movement system in the next-generation prototype.

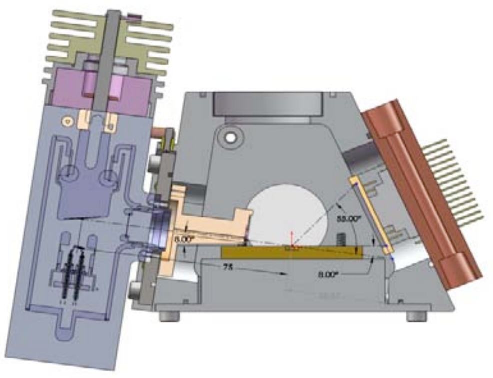

Figure 1. Diagram of the first implementation of the XTRA breadboard instrument. Collimated X-rays strike a powdered regolith sample at an 8° angle. Diffracted X-ray photons from 8-55° 2θ are directly detected by the X-ray sensitive CCD. An XRF spectrum of elements present is also recorded.

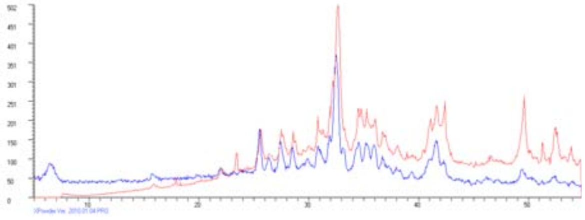

Figure 2. Comparison of XRD data from CheMin lab prototype with XTRA breadboard (red) from lunar soil #14163 (Courtesy, Jeff Taylor, HIPG).

Hybrid XRD: A new type of planetary XRD instrument has been developed that makes both powder and single-crystal XRD measurements, making it possible to analyze minerals with limited to no sample preparation.[3] pXRD is utilized when fine-grained samples are presented to the instrument, either "as received" or after preparation with a grinding tool. Single-crystal XRD (sXRD) using polychromatic radiation (Laue diffraction) is utilized when samples are too coarse for pXRD. Laue analysis allows identification of minerals in unprepared samples and enables ab-initio determination of crystalline phases unknown to current crystallographic databases. In parallel to either type of diffraction analysis, the instrument provides X-ray fluorescence (XRF) data for elemental analysis of the sample. A possible implementation of the instrument concept is presented in Figure 3 in the form of a contact instrument fitted to the robotic arm of a rover. Alternatively, the instrument could be installed inside a rover/lander for analysis of delivered unprepared samples.

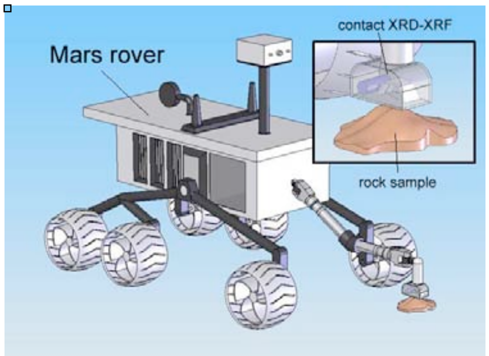

Figure 3. Implementation of a hybrid XRD/XRF instrument on a rover arm. Another possible implementation is onboard the rover for analysis of "as delivered" samples (soils, rock fragments, etc.).

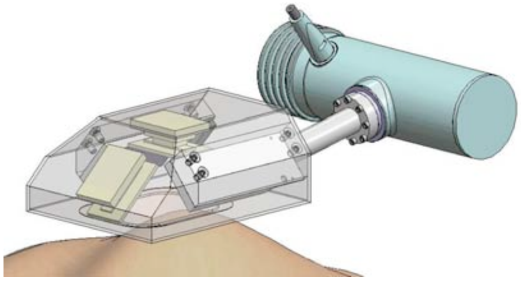

Figure 4. Layout of the critical components of the Hybrid XRD/XRF system. From right to left, X-ray tube, collimator and sensor head.

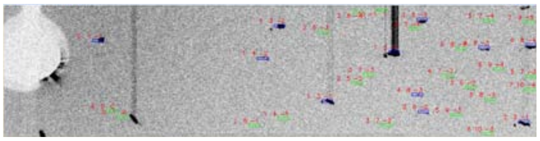

Figure 5. Laue image of an olivine crystal, marked with miller indices found by analytical software. Vertical lines result from the spreading of X-ray signal during CCD readout at positions of intense diffraction.

MμMMS: The Mars Micro-Mineralogical Mapping Spectrometer (MμMMS) is intended to map an unprepared or "ratted" postage stamp-sized surface of material. Initial tests confirm <100μm lateral spatial resolution in elemental maps of geological materials.

Spacecraft Qualifiable Components: All three described instrument concepts utilize the same basic components: A high voltage power supply (28KeV), a grounded cathode X-ray tube, and a single-photon counting X-ray sensitive CCD camera. Each of these components has been built with a space qualifiable design: The power supply, built by Battel Engineering through ASTID funding, has a mass of ~500 g. and operates at 10 watts; the X-ray tube, built by by InXitu, Inc. through SBIR funding weighs 34 g and interfaces with the power supply; the CCD, utilizes an E2V imager and electronics built by Baja Technologies. The path to a flight-capable instrument is a matter of instrument refinement, not component qualification.

Simplified Sample Preparation and Delivery Systems For Small Rovers and Landers: Honeybee Robotics has developed a core acquisition and caching system (Fig. 6) for Mars Sample Return that will fit on a small rover.[4] Surfaces of acquired cores can be imaged and analyzed before caching. Other specialized bits acquire powder which can be transferred pneumatically, or gravity-deposited into instrument inlet ports. Other instrument concepts include drills and sample collection/preparation devices.

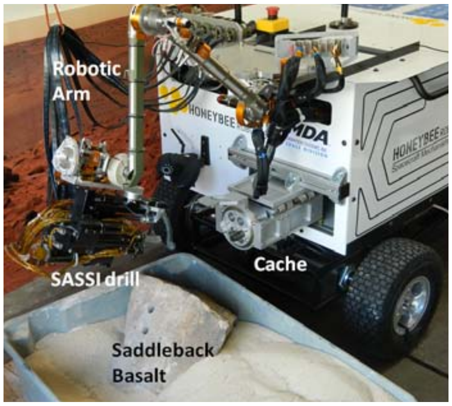

Figure 6. Sample acquisition and Caching System

Conclusions: A post-MSL robotic Mars exploration program does not require a reduction in lander or rover capabilities, or a less ambitious science-driven instrumentation program. Miniaturized and simplified (but increasingly capable) instruments are being developed for NASA, and also in the private sector for commercial and other governmental applications. This, combined with the development of spaceflight qualifiable components and subsystems *before* instruments are selected for flight, will ensure that payloads can be developed within schedule and budget.

References:

[1] http://msl-scicorner.jpl.nasa.gov/Instruments/CheMin/.
[2] Sarrazin, P., et al. (2011) *LPSC XXXXII, abstr. #2280.*
[3] Sarrazin, P., et al. (2009) *LPS XXXX, abstr. #1496.*
[4] Paulsen, G. et al. (2012) *LPS XXXXIII, abstr. #1151.*