CHEMCAM SCIENCE OBJECTIVES FOR THE MARS SCIENCE LABORATORY (MSL) ROVER

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Overview: ChemCam consists of two remote sensing instruments. One, a Laser-Induced Breakdown Spectroscopy (LIBS) instrument provides rapid elemental composition data on rocks and soils within 13 m of the rover. By using laser pulses, it can remove dust or profile through weathering layers remotely. The other instrument, the Remote Micro-Imager (RMI), provides the highest resolution images between 2 m and infinity. At approximately 80 μRad field of view, its resolution exceeds that of MER Pancam by at least a factor of four. The ChemCam instruments are described in a companion paper by Maurice et al. [1]. Here we present the science objectives for the ChemCam instrument package.

Introduction: Planetary surfaces can be difficult places for accurate remote sensing. Orbital remote sensing can obtain average spectral compositions over large areas. Rover-based remote sensing can be more challenging for several reasons: a) individual rocks can be completely dust-covered, b) their suface textures can make them poor reflectors at wavelengths where telltale emission or reflectance peaks would otherwise be seen, and c) weathering coatings can obscure the true composition of the rock. Weathering coatings on a regional scale may also fool orbital remote sensing [2].

The LIBS instrument uses a pulsed laser providing 40 mJ to a small (≤1 mm) spot. The laser produces a plasma from the ablated atoms. The plasma radiates at visible and UV wavelengths characteristic of the elements (and in some cases molecules) present in the sample. The LIBS spectrographs record the spectra and allow identification of the rock type and quantification of the composition. The laser removes dust at up to ~1 mm/pulse [3], and can remotely profile into rock samples with weathering rinds at rates of ≥0.3 μm/pulse. The LIBS instrument can thus depth profile several hundred microns in twenty minutes.

The utility for the LIBS instrument can be understood by considering some of the MER Mars rover scenarios. The Opportunity rover landed in Eagle Crater, within a few meters of a rock outcrop [4]. LIBS would have allowed immediate identification of the composition of the rock outcrop rather than having to wait many days until the rover could drive up to the rocks and brush them off. Other features have remained inaccessible to the rover because of the terrain. Likewise, the composition of the hematite spherules known as "blueberries" could not be determined immediately because these features were much smaller than the APXS sensor head. Their composition was eventually determined when many blueberries were found in a single location. Because LIBS analyses are made on spots ≤1 mm in diameter, LIBS can immediately identify the composition of small features, not only those similar to blueberries, but also layers, for example, within a finely stratified sedimentary rock. In such applications the remote micro-imaging function of ChemCam will be crucial in guiding the LIBS laser to specific features.

ChemCam Science Objectives: As a science team, we view the following as the current most pressing issues in Mars science:

- Composition of sedimentary deposits, and what they tell us of Mars' climate history. The SNC meteorites, Viking, and Pathfinder did not give direct information on sedimentary materials. That the Mars surface has abundant sedimentary surface materials was evident from orbital imagery [5]. However, direct measurements were only recently made with MER. Critical questions include the origin, extent, and duration of large bodies of water responsible for sediments in the Arabia and Meridiani regions. Micro-imaging and trace element chemistry will greatly aid the interpretation of the Mars sedimentary record.
- Nature and origin of the surficial fines and aerosol dust composition. The origin of the high sulfur and chlorine abundances in the dust has been an open question ever since Viking [6]. The finding of sedimentary sulfate deposits at Eagle Crater show that the water from which these deposits formed was also high in sulfur. The origin of the enrichment of these elements on the surface is still unknown, however low-temperature brines, hydrothermal fluids, and volcanic aerosols have distinctive minor and trace element chemical signatures that may allow the determination of the origin of this mobile element component [e.g., 7].

- Composition of the Mars crust. The composition of the SNC meteorites, inferred to be from Mars, suggests a basaltic composition for some of the Martian crust. But how extensive are basaltic compositions on Mars? The Thermal Emission Spectrometer (TES) observations on Mars Global Surveyor found two different kinds of signatures, one of which was associated with the basaltic compositions from Viking and SNC meteorites, and the other was suggested to be andesitic [e.g., 8]. The andesitic interpretation was consistent with the original data from the Alpha-Proton X-ray Spectrometer (APXS) on Pathfinder [9], but the silica content of the Pathfinder site rocks was later revised downward significantly, to make it consistent with basalt (Bruckner et al., 2003). The TES observations, however, could be caused by weathering of basalt [2] which would imply that Mars' surface volcanism is entirely basaltic. The recent MER results raise the question of how much of the near-surface material is igneous and how much is sedimentary. Additional rock and soil compositions are important because the soils may represent an average crustal composition due to aeolian erosion, even though variations exist in some elements based on global gamma ray data (e.g. [11]).
- Organic content of Mars' sediments, and evidence of past life. Sedimentary deposits are also exciting because of their potential for finding evidence of past life on Mars. Without Beagle, we must wait several more years to determine the presence or absence of organic materials in sedimentary deposits. The ChemCam experiments will also help characterize and select samples for organic analysis by the in-situ MSL experiments.

ChemCam addresses four of the five broad MSL mission objectives, including a) Characterize geology of the landing region, b) Investigate planetary processes of relevance to past habitability, including the role of water, c) Assess the biological potential of target environments, and d) Investigate the presence of materials toxic to plants or humans.

Defined Investigations: The ChemCam science team mapped the mission objectives and critical questions into eleven defined investigations. They are briefly described as follows:

1. Rapid remote rock identification, for rocks within 13 m of the rover. These would be qualitative analyses looking for samples worthy of further study.
2. Soil and pebble surveys. Daily analyses of the soils and/or pebbles near the rover will help understand the range of compositions within any location and regional changes in soil compositions. It may provide information on soil maturity at various locations. RMI images collected along with LIBS spectra will provide an extensive dataset of correlated images and spectra.
3. Quantitative analysis of rocks and soils, including trace elements. These less frequent analyses will require in-situ calibration with standards on board the rover.
4. Detection of hydrated minerals by observing the H emission line at 656 nm.
5. Rapid remote identification of surface ices using both the OH molecular band and H emission line.
6. Analysis of weathering and depositional coatings or rinds on rocks, by depth profiling up to a millimeter or more into rocks and observing changes in spectra with depth.
7. Remotely observing rock morphologies with the RMI resolution of 0.08 mRad.
8. Analysis of rocks and soils that are inaccessible to the rover itself.
9. Assist in arm and drill sampling. Both LIBS and RMI have close focusing capabilities (presently to 2 m), allowing them to observe/analyze samples that are scooped or cored before they are fed to the in-situ instruments.
10. Remote identification of organic materials. Detection of CN and C_2 molecular bands at the 20% composition level will allow remote detection of organics if present in relatively high abundances.
11. Assist in preparation for human exploration by checking for abundances of Be, Pb, Cd, As well above hazardous limits for humans.

To carry out these investigations, the ChemCam Science Team has planned a healthy strawman campaign of nearly 7 "measurements" per sol consisting of ~12 RMI images per sol (typically 1 prior to and 1 subsequent to each LIBS analysis), 915 spectra with 945 laser shots per sol, packaged in ~12 Mb per sol. A typical measurement requires only 0.7 W-hr and 6 minutes, including sample acquisition.

References: [1] Maurice S. et al. (2005) this volume. [2] Wyatt M.B. and McSween H.Y.Jr. (2002) Nature 417, 263-266, 2002. [3] Knight A.K. et al. (2000) Appl. Spectrosc. 54, 331-340. [4] Squyres S.W. et al. (2004) Science 306, 1698-1703. [5] Edgett K.S and Malin M.C. (2002) Geophys. Res. Lett. 29, 2179. [6] Clark B.C. et al. (1982) J. Geophys. Res. 87, B12, 10059-10067. [7] Newsom H.E. et al. (1999) J. Geophys. Res. 104, 8717-8728. [8] Bandfield J.L. et al. (2000) Science 287, 1626-1630. [9] Reider R. et al. (1997) Science 278, 1771-1774. [10] Bruckner J. et al. (2003) J. Gephys. Res. Planets, 108, E12, 8094. [11] Taylor G.J. et al. (2004) Lunar Planet Sci. XXXV, 1808.