CHEMCAM REMOTE ANALYSES AND IMAGING ON THE MARS SCIENCE LABORATORY 2007 'SLOW MOTION' FIELD TEST. R.C. Wiens[1], S. Clegg[1], J. Barefield II[1], D. Vaniman[1], N. Lanza[2], H. Newsom[2], K. Herkenhoff[3], N. Bridges[4], D. Blaney[4], S. Maurice[5], O. Gasnault[5], J. Blank[6], M.D. Dyar[7], R. Milliken[8], J. Grotzinger[8], J. Crisp[4], and the ChemCam and MSL teams [1]LANL (Los Alamos, NM; rwiens@lanl.gov), [2]UNM (Albuquerque, NM), [3]USGS (Flagstaff, AZ), [4]JPL, Caltech (Pasadena, CA),[5]CESR (Toulouse, France), [6]SETI (Mt. View, CA), [7]Mount Holyoke College (South Hadley, MA) [8]Caltech (Pasadena, CA),

Introduction: Instrument teams from the Mars Science Laboratory (MSL) rover mission completed a blind field test to rehearse both the instrumental analysis and decision making processes. MSL is scheduled to launch in late 2009 with a suite of ten instrument packages. The 2007 slow motion field test was the first such exercise for the MSL team. Participating instrument teams included ChemCam, CheMin, APXS, SAM, and the cameras—MastCam, MAHLI, and Hazcam and Navcam. Here we report on the analyses performed and the imaging simulated for the ChemCam remote sensing instruments.

The ChemCam suite [1,2] consists of a laser-induced breakdown spectrometer (LIBS) capable of active elemental analyses of samples within 9 m of the instrument. LIBS' ability to remotely remove dust and weathering layers is expected to give it a significant advantage in the Martian environment. This was the first NASA-sponsored field test of LIBS in over five years. ChemCam also carries a remote micro-imager (RMI) capable of context imaging at 80 μRad resolution at any distance.

Field Test Arrangement: As a low-impact, low budget alternative to sending instruments into the field, samples were selected from a field site, the location of which was not revealed to MSL participants. The "rover team" (RM, supported by JC and JG) took extensive imaging of the site using a handheld digital camera and provided an air photo image to simulate orbital remote sensing. One "archetype" sample representing each rock and soil type was sent to ChemCam, CheMin, and SAM teams for analysis using prototype or similar laboratory instruments. In addition, one sample of each was analyzed for bulk chemistry using conventional methods (ICP, INAA, and LECO for S and Cl), and from that, simulated results were generated for APXS. Field test participants were not allowed to see or touch samples to keep the test perfectly blind. The analyses were carried out by people not on the MSL field test team. To allow time for laboratory analyses as well as time for the rover team to perform new imaging for each sol, the test was done in slow motion, with one month between sols, from May to September. For the first sol, participants were given an orbital image and Navcam and MastCam images of the site.

Each rover action, including driving, approaching, using the sample arm, or carrying out instrument analyses, cost a fixed number of resource tokens. The token allocation was 200 per sol. Each ChemCam analysis, including both context image and chemical analysis, cost only one token, reflecting the instrument's low resource usage. However, the instrument was limited to 30 analyses per sol, realistic for its expected laser lifetime of ~20,000 analyses. On most sols the maximum of 30 analyses were requested by the MSL field test team. Given the small LIBS footprint of < 1 mm diameter, multiple analyses were often done on a single rock to check for heterogeneity. Unbeknownst to the MSL field test participants, the rover team determined which rock type was representative of each of the many analysis requests and instructed those carrying out the analyses which of several archetype samples to use for a given analysis.

Analysis Description: Samples delivered to the ChemCam team were placed in a Mars chamber at LANL filled with ~7 Torr of CO_2. The samples were analyzed at a distance of 4 m from a laboratory LIBS apparatus designed to simulate the ChemCam instrument [3]. Each LIBS analysis consisted of 50 laser shots, with the corresponding spectra averaged together. LIBS data were processed with two multivariate analyses techniques. First, Partial Least Squares (PLS) analysis was used to generate a calibration model. Principal Components Analysis (PCA) was used to identify the spectral variations in all of the samples.

ChemCam RMI images were simulated by approximately matching the field of view and pixel resolution of images taken by the rover team in the field.

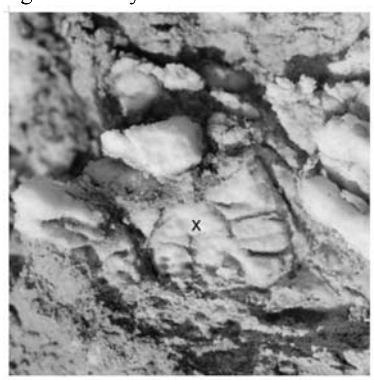

Fig. 1. Simulated ChemCam RMI image (~8x8 cm at ~4 m) of calcium sulfate grains showing their texture. An "x" marks the spot selected for remote LIBS.

Results of the First Analysis Sol: As the sole remote-sensing composition instrument on MSL, ChemCam provided the first compositional results from the site, along with one touch-and-go APXS analysis. ChemCam immediately identified dolomite as one of the major rock types, confirmed by an APXS analysis, which lacked the carbon identification available from ChemCam. ChemCam also observed a high-silica (>60% SiO_2) composition for gray mudstone/siltstone. Another rock type, devoid of Si and rich in Ca, appeared to include sulfur emission lines, giving a tentative identification as a calcium sulfate. The initial LIBS standards consisted of only basaltic and andesitic compositions. These turned out to be poorly suited to the field site and were supplemented by several dolomite and gypsum standards in subsequent sols.

The simulated ChemCam RMI provided context images showing the exact location of the LIBS analysis. The RMI images, along with MastCam images, supported the identifi-

Table 1. Compositions (wt. % ± std. dev., n=7-8) determined by LIBS

	SiO_2	Al_2O_3	FeO	MgO	CaO	Na_2O	K_2O	CO_2	SO_3
Mudstone	61.0±3.6	14.0±0.9	9.6±2.6	5.4±1.6	4.9±3.6	3.8±0.4	1.5±0.4		
Dolomite				19.2±0.6	33.5±0.7			47.3*	
Sulfate				8.2±0.7	31.1±0.9				60.7*

**CO_2 and SO_3 abundances estimated stoichiometrically.*

cation of dolomites and sulfates based on the characteristic weathering textures of these rocks (Fig. 1).

Results of Subsequent Sols: The MSL team drove towards nearby outcrops. Before arrival, ChemCam LIBS analyses confirmed the outcrops to be Ca-sulfate based on comparison with the LIBS standards. The LIBS results for all three rock types examined are given in Table 1. The standard deviations include compositional heterogeneity between analysis spots. In this exercise we did not calibrate the C or S abundances, so the results given in Table 1 were estimated stoichiometrically based on CaO and MgO abundances and the absence of other elements. LIBS analyses also detected H in the sulfate samples, though H abundances were not calibrated and are not included in Table 1.

The ChemCam results revealed compositions ranging from pure gypsum to mixtures of gypsum and dolomite, with some contribution from a silicate material as well. This is shown in a principal component analysis diagram (Fig. 2).

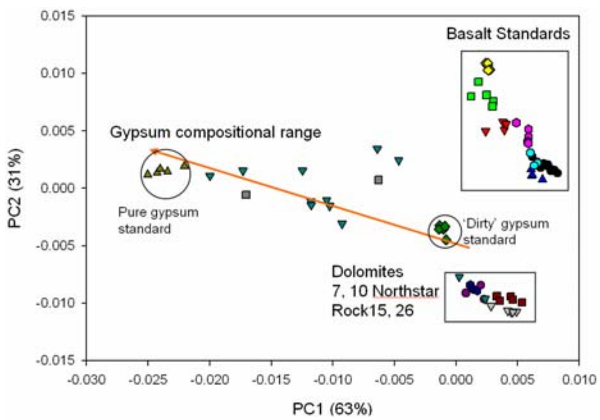

Fig. 2. Principal components plot of ChemCam LIBS results from the ChemCam slow motion field test sol 3. Data points within the circles are from two gypsum standards. Analyses from the surface of the archetype rock representing the bedrock trend between pure gypsum and the other end members. The archetype rock representing some of the float rock plot in the lower box alongside dolomite standards. A slight trend towards higher silica, represented by the basalt and dolomite standards in the upper box, is seen in some of the bedrock analyses.

Lessons Learned: The field location turned out to be the Guadalupe Mountains near Carlsbad, New Mexico, USA, where interbedded dolomites, anhydrite/gypsum, and mudstones preserve a record of restricted sulfate-dominated evaporate sedimentation. The following lessons were noted:

1. ChemCam is important to the tactical mission of MSL, accounting for 97 of the 107 decisional analyses (those downlinked in time for next-sol planning) selected for APXS, ChemCam, CheMin, and SAM during the entire exercise. Each of the 97 ChemCam analyses included both RMI images and LIBS analyses.
2. Using ChemCam together with observations from MAHLI, MastCam, APXS, CheMin, and SAM allowed a complete geologic interpretation of the site.
3. In comparing the LIBS data with independent analyses of the archetype samples carried out by the rover team, the LIBS gypsum results apparently contained excessive Mg, and similarly, the LIBS results on the mudstones were low in SiO_2 (70% actual) and high in Al_2O_3. In both cases, the LIBS result was due to surface alteration, confirmed by surface vs. interior analyses after the end of the field test. In fact, the LIBS team had not run laser cleaning shots (to remove dust and outer coatings) prior to analyzing each spot, as is planned for analyses on Mars. These results highlighted the importance of remotely laser-cleaning the samples prior to analyses. The presence of surfacial components would have shown up in depth profiling mode with ChemCam, which was not exercised for this simulation.
4. Standards that include measured carbon abundances will be important to ChemCam.
5. A representative library of standards is critical to have for LIBS prior to landing on Mars.
6. Rapid laboratory analyses of Mars analogues is crucial to understanding the LIBS results to be seen on Mars. The ChemCam team must be ready to support unexpected results with new Mars analogs.
7. Much work remains to be done in terms of characterizing hydration state and many other characteristics in order to take full advantage of the LIBS technique. This work is critical for understanding Mars geochemistry.
8. The test was a very important learning tool for those on the MSL team, both in understanding the sol-to-sol decision process and seeing how the instruments collaboratively analyze a field site.
9. Many different skills are useful in the team. It was very interesting to experience the interaction between geomorphologists, sedimentary petrologists, experts in various instrumental techniques, and long-term planners. The ChemCam team benefited from interactions with colleagues on the MSL team who contributed to spot selection and interpretation of analyses during the field test.

References: [1] Maurice S., Wiens R., Manhès G., Cremers D., et al. (2005) *Lunar Planet. Sci. XXXVI*, 1735. [2] Wiens R., Maurice, et al. (2005) *Lunar Planet. Sci. XXXVI*, 1580. [3] Clegg S.M., Wiens R.C., Barefield J.E., Sklute E., and Dyar M.D. (2008) Quantitative Remote Laser Induced Breakdown Spectroscopy by Multivariate Analysis. Spectrochimica Acta B., submitted.