MINERALOGY BY X-RAY DIFFRACTION ON MARS: THE CHEMIN INSTRUMENT ON MARS SCIENCE LABORATORY. D.T. Vaniman¹, T.F. Bristow², D.L. Bish³, D.W. Ming⁴, D.F. Blake⁵, R.V. Morris⁶, E.B. Rampe⁷, S.J. Chipera⁸, A.H. Treiman⁸, S.M. Morrison⁹, C.N. Achilles⁹, R.T. Downs⁹, J.D. Farmer⁹, J.A. Crisp¹⁰, J.M. Morookian¹⁰, D.J. Des Marais¹¹, J.P. Grotzinger¹¹, P. Sarrazin¹², and A.S. Yen¹³. ¹Planetary Science Institute, Tucson, AZ 85719, dvaniman@psi.edu; ²SETI Institute, Mountain View, CA; ³Department of Geological Sciences, Indiana University, Bloomington, IN; ⁴NASA Johnson Space Center, Houston, TX; ⁵NASA Ames Research Center, Moffett Field, CA; ⁶Chesapeake Energy, Oklahoma City, OK; ⁷Lunar and Planetary Institute, Houston, TX; ⁸Department of Geosciences, University of Arizona, Tucson, AZ; ⁹School of Earth and Space Exploration, Arizona State University, Tempe, AZ; ¹⁰Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA; ¹¹Division of Geologic and Planetary Sciences, California Institute of Technology, Pasadena, CA.

Introduction: To obtain detailed mineralogy information, the Mars Science Laboratory rover Curiosity carries CheMin, the first X-ray diffraction (XRD) instrument used on a planet other than Earth. CheMin has provided the first in situ XRD analyses of full phase assemblages on another planet.

The CheMin Instrument: CheMin uses a Co X-ray source, powder samples in piezo-driven vibrating cells, and a CCD detector in transmission geometry [1]. The CCD is cooled during operation and is energy-selective, with a quick read cycle that allows single-photon recognition and energy resolution of ~225 eV, sufficient to resolve diffraction Co Kα and Kβ. The CCD produces 2D diffraction patterns (Figure 1) that are processed into 1D Co Kα patterns with ~0.3° 2θ resolution. The 1D XRD patterns are analyzed for phase identification and quantification, using both Rietveld analysis and FULLPAT pattern fitting to calculate mineral proportions [2,3; Figure 2].

Figure 1: Colorized 2D CCD XRD patterns of an eolian sample (Rocknest) and a mudstone (John Klein). The region of smectite 001 diffraction, absent in Rocknest, is indicated in the John Klein pattern.

Samples: CheMin has collected XRD data from three different powder samples: scoop samples from an eolian deposit (Rocknest) and two drill samples from a mudstone (John Klein and Cumberland). The mudstone is informally named as the Sheepbed member of the Yellowknife Bay formation.

Figure 2: 1D XRD pattern of John Klein with observed (blue) versus calculated (red) patterns, and difference curve at the bottom (gray). Vertical line marks the smectite 001 diffraction maximum at ~10 Å.

The Rocknest eolian deposit is comprised of plagioclase (~An57), Fe-forsterite (~Fo62), augite, pigeonite, and magnetite; minor anhydrite and quartz; and sandine, hematite and ilmenite near detection limits. A significant amount of the sample (~30%) is X-ray amorphous [2].

The mudstone samples, John Klein and Cumberland, contain smectite, plagioclase (~An44), augite, pigeonite, Fe-forsterite (~Fo51), orthopyroxene and magnetite; minor sandine, bassanite, anhydrite, akaganite and pyrrhotite; and quartz, hematite, ilmenite, pyrite and halite near detection limits. The mudstone also has a significant (~30%) X-ray-amorphous component [4]. The discussion that follows is focused on the mudstone mineralogy, which provides evidence for a potentially habitable lacustrine environment.

Clay Mineral Characterization: Clay minerals were not found in the Rocknest eolian deposit but comprise ~20% of the mudstone samples. Despite challenges of remote operation on Mars, details about the clay minerals can be extracted from CheMin diffraction data. Typical XRD analysis of clay minerals on Earth can include preparation of oriented mounts, control of relative humidity, cation-exchange treatments, gleycation, and heat treatment that are not possible on Mars. Moreover, the upper 20 limit in CheMin is ~53°, precluding measurement of the 06l diffraction band (above 70° Co Kα) for determination of trioctahedral or dioctahedral clay phases.

The discussion that follows is focused on the mudstone mineralogy, which provides evidence for a potentially habitable lacustrine environment.
tahedral character. However, the less-commonly used position of the maximum in the 02\(2\) two-dimensional diffraction band is similarly related to the \(b\) unit-cell parameter and can be used to distinguish trioctahedral (~22.5° Co Ka; 4.59 Å) from dioctahedral (~23.1° Co Ka; 4.47 Å) minerals (Figure 3). The 02\(2\) bands in both mudstone samples suggest turbostratic stacking and we interpret these clay minerals as trioctahedral smectites.

The XRD pattern of John Klein has a broad 001 peak at ~10 Å, corresponding with smectite or illite (Figure 2). Low K content, and a broad 001 peak with lack of other well-defined peaks, such as an 002 peak at 5 Å, argue against the presence of well-crystallized phyllosilicates such as mica or illite. In addition, peaks for kaolinite or chlorite-group minerals at 7 Å are absent. The low-angle region of the Cumberland XRD pattern has a second 001 peak at ~13.2 Å. This larger interlayer spacing in the Cumberland sample is of considerable interest because complete collapse of a smectite would be expected in the very dry conditions within CheMin (<1% RH). Possible explanations include H₂O retention in the interlayers by high hydration-energy cations, such as Mg or Ca, and partial pillaring via incipient chloritization. These possibilities are being addressed in the lab [5] and will be addressed in the field as more samples are analyzed at Gale crater.

Model of clay mineral and magnetite authigenesis: The 02\(2\) diffraction band maximum is very similar in John Klein and Cumberland and indicates a trioctahedral clay mineral such as ferrian saponite [6,7]. The mudstone has a surprisingly high abundance of magnetite (~4%) for a fine-grained (<50 μm) sediment. High magnetite content and dearth of Fe-forsterite, relative to other mafic minerals from basaltic sources, has led to a model of authigenesis with smectite and magnetite produced by aequous alteration of Fe-

Eighth International Conference on Mars (2014)
1499.pdf

References: