MINERALOGY OF EOLIAN SANDS AT GALE CRATER. C.N. Achilles[1], D.T. Vaniman[2], D.F. Blake[3], T.F. Bristow[3], E.B. Rampe[4], D.W. Ming[5], S.J. Chipera[6], R.V. Morris[5], S.M. Morrison[1], R.T. Downs[1], K.V. Fendrich[1], B.L. Ehlmann[7,8], A.S. Yen[8], P.C. Sarrazin[9], A.H. Treiman[10], P.I. Craig[10], M.G.A. Lapotre[7], K.S. Edgett[11], R. Gellert[12], J.A. Crisp[8], J.M. Morookian[8], J.P. Grotzinger[7], D.J. Des Marais[3], and J.D. Farmer[13], [1]University of Arizona (cheriea@email.arizona.edu), [2]Planetary Science Institute, [3]NASA Ames, [4]Aerodyne Industries, Jacobs JETS Contract at NASA JSC, [5]NASA Johnson Space Center, [6]Chesapeake Energy, [7]California Institute of Technology, [8]JPL/Caltech, [9]SETI, [10]Lunar and Planetary Institute, [11]Malin Space Science Systems, [12]Dept. of Physics, University of Guelph, [13]Arizona State University.

Introduction: The Mars Science Laboratory rover *Curiosity* has been exploring outcrop and regolith in Gale crater since August 6, 2012. During this exploration, the mission has collected 10 samples for mineralogical analysis by X-ray diffraction (XRD), using the CheMin instrument. The CheMin (<u>Che</u>mistry and <u>Min</u>eralogy) instrument on the Mars Science Laboratory rover *Curiosity* uses a CCD detector and a Co-anode tube source to acquire both mineralogy (from the pattern of Co diffraction) and chemical information (from energies of fluoresced X-rays). A detailed description of CheMin is provided in [1].

As part of the rover checkout after landing, the first sample selected for analysis was an eolian sand deposit (the Rocknest "sand shadow" [2,3]). This sample was selected in part to characterize unconsolidated eolian regolith, but primarily to prove performance of the scoop collection system on the rover. The focus of the mission after Rocknest was on the consolidated sediments of Gale crater, so all of the nine subsequent samples were collected by drilling into bedrock composed of lithified sedimentary materials, including mudstone and sandstone. No scoop samples have been collected since Rocknest, but at the time this abstract was written the mission stands poised to use the scoop again, to collect active dune sands from the Bagnold dune field.

Several abstracts at this conference outline the Bagnold dune campaign [4,5] and summarize preliminary results from analyses on approach to the Namib dune sampling site [6,7,8]. In this abstract we review the mineralogy of Rocknest, contrast that with the mineralogy of local sediments, and anticipate what will be learned by XRD analysis of Bagnold dune sands.
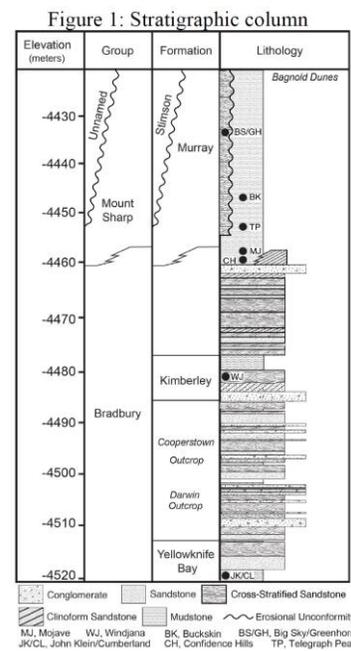
The Rocknest model of eolian sand: The mineralogy of the Rocknest sand was as anticipated, representing a composition typical of martian basalt. The CheMin analysis (Table 1) showed abundant plagioclase (~An50), forsteritic olivine (~Fo58), augite, and pigeonite, with minor K-feldspar, magnetite, quartz, anhydrite, hematite, and ilmenite. The Rocknest sample also contains ~27% amorphous material, likely a hydrated Fe^{3+}-containing amorphous phase and possibly material resembling hisingerite. The amorphous component is similar to that found on Earth in places such

Table 1: Mineralogy of the Rocknest eolian sand [2,3]

Mineral	Wt.%	2σ
Andesine (~An50)	29.8	1.0
Forsterite (~Fo58)	16.4	0.8
Augite	10.7	1.2
Pigeonite	10.1	1.2
Sanidine	0.9	0.4
Magnetite	1.5	0.4
Quartz	1.0	0.4
Anhydrite	1.1	0.2
Hematite	0.8	0.2
Ilmenite	0.7	0.2
Amorphous	27	~10

as soils on the flanks of Mauna Kea volcano, Hawaii [2]. The crystalline component is very similar to normative basalt mineralogies predicted from Gusev Crater on Mars and is also qualitatively similar to mineralogies of martian basaltic meteorites.

Comparison of the Rocknest eolian sand with Gale crater's consolidated sediments: The drill samples collected from sedimentary rocks following the Rocknest scoop analysis (Figure 1) include smectite-ric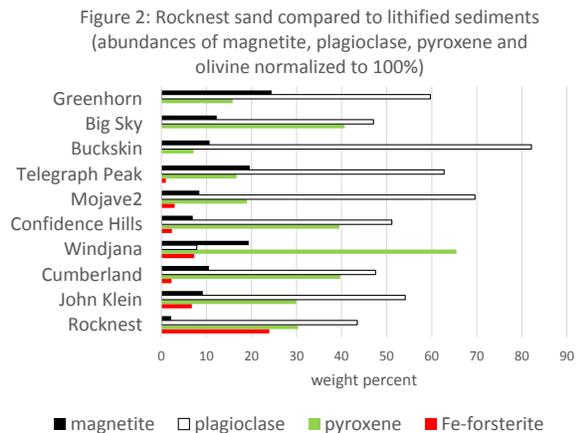h mudstones (John Klein and Cumberland) of Yellowknife Bay, potassic sandstone (Windjana), mudstones of the Pahrump formation (Confidence Hills, Mojave2, Telegraph Peak), a high-silica laminated mudstone (Buckskin), and a basaltic cross-stratified eolian sandstone (Big Sky) along with its diagenetically modified equivalent near a penetrating fracture (Greenhorn). The Rocknest sand

Figure 1: Stratigraphic column

is basaltic and of decidedly olivine-normative composition. This sample differs considerably from the subsequently analyzed lithified sedimentary rocks that have little or no olivine.

Figure 2 shows the relative abundances of the principal minerals that may represent basaltic sources in the Rocknest sand and the subsequent sediment samples: olivine (moderately forsteritic to slightly fayalitic), plagioclase (andesine), magnetite, and pyroxenes (augite and pigeonite, with less common orthopyroxene). The sedimentary rocks sampled subsequent to the Rocknest sample are listed in relative stratigraphic position, within a sequence of ~85 m thickness.

Figure 2: Rocknest sand compared to lithified sediments (abundances of magnetite, plagioclase, pyroxene and olivine normalized to 100%)

There is considerable confidence that olivine, pyroxenes, and plagioclase are detrital and from relatively mafic igneous sources. Interpretation of magnetite as a detrital igneous phase in Cumberland and John Klein is thought to be unlikely [9], based on the surprisingly low abundance of olivine in these mudstones contrasted with their abundant pyroxene and plagioclase and in consideration of reaction models for these two samples that support production of smectite plus magnetite as a result of olivine reaction with trace quantities of O_2 or by production of hydrogen [10]. However, the high concentrations of magnetite seen in other samples, coupled with a low abundance of clay minerals (<10%) cannot be explained with this olivine reaction model. Occurrences of jarosite in the lowermost Murray formation indicate possible acid sulfate reactions that may complicate the authigenic history in that part of the section.

It is notable that olivine is absent in the sediments higher up in the Murray section – Buckskin and the unconformably overlying Stimson formation, from which the Big Sky/Greenhorn set of samples were derived. These sedimentary rocks are close below the Bagnold dune field and clearly not a significant local source of sand for the Bagnold dunes.

Current views of Bagnold dune mineralogy: Orbital spectroscopy has identified the Bagnold dunes as basaltic and olivine-rich [e.g., 11,12]. At orbital resolution, analysis suggests variable mineral abundances, such as observable concentration of olivine in barchan dunes versus pyroxene concentration in longitudinal dunes [12]. Analysis of CRISM data suggests eolian fractionation of mineralogy [6] and passive spectra from *Curiosity* indicates some variation in olivine versus ferric phases [13]. APXS results for these sands are similar to the Rocknest eolian sand, but with differences that may be reflected in mineralogy. The Bagnold sands are somewhat lower in S than the Rocknest sands, which had a significant component of anhydrite (Table 1); Ca-sulfates (anhydrite and basanite) have been persistent from Rocknest through all of the sedimentary bedrock, most commonly filling ubiquitous fractures; analysis of the Bagnold dune sand will determine whether these phases occur in the active dunes.

Expectations for XRD analysis at the Bagnold dunes: It is anticipated that the CheMin instrument will analyze two samples from the Bagnold dunes, first from the relatively active Namib dune and second from a less active dune, Kalahari [4]. CheMin data for these dune samples are restricted to the <150 um size fraction, but with supporting analysis of other instruments on *Curiosity*, and comparison with the same size fraction at Rocknest, these results will be in a known context. Determination of the relative abundances of olivine, magnetite, hematite, ilmenite, feldspars, pyroxenes, other crystalline phases, and amorphous components at Bagnold will provide a basis for constraining possible sources of eolian detritus between the currently active dunes at the base of Mount Sharp and the older Rocknest eolian detritus farther out in the Gale crater moat.

References: [1] Blake D. et al. (2012) *Space Sci. Rev.* doi: 10.1007/s11214-012-9905-1. [2] Bish D.L. et al. (2013) *Science*, *341*, DOI: 10.1126/science. 1238932, [3] Blake D.F. et al. (2013) *Science*, *341*, DOI: 10.1126/science.1239505, [4] Bridges N. et al. this conference, [5] Ehlmann B.L. et al. this conference, [6] Lapotre M.G.A. et al. this conference, [7] Cousin A. et al. this conference, [8] Ewing R.C. et al. this conference, [9] Vaniman D. T. et al. (2013) *Science, 343* doi: 10.1126/science.1243480. [10] Bristow T. F. et al. (2015) *Am. Min., 100*, 824-836, [11] Rogers A.D. and Bandfield J.L. (2009) *Icarus, 203*, 437-453, [12] Seelos K.D. et al. (2014) *Geophys. Res. Lett., 41*, DOI: 10.1002/2014 GL060310, [13] Johnson J.R. et al. this conference.